CHILDREN’S AND ADULTS’ VISUOSPATIAL AND TEMPORAL MEMORY ABILITIES USING PICTURE COMMUNICATION SYMBOLS

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BY
OLIVIA SWIM

DR. BARRY T. WAGNER – ADVISOR

BALL STATE UNIVERSITY
MUNCIE, INDIANA

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This study investigated abilities of typically developing third-grade children and college-aged adults to identify, locate, and sequence picture communication symbols. Participants where asked to recreate 4 x 4 grid displays during a working memory task that assessed visuospatial and temporal memory through feature binding. Results revealed that children and adults demonstrated an equal mean proportion of recall on such features as object recall, location recall, and object-location binding, with a range of performance between 74%-to-100%. Additionally, developmental trends were obtained between the two groups on object-sequence and location sequence binding, with children recalling approximately 25% and adults recalling 55% (for both features). These data suggest that feature binding, especially object-sequence and location-sequence, undergoes maturation with age through adulthood. Nevertheless, it appears that without explicit feature binding intervention, both children and adults will demonstrate some challenges with visual-graphic communication given that feature binding ability for complex working memory tasks remains marginal in performance through adulthood.
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CHAPTER 1
INTRODUCTION AND REVIEW OF LITERATURE

Children who rely on augmentative and alternative communication (AAC) must manifest visuospatial and temporal memory (VSTM) abilities to successfully identify, locate, and sequence visual-graphic (VG) symbols. In order to create meaningful language, AAC users must mentally transcribe a thought into a visual modality. This first requires the user to identify which picture communication symbols (PCSs\(^1\)) can accurately represent the language (vocabulary) of a given utterance. Then, each PCS must be located on the AAC display (aided system), often involving a lengthy navigation process through multiple communication pages. In addition, this search process must adhere to a specific sequential order according to the morphosyntactic rules of our language. If any of these steps are omitted or executed incorrectly, the AAC user could face a frustrating and possibly irreparable communication breakdown (Higginbotham, Shane, Russell, & Caves, 2007).

Children are especially susceptible to aided communication breakdowns. For example, creating multi-word utterances using VG displays with aided system is inherently different from oral communication (Higginbotham, Shane, Russell, & Caves, 2007; Wilkinson & Jagaroo, 2004). Notably, the visual nature of the task places enormous working memory (WM) demands on AAC users given the complexity and design of VG displays. These same types of WM demands are not placed on oral speakers, as no VG display is needed for oral communication. In addition to the demands associated with VG displays.

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\(^1\) The Picture Communication Symbols (PCS) by Mayer-Johnson LLC. All Rights Reserved Worldwide. Used with permission. 2100 Wharton Street, Suite 400, Pittsburgh, PA 15203; phone: 1-800-588-4548; URL: http://www.mayer-johnson.com/
displays, children's visuospatial and temporal memory (VSTM) may influence communication outcomes, especially if there are developmental contributions.

In order to address VSTM development in regard to VG displays, Wagner and Shaffer (in-review) conducted a developmental study to assess school-aged children's VSTM abilities. These researchers determined that even typically developing fifth-grade students did not demonstrate all of the necessary abilities needed to identify, locate, and sequence PCSs on grid displays during a visual search task. The inability to identify, locate, and sequence PCSs could be attributed to developmental factors related to VSTM, as no developmental trajectory related to VG displays has been determined. Moreover, given that Wagner and Shaffer (in-review) found only found a significant difference in location-sequence binding abilities between 1st and 3rd graders, it is logical to examine adults' VSTM to determine whether these memory functions continue to develop throughout adolescence and adulthood.

In order to move this line of research forward, this investigation will employ a replicated cognitive science methodology (identical to Wagner & Shaffer, in-review) with the addition of auditory input to further explore the development of VSTM. Therefore, the purpose of this study is to examine VSTM development of 3rd graders and college-aged adults during an experimental picture span task. Specifically, this study will determine whether developmental differences exist when identifying, locating, and sequencing VG symbols. Picture span is a measure of WM and appears applicable to this study because it simulates many of the WM demands often associated between AAC users and their communicative partners. While this research inquiry is primarily concerned with the development of VSTM, this line of research also begins to explore why so many children
exhibit difficulty communicating with VG displays. Lastly, developmental data will also be presented on picture span that could serve as baseline data when providing clinical services to children with complex communication needs, as no previous research has evaluated VSTM of adults with respect to VG displays and memory function.

**Review of Literature**

The review of literature is comprised of three main areas: a) developmental cognitive science, b) working memory and attention, and c) AAC display design. The purpose of this review is to familiarize the reader with the literature related to the research questions proposed in this study. The research questions will be presented at the end of this review of literature.

**Cognitive Science**

Researchers in AAC have not extensively integrated principles of cognitive science into the field. However, cognitive science would appear to be an important discipline for AAC research to draw upon given the nature and demands associated with VG aided communication. Much of the current research in cognitive science has focused on how people synthesize information to assemble cohesive memories (Chalfonte & Johnson, 1996; Lorsbach & Reimer, 2005; Postma, van Asselen, Keuper, Wester, & Kessels, 2006; Schumann-Hengsteler, 1992). Feature binding, the gluing of information together, is how we create a unified memory, and is considered a non-automatic and highly complex process (Chalfonte, & Johnson, 1996; Chalfonte, Verfaellie, Johnson, & Reiss, 1996; Lorsbach & Reimer, 2005; Postma et al., 2006). Feature binding is a critical ability for children who use VG aided systems (Wagner and Shaffer, in review). For example, during the process of binding, target and contextual memory must work together as a unit of
memory to recall visuospatial and temporal information. Target memory refers to how we remember the identity of what we actually see in front of us. Contextual memory is the assimilation of spatial memory, which specializes in object location, with temporal memory, which deals with an object's order-in-time (Kessels, Hobbel, & Postma, 2007). Of course, VG aided communication would fail if target and contextual memory do not work as a single unit of memory. In other words, what positive communication outcomes would occur for an AAC user who knows the identity of a particular symbol, but is unable to recall where that symbol is located or the sequence in which that symbol should be encoded when producing multiple-word utterances? Again, successful VG communication is contingent upon the integration of target and contextual memory.

