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Research Article

Consistent Symbol Location Affects Motor Learning in Preschoolers Without Disabilities: Implications for Designing Augmentative and Alternative Communication Displays

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Purpose: Designing augmentative and alternative communication (AAC) displays that minimize operational demands is an important aspect of AAC intervention. The current study compared the effect of 2 display designs on the speed of locating target words by preschoolers without disabilities.
Method: Across 5 sessions, participants in the consistent condition (n = 12) were asked to locate symbols on arrays that did not change, whereas participants in the variable condition (n = 12) utilized arrays where the symbols changed locations each session.
Results: No difference in response time across conditions was noted during the 1st session; however, by the 5th session, participants in the consistent condition demonstrated significantly faster response times than participants in the variable condition.
Conclusions: The current study illustrated an advantage of consistent symbol location for preschoolers without disabilities. Clinical applications for incorporating consistent symbol location into AAC display design are discussed; however, replication with children who use AAC is critical.

Children who have severe speech or language difficulties rely on augmentative and alternative communication (AAC) to either supplement their speech or replace it entirely. AAC systems have been shown to support communication in young children, with interventions resulting in gains in vocabulary and grammatical development (Binger & Light, 2007; Wright, Kaiser, Reikowsky, & Roberts, 2013), as well as increases in communication turns, function, and initiation (e.g., Dicarlo & Banajee, 2000). AAC provides children with the ability to meet their communication needs, as well as development language.

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However, communication using any modality requires a variety of cognitive processing skills, including various forms of attention and memory as an individual receives and processes an incoming message and formulates and transmits a response. Aided AAC adds an element of visual processing that increases the cognitive demands (Thistle & Wilkinson, 2012). Wilkinson and Jagaroo (2004) discussed the importance of considering how AAC display design influences the visual processing of that display. They suggest that effective display design results in a reduction of the demands of learning and using AAC. Reducing the demands may allow the child to increase their operational competence, thus freeing up internal resources to allocate toward language and communication gains.

AAC display design encompasses elements such as vocabulary selection, features of the graphic representations of that vocabulary, and organization of those representations (Thistle & Wilkinson, 2015). Research related to each of these design elements has drawn on key principles both from the field of speech-language pathology and related disciplines. Typical language acquisition of word classes can inform our vocabulary selection. Although a

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child's first word is often a noun, the early lexicon of children without disabilities includes a variety of word classes (e.g., nouns, verbs, social terms; Owens, 2016). Building on this, research has shown that providing graphic symbols representing a range of word classes to children with disabilities supported their learning and use of those symbols for a variety of communicative functions (Adamson, Romski, Deffebach, & Sevcik, 1992; Light & Drager, 2005). Additional research describing word use by typically developing children illustrates the importance of providing a range of word types, especially high-frequency words that can be used across a variety of contexts (Banajee, Dicarlo, & Stricklin, 2003).

Principles of cognitive processing can inform the features of graphic representations and organization of symbols in grid-based systems. For instance, the iconicity theory suggests that more iconic symbols, which closely resemble their referent, are easier to learn than less iconic symbols; however, more iconic symbols may be less apt to generalize than those that are more generic (Schlosser & Sigafoos, 2002). Theories of visual processing have been applied to research related to the organization of symbols (Wilkinson & Jagaroo, 2004). Specifically, manipulations of the visual feature of color, both internal to the symbols and symbol backgrounds, have been studied extensively to provide evidence regarding symbol organization (Thistle & Wilkinson, 2009, 2017; Wilkinson, Carlin, & Jagaroo, 2006; Wilkinson, Carlin, & Thistle, 2008; Wilkinson & McIlvane, 2013; Wilkinson, O'Neill, & McIlvane, 2014; Wilkinson & Snell, 2011). This line of research has illustrated that clustering like-colored symbols together results in faster and more accurate search than when symbols of similar color are not grouped together and that background color did not systematically provide an organizational cue to young children.

Grid-based display organization may also be informed by principles of motor learning. Dukhovny and Thistle (2017) presented a review of motor learning principles and their potential application to speech-generating device use. Motor learning is evident when an individual has acquired motor movements that allow for the completion of a goal-directed action (Gentile, 1972). Schmidt (1975) used the term generalized motor program to describe the basic form or pattern of motor movement that occurs as a result of motor learning. In the communication sciences and disorders field, motor learning has been discussed in the context of motor speech disorders (cf. Maas et al., 2008).

