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Manual motor-plan similarity affects lexical recall on a speech-generating device: Implications for AAC users

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ABSTRACT: Language production via high-tech alternative/augmentative communication (AAC) devices involves use of motor sequences that are determined by the visuo-spatial characteristics of a particular device. The current study uses traditional short-term memory tasks with device-based output to demonstrate that words are stored in a device-specific modality for short-term device-based recall. Clinically, these findings suggest that switching AAC devices or changing the location of symbols on a grid, as is frequently done in response to AAC-users' growing vocabulary, may be detrimental to fluency in production and to working memory load.

Keywords: AAC; short-term memory; SGDs

1. Introduction

Phonological representations of words in neurotypical talkers are shaped by spoken input and spoken output (Levelt, Roelofs, & Meyer, 1999). Phonological representations play a profoundly important role in language functioning in part because of their role in short-term memory and recall (cf. Baddeley (2003): Phonological characteristics of words, such as word length, phonological similarity of target items in word lists, and phonological neighborhood density, i.e. the number of words in the lexicon that are phonologically similar to a target word, affect short-term memory recall in neurotypical talkers (Halliday, Hitch, Lennon, & Pettipher, 1990; Jefferies, Frankish, & Lambon Ralph, 2006).

If the nature of lexical representations in short-term memory is based on phonological representations of words in typical speakers, then the nature of phonological representations in aided communicators might be radically different, reflecting the device-users' reliance on a non-speech output modality: Augmentative and Alternative Communication (AAC) methods for expressive communication involve language production via systems of graphic representations, e.g. by touching symbols on a screen, (Sutton, Soto, & Blockberger, 2002). Word production in aided AAC thus involves visuo-spatial representations, not phonological ones. Therefore, one possibility is that lexical representations in AAC users' short-term memory might be organized wholly or primarily according to non-phonological characteristics of words, based on visuo-spatial characteristics. In a previous study (Dukhovny & Soto, 2013), we asked whether individuals who used aided communication nevertheless retained phonological encoding in short-term recall of word lists. This was found to be the case. That finding raises the possibility that word form representations in AAC users, or the word recall task itself, fail to reflect the non-speech output modality altogether. If so, then word form representations of AAC users might be organized along similar lines as neurotypical talkers' representations. The aim of the current study is to determine whether lexical representations of AAC users do, in fact, reflect characteristics of the non-speech output modality. We do this by asking whether word recall patterns in individuals who use aided communication reflect encoding specific to the aided AAC device. To preview our results: we find that recall via a speech-generating device (SGD) showed effects of similarity in SGD-based production. We argue that these effects are analogous to effects of phonological similarity in neurotypical talkers, and that lexical representations in AAC users reflect SGD-based motor plans. These findings have clinical implications. Most non-speaking children begin by using "nonelectronic communication boards or simple AAC technologies" (Light & Drager, 2008), typically tools that have limited consideration for consistency of grid arrangement and icon locations. As a child's needs grow, the child may be switched to a more complex device, with the icon grid completely rearranged for access to more vocabulary. We argue that the practice of starting with simple technologies and switching to unrelated complex devices later in life may negatively affect language development by preventing development of fluency and impacting short-term memory function: changing the location of items in grids necessitates changing the lexical representation an aided AAC-user may have formed for those items.

1.1 Phonological short-term storage

One way to investigate the nature of word form representations is to test which lexical properties, and what aspects of stimulus presentation, affect short-term memory recall (Baddeley, 2003). To the extent that aided communicators' representations of word forms are shaped by their experience using a non-speech output modality, one would expect differences between typical speakers' and aided communicators' responses to short-term memory recall tasks.