Feature binding is a cognitive process that can allow researchers a means to assess target and contextual memory applicable to VG displays. Feature binding can be assessed through object recall (target memory), location recall (contextual memory), object-location binding (target + contextual memory), object-sequence binding (target + contextual memory), and location-sequence binding (contextual + contextual memory). Numerous studies from cognitive science have examined feature-binding abilities in typically developing children (Chalfonte & Johnson, 1996; Kessels et al., 2007; Lorsbach & Reimer, 2005; Schumann-Hengsteler, 1996), and in atypical populations (Jarrold, Phillips, & Baddeley, 2007; Kessels, Rijken, Banningh, Van Schuylenborgh, & Rikkert, 2010; Postma et al., 2006). Research has suggested that typically developing children were much better at remembering target features (object identity) than contextual features (object location and sequence) (Chalfonte & Johnson, 1996; Kessels et al., 2007; Lorsbach & Reimer, 2005; Schumann-Hengsteler, 1996). When comparing performance across multiple age groups,
the ability to bind target and contextual features (identity + location or identity + sequence) was more advanced in fourth and sixth graders than in kindergarteners and third graders (Kessels et al., 2007; Lorsbach & Reimer, 2005; Shumann-Hengsteler, 1992).

Although feature binding abilities improved with age throughout elementary school for typically developing children, studies have shown that atypical populations perform poorly on feature binding tasks (Jarrold et al., 2007; Kessels et al., 2010; Kessels et al., 2007; Lorsbach & Reimer, 2005; Schumann-Hengsteler, 1992). Studies involving people with various disorders (e.g., William’s syndrome, learning disability) have revealed extensive difficulty with binding target and contextual features when compared to control groups (Jarrold et al., 2007; Kessels et al., 2010).

In summary, little is known presently about the role target and contextual memory plays in VG communication. Feature binding appears to be an important developmental ability for children who use VG symbols to communicate. To date, only one study by Wagner and Shaffer (in review) has examined feature binding related to the AAC field. This study expanded upon existing cognitive science research by examining participants’ abilities to simultaneously recall objects, locations, and sequences. While cognitive science has provided some developmental data on VSTM, future studies are needed in AAC to better understand feature binding in particular to VG aided communication.

**Working Memory and Attention**

Since WM and attention are critically important to oral speakers (Baddeley, 2007; Chalfonte et al., 1996; Chun & Turk-Browne, 2007; Jarrold et al., 2007; Light, Parsons, & Drager, 2002), it would appear equally as important to AAC users. Many researchers would agree that WM and attention play an active role in VG communication. In order to
understand memory and attention, Baddeley (2007) proposed a multi-component model of WM, which illustrates a limited-capacity neurocognitive system for the processing and storage of information. Within this model, the visuospatial sketchpad has a rehearsal mechanism for all visuospatial stimuli. Once visuospatial stimuli have been retained in WM through rehearsal, it is then stored into long-term memory for later use. Nevertheless, the demands of VG aided communication are significant, and difficulty identifying, locating, and sequencing VG symbols may always be a challenge if the necessary WM resources are not available to the AAC user. Many opportunities for rehearsal and/or meaningful practice (with the VG display) will be needed before memories are eventually stored into long-term memory. Therefore, before memories are stored into long-term memory, AAC service providers will need to consider intervention strategies to improve information retention (i.e., identifying, locating, and sequencing VG symbols) in WM.

Individual WM capacity has been assessed in the literature using picture span and word span tasks, in which a person’s ability to recall auditorally presented word lists is assessed as the number of words per list increases gradually (Dempster, 1981; Furth & Milgram, 1973; Paivio & Csapo, 1973; Wagner & Shaffer, in review). This literature indicates that a person’s word span increases with age for both visual and auditory stimuli, with recall of auditorally presented stimuli exceeding that of visually presented stimuli. Some studies suggest that this may be a result of auditory stimuli creating a phonological code, which could tap into the phonological loop in Baddeley’s WM model (Baddeley, 2003). However, as AAC users must allocate their limited memory resources between recognizing visual information, such as PCSs, and accessing it by pointing to create an
auditory output, the effects of these multiple modalities are difficult to determine and assess.

Due to the multi-modal demands of AAC, attention plays a critical role in AAC users’ abilities to allocate cognitive resources between sustained and divided attention when using VG displays during the communication process. For example, sustained attention requires a person to keep in mind a desired utterance s/he wishes to communicate during an on-going conversation. In contrast, divided attention is necessary to alternate among a communicative partner, VG display, and the specific symbols needed to create an utterance (Thistle & Wilkinson, 2012). Clearly, the attentional demands of aided communication are significant, as children must focus on identifying, locating, and sequencing VG symbols while also participating in the communication process.

**AAC Display Design**

Because children have significant difficulty using VG displays, researchers have investigated language organizations, system layouts, color cues, and display permanence. Studies have revealed that organizational and perceptual modifications to displays can help children identify and locate VG symbols (Drager & Light, 2010; Drager et al., 2004; Drager, Light, Speltz, Fallon, & Jeffries, 2003; Light et al., 2004; Thistle & Wilkinson, 2009; Wilkinson, Carlin, & Jagaroo, 2006; Wilkinson, Carlin, & Thistle, 2008; Wilkinson & Snell, 2011). For example, fixed displays (with no linking to other communication pages) have been found to reduce cognitive demands. When using fixed displays, AAC users access recognition memory since symbols are always visible to the user (Hochstein, McDaniel, & Nettleton, 2004). This certainly is not the case with dynamic displays where pages link from one page to another. Dynamic displays require users to access recall memory since
many of the VG symbols are not apparently visible to the user. Additionally, visual scene displays are also known to reduce cognitive demands because language concepts are embedded in a meaningful context such as a picture (Wilkinson & Hennig, 2009). It has also been suggested that visual scene displays reduce cognitive demands because they allow children to tap into episodic memory through their previously known experiences (Wilkinson & Hennig, 2009).