Motor learning theory posits that automaticity can be acquired through repeated practice and evaluation (Fitts & Posner, 1967; Gentile, 1972). Further, individuals progress through stages of motor learning, regardless of whether that skill is learning to ride a bike, knit a sweater, touch type, or play an instrument. Specifically, when first learning a motor skill, explicit processing of task components is required. For instance, when first learning to touch type, an individual thinks about what letters are accessed with each finger. With practice, the need to consciously think of the location of each letter fades, and the individual types fluently and with little conscious effort (Fitts & Posner, 1967; Gentile, 1972). While touch typing is not a perfect metaphor given the underlying literacy skills required to type, it is possible that, much like typing, the motor act of selecting symbols on a display may require less cognitive effort with practice.

Additionally, practice schedule influences the development of motor learning, with distributed (i.e., frequent, short duration) practice being more effective than massed (i.e., infrequent, long duration) practice (Donovan & Radosevich, 1999). Research also suggests that purposeful practice results in faster motor learning than practice without functionality (Ferguson & Trombly, 1997). Consideration of these motor learning principles may inform AAC display design and intervention (Dukhovny & Thistle, 2017).

Motor Learning Applications

Motor learning theory has been applied in AAC practice. Thistle and Wilkinson (2015) reported that one third of speech-language pathologists (SLPs) surveyed consider motor learning when designing displays for their clients; however, these results may underestimate the practice, as participants were not directly asked about motor learning. Similarly, in a focus group of SLPs discussing display design for students with autism, five of the seven SLPs reported utilizing consistent symbol location for their students (Boster & McCarthy, 2018). Anecdotal and case study reports suggest motor learning in aided AAC use. Language Acquisition through Motor Planning (The Center for AAC and Autism, 2017) incorporates consistent symbol locations as one component of its approach to teaching aided AAC.

Further, preliminary research supports the application of motor learning theory in aided AAC use. Dukhovny and Zhou (2016) asked adults without disabilities to locate target symbols under two conditions: size and location. In the size condition, the size and location of the symbols changed after the initial training. This emulated the change to a layout that occurs when increasing the number of vocabulary items available on an AAC display. In the location condition, the size and location of the symbols remained constant from training to testing trials. In both conditions, during training trials, only six symbols were visible, whereas during testing trials, 40 symbols were visible. The location condition emulated the hiding, or masking, feature available on many systems. Participants demonstrated faster and more accurate selection of target symbols under the location-centered condition.

Wilkinson et al. (2014) provided both behavioral and neuroimaging data that support motor learning in visual search tasks that approximate aided AAC use. Following a brief training period, participants searched for target symbols on 16-symbol arrays. Behaviorally, participants demonstrated faster response times locating symbols when those symbols remained in a stable location during training and testing trials compared to when those symbols were shuffled across trials. Additionally, the brain imaging data showed recruitment of motor regions during the consistent conditions compared to the shuffled conditions. Together, these studies support the development of motor learning in adults during a visual search task for complex symbols.

Although there have been no empirical studies examining the development of motor learning by children using AAC, a number of studies do suggest that children with disorders that often benefit from AAC (e.g., cerebral palsy, autism spectrum disorders) do demonstrate motor learning when performing noncommunicative movements such as limb movements (Burtner, Leinwand, Sullivan, Goh, & Kantak, 2014; Dziuk et al., 2007; Thorpe & Valvano, 2002). For example, with practice, children with cerebral palsy and children with Down syndrome demonstrate improvements performing a newly learned motor movement (Burtner et al., 2014; Latash, 2007; Thorpe & Valvano, 2002). Further, children with autism show improvements in motor learning when provided with explicit instruction in the skill (Dziuk et al., 2007). These studies suggest that children with disabilities show evidence of motor learning, at least when acquiring noncommunication-related skills.

Research Questions

Given the limited empirical research exploring the effect of motor learning with children, the current study asked: What is the effect of consistency of symbol location on preschoolers' speed of locating target symbols on an AAC display? Examining this question extended the current research regarding motor learning in AAC display use in two ways. We examined motor learning in children aged 3;1 (years;months) to 5;5 and over the course of five sessions. Previous research has demonstrated motor learning in adults without disabilities, lending support for considering motor learning when designing AAC for adults with acquired disabilities. However, it is critical to identify if motor learning develops in a similar way in children. Despite research suggesting that children with developmental disabilities demonstrate motor learning, we chose to begin this line of research with children without disabilities for two reasons. First, there has been a historical precedence of mapping the effects of manipulations to AAC display designs on children without disabilities to identify the best combinations to extend to children who use AAC (e.g., Drager et al., 2004; McCarthy et al., 2006; Wilkinson et al., 2006). Second, we felt an ethical responsibility to children who use AAC to maximize our research and related intervention time with them by confirming proof-of-concept rather than asking them to utilize a display that may be counter to their goals of developing language and communication skills. Certainly, this affects the generalizability of the results, as discussed in the limitations.