In an influential model of working memory created by Baddeley (2003), short-term representation of words as phonological forms, known as the "phonological loop" and consisting of a phonological store and accompanying rehearsal function, was suggested and has been supported with research done largely through the related paradigms of non-word repetition and list recall (Gathercole & Baddeley, 1993 Ch. 1). Within list recall, findings of *phonological similarity, word length* and *articulatory suppression* effects are taken as evidence of the phonological nature of short-term word representations (cf. 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. The *word length effect* describes the pattern whereby success in short-term list recall decreases as word length increases. This effect of word length disappears when participants are asked to continuously repeat an irrelevant word during storage, resulting in the *articulatory suppression* effect. All three effects point to words being stored as phonological strings (Conrad & Hull, 1964; Hitch, Halliday, Schaafstal, & Heffernan, 1991). The relative contributions of production vs. input to phonological storage are differentiated somewhat by studies of individuals with profound speech disorders. These individuals also appear to store words phonologically (Dukhovny & Soto, 2013; Larsson & Dahlgren Sandberg, 2008), but their phonological working memory is less efficient and phonological effects are inconsistent (Card & Dodd, 2006; Carlesimo, Galloni, Bonanni, & Sabbadini, 2006; Foley & Pollatsek, 1999; Larsson & Dahlgren Sandberg, 2008), suggesting that speech production plays a role in developing robust phonological representations. The effects of production on storage are further explicated by findings indicating that short-term storage can also rely on non-phonological representations stemming from non-speech production modalities (Pa, Wilson, Pickell, Bellugi, & Hickok, 2008; Reisberg, Rappaport, & O'Shaughnessy, 1984).

1.2 Non-phonological short-term storage

The storage+rehearsal structure observed in studies of the phonological loop is not unique to storage of speech sounds. Research on short-term recall in American Sign Language has demonstrated effects very similar to those found in spoken recall, but in the signed modality (Wilson, 2001, Wilson & Emmorey, 1997, 1998 in Pa, et al., 2008). Akin to the phonological similarity effect, lists of signs with similar structures, e.g. those similar in hand shape or movement, are remembered less successfully than lists of signs with dissimilar structures. In a pattern similar to the effect of articulatory suppression, people who are forced to produce an irrelevant sign as they are remembering sign lists are less successful in sign recall. These findings point to a short-term storage mechanism available in sign language that, like phonological short-term storage, includes modality-specific storage and rehearsal. Sign-based effects on short-term recall have been found not only in deaf signers, but in hearing signers who are fluent bilinguals in English and ASL (Pa, et al., 2008). Additionally, in designs similar to the design of the current experiment, a small number of studies have used brief trainings to replicate phonological loop effects in other modalities. Reisberg, et al. (1984), trained neurotypical subjects to remember digit lists via sequences of pre-learned finger movements. Participants were given a series of digit span tasks, along with a “finger suppression” component that required subjects to drum their fingers on a table while remembering number lists. Demonstrating an effect similar to that of articulatory suppression, drumming interfered with finger-based rehearsal, though not with classic phonological rehearsal, suggesting that subjects were storing number lists via sequences of finger movements. A similar effect was achieved by Wilson and Fox (2007), who asked subjects to recall sequences of non-linguistic gestures after a one-time training. 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. Research outside of AAC suggests, therefore, that short-term storage ”loops” can be created across a range of modalities, based on task requirements. Storage in phonological form has the significant advantage of experience, and it is known that short-term phonological storage is supported by long-term phonological representations (Gathercole, Frankish, Pickering, & Peaker, 1999). Alternative production modalities introduced for experimental purposes via a single training are not likely to form lasting representations. However, long-term use of alternative production modalities may lead to formation of more stable non-phonological representations (Yang, Gallo, & Beilock, 2009). The possibility of short-term and long-term language storage in non-phonological modalities has significant clinical relevance for aided communication via speech generating devices (SGDs).

1.3 Motor plans in SGD-driven communication

SGDs, a popular and rapidly growing type of aided AAC, are electronic AAC devices with speech-generating capability, used for expressive communication by people with limited or no functional speech (ASHA, 2011). The language input received by SGD users throughout language acquisition is typically spoken, so SGD users develop and use phonological representations of words, though somewhat less successfully than typical speakers (Card & Dodd, 2006; Foley & Pollatsek, 1999). Language output via SGD, however, differs from speaking in several vital ways (Lloyd, Loncke, & Arvidson, 1999). The most apparent difference between SGD-driven production and speaking is that, unlike speaking, SGDs typically require the user to navigate through some form of graphic (picture, drawing and/or text) representation of meaning. While some devices use standard orthography, many represent language via an array of non-orthographic visual symbols, to increase rate of communication and to accommodate pre-literate users (Beukelman & Mirenda, 2005, p. 28). Graphic representations are typically placed in grids on a screen, as demonstrated in Figure 1, and organized in categories, including semantic (e.g. “transportation” or “food”), syntactic (e.g. verbs or adjectives) and/or episodic (e.g. words necessary for a medical appointment) categories (e.g. Schlosser, 1997). SGDs that allow a user to produce complex language via graphic representations typically require users to access a sequence of anywhere from one to several on-screen ‘icons’ on the grid to ‘speak’ a word. The access sequence typically reflects some form of semantic categorization and is therefore not directly correlated with the number of sounds or letters in that word. Frequently, for the sake of increasing the rate of communication, an icon or icon sequence may represent a whole phrase or sentence.