Because children have such trouble locating VG symbols regardless of language or system layout, color cueing has also been investigated in relation to children’s difficulties locating VG symbols on aided communication systems. Uniquely and prominent foreground colored symbols have been proven to help typically developing children locate symbols. However, VG symbols with background color only hindered children’s speed of locating symbols (Thistle & Wilkinson, 2009; Wilkinson, Carlin, & Jagaroo, 2006; Wilkinson, Carlin, & Thistle, 2008). For atypical populations, clustering VG symbols of similar internal color increased children’s speed and accuracy of locating target VG symbols (Wilkinson, Carlin, & Thistle, 2008).

**Summary**

In summary, the review of literature indicates that very few studies have been conducted to address the VSTM demands of AAC aided communication. The purpose of this experiment is to expand the developmental data by examining VSTM abilities of children and adults. By examining both third-grade children and adults in conjunction with prior research (Wagner & Shaffer, in review), a developmental trajectory of VSTM abilities can be established. This study also extends Wagner & Shaffer by incorporating auditory input to the task. This trajectory can provide guidelines for when the
developmental progression reaches its full capacity, and whether the ability to bind object identities, locations, and sequences will always present challenges to AAC users regardless of age and maturation.

**Research Questions**

The following research questions were addressed:

1. What are the picture spans of third-grade children and college-age adults when provided a visuospatial and temporal working memory task with auditory input?

2. What features of memory (i.e. target, contextual, or the integration of target and contextual) are most affected when memory capacity is stressed?

3. Are there developmental differences in feature binding?
   a. Are there developmental differences in target memory as evidenced by the ability to recall objects?
   b. Are there developmental differences in contextual memory as evidenced by the ability to recall locations and bind objects to location and sequence?
CHAPTER 2

METHODOLOGY

Key Terms

*Aided communication* – any type of communication that requires external support, such as pointing, pictures, or visual-graphic displays

*Augmentative and alternative communication* – "attempts to study and when necessary compensate for temporary or permanent impairments, activity limitations, and participation restrictions of individuals with severe disorders of speech-language production and/or comprehension, including spoken and written modes of communication" (ASHA, 2005, p.1)

*Children with complex communication needs* – children with severe motor or speech limitations that require alternative methods, such as augmentative and alternative communication, to express their basic wants and needs

*Contextual memory* – includes both spatial/location and temporal/sequential information

*Distracter PCSs* – those presented intermixed with the stimuli PCSs below the response board

*Dynamic displays* – visual-graphic symbols are located on multiple displays requiring the user to navigate among many linked displays

*Episodic memory* – memory for autobiographical information that is both unique to the person, and tied to a specific time and place

*Feature binding* – the process in which objects, locations, and their sequences are glued together to form a singular memory representation

*Grid displays* – visual-graphic symbols are organized in a decontextualized grid
**Picture Communication Symbols (PCSs)** – a type of VG symbol; simple colored line drawings with labels

**Picture span** – the highest trial in which all PCSs objects, locations, and sequences were recalled correctly

**Response board** – blank 4 x 4 grid

**Stimulus board** – 4 x 4 grid comprised of various numbers and arrays of PCSs

**Stimuli PCSs** – those presented on the stimulus board

**Target memory** – object identity

**Visuospatial and temporal memory (VSTM)** – object-location memory

**Visual-scene displays** – visual-graphic symbols are embedded in contextualized scenes

**Visual-graphic displays** – any organizational array of visual-graphic symbols

**Working memory** – where information can be manipulated and stored
Research Design

Descriptive and experimental statistics were used to analyze the data for this study. For research question one (picture span), both descriptive and experimental statistics were used. Central tendency measures were used to determine the average picture span of the participants, whereas experimental research determined whether differences existed between the groups. For research question two (overall analysis), the percentage of participants’ scoring all features correct was computed for both trials 1 and 2. For research question three (individual analysis), the mean proportion of items recalled was computed.

Participants

Typically developing third-grade children were recruited from two public school classrooms located in northeast central Indiana. Typically developing college-aged adults were recruited at Ball State University in Muncie, Indiana from various departmental majors. Initial inclusionary criteria prior to the study included (a) no identified speech, cognitive, physical, or sensory impairments; (b) no prior experience with AAC technologies; and (c) parental consent and/or participant assent to participate. After these criteria were met, all participants were required to score within +/- 1 standard deviation on the Peabody Picture Vocabulary Test-Fourth Edition (PPVT-4, Form A) (Dunn & Dunn, 2007) and on the Test of Nonverbal Intelligence-Fourth Edition (TONI-4, Form B) (Brown, Sherbenou & Johnsen, 2010). These standard scores reflect typical vocabulary and cognitive development.

Twenty out of 26 third-grade children (PPVT-4 $\bar{x}$ total score = 99.84, $\sigma$ = 5.96; TONI-4 $\bar{x}$ total score = 103.16, $\sigma$ = 7.09) qualified to participate in the experiment after the initial testing was completed. Therefore, the final pool of the third-graders included 12
males and 7 females, for a total of 19 participants. The chronological ages for third-grade children ranged from eight years and four months to ten years and nine months \((\bar{\text{age}} = 8;8, \sigma = 0;6)\). Twenty out of 27 college-aged adults \((PPVT-4 \bar{\text{ age}} = 104.37, \sigma = 7.13; TONI-4 \bar{\text{ age}} = 101.00, \sigma = 9.20)\) qualified to participate in the experiment. The final pool of participants included 4 males and 15 females, for a total of 19 participants. The chronological ages for the college-aged participants ranged from nineteen years and eleven months to twenty-three years and three months \((\bar{\text{age}} = 21;6, \sigma = 0;10)\).