Method

Participants

Two groups of preschoolers (3;1–5;5) without disabilities from the Midwestern United States participated in this study. This age range was chosen to ensure that children could complete the task. Pilot testing revealed that children under age 3 struggled to locate the target symbol in this size array and would have needed modified procedures, resulting in a loss of research control. Previous research has illustrated age-related differences in responding across a variety of dependent variables, where children under age 4 perform differently than children over age 4 (Drager et al., 2004; Light et al., 2004; Thistle & Wilkinson, 2009; Wilkinson et al., 2008). However, visual inspection of individual response times showed that regardless of age, participants showed similar trends of responding.

Of the 24 participants, 18 were female and six were male. Participants in the two experimental groups (e.g., consistent symbol location; variable symbol location) were age and gender matched. The mean chronological age of participants in the consistent group was 50.25 months (range = 37–65); the mean chronological age of participants in the variable group was 51.58 months (range = 36–64). An independent-samples t test revealed no significant difference in age, $t(22) = 0.386$, $p = .70$. Per parent report, participants had no known sensory impairments. The Preschool Language Scale–Fifth Edition Screening Test (Zimmerman, Steiner, & Evatt Pond, 2016) was used to confirm typical language development.

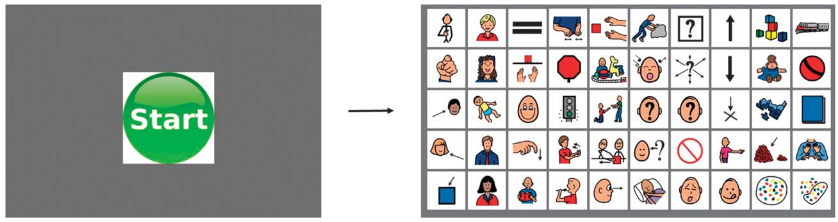
Materials

Participants completed the visual search task using a three-ring binder of stimulus pictures and a 29.2-cm touch screen tablet. Both the binder and the tablet were placed on the table in front of the participant. At the beginning of each trial, a green circle with the word *start* was located in the center of the touch screen tablet. Participants were instructed to view the target picture in the binder, then touch start, and then locate the target picture on the array (see Figure 1). Once the participant located the target, the researcher turned the page in the binder to present the next target.

Participants underwent one of two conditions: consistent and variable. In both conditions, a different target was presented for each trial, but this order of targets remained the same across all sessions. Targets were evenly distributed across grammatical categories, with two trials of each word type. In the consistent condition, the location of all symbols on the response array remained stable across trials and sessions. Boardmaker[1] (Mayer-Johnson, 2014) symbols were grouped by part of speech, with two columns of nouns (limited to people), four columns of verbs, two columns of adjectives, and two additional columns of nouns that in a sentence would function as an object (limited to toys). There were no visual cues (e.g., borders or color coding) signaling these groupings. In the variable condition, the location of the symbols on the array shuffled within the part of speech groupings, although the people

[1]Boardmaker® is a product of Mayer-Johnson, LLC, Solana Beach, CA. www.mayer-johnson.com

Figure 1. Screenshots of the touch screen tablet. Response time was measured as the time between touching the start key (a) and touching any key on the response array (b). The Picture Communication Symbols © 1981–2015 by Tobii Dynavox. All rights reserved worldwide. Used with permission. Boardmaker® is a trademark of Tobii Dynavox.



nouns shuffled only within the first two columns and the toy nouns shuffled only within the final two columns. Therefore, the location of the target was different across all trials and sessions. Clinically, it is unlikely that symbols on an array would change locations upon each use; however, the variable condition was meant to approximate and amplify the effect of symbol re-organization that often occurs when new symbols are added to a display, in order to be a clear research contrast to the consistent condition. The trade-off in ecological validity for research control is addressed in the limitations.