Figure 1 here.

Some strategies initially help users remember where the necessary icons are located. These strategies, some of which were used to train subjects in the current study (see section 2.4, Procedure), can be based on word meanings and semantic association. For example, Unity, a system of language organization used with the Prentke Romich brand of SGDs, uses semantic elaboration (i.e., story-telling) strategies to match a concrete picture with an abstract concept (Oxley & Norris, 2000) and semantic compaction strategies 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 characteristics of the SGD, such as color-coding groups of icons for easier visual access (e.g. 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. All of these strategies, however, are most relevant only for the initial learning phases of device use.

While organizational strategies initially help users learn the locations of items on SGDs, constant explicit visual searching for target SGD locations is cognitively very demanding. In other production modalities, such as writing and typing, the cognitive load appears to be significantly reduced when the production process is automated (Grabowski, 2010). Anecdotal evidence suggests that, just like typists, SGD-dependent communicators gain automaticity with training . Long-term users of SGDs report that they access their devices in a process akin to “blind typing,” with limited or no visuo-spatial search. In the words of one SGD user, “you could put a towel over my screen and I would still know exactly where to go for all the words” (Bidstrup & Faso, 2010). In other words, SGD-based communicators appear to develop device-specific representations of output targets.

A description of device-specific representations of words is vital to our understanding of SGD-based communication, as well as to a broader understanding of the mechanisms of language storage. The current exploratory study began to address this topic by using traditional list recall tasks to evaluate the role of device-specific representations in short-term encoding. Within traditional list recall tasks, relatively poor short-term recall of phonologically similar words has been interpreted as evidence of phonological storage (Baddeley, 2003). Likewise, relatively poor recall of signed words with similar sign structures has been taken to mean that list items were represented as signs (Wilson & Emmorey, 1997). The current study explored the effects of similarity in device-based production plan on success of short-term recall.

1.4 Current study

The purpose of this study was to look for the presence of SGD-based encoding of words during short-term list recall. One of the signature effects of phonological encoding has been the phonological similarity effect, whereby lists compiled of similar-sounding words are harder to recall. Likewise, SGD-based production plans for words can be more or less similar. Similarity in SGD-based production of words was described in this study according to several variables, including proximity of icon locations on the device screen, direction of movement between sequential access steps and number of steps in an access sequence (see section 2.2.2, Definition of motor plan similarity). Subjects' short-term memory was then assessed for lists comprised of SGD-similar and SGD-dissimilar words, recalled via SGD and via spoken response. Similarity in SGD-based production plans was predicted to decrease success of SGD-based recall, but not spoken recall.

2. Methods and materials

2.1 Participants

Twenty neurotypical adults (age 18-53, average age 23, 12 female and 8 male) were recruited via university advertisements and consent was obtained following the guidelines of the Institutional Review Board at UC Berkeley. Subjects were monolingual native English speakers who had never interacted with a SGD before.

2.2 Materials

2.2.1 Stimulus representations:

Two sets of eight black and white drawings of common objects were selected from the International Picture Naming Project (IPNP) database (Szekely et al., 2004).

Set One (dissimilar motor plans) included items with dissimilar SGD-based production sequences (see section 2.2.2, Definition of motor plan similarity). Set Two (similar motor plans) included items with similar SGD-based production sequences. Sets were comprised of one-syllable words (see Table 1) and were matched for average frequency (Brysbaert & New, 2009; Student's t-test, two-tailed, t=0.97, p=0.35, n.s.), number of phonemes (Coltheart, 1981; Student's t-test, two-tailed, t=0, p=1, n.s.) and number of steps required for production on the selected SGD (t(14)=0.37, p=0.72, n.s.). Because the SGD display is organized in part according to semantic categories, several items that shared similarities in motor plan were also semantically related. However, because the item sets were the same across output conditions, any effects of semantic similarities on recall were controlled across conditions.