**Materials**

**Tests**

The *Peabody Picture Vocabulary Test-Fourth Edition* (*PPVT-4, Form A*) (Dunn & Dunn, 2007) measures receptive vocabulary abilities. The *PPVT-4* has a median internal consistency reliability of .95 and an average correlation of .69 validity. The *Test of Nonverbal Intelligence-Fourth Edition* (*TONI-4, Form B*) (Brown, Sherbenou & Johnsen, 2010) measures nonverbal intelligence. The *TONI-4* has a median internal consistency reliability of .96 and interscorer reliability of .99 (Brown, Sherbenou & Johnsen, 2010).

**Picture Communication Symbols (PCSs)**

PCSs are simple colored line drawings with labels. Stimuli and distracter PCSs depicted common single-noun words (e.g., “doll, flag, kite”), and were shown on a white background. Two hundred ninety-six different PCSs were presented in this study. Three hundred seven PCSs were used for this study. Refer to Appendix A for a list of PCSs presented in each trial.

Currently, no data has been collected on the developmental age of acquisition for PCSs, although a pilot study was conducted prior to this study to determine whether
typically developing children could identify the PCSs. Fourteen first-, third-, and fifth-grade children were presented all of the 307 PCS items in arrays of 9 items per trial. Children were asked to point to PCS items presented verbally by the examiner. Of 307 PCS items, 93% of the stimuli were correctly identified by all three groups of children. Third and fifth grade children did not exhibit any item errors with the PCS items, while two first grade children incorrectly identified the item “grapefruit” and one first grade child misidentified “mailbox” and “cake” (Wagner & Shaffer, 2011).

**Stimulus and Response Boards**

The stimulus and response boards both consisted of four vertical columns containing four boxes and four horizontal rows containing four boxes (also known as 4 X 4 fixed communication display). The size of each cell was 4.76 cm in width and 3.17 cm in height. Twenty-six stimulus and response boards were created using Macromedia Director 2004 MX and Photoshop 7. Stimulus boards contained Picture Communication Symbols (PCSs). Throughout the experiment, 185 PCSs were used as stimulus items displayed on the stimulus boards, and 111 PCSs were used as distracter items underneath the response boards. Response boards contained a blank 4 x 4 grid above a black line. Below the black line, all previously displayed stimulus PCSs and 4 distracter items were available for placement. Please refer to Appendix A for example stimulus and response boards used in the study.

*Figure 1*

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2 Macromedia Director 2004 MX software was published by Macromedia, Inc. Address: 2548 Zanker Road, San Jose, CA 95131-9849. Phone: 1-800-470-7211. Web site: [http://www.macromedia.com](http://www.macromedia.com).

3 Adobe Photoshop 7 was published by Adobe Systems, Inc. Address: 345 Park Avenue, San Jose, CA 95110-2704. Phone: 408-536-6000. Web site: [http://www.adobe.com](http://www.adobe.com).
Example of Stimulus Board for Experimental Trial 10B

Figure 2
Example of Response Board for Experimental Trial 10B

Equipment

Note: The stimulus and response boards were displayed on a calibrated 15-inch (38 cm) Elo 1000 Series 1515L Touch Screen LCD Monitor⁴, connected to a Gateway Professional CA6 Windows XP laptop computer⁵.

Procedures

Each participant met with the primary investigator for two sessions. All participants were seen individually. During the first session, the Peabody Picture Vocabulary Test-Fourth

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⁵ Gateway laptop computers are manufactured by Gateway, Inc., 7565 Irvine Center Drive, Irvine, CA 92618; phone: 1-877-845-9730; URL: http://www.gateway.com.
Prior to presenting the experimental condition to the participants, the following instructions were provided:

“Today we’re going to play a computer game where we look at pictures. First, you will see the pictures on the screen and hear their names, then they will disappear. After the pictures go away, you have to remember the pictures, the boxes the pictures went in, and the order you saw them come on to the screen. You will move the pictures with the tip of your pointer finger. Let’s practice!”

“See how the picture gets big when you move it with your pointer finger? We want the picture to be big when we put it in the box. The pictures will only move when they are big. Make sure each picture is big before you go on to the next picture.”

If the participant was correct with the two-picture practice sequence, the examiner said:

“Great job! You remembered the pictures, the boxes they went in, and the order they came on the screen.”

If the participant was incorrect with the two-picture practice sequence, the examiner said:

“You did a great job keeping the pictures big, but let’s try one more time. It’s important that you remember the pictures, the boxes they went in, and the order they came on the screen.”

For all participants, the examiner said:

“If you ever change your mind, you need to put all the pictures back below the black line and start again, like this.”

“Now we are going to start our game! Try to remember all the pictures, the boxes they went in, and the order they came on the screen.”

The number of PCSs ranged from 1 to 13 within a given trial. Trials 1 and 2 each consisted of 1 stimulus PCS being presented on the stimulus board, followed by a response board. Trials 3 and 4 consisted of 2 stimulus PCSs presented on the stimulus board, followed by a response board, and so on. PCSs each appeared on the screen for 5 seconds.
as the computer said the accompanying PCS name. After all PCSs were displayed within a
given trial, the response board appeared. The response board was always shown above a
black line, with the stimulus PCSs intermixed with 4 distracter PCSs presented at a smaller
size below the black line. This design was implemented to maximize space availability for
the PCSs on the response boards. When a PCS was officially placed in a box within the
response board, it returned to its original size of 2.85 cm in width and 1.90 cm in height.

Once a participant completed a trial, s/he verbally confirmed completion, and the
primary investigator manually transitioned from the response board to the next stimulus
board using the Gateway computer. Responses were automatically saved to the computer's
hard drive, and later scored individually. All participants completed a minimum of 20
experimental trials, resulting in a total of 10 PCSs. If a picture span had not been reached by
the 20th trial, participants could continue up to 26 trials in order to establish a picture span,
or a total of 13 PCSs.