Procedure

Participants completed a total of nine trials each session. The 1st trial was used to demonstrate the task to the participants; therefore, average response time to locate the target was calculated based on eight trials per session. Participants underwent a total of five sessions, with an average of 3 days between each session. Due to scheduling conflicts, the range of time between sessions was 1–15 days. The two participants who had 15 days between sessions were each in different conditions. The average length of data collection period per participant (data collection sessions plus days between sessions) was 14 days (range: 6–28 days).

Response time was measured by the software (MTS-III; Dube, 1991) and represented the elapsed time from the moment the start image was touched until a symbol was touched on the response screen. During each session, researchers tracked behavioral responses on a data sheet, noting if the participant appeared distracted or made errors. Average response time was calculated for correct responses only; error trials were removed from the average response time calculation. Sessions with fewer than five correct trials were removed from analysis.

Procedural Integrity

Consistent application of procedures was ensured by training all researchers on the procedures of the experiment. A step-by-step instruction page was included with all research materials for researchers to review while conducting the experiment. Finally, research assistants collected data in teams and noted adherence to the procedures. Procedural reliability was formally calculated for 20% of data collection sessions with 99% reliability.

Analysis Plan

Data failed to meet assumptions of normality and homogeneity; therefore, nonparametric statistics were calculated to evaluate participant differences in response time. The Wilcoxon signed-ranks test, the nonparametric equivalent of the related-samples t test, was performed to determine if significant differences existed within groups across sessions. A Mann–Whitney U test, the nonparametric equivalent of the t test for independent samples, examined differences between groups at session 5.

Results

Figure 2 shows the average response time of correct trials at the 1st and 5th sessions for the two groups of participants. Regardless of group, participants had an average response time of 6.0 s during the 1st session. During the 5th session, participants in the consistent condition had an average response time of 3.3 s, whereas participants in the variable condition had an average response time of 6.0 s. During intermediate sessions (e.g., sessions 2, 3, and 4), the consistent condition was, on average, 2 s faster than the variable condition. This learning trend is apparent in Figure 3, where the average response time was faster over time

Figure 2. Average response time by group on the first and fifth sessions (error bars represent ±1 *SD*).

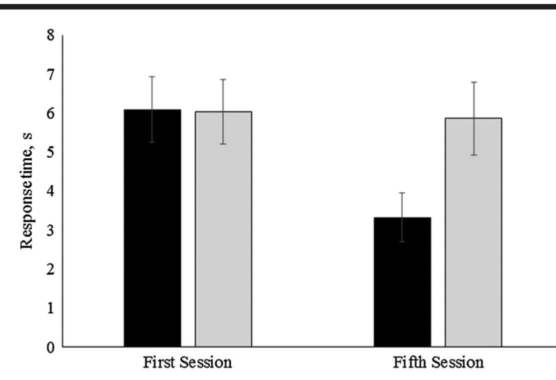
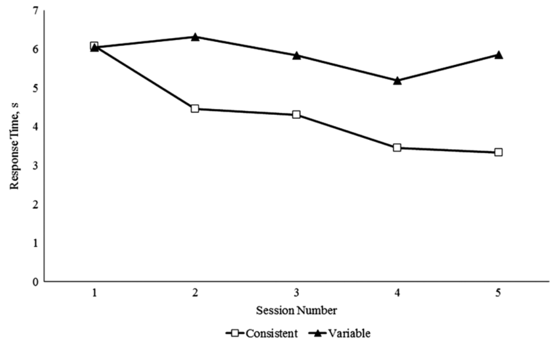


Figure 3. Average response time by group across each session.



in the consistent group and remained fairly stable in the variable group.

A Mann–Whitney *U* test revealed significantly faster response times in the consistent group ($Md = 2.7$) compared to the variable group with a large effect size ($Md = 5.3$), $U = 32.5$, $z = -2.28$, $p = .02$, $r = .47$. Wilcoxon signed-rank tests were performed to compare the performance within groups. In the consistent group, participants were significantly faster at the 5th session compared to the 1st session, $z = -2.8$, $p = .005$, with a large effect size, $r = .63$. The response time was faster from the 1st session ($Md = 5.6$) to the 5th session ($Md = 2.7$). Participants in the variable group did not respond significantly differently across the 1st ($Md = 5.1$) and 5th ($Md = 5.3$) sessions, $z = -.71$, $p = .48$, $r = .14$.

Given the small group size and individual variability that precluded parametric statistics, individual responding was reviewed to identify any responding that deviated from the group means. A comparison of the 1st-session response time to the 5th-session response times revealed that all participants in the consistent group responded faster in the 5th session than in the 1st session, with a range of 1.5–6.1 s difference. Participants in the variable group demonstrated greater individual variance, with nine participants demonstrating faster times in the 5th session than in the 1st session, ranging from 0.4 to 3.0 s. Although most variable group participants made minimal improvements in response times, it is important to note the one participant who was 3.0 s faster, on par with the advantages conferred by the consistent symbol array.