Table 1 here

2.2.2 Definition of motor plan similarity:

Similarity of SGD-based access sequences (motor plans) was defined on the basis of three factors: adjacency of icon locations on the device screen, direction of movement between sequential access steps and number of steps in a sequence. Icons were defined as "adjacent" when located within ranges of three icons by three icons, except in the top row of the grid, where the range was defined as four icons by one icon. Sequential areas of access are demonstrated in Figure 2. In Unity-based language organization, the majority of access sequences representing nouns are typically completed in the top row, known as the “activity row”. The sequence of movements from range to range was maintained across stimuli, with exceptions for the exact repetition of a step and access to a “more” icon that activated a new set of icons for the top row only. SGD-based access length was limited to three and four access steps.

Figure 2 here.

2.2.3 SGD

Responses for SGD-based tasks were provided via a Vantage Lite speech generating device with the Unity language compaction system (Figure 1, ("Vantage Lite," 2012). 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. This study used the “60-sequenced” template, which is a dynamic grid consisting of sixty icon locations, designed to represent words and phrases by accessing sequences of icons. Interface settings were set to suppress written words, with only graphic representations (color line drawings) remaining on individual icons.

2.3 Design

Means of output (spoken vs. SGD) and word characteristics (similar motor plans vs. dissimilar motor plans) were manipulated as within-subjects factors, resulting in four recall tasks. Order of tasks was counter-balanced across subjects. Each recall task consisted of six lists and each list in a task had six items (Hitch, et al., 1991), resulting in

36 recall trials. Items for each list were selected at random from the set of eight (Hitch, et al., 1991; Hitch, Halliday, Schaafstal, & Schraagen, 1988) using a random number generator function in Microsoft Excel 2007 and items were never repeated within lists.

2.4 Procedure

Subjects were tested individually in a single session that lasted approximately 30 minutes. Word lists for each task were presented in slide show format on a computer monitor.

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”). Demonstration of the sequence was combined with a one-sentence narrative to facilitate initial access to the sequence (Prentke Romich, 2011). For example, the icon sequence representing “kite” was demonstrated with the narrative “in containers, we keep toys like a…” (please see Appendix: Item narratives for SGD training). 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. Pre-training 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 before beginning the recall task.

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, Chincotta, Stafford, & Turk, 2002; Larsen & Baddeley, 2003). In each condition, after two practice lists, six lists were presented for immediate recall. Subjects were encouraged to guess if they were unsure and to recall items as quickly as possible. After completing recall of six lists, subjects repeated the procedure with the next stimulus set. Responses were recorded as correct/incorrect by a student research assistant using a response key that was not visible to participants.

2.5 Scoring and data analysis

Recall success in each task was defined as the sum of items recalled in the correct serial order across six trials (Hitch, et al., 1991; Larsson & Dahlgren Sandberg, 2008). Data were analyzed using a two-factor, repeated measures ANOVA design, with factors being word characteristic (similar motor plans vs. dissimilar motor plans) and output modality (spoken vs. SGD).

3. Results

Subjects' rates of recall across the four tasks are summarized in Table 2.

Table 2 here

The analysis revealed a significant main effect of output modality ($F(1, 19) = 6.58$, $p=0.019$), though no evidence of a significant main effect of word characteristic (F (1,19)

= 1.53, p=0.231) or interaction of word characteristic and output modality (F (1,19) = 2.76, p=0.11). Fisher's LSD test (one-tailed) was then used to assess the directional prediction that recall success would be more negatively affected by motor plan similarity during SGD-based output than during spoken output. Fisher's LSD test revealed that motor plan similarity had a marginally stronger effect in the SGD output condition than in the spoken output condition (t (19) = 1.65, p=0.058, one-tailed, with significant difference defined as α=0.05). This suggests that similarity of SGD plan was selectively affecting recall conducted via SGD-based output.

4. Discussion

4.1 Summary

The results demonstrate a stronger effect of SGD-based motor plan similarity on SGD-based recall than on spoken recall. Unlike spoken recall, recall via SGD showed a negative effect of similarity in device-based production plans, akin to the negative effect typically triggered by phonological similarity. Findings of similarity, length and suppression effects in list recall have long been used to describe short term memory. Evidence of a motor plan similarity effect in the current study lends credibility to the initial definition of SGD-based motor plan similarity and paves the way for further exploration of SGD-based production and recall. The current findings suggest that, even with brief training, subjects were accessing SGD-based representations for device-driven recall. The effect of SGD plan similarity is particularly notable given the subjects' limited exposure to the SGD. It is also consistent with findings of short-term storage in other modalities, including formal signs, finger tapping and gestures (Pa, et al., 2008; Reisberg, et al., 1984; Wilson & Fox, 2007), in suggesting that phonological form is not the only option for short-term storage of words.