**Scoring of Responses**

Scoring was performed on the set of trials that exceeded each participant’s picture span by
one PCS. Picture span was determined as the number of PCSs recalled prior to missing a
set of trials with the same number of PCSs. A set of trials included 2 trials with the same
number of PCSs. For example, if a child missed a set of trials containing 4 PCSs, the picture
span was determined to be 3. In this example, the trials with 4 items were used for scoring,
and are referred to as the “picture span + 1” trials.

Five different developmental abilities were scored including object recall (OR),
location recall (LR), object-location binding (OLB), object sequence binding (OSB) and
location sequence binding (LSB). Scoring was conducted on each overall trial and on each individual PCS item within the trial.

**Overall Trial Scoring**

Each trial was assessed for the following:

- Were all objects recalled over the entire trial?
- Were all locations recalled over the entire trial?
- Were all objects appropriately bound to the correct location over the entire trial?
- Were all objects “played” in the correct sequence over the entire trial?
- Were all locations “played” in the correct sequence over the entire trial?

Each of the above questions were scored using a plus/minus scoring system. A score of “could not be determined” (CND) was given when binding could not be evaluated. With all binding abilities (object-location, object-sequence, location-sequence), both features must have earned a plus score for the entire trial to be evaluated. If a participant did not recall all objects correctly, object-location binding and object-sequence binding could not be accurately evaluated, resulting in a CND score.

**Individual Item Scoring**

As overall trial scoring did not fully illustrate each participant’s true abilities for the five developmental abilities, individual item analysis was completed. For example, if a participant recalled one item incorrectly out of five total items in a trial, overall analysis would reflect a negative score for all of object recall. As such, overall trial scoring did not give participants credit for all correct responses. Due to this, individual items were also
scored to gain a more comprehensive understanding of patterns of error in recall and binding.

Each individual item was assessed for the following:

- Was the object recalled correctly within the trial?
- Was the location recalled correctly within the trial?
- Was the object bound to the correct location within the trial?
- Was the object “played” in the correct sequential position within the trial?
- Was the location “played” in the correct sequential position within the trial?

For object-sequence and location-sequence binding, the final sequential position was scored independent of other items in the trial. As such, no items were scored CND in individual item scoring. Additionally, omissions, additions, and self-corrects had to be addressed when scoring object-sequence and location-sequence binding. For item omissions or additions, the final sequential position was adjusted. For instance, if the fourth object out of six total was omitted, the positional count of the last 2 objects was reduced by 1. Therefore, item 5 could only be “played” correctly on the 4th move. In the case of additions and self-corrects, remaining items were scored according to a plus 1 position.

**Self-corrections for Individual Item Scoring**

Self-corrections had to be specially scored for trials in which participants “played” an object initially and later relocated it or took it off the grid completely. For location recall and object-location binding, the location score was determined to be the final position of the self-correction. Alternatively, object-sequence and location-sequence binding were
scored based on the first object or location placement, and the self-correction move was not scored for sequence.
CHAPTER 3

RESULTS

Picture Spans

For both third-grade and college-aged participants, picture spans were calculated to determine the highest number of objects and their corresponding locations and sequences that could be recalled with 100% accuracy. Third-grade participants had a mean picture span of 3.68 with a standard deviation of 1.701. As hypothesized, college-aged participants were able to recall more, with a mean picture span of 6.53, and a standard deviation of 2.525. A two-way factorial analysis of variance (ANOVA) revealed significant differences between third-grade children and college-aged adults, $F(1, 37)=13.578, p < .001$, with a large effect size (Cohen, 1988) of $f=0.52$ (partial $n^2 = 0.2128$). There were no significant differences for gender or interactions between level of participants and gender at the probability of $p < .05$.

Figure 3
Means and Standard Deviations of Picture Span
Overall Trial Analysis

Overall trials were scored using a binary (+/-) system to show the percentage of participants who were able to recall and/or bind all features in a given trial. Data were obtained from the two trials past a participant’s picture span, as determined by the level at which participants’ abilities to identify, locate, sequence, and bind PCS features failed. Looking at abilities on the two trials past picture span allowed for the analysis of the trials and features in which VSTM was under stress. An adjusted N for each feature (object-location binding, object-sequence binding, and location-sequence binding) was determined based on prerequisite abilities. For example, if a participant did not recall all objects correctly, object-location binding responses were marked as “could not be determined” (CND) for object-location binding. It was determined that if a participant did not recall all objects correctly, his or her ability to correctly bind objects to locations could not be thoroughly evaluated. This system of CND scoring was also applied to object-sequence and location sequence binding.

Descriptive data is provided in Table 1 and Figure 4 for the overall analysis. The percentages of participants who were correct for all features in overall trials are provided. For object recall in both trials 1 and 2, 63% - 84% of participants were able to correctly recall this feature. For location recall, 47% – 80% of participants placed all PCSs in the correct locations on the response board. When participants’ abilities to bind the appropriate PCSs to the correct locations were evaluated, 71% – 100% of participants were successful. Participants’ abilities to bind PCSs to location ranged from 0% -27% accuracy.
Lastly, only 0% – 10% of participants were able to bind PCSs to locations and sequential order.

Table 1

**Percentages of Participants Correct Per Trial**

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<td></td>
<td>Trial 1</td>
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<tr>
<td>Object Recall</td>
<td>79%</td>
<td>84%</td>
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<tr>
<td>Location Recall</td>
<td>80%</td>
<td>63%</td>
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<tr>
<td>Object-Location Binding</td>
<td>100%</td>
<td>90%</td>
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<tr>
<td>Location-Sequence Binding</td>
<td>0%</td>
<td>10%</td>
</tr>
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</table>

Figure 4

**Percentage of Features Correct**

Note. Features indicated on the abscissa (x-axis) are object recall (OR), location recall (LR), object location binding (OLB), object sequence binding (OSB), and location sequence binding (LSB). The ordinate (y-axis) defines the % of participants with a correct score on the observed feature. Numbers given in parentheses represent the total N of participants who could be scored for that feature. See text for further explanation.
When analyzing the percentage of participants with features correct within overall trials, variability of performance was noted between trials for both third-grade children and college-aged adults. There was more variability between trials for adults than children on all features except for location recall. There was also variability between third-grade children and college-aged adults on all features except for location-sequence binding. This variability could be due to the reduced N, with some features being based on a population of fewer than 10 participants, such as object-location binding; whereas other features, such as object-recall, were based on a population of up to 19 participants. These reduced Ns increase the potential for outliers to affect the overall trends.