Further, the individual responding across each session was plotted to identify participants who did not follow the group pattern across each session. In each group, one third of participants (4 of the 12 per group) demonstrated a response pattern different from the larger group pattern. For instance, two participants (one from each group) responded slower each successive session. Two participants in the variable group showed initial gains (i.e., session 2 was faster than session 1), with later slow downs (i.e., session 5 was slower than session 2). The number of days between these two participants' sessions could not explain this trend, as one participant had a gap of several days between the 1st and 2nd sessions, whereas the other had a large gap between later sessions. These examples illustrate an idiosyncratic nature of the individual variability.

Discussion

The current study offers preliminary evidence that young children without disabilities demonstrate motor learning with experience locating symbols on an array. In this task, participants located target symbols faster when symbol location was held consistent across sessions than when symbol location varied. It is important to note that the study task was not communicative in nature; however, these results extend previous research with adult participants illustrating that procedural memory may be utilized in visual search tasks (Dukhovny & Gahl, 2014; Dukhovny & Zhou, 2016; Wilkinson et al., 2014). Although the search for a symbol is only one component of communicating via aided AAC, the results provide preliminary evidence toward building evidence-based practice by connecting theory (Dukhovny & Thistle, 2017) and practice (Thistle & Wilkinson, 2015) to empirical study.

The results of the current study represent a first step toward validating the application of motor learning principles to AAC display design for children. Clinicians have many decisions to make when designing AAC displays in order to provide a system that best supports the child's communicative competence (Thistle & Wilkinson, 2015). Designing a display that supports motor learning may ultimately make communication easier by moving the search for symbols from a time-consuming visual search to a subconscious automatic action. After five exposures to the materials, some participants using the variable location arrays demonstrated minimal gains in response times, perhaps suggesting some advantage of experience with the task. However, all participants using the consistent location arrays showed improved response times, with an average of a 3-s advantage. Beukelman and Mirenda (2005) estimated the average rate of aided communication to be 15 words per minute. Any design feature that contributes to increasing that rate of communication should be considered.

Clinical Implications

In conjunction with previous research (Dukhovny & Zhou, 2016; Wilkinson et al., 2014), the current study provided preliminary evidence for designing AAC displays that hold symbol location consistent over time. As with all design decisions, the child's capabilities must be taken into consideration. Holding symbols consistent represents one of many design decisions where application of one design aspect does not necessarily preclude application of other considerations. For example, when designing a display that capitalizes on motor learning, the clinician will also need to consider the child's visual and motor skills and abilities.

Consistency of symbol location should be considered when a child's needs call for an initially limited set of graphic symbols. If the child is unsuccessful when the full set of vocabulary is visible, whether the lack of success is caused by sensory, motor, or cognitive resources, limiting the number of visible vocabulary items on each page may be beneficial. One layout is what Dukhovny and Zhou (2016) termed size-centered, where the size of the symbols is determined by the number of symbols and available screen size. For example, suppose a child demonstrated greater success when symbols were limited to 10 per page, compared to 40 per page. In a size-centered arrangement, the 10 symbols would be sized to encompass the entire screen size. When the child progressed beyond the 10 symbols, new symbols would be added, and all symbols would be smaller so they could all fit on the screen. Another layout possibility, termed location-centered (Dukhovny & Zhou, 2016), holds size and location constant and is consistent with motor learning theory and the current research. A display using location-centered symbols would have placeholders for the total number of symbols to be available at some point. For the child who needs a limited set, only those symbols are visible, whereas the rest of the symbols are not visible. For the child who also has visual and motor limitations, the size of the symbol, as well as any spacing between symbols needed to reduce miss-hits, would remain the same, thus supporting visual, motor, and motor learning. The current study lends support toward using a location-centered design because as the number of vocabulary items available on the display increases, symbols are programmed or revealed, resulting in no changes to the previously learned symbols.

In order to design a location-centered display that supports motor learning, clinicians need to plan for the future, while also supporting the child's current needs. Many AAC systems allow for symbols to be hidden. When hidden, the symbol is not visible and cannot be selected, but the location in which that symbol resides on the display remains reserved. Supporting motor learning when designing paper-based systems can be accomplished by covering existing symbols, or leaving cells in the array blank. When planning intervention, the clinician will need to decide on the array size appropriate for the future and on the symbols that should be visible today and have a plan for teaching additional vocabulary.