4.2 Limitations

Given that the stimuli were easily nameable pictures of common words, recent findings of phonological encoding in SGD-based recall (Dukhovny & Soto, 2013) and the fact that this study focused on non-disabled participants with robust phonological systems, it is likely that stimuli were also encoded phonologically. In addition, given that the study was conducted with an authentic SGD interface, where icons on the grid contain line drawings and color, it is likely that participants also benefitted from some visual cues in both conditions of SGD-based recall. Further research is necessary to determine the stage in the recall process when SGD-based representations were activated and the supporting role of internal visual characteristics of accessed icons. As suggested by an anonymous reviewer, one way to do this is by removing graphics entirely off the grid to isolate motor planning effects. A related unanswered question has to do with the minimum number of practice trials that may result in true automaticity on an SGD. In this study, participants were required to produce all SGD-based sequences without error before beginning the recall task and were asked to complete the recall task "as quickly as possible." In further research, it will be useful to collect data on rates of device-based production, akin to speech rate. Nevertheless, the specific deleterious effects of device plan similarity demonstrate that subjects were using motor production plans to conduct SGD-based recall.

4.3 Future directions

This study provides initial support for the use of motor sequences in SGD-based language production. Clinical and theoretical implications of these findings are conditional on further research that should continue to assess the relative influence of phonological, semantic, graphic and spatial properties of icons on recall rates and accuracy. If supported with further research findings, evidence of SGD-based motor plans for production will have significant practical clinical implications. As an anonymous reviewer points out, prior research in AAC design has focused primarily on facilitating visual search of the SGD interface by comparing the effectiveness of visual properties of the symbols on the grid, such as iconicity and use of color cues (Thistle & Wilkinson, 2009). Developing motor plan automaticity is a complementary and, in later stages of device use, possibly more efficient, approach to reducing the cognitive load of production (Grabowski, 2010). If SGD-based production quickly becomes automatic, as the current study suggests, one implication is that, with continued SGD use, location of symbols on a grid becomes more relevant to fluent SGD production than the internal visual characteristics of the symbols. Therefore, in planning SGD design and intervention, location of symbols on the AAC device, and the resulting motor plans for accessing symbols, must be taken into account along with visual considerations.

The findings of this study are relevant to a discussion of effects of automaticity on language learning and production in AAC that is just beginning to emerge (AAC and Autism, 2011). As far back as 2008, best practices suggested that “future research is required to redesign AAC technologies […], specifically to […] reduce the learning demands through utilization of developmentally appropriate representations, organizations, layout, navigation, selection, and output (Light & Drager, 2008)." Currently, though at least one major producer of SGDs presents automaticity of production as an end goal in the use of a device (Prentke Romich, 2011), most SGD producers do not take motor learning into account. This is particularly true in the large market for SGDs with capacity for anywhere between a handful and several hundred icons. There is little to no discussion of motor learning with these devices, nor of the cognitive load that may be invoked if users switch to more complex unrelated devices later in life (e.g. AttainmentCompany, 2013). Evidence of automaticity in SGD-based production would speak in favor of introducing devices with adult-like language capacity earlier in a user's life, to allow the user to maintain automaticity of production.

Evidence of device-based motor representations also raises questions about the characteristics of SGD-based storage and its relationship with phonological storage. Phonological encoding is present even in SGD-based recall (Dukhovny & Soto, 2013), while SGD-based encoding in the current study was limited to SGD-based recall and did not affect spoken recall. With greater exposure, however, representations of alternative production modalities may penetrate other language functions. For example, fluent typists are affected by keyboard-specific motor plans for words even when they do not have a keyboard in front of them (Beilock & Holt, 2007; Yang, et al., 2009)   . Phonological representations have a range of well-described characteristics that affect language storage and processing, including quicker access to words with certain phonological properties (Gathercole, et al., 1999). Individuals who need AAC for communication secondary to profound developmental speech disorders frequently demonstrate signs of inefficient or impaired phonological storage (Card & Dodd, 2006; Carlesimo, et al., 2006; Larsson & Dahlgren Sandberg, 2008). Further description of the properties of device-based word representations and their relationships with phonological representations may provide opportunities to support or compensate SGD users' phonological storage with comparable storage in alternative modalities.

Appendix

Item narratives for SGD Training

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 ____.

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