**Individual Item Analysis**

Overall trial scoring did not capture a complete picture of participants’ abilities to recall the five features (object recall, location recall, object-location binding, object-sequence binding, location-sequence binding), as a single error in any of the five features resulted in an incorrect overall recall score for the entire trial. For example, if a participant incorrectly recalled one location out of a symbol set of nine PCSs for a given trial, the entire trial would be incorrect despite the other remaining eight correct locations for that trial. Data from the individual item analysis (see Figure 5) revealed that object recall, location recall, and the binding of objects and locations ranged from 74% – 100% (mean proportion of recall) for both children and adults. In contrast, the ability to bind objects to sequences and locations to sequences ranged from 26% – 66%. 
**Figure 5**

*Means and Confidence Intervals of Individual Feature Recall*

Note. Features indicated on the abscissa (x-axis) are object recall (OR), location recall (LR), object location binding (OLB), object sequence binding (OSB), and location sequence binding (LSB) for the grade levels, first (1), third (3) and fifth (5). The ordinate (y-axis) defines the proportion of correct features for the individual item scoring and analysis. This analysis included all study participants.

Regardless of age, both third-graders’ and adults’ were less able to bind sequence. There was also much more variance between the age groups regarding performance on object-sequence and location-sequence binding. This type of individual analysis is critical, because object-location binding appeared to be the strongest ability according to overall analysis with a mean range of performance from 71-100%. However, individual item analysis revealed that object-location binding actually had a range of performance of 74-78%.
CHAPTER 4

DISCUSSION

The discussion will address the research questions posed in this study. Additionally, clinical implications, study limitations and future research directions will be discussed.

**Research Question 1**

What are the picture spans of third-grade children and college-aged adults when provided a visuospatial and temporal working memory task with auditory input?

The results of the picture span data showed adults’ picture spans were significantly larger than the children’s picture spans. Therefore, these results suggest a possible developmental progression from childhood to adulthood with the ability to identify, locate, and sequence VG symbols. Murray and Goldbart’s (2011) found that there were significant differences in memory span between three-year-olds and six-year-olds, with the older children recalling a greater number of items. Given that WM capacity systems are fixed (Baddeley, 2007), the adults in this study may have been able to maintain information in memory by incorporating rehearsal strategies that were not used by the third-grade children. Because aided communication systems and VG displays in particular place demands on WM (Drager & Light, 2010; Drager et al., 2004; Drager et al., 2003; Thistle & Wilkinson, 2012; Wagner, Wilkinson, McCarthy, & Jagaroo, 2008; Wilkinson & Hennig, 2009), it may be beneficial to implement rehearsal strategies during the intervention process when working with children who use VG displays for communication.

The relatively modest picture spans obtained in this study may have been influenced by the level of experience with the experimental task. While study participants...
were trained on the task, it cannot be ascertained whether increased picture spans would be achieved with more exposure to the experimental task. It is important to confirm these picture span estimates in a future study with repeated task exposure. If picture span increases with additional task exposure, then memory capacity may be larger than these estimate suggest.

**Effect of Auditory Input on Picture Span**

This study extended the work of Wagner and Shaffer (in review) by comparing feature binding abilities of third grader and college age adults. The study also differed in that it included auditory input during the task, that is the PCS names were spoken by the computer. When the picture span abilities of the third graders from this study are compared to Wagner and Shaffer (in review), the performance was almost identical. The third graders in the Wagner and Shaffer (in review) study had an average picture span of 3.76, while the third graders in this study had an average picture span of 3.68. Based solely off of these data, it would appear that the auditory input offered no benefit in regards to picture span.

**Research Question 2**

What features of memory (e.g., target, contextual, or the integration of target and contextual) are most affected when memory capacity is stressed (as evidenced by the overall data analysis)?

This analysis of data revealed that target memory for object identity was more advanced than contextual memory for location. Moreover, target memory was also more advanced than object-location binding, object-sequence binding, and location-sequence binding. Binding challenges were especially noticeable in the third-graders' performance.
It was noted, however, that if participants could identify both objects and locations, both third-grade children and college-aged adults demonstrated competency binding these two features together.

These data begin to illustrate the complexity of using VG displays to communicate. Recall that successful VG communication is contingent upon binding objects, locations, and sequences. These results suggest that even the adults demonstrated substantial challenges recalling contextual information (e.g., difficulty recalling locations and binding objects to location and sequence). One could argue that challenges with contextual memory could be attributed to underdeveloped VSTM abilities. However, this would appear questionable given that the adults were typical in development and their memory systems are fully developed. Therefore, a second plausible hypothesis is that this experimental task may be too difficult for many persons regardless of age or developmental level. Because this experimental task simulates many of the cognitive demands imposed on children who use VG displays for communication, these findings could be discouraging to AAC service providers and their clients. Findings from this study support other research in the field regarding the demands associated with feature binding in VG communication (Oxley, 2003; Sutton et al., 2010).

**Effect of Auditory Input on Feature Binding**

When results of the current study are compared to Wagner and Shaffer (in review), the addition of auditory input to the task resulted in a higher percentage, 62-80%, of third graders scoring 100% correct on location recall versus 30-35% for the same task without auditory input. A smaller non-significant improvement (74% versus 70%) was also noted in the location recall for individual items. In contrast, binding of sequence (both location
and object) appears to have been detrimentally and significantly affected when both overall and individual item accuracy are considered. Proportion of object sequence binding for individual items was 43% in this study versus 68% in the non-auditory condition. Proportion of location sequence binding for individual items was 26% in this study versus 44% in the non-auditory condition. A future study directly comparing the auditory and non-auditory input conditions is needed to validate these preliminary findings.