Consideration of motor learning through consistent symbol location is also important when designing a system that has symbols included on multiple pages. For instance, symbols that support navigation, such as a symbol to return to the previous page or navigate directly to the home page should be placed in the same place on each page. Additionally, for systems that support requesting, personal pronouns and requesting verbs (e.g., want) should be placed in the same location across all pages of items the child could request.

Further, clinicians can support motor learning when designing a backup system. Regardless of the specific primary system, there are likely times when that system is either not available (e.g., technical failure) or inappropriate for the environment (e.g., high-tech system at the splash park or pool). It is critical to have a backup system ready for use during such times. A backup system that mirrors the primary system capitalizes on developed motor learning.

Limitations and Future Directions

While the current study demonstrated that preschoolers without disabilities demonstrated motor learning with repeated exposure to stable visual arrays, it is possible that children with disabilities would respond differently. Visual processing and motor challenges could influence a child's ability to locate and select symbols in a way that disrupts the motor learning. Alternatively, if such challenges only slowed the motor learning, rather than inhibited it, this would provide further support for the importance of designing a display that encouraged motor memory development. Additionally, the current study did not explore the potential relationship between linguistic skill and visual search response time. It is possible that the linguistic knowledge of the participants would be greater than their peers who use AAC may have and that this linguistic knowledge could afford a benefit in the search. For instance, it is possible that participants noticed that the symbols on the display were organized by part of speech and used that knowledge to aid their visual search. Given the differences in children with and without disabilities, future research must explore the potential development of motor memory in children who use AAC.

Additionally, research is needed to explore multiple access methods. Such research could examine if motor learning develops regardless of the access point, or how motor learning is affected by use of a stylus, eye gaze, or head pointer. In a related theme, research could examine the use of multiple access points. For example, could we capitalize on motor learning by emulating touch typing, teaching children to use multiple fingers in specific sequences and symbol locations to construct utterances? Other questions of interest may address the development of motor learning when using alternate access, including examination of differences in motor learning across scanning methods (e.g., direct, indirect, or step scanning). Research addressing these questions is important to expand our knowledge and application of motor learning to clinical practice.

This study focused on single-selection icons during a matching task, whereas most speech-generating devices require multiple selections to locate a single word. Initial evidence with adults implicates motor memory in the acquisition of multiple selections (Dukhovny & Gahl, 2014); however, future research is needed to confirm this effect in children who use AAC. Further, the current study measured responses to a matching task, which lacks the demands of communication. The generative and social demands of communication, as well as attention and memory skills involved in AAC (e.g., Thistle & Wilkinson, 2012, 2013), exceed the demands involved in locating a target to match a symbol. Further research is needed that examines the effect of motor memory development within the context of real-life communication activities. Similarly, it is important to recognize that children who use AAC are not just learning the location of symbols, but learning the language that underlies the combination of symbols. Research should explore the intersection between motor learning and language development to further our understanding of motor learning in multisymbol utterances.

Another area for additional study is maintenance of the motor learning. The current study did not measure retention of the motor skill; however, motor learning theory suggests practice is a key component to learning a skill (e.g., Fitts & Posner, 1967; Gentile, 1972), which was echoed by adults who use AAC (Rackensperger, Krezman, McNaughton, Williams, & D'Silva, 2005). Studies of limb and speech motor learning have illustrated a difference in the conditions of practice, where random practice results in greater learning than blocked practice (Brady, 1998; Wong, Whitehill, Ma, & Masters, 2013). Yet, simply practicing a skill, even under the optimal schedule, does not necessarily predict future performance of that skill. Feedback type (related to performance vs. related to results), frequency, and timing can influence the execution of a skill (see Maas et al., 2008 for discussion). Other research has demonstrated that purposeful practice results in greater retention than rote practice (Ferguson & Trombly, 1997). The current study represents an example of practice that was not purposeful, whereas using an AAC system to achieve a communication goal would provide purposeful practice. Future research should seek to describe learning and practice opportunities needed to maintain the benefits of motor learning, as it is likely these practice conditions interact.

The current study found that symbol selection is faster when symbols on the array remain in consistent locations rather than change locations across exposures. These findings may support the practice of designing AAC displays that highlight consistent symbol location. Future research is needed to validate this practice in clinical populations across a variety of communicative tasks.

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