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Visual and auditory verbal long-term memory in individuals who rely on augmentative and alternative communication

Michal Icht¹, Yedida Levine-Sternberg¹ and Yaniv Mama²

¹Communication Disorders, Ariel University, Ariel, Israel; ²Behavioral Sciences and Psychology, Ariel University, Ariel, Israel

ABSTRACT
Augmentative and alternative communication (AAC) technologies provide individuals who have complex communication needs with an effective means to communicate. Yet the effect of these technologies on long-term memory is unclear. In addition, little is known regarding the impact of learning modality on memory performance of individuals who rely on AAC. The aim of this study was to explore the effect of AAC technologies on the visual and auditory verbal long-term memory abilities of 12 young persons who relied on AAC and had intact cognitive abilities. Participants performed 2 verbal memory tasks, in which familiar words were visually or aurally (i.e., auditorily) presented. The words were either actively produced using the AAC system or not produced (merely read or heard; a production effect paradigm). Memory tests followed. A production benefit (higher recognition rates for produced than no-produced words) was documented in both the visual and the auditory tasks. These findings support the active production of words via the AAC system as a memory strategy. Such technique may be easily used in everyday situations as well as in educational contexts. The results showcase the cognitive benefits of AAC system usage and provide significant insights into rehabilitation.

Introduction
Augmentative and alternative communication (AAC) techniques may serve to enhance receptive and expressive communication in individuals with severe speech and language impairments (Millar, Light, & Schlosser, 2006; Roth & Cassatt-James, 1989; Schlosser & Wendt, 2008); however, the effect of AAC use on cognitive abilities in general, and on long-term memory functioning in particular, is not clear. Memory is a key aspect in cognitive functioning and is vital for various experiences (Eysenck, 2012; Larsson & Dahlgren Sandberg, 2008). It can be described as a complex system that is made up of a sensory processor (iconic memory in vision and echoic memory in audition), short-term (or working) memory, and long-term memory. Research provides evidence that these sub-systems are related to one another, with the output from one system providing input to another (e.g., Serial, Parallel, Independent, or SPI; model; Tulving, 1995).

The literature concerning memory abilities of adults who rely on AAC typically describes memory impairments and limited memory capacity (Larsson & Dahlgren Sandberg, 2008; Parker, 1987; Taibo, Iglesias, Raposo, & Méndez, 2010). The high prevalence of memory impairments in these individuals is not surprising, given the fact that, in many cases, they have severe congenital physical and speech impairments that are associated with underlying brain damage (e.g., cerebral palsy; Smith, 2001, 2003). In addition, they may lack articulatory ability, and thus have a reduced sub-vocal rehearsal mechanism (i.e., silently rehearsing sounds or words in a continuous loop, "refreshing" items in the phonological store), which is necessary to prevent verbal information from decaying. As a result, their phonological working memory is impaired (Baddeley, 2002; Baddeley & Hitch, 1974; Smith, 2003). Possibly, the speech impairments and the ensuing inability to use the articulatory loop adversely affect construction and storage of phonological units and reduce the temporary retention of phonological sequences. This may lead to indistinct phonological representations that easily fade, negatively affecting the development of verbal memory abilities. Indeed, several studies have shown that individuals with profound speech disorders demonstrate less efficient phonological working memory (Card & Dodd, 2006; Carlesimo, Galloni, Bonanni, & Sabbadin, 2006; Foley & Pollatsek, 1999; Larsson & Dahlgren Sandberg, 2008) and reduced memory capacity for verbal material (Roth & Cassatt-James, 1989; Smith, 1992).

It can be assumed that a likely outcome of limited working memory abilities is long-term memory difficulty (Mann & Brady, 1988). Take, for example, an individual who uses a speech-generating device (SGD) with a set of permanently placed icons (picture, drawing and/or text). These graphic representations are typically placed in grids on a screen, and the SGDs typically require the user to navigate through the icons to represent meaning (Dukhovny & Soto, 2013). SGDs that allow for the production of complex language require users to select a sequence of icons on the grid to utter a word or a sentence. Successful use of such devices (i.e.,
accurate message retrieval) requires the user to memorize the available messages, learn the associations between the icons and the related messages (notably, sometimes several graphic representations cue the same ideas), and remember related information such as the locations of different symbols on the screen (Oxley & Norris, 2000). There is some evidence that experienced users of SGDs gain automaticity with training, and that they access their devices in a process comparable to blind typing (Dukhovny & Gahl, 2014). It can be assumed that long-term memory abilities play a role in such automaticity of production, and that poor auditory (verbal) memory abilities due to weak phonological representations may negatively affect SGD use. However, to the best of our knowledge, there has not been a direct evaluation of such capabilities, and despite the importance of long-term memory in daily functioning (as well as in rehabilitation), the literature seems silent on long-term memory abilities of individuals who rely on AAC.

Another important issue regarding memory performance of individuals who rely on AAC concerns the learning (or study) modality. In everyday life, informal as well as formal learning occur via several sensory modalities. Some of the information is available visually (e.g., written texts, graphs, or pictures). Other learning materials are aurally presented (e.g., oral presentations, or radio broadcasts). In many situations, multi-modal information is presented (i.e., auditory and visual; for instance, video clips). The literature indicates that learning modality affects long-term memory performance. Specifically, the long-term modality effect (Conway & Gathercole, 1987) refers to superior recall of recent information; for instance, video clips). The literature indicates that learning modality affects long-term memory performance. Specifically, the long-term modality effect (Conway & Gathercole, 1987) refers to superior recall of recent information (e.g., written texts, graphs, or pictures). Other learning materials are aurally presented (e.g., oral presentations, or radio broadcasts). In many situations, multi-modal information is presented (i.e., auditory and visual; for instance, video clips). The literature indicates that learning modality affects long-term memory performance. Specifically, the long-term modality effect (Conway & Gathercole, 1987) refers to superior recall of recent information presented aurally compared with recent information presented visually (Glenberg, 1984).

This relationship between learning modality and long-term memory performance is relevant in many learning situations and is highly important for individuals who rely on AAC. The generally severe nature of their speech and language deficits necessitates effective educational and intervention programs, which involve a careful selection of the most appropriate learning modality. This is of special importance for those with sensory impairments, which greatly restrict the ability to learn through visual or auditory input. Many individuals who require AAC are at risk for visual impairments (e.g., loss of visual acuity, loss of visual field, reduced contrast sensitivity; Kovach & Kenyon, 2003), while others have hearing impairments as a secondary disability (Binger & Light, 2006). Consequently, they are likely to experience severe limitations in learning. Identifying the superior learning modality for these individuals is important to ensure effective intervention, especially because multi-modality is not always preferred over one modality for these learners (Alant, Bornman, & Lloyd, 2006). In fact, many aided AAC systems rely on the visual modality, such as a communication boards, manual signs, or gaze communication (Wilkinson & McIlvane, 2013). As such, visual information processing may be more strongly developed than auditory information processing in individuals who rely on AAC (Laws, 2002).

Another factor that may affect memory performance of individuals who rely on AAC is the use of memorization techniques (or mnemonics) to improve memory functioning and compensate for memory deficits (Light & Lindsay, 1991). Because memorization and remembering constitute basic and essential functions for daily performance, learners actively use mnemonic devices, which are learning aids to improve memory (Carlson, Heth, Miller, Donahoe, & Martin, 2009). Mnemonics make use of elaborative encoding, retrieval cues, and imagery as tools to encode information in a way that allows for efficient storage and later retrieval. Commonly used mnemonics are often verbal, but may also be visual, kinesthetic, or auditory. For example, children remember the alphabet by singing the ABCs (music mnemonics). Mnemonics use is considered effortful and requires motivation and attention. Yet, with practice and training, strategy use may become easier and even automatic, and a learner may be able to successfully apply more complex and sophisticated strategies (Flavell, 1970; Makela et al., 2019). Given the key role of mnemonics in learning, identifying suitable memory enhancement strategies and practicing to allow strategy mastery are important for learners as well as for educators.

Learning to effectively use mnemonics that can assist in new learning is necessary for individuals who rely on AAC, as memory strategies may be used as facilitators to compensate for limitations in the size of working memory and possible long-term memory deficits (Light & Lindsay, 1991). For example, for an AAC user, selecting an icon on the SGD for feedback can serve the function of simple rehearsal. Reviewing the icons systematically over multiple trials (to discover and learn which messages are available) is analogous to repeated verbal rehearsal. Organizational strategies (e.g., clustering, sorting, and categorizing) are analogous to sorting SGD messages into groups (for a review of memorization strategies applicable to SGD use, see Oxley & Norris, 2000).

In recent years, vocal production (i.e., saying words aloud) has been suggested as an effective mnemonic device, which can easily be used with significant memory benefits. The memory benefit of produced items relative to no-produced items (e.g., reading silently) has been referred to as the production effect (Icht & Mama, 2019; MacLeod, Gopie, Hourihan, Neary, & Ozubko, 2010). Many types of active productions (e.g., mouthing, writing, typing; Forrin, MacLeod, & Ozubko, 2012; Mama & Icht, 2016a) improve subsequent retention of produced items relative to no-produced items. Typically, with visually presented material, vocal production was found to yield the highest memory gain compared to other unique productions (Bodner & MacLeod, 2016). For many learners, saying aloud is a very simple act, performed easily, naturally, and effortlessly, thus vocalization of the relevant portion of the study material has been offered as a memorization strategy (Mama, Fostick, & Icht, 2018; Ozubko, Hourihan, & MacLeod, 2012). Over the last decade, the production effect has been documented in individuals across the life span, from preschool (Icht & Mama, 2015) through late adulthood (Lin & MacLeod, 2012). Vocal production was found to enhance memory for special populations,
such as adults with attention-deficit disorder (Mama & Icht, 2019) and hearing-impaired individuals (Taitelbaum-Swead, Icht, & Mama, 2017; Taitelbaum-Swead, Mama, & Icht, 2018). It was found to enhance memory even for individuals for whom speech presents a challenge (e.g., adults with acquired dysarthria; Icht, Bergerzon-Biton, & Mama, 2019).

Much of the research suggests that the mechanism underlying the production effect is encoding distinctiveness (or a distinctiveness heuristic, a response mode based on participants’ awareness that a positive recognition decision should include recollection of distinctive details; Forrin et al., 2012; MacLeod et al., 2010). According to this approach, the memory benefit results from deeper and broader encoding of the produced words at study. Namely, vocalization involves more distinct encoding processes (visual, motor and auditory processing) relative to silent reading, which involves only a single process (visual). The larger the number of unique encoding processes occurring in learning, the greater the memory advantage (Forrin et al., 2012; Mama & Icht, 2016a; Mama & Icht, 2018). Note, various active learning strategies, which involve participation and engagement in the learning process, typically result in enhanced memory and improved learning outcomes relative to passive learning (for related findings in the context of AAC, see: Gregory, Soderman, Ward, Beukelman, & Hux, 2006).

Given the simplicity of vocal production, along with its consistent memory advantages, the purpose of this study was to assess the effectiveness of this memory strategy on long-term verbal memory performance of individuals who rely on AAC (with no diagnosis of cognitive impairments). Because it has been hypothesized that long-term memory performance depends on the presentation mode of the study items (Conway & Gathercole, 1987), the participants’ performance in the visual and the auditory modalities was compared. The following research questions were asked: (a) does production using the AAC system improve long-term verbal memory for individuals who rely on AAC, and (b) what is the superior learning modality for this group of learners is, visual or auditory. In order to answer these questions, a modified version of the production effect was used, in which half of the study material was produced by the AAC system (direct selection of the word’s letters on the SGD grid and subsequent voice output) while the remaining half was learned by no-production (silent reading or hearing), followed by a memory test (visually presented recognition test). Based on previous results (Icht, Ben-David, & Mama, 2020a; Icht et al., 2019; Icht & Mama, 2015; Mama & Icht, 2016a; Wilkinson & McIlvane, 2013), a significant production benefit was expected, with superior memory performance in the visual modality.

Method

Participants

The participants for this study were 12 individuals (eight males and four females) with complex communication needs who did not have a cognitive impairment (aged between 9 and 32 years; $M = 20; SD = 8$ years). All were experienced users of a SGD as their primary method of communication, with high perceived ease of use (per self- and speech-language pathologist-, SLP-, report). All met the following inclusion criteria: (a) had used a virtual standard QWERTY keyboard on their SGD (iPad, or computer with or without eye-gaze technology) for at least 2 years; (b) had used a form of direct selection to formulate messages (e.g., pointing at or touching the screen or using eye-tracking technology); (c) spoke Hebrew as their only or dominant language; (d) had at least basic literacy skills (all were able to recognize letters and to correctly spell familiar and short words out of context, per SLP report), all past or present students of the special education system; (e) had not been diagnosed with a cognitive impairment, per educational and clinical records; and (f) had vision and hearing within normal limits, with or without correction, per medical records.

Exclusion criteria were: (a) hearing loss greater than 30 dB (affecting ability to hear auditory stimuli); (b) visual impairments not correctable with glasses (imparing ability to see visual stimuli clearly); and (c) cognitive impairments or difficulties to follow study instructions.

Of the 12 participants, eight had an estimated cognitive function within the normal range (according to their medical and educational records, and general level of function in everyday life), and four were judged to have a learning disability. Five had vision within normal limits, and seven had a visual impairment and used glasses. A single participant had hearing impairment and used a bone-anchored hearing aid. Seven participants were non-speaking and five had minimal functional speech with very low intelligibility, per SLP report. Note, the non-speaking participants were included since the production conditions did not involve speech (verbal production) but producing the target word using the AAC device (selecting the word’s letters on the SGD grid). Literacy skills were assessed by the SLPs, based on spelling abilities (for regular and irregular words, high and low frequency words), and on reading comprehension, and by parental or self-report on reading habits (e.g., reading novels or newspapers, home computer use, including e-mails, Facebook, etc.). Literacy level was scored on a 4-point scale, by SLPs (1: basic literacy level, could write and read in about the 4th grade level; 2: 7/8th-grade level; 3: 11th/12-grade level; 4: high or adult literacy level; see: Bar-On, 2011). Two participants scored 2, five scored 3, and five scored 4. Participants’ characteristics are presented in Table 1.

The second author contacted SLPs who work in the field of AAC via e-mail, informed them regarding the study and its goals and asked for their assistance in the recruitment of appropriate participants (present or former clients). The SLPs contacted 15 parents or legal guardians, who also received written and oral information about the study. Of the 15, 12 provided oral consent for their child to participate and were subsequently invited to attend a meeting about the study in their home, in which their written consent was obtained. All participants gave their consent (orally for those participants
Table 1. Participants’ background data.

<table>
<thead>
<tr>
<th>No.</th>
<th>Age (years), Gender</th>
<th>Etiology</th>
<th>Cognition and sensory status (vision and hearing)</th>
<th>Speech production abilities and literacy level*</th>
<th>AAC system</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9, M</td>
<td>Spinal Muscular Atrophy</td>
<td>Normal cognitive function, normal vision with glasses, normal hearing</td>
<td>Non-speaking, literacy level = 3 (above grade level)</td>
<td>Eye-tracking technology with virtual keyboard</td>
</tr>
<tr>
<td>2</td>
<td>12, F</td>
<td>Cerebral Palsy</td>
<td>Normal cognitive function, normal vision with glasses, normal hearing</td>
<td>Non-speaking, literacy level = 4</td>
<td>Eye-tracking technology with virtual keyboard</td>
</tr>
<tr>
<td>3</td>
<td>25, M</td>
<td>Cerebral Palsy</td>
<td>Normal cognitive function, normal vision, normal hearing</td>
<td>Non-speaking, literacy level = 3</td>
<td>Computer with special hand typing keyboard</td>
</tr>
<tr>
<td>4</td>
<td>26, M</td>
<td>Cerebral Palsy</td>
<td>Normal cognitive function, normal vision, normal hearing</td>
<td>Non-speaking, literacy level = 4</td>
<td>Eye-tracking technology with virtual keyboard</td>
</tr>
<tr>
<td>5</td>
<td>28, M</td>
<td>Cerebral Palsy</td>
<td>Normal cognitive function, normal vision, normal hearing</td>
<td>Non-speaking, literacy level = 3</td>
<td>Computer with special hand typing keyboard</td>
</tr>
<tr>
<td>6</td>
<td>28, M</td>
<td>Primary Lateral Sclerosis</td>
<td>Learning disability, normal vision with glasses, normal hearing</td>
<td>Non-speaking, literacy level = 2</td>
<td>Eye-tracking technology with virtual keyboard</td>
</tr>
<tr>
<td>7</td>
<td>29, M</td>
<td>Cerebral Palsy</td>
<td>Normal cognitive function, normal vision with glasses, normal hearing</td>
<td>Non-speaking, literacy level = 4</td>
<td>Eye-tracking technology with virtual keyboard</td>
</tr>
<tr>
<td>8</td>
<td>10, M</td>
<td>Rubinstein–Taybi Syndrome</td>
<td>Learning disability, normal vision with glasses, mild hearing impairment with bone-anchored hearing aid</td>
<td>Minimal speech productions, low intelligibility, literacy level = 4</td>
<td>iPad keyboard (touch screen)</td>
</tr>
<tr>
<td>9</td>
<td>14, F</td>
<td>Cerebral Palsy</td>
<td>Learning disability, normal vision with glasses, normal hearing</td>
<td>Minimal speech productions, low intelligibility, literacy level = 2</td>
<td>iPad keyboard (touch screen)</td>
</tr>
<tr>
<td>10</td>
<td>14, F</td>
<td>Cerebral Palsy</td>
<td>Learning disability, normal vision with glasses, normal hearing</td>
<td>Minimal speech productions, low intelligibility, literacy level = 3</td>
<td>iPad keyboard (touch screen)</td>
</tr>
<tr>
<td>11</td>
<td>14, F</td>
<td>Cerebral Palsy</td>
<td>Normal cognitive function, normal vision, normal hearing</td>
<td>Minimal speech productions, low intelligibility, literacy level = 4</td>
<td>iPad keyboard (touch screen)</td>
</tr>
<tr>
<td>12</td>
<td>32, M</td>
<td>Pelizaeus-Merzbacher Disease</td>
<td>Normal cognitive function, normal vision, normal hearing</td>
<td>Minimal speech productions, low intelligibility, literacy level = 3</td>
<td>iPad keyboard (touch screen)</td>
</tr>
</tbody>
</table>

*Literacy level was scored on a 4-point scale, per SLP report, from 1 (basic literacy level; could write and read in about the 4th grade level) to 4 (high or adult literacy level).

with speech ability, or by typing on their SGD keyboard for the remaining non-speaking participants) and received a gift-card of the equivalent of 25 US dollars for participation.

All participants were tested individually in a quiet room in their home, accompanied by two research assistants (Speech-Language Pathology students) blinded for study goals. During the experimental session, the SGD and the experimental laptop computer were positioned in front of the participant (on a desk or on the wheelchair tray; see Figure 1). One of the research assistants was seated next to the participant, controlling the task and test presentation, and the other one coded the participant’s responses.

Research design

This study utilized a quantitative approach to evaluate visual and auditory verbal long-term memory of individuals who rely on AAC. A visual depiction of the research design is presented in Figure 2. Each participant performed two experimental tasks, visual and auditory, in a counterbalanced order. In each task, 30 study words were visually or aurally presented, 15 to be produced by the AAC system and 15 to be read silently or heard (no-production conditions), in random order. Presentation of stimuli was controlled by a research assistant. Following each study phase, the participants performed a yes/no recognition test (visually presented). The dependent variable was recognition rate (hit rates, that is the probability of responding “yes” to words that were actually studied, calculated by the number of correctly recognized words, as coded by the research assistant, divided by the total number of words presented at test), and the independent variables were the learning modality (visual, auditory), and the learning condition (production, no-production). Analysis was conducted using a within subject design, $2 \times 2$ repeated measures ANOVA. This study was approved by the institutional ethics committee of the authors’ institution.

Materials

The pool of study words consisted of 120 familiar four-letter Hebrew disyllabic concrete nouns, with frequencies of greater than 12 per million (e.g., “Cat”, “Orange”, “Cabinet”, taken from: Mama & Icht, 2016b, Mama & Icht, 2019). The similar word length (two syllables, four letters) was important to equate the presentation as well as the production procedure (selecting the letters of the target words in the production condition). These words were pronounced by a male
speaker and recorded in a professional radio studio using the Samplitude classic 8.1 program and a TCS-6 microphone. From this pool, a random sample of 30 words was selected for the visual task and a different sample of 30 words was selected for the auditory task, for each participant. The remaining 60 words were used as distractors in the memory tests.

For the visual learning condition, the 30 written words were presented one-by-one at the center of a 15-inch (38 cm) laptop computer. The words were presented in 28-point Arial black font (a familiar, large, and legible font) against a white background. For the auditory learning condition, 30 words were aurally presented, one by one, via personal computer speakers connected to the laptop computer, each located at the height of the listener’s head on either side. The words were played at a comfortable level, controlled by a research assistant.

In each experimental trial, visual and auditory, a small visual symbol (sized 3 × 3 cm/1.18 × 1.18 inch) appeared at the upper part of the computer screen (above the written study word for the visual task, or solely for the auditory task). The symbol indicated the appropriate learning condition for each word; a KEYBOARD symbol indicated production by the AAC system. In this condition, participants were instructed to spell the target word using their personal SGD keyboard. They were asked to “type” all four letters, even if word prediction feature was available. Typing the word was followed by an auditory voice output (speech) generated by the device. An EYE symbol indicated silent reading (no-production condition for the visual task), and an EAR symbol indicated listening (no-production condition for the auditory task).

**Procedures**

As a first step, the participants heard a brief description of the experiment. They were required to learn each word according to the visual symbol (a KEYBOARD, an EYE, or an EAR symbol), and were told that a memory test would follow. Then, the first experimental task (visual or auditory, in a counterbalanced order) began. One of the experimenters
(research assistants) sat next to the participant (both viewing the computer screen) controlling the test presentation by pressing the spacebar at the end of each experimental step. To verify that participants understood the task, and to reduce the likelihood of participants’ errors, a short practice phase was completed, in which the word “Example” appeared twice in each learning condition (production and no-production). Each experimental step began with the visual presentation of a visual symbol (a KEYBOARD, an EYE, or an EAR) for 1 s. Then, the study word was visually or aurally presented. In the production conditions, the symbol (with the written word for the visual condition, or solely for the auditory condition) remained visible until the participant finished typing the word, and then the word was generated by the SGD (voice output). The research assistant controlled the presentation rate using a digital timer and confirmed that the presentation duration was approximately similar for the produced and no-produced words for each participant (i.e., the presentation times of the non-produced words were equated to those of the produced words; note, since all words were four letters in length, production times were highly comparable). Following a 1 s blank screen, the next experimental step began. The research assistant ascertained the accuracy of responses: “typing” in the production conditions, silent reading or listening in the no-production condition (no errors occurred for both study modalities). After completion of the presentation of the study list (the first 30 words), participants were given a 5 min break.

Then, the participants performed the yes/no recognition test. A total of 60 words were visually presented: 15 produced words from study, 15 no-produced words from study, and 30 new words from the original pool. The 60 written words were presented at the center of the computer screen one at a time in random order (under the control of the DirectRT program). Words remained visible at the center of the screen until the participant responded (yes or no). One of the experimenters controlled the rate of the test presentation by pressing the spacebar. Another experimenter coded the participants’ responses. Due to individual differences in response times, the test was conducted without a time limit. Following the first task, participants were given a 10 min break, and the second task (visual or auditory) began, in a similar procedure – practice, study phase, and memory test. The whole experimental session lasted up to 1 hr.

**Data analysis**

**Selected measures**

The production effect literature suggests that analyzing recognition memory should include both hit rates and false alarms (FAs) and a signal detection measure of memory discrimination (d') which takes into account the combined effects of both factors (Fawcett, 2013). A dependent sample t-test between the auditory and the visual tasks indicated that FAs did not differ between the two tasks (visual task: M = .11; auditory task: M = .06; t(11) = 1.1, p = .15). Because the current study used a mixed-list design, FAs and d’ could not be compared across the conditions in each task (separate FA rates for the produced and no-produced study items cannot be obtained from such experimental design; Forrin, Groot, & MacLeod, 2016), therefore, these comparisons were avoided, and the study focused on comparison of hit rates.

**Testing data distributions for normality**

Data normality was tested using the Shapiro–Wilk test (for a similar procedure, see: Icht et al., 2020b), which showed that overall memory performance (hit rates) followed normal distribution (p = .76).

**Assessing possible effects of age and type of AAC device operation**

For each participant, a general memory score (a composite of hit rates for produced and no-produced words) was calculated. Participants were divided into two sub-groups according to their age, and an independent sample t-test was performed to compare the general memory scores between the groups. Similar analysis was conducted to reveal possible effect of type of AAC device operation (aided direct selection vs. unaided pointing), again dividing the participants into two sub-groups and comparing their general memory scores.

**Main analysis**

To test the difference in performance between the two modalities and learning conditions, a 2 × 2 repeated-measures analysis of variance (ANOVA) was conducted, with learning modality (visual, auditory), and learning condition (production, no-production) as within-subjects variables. All analyses were performed with IBM SPSS 24.0 software.\footnote{DirectRT program 4 v. 2016 is a software from Empirisoft which enables stimulus presentation (visual and auditory).}
Results

Figure 3 presents the results of the recognition tests (hit rates) for the produced and no-produced word, for the visual task (left panel; Produced words: $M = .82$, $SD = .18$; No-produced words: $M = .61$, $SD = .22$) and for the auditory task (right panel; Produced words: $M = .93$, $SD = .09$; No-produced words: $M = .59$, $SD = .21$).

Given the wide age range of the participants (9–32 years), as a first step it was verified that age did not affect memory performance. We divided the participants into two subgroups according to their age, 9–14 years ($n = 6$) and 15–31 years ($n = 6$). For each participant, we calculated a general memory score, which is a composite of hit rates for produced and no-produced words. An independent sample t-test revealed no difference in overall memory performance between these sub-groups, $t(10) = .626$, $p = .546$. Similar analysis was conducted in order to compare overall memory performance between the sub-group of participants who used aided direct selection (eye-tracking technology with virtual keyboard, $n = 5$) vs. unaided pointing (special hand typing keyboard or iPad keyboard, $n = 7$). An independent sample t-test revealed no difference in memory performance between these sub-groups, $t(10) = 3.24$, $p = .752$.

A 2 x 2 repeated-measures analysis of variance (ANOVA) with learning modality (visual, auditory), and learning condition (production, no-production) as within-subjects variables, indicated a significant main effect for learning condition, $F(1,11) = 38.732$, $p < 0.001$, $\eta^2_p = 0.779$. No main effect for learning modality was found, $F(1,11) = 1.916$, $p = 0.194$, $\eta^2_p = 0.148$, nor a learning condition X learning modality interaction, $F(1,11) = 2.245$, $p = 0.162$, $\eta^2_p = 0.169$.

Discussion

Studying memory abilities in individuals with complex communication needs is of theoretical and clinical significance. On the one hand, many individuals who rely on AAC, regardless of etiology, show memory difficulties (Larsson & Dahlgren Sandberg, 2008; Taibo et al., 2010). Presumably, their impaired articulatory system negatively affects their sub-vocal rehearsal mechanism, resulting in reduced phonological working memory (Smith, 2003). On the other hand, the use of an AAC system poses various memory-related challenges, such as remembering arrays containing large numbers of symbols and navigating to locate symbols that are temporarily hidden from view (Light et al., 2019; Mizuko, Reichle, Ratcliff, & Esser, 1994; Thistle & Wilkinson, 2013). Clearly, memory difficulties can impair the ability to use the AAC device easily and effectively.

Given the important role of memory abilities in daily life, the current study aimed to investigate verbal long-term memory performance in individuals with complex communication needs who rely on AAC (with no diagnosis of cognitive impairments). The study tested whether producing study words by the AAC device (“typing” the word to generate a voice output) improves their memory in visual and auditory modalities. Using unimodal presentation of the study items enabled an assessment of the underlying verbal memory processes in each modality separately, eliminating possible modality-based biases (Penney, 1989). Participants were presented with lists of words – half of them learned by production, and half by no-production. Following the study phase, memory tests were performed. The results indicated production benefits (i.e., higher recognition rates for produced than no-produced words, in both study modalities, visual and auditory). The size of the production effect was similar across visual and auditory modalities.

The benefits of studying by production

The first finding of the current study is the production effect. It has been defined by Bodner and MacLeod (