**Research Question 3**

Are there developmental differences in feature binding (as evidenced by the individual analysis)?

The individual item analysis data showed that third-graders and college-aged adults had similar developmental abilities for both single features of target (object recall) and contextual memory (location recall). Object and location recall reached near 100% accuracy for both adults and children. Additionally, their developmental abilities were also similar when binding target to contextual memory for the feature object-location binding with accuracy ranging from 75% - 89%. It can also be said that all of these features were relatively intact developmentally with a range of performance between 71% to 100%. Further data analyses revealed developmental differences between third-graders and adults when binding target to contextual memory (object-sequence) as well as binding two contextual features together (location-sequence binding). Of course, the adults demonstrated more sophisticated binding abilities with these two features. However, their performance levels would still suggest challenges with these two features, as the adults only obtained 62% accuracy with object-sequence binding and 55% accuracy with
location-sequence binding. The third-grade children obtained a performance near 28% accuracy for both object-sequence and location-sequence binding.

By visual inspection and broad interpretation of the individual features, it would be suggested that target memory (object recall) was more developed than contextual memory (location recall and object-location binding). Additionally, contextual memory involving temporal memory (object-sequence binding and location-sequence binding) appeared to be least developed in both groups of participants. However, the college-aged participants displayed more advanced object-sequence and location-sequence binding abilities compared to the third-grade participants.

Clinical Implications

Many researchers from cognitive science have suggested the importance of memory strategies or mnemonics for the retention of information into WM (Oxley, 2003; Oxley & Norris, 2000; Shumann-Hengsteler, 1992). Many of these mnemonic strategies can also be applicable to the field of AAC, and more specifically to VG communication. For example, Oxley and Norris (2000) have suggested a number of strategies that could be implemented to improve the communicative competency for individuals who use VG aided communication. Some of these strategies include: a) repeated rehearsal (memorizing specific VG symbols and their associated messages for later use), b) metamemory (special insight about using particular markers (gold stars) to assist in the identification of symbols, locations, and sequences), and c) opportunities for systematic and logical searching (providing explanations on the organization of the display during errorless learning activities).
Additionally, other benefits could be obtained by reducing the cognitive demands of the task by simplifying the display. This could be accomplished by initially matching the children’s picture span to the number of VG symbols displayed at a given time (Wagner et al., 2008). For example, a child with a picture span of 4 may be best suited for a display that initially has 4 symbols present at a time. As the child becomes more familiar with the display and automaticity increases through meaningful practice, additional VG symbols could be added to the display. Individual features could also be trained according to developmental levels. For example, AAC service providers could first focus on object identities, followed by locations, and then sequences. After individuals become experts on each individual feature, emphasis could then be placed on feature binding. As a result of teaching individual features and binding, it is likely that AAC users will become more aware of the complexity of VG communication and the necessary learning steps involved.

Beginning with the earliest developing ability, AAC service providers could train object identity by initially selecting a small number of meaningful VG symbols, such as those for preferred toys or activities, and show children how they correspond to concrete items. Once this relationship is established, service providers can increase the number of VG symbols and train through explicit procedures. Moving on to location, service providers can utilize the ever-increasing number of technological applications and device programming options to reduce the cognitive demands of object location. Specifically, AAC service providers may want to consider using memory-based AAC applications, such as “PCS Memory” (Mayer-Johnson, 2013), to intently focus on object-location abilities. Depending upon the programming options available on an individual’s device, service providers could potentially take advantage of hidden buttons in which a small number of
VG symbols are present on the screen at a time until all of their locations have been memorized. Then, more VG symbols can be revealed without changing the locations of the originally trained symbols.

The clinical implications of improving AAC technology through better organization of VG symbols on existing devices has also been examined. The majority of research regarding the organization of VG symbols has focused on young AAC users, finding that clustering symbols by color and organizing VG symbols in static grid displays or visual scene displays fosters communication (Drager & Light, 2010; Drager et al., 2004; Drager et al., 2003; Light et al., 2004; Thistle & Wilkinson, 2009; Wilkinson et al., 2006; Wilkinson et al., 2008; Wilkinson & Snell, 2011). In addition to the changes clinicians can make to VG aided displays, it is critical to consider possible system changes that could lessen the cognitive demands of communication using VG symbols. Research revealing the difficulty both children and adults experience sequencing and binding PCSs would suggest that drastic system technology improvements may be needed in the way AAC users compose multi-symbol utterances (Wagner & Shaffer, 2011; Wagner et al., 2011).

Until improved AAC system technology exists, AAC providers can still make great strides by understanding the demands of VG communication and trying a variety of strategies to reduce them.

**Limitations and Future Research**

This study begins to illustrate developmental trends of VSTM abilities in children and adults. This experimental study required participants to complete a non-communicative task in a controlled environment, which is not identical to the task and demands of true VG communication. For example, participants in this study did not have to
attend to a communicative partner or create meaningful of grammatically correct utterances. Due to this, the study may not fully describe the challenges and limitations AAC users face in their daily lives.

Moving forward, researchers may want to consider designing experimental tasks that more closely mirror the interactions between AAC users and their communication partners. These experimental tasks should also evaluate whether or not auditory input affects memory span, and more specifically, picture span for AAC users. By creating more ecologically valid and realistic experimental tasks, researchers can better understand the challenging task of VG communication and the demands it places on WM.

Future studies could also examine the memory abilities of atypical populations completing VSTM tasks as they relate to VG communication. All participants in this study were typically developing. While the performance of typically developing individuals may begin to illustrate some of the complexities of VG communication, atypical populations must be evaluated in order to address their needs in future VG display and device design.

Future research into VG display design would also be warranted, and could include hypotheses that reflect our growing understanding of VSTM development. For example, studies could examine the effect of creating VG displays that initially match the number of VG symbols on the display at a given time to the user’s picture span to reduce WM demands. Future studies could examine the impact of experience and familiarity with displays on VSTM abilities.

**Conclusions**

In summary, these data add to current research that seeks to establish a developmental trajectory of typical feature binding abilities by examining individuals’
abilities to identify, locate, and sequence VG symbols. The individual features of memory and feature binding have been examined, demonstrating a range of strengths (object recall/target memory) and weaknesses (object-sequence and location-sequence binding/contextual memory) across both participant age groups. These data can serve as a basis for further investigation into the capabilities and limitations AAC users’ possess and the way AAC providers can redesign displays to accommodate the users’ highly diverse needs.
References


development for students with AAC needs (pp. 313-334). Baltimore: Brookes Publishing Company.


### Appendix A
### PCS Assignments

#### Practice 1
- **Doll** – S – (11), 5
- **Kangaroo** – D – 1
- **Cookies** – D – 2
- **Blocks** – D – 3
- **Saw** – D – 4

#### Practice 2
- **Popsicle** – S – (10), 6
- **Camel** – S – (3), 4
- **Bacon** – D – 1
- **Computer** – D – 2
- **Brush** – D – 3
- **Iron** – D – 5

#### Trial 1
- **Pig** – S – (5), 5
- **Ticket** – D – 1
- **Dog** – D – 2
- **Monster** – D – 3
- **Angel** – D – 4

#### Trial 2
- **Fruit** – S – (6), 5
- **Salt** – D – 1
- **Turtle** – D – 2
- **Sweater** – 3
- **Nail** – D – 4

#### Trial 3
- **Pen** – S – (11), 2
- **Kleenex** – S – (1), 4
- **Chair** – D – 1
- **Candle** – D – 3
- **Slide** – D – 5
- **Hamburger** – D – 6

#### Trial 4
- **Skates** – S – (1), 1
- **Kite** – S – (8), 3
- **Shower** – D – 2
- **Ear** – D – 4
- **Celery** – D – 5
- **Socks** – D – 6

#### Trial 5
- **Sunglasses** – S – (14), 3
- **Piano** – S – (7), 4
- **Toaster** – S – (5), 2
- **Lion** – D – 1
- **Train** – D – 5
- **Muscle** – D – 6
- **Scarf** – D – 7

#### Trial 6
- **Drawer** – S – (9), 5
- **Owl** – S – (11), 1
- **Fish** – S – (6), 3
- **Straw** – D – 2
- **School** – D – 4
- **Skateboard** – D – 6
- **Sundae** – D – 7

#### Trial 7
- **Bed** – S – (6), 3
- **Whistle** – S – (14), 5
- **Drum** – S – (15), 4
- **Tongue** – S – (3), 6
- **Key** – D – 1
- **Comb** – D – 2
- **Swing** – D – 6
- **Bicycle** – D – 8
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<tr>
<td>Triangle – S – (7), 6</td>
<td>Mouse – S – (9), 5</td>
<td>Rake – S – (9), 5</td>
</tr>
<tr>
<td>Milk – S – (13), 11</td>
<td>Seal – S – (7), 4</td>
<td>Eyes – S – (14), 11</td>
</tr>
<tr>
<td>Bathtub – S – (10), 4</td>
<td>Watch – S – (10), 12</td>
<td>Pudding – S – (1), 2</td>
</tr>
<tr>
<td>Strawberry – S – (16), 9</td>
<td>Waffle – S – (4), 8</td>
<td>Farm – S – (16), 4</td>
</tr>
<tr>
<td>Hose – S – (9), 5</td>
<td>Lamp – S – (2), 6</td>
<td>Cake – S – (15), 6</td>
</tr>
<tr>
<td>Banana – D – 5</td>
<td>Peach – D – 1</td>
<td>Firefighter – S – (12), 3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mosquito – S – (7), 6</td>
</tr>
<tr>
<td>Rock – S – (12), 7</td>
</tr>
<tr>
<td>Paintbrush – S – (6), 4</td>
</tr>
<tr>
<td>Fireplace – S – (14), 5</td>
</tr>
<tr>
<td>Dinosaur – S – (15), 8</td>
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<tr>
<td>Flashlight – S – (3), 2</td>
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<tr>
<td>Pancakes – S – (13), 11</td>
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<tr>
<td>Fan – S – (1), 12</td>
</tr>
<tr>
<td>Umbrella – S – (8), 10</td>
</tr>
<tr>
<td>Ship – S – (4), 1</td>
</tr>
<tr>
<td>Book – S – (10), 9</td>
</tr>
<tr>
<td>Letter – S – (16), 13</td>
</tr>
<tr>
<td>Calendar – S – (2), 3</td>
</tr>
<tr>
<td>Bird – D – 2</td>
</tr>
<tr>
<td>Elephant – D – 10</td>
</tr>
<tr>
<td>Oven – D – 12</td>
</tr>
<tr>
<td>Lizard – D – 17</td>
</tr>
</tbody>
</table>
Key:
S = Stimulus Items
D = Distracter Items
Serial Order
The presentation of the PCSs on the stimulus boards was presented as listed above in descending order from top to the bottom of the list for each trial (e.g., trail 3B, drawer was presented first, owl secondly, and fish thirdly).
(#) = Cell Location on Stimulus Board
Boxes on stimulus boards were numbered 1 through 16 from left to right, for each column and row (e.g., (1) was identified as first cell for column and row and (16) was identified as last cell for column and row).
# = Cell Location on Response Boards
Boxes on response boards were numbered 1 through 17 from left to right for each column and row (e.g., 5 was identified as the fifth cell from the right on the first row). Response boards were designed so that 9 PCSs were placed in each row before the 10th PCS was assigned to the second column and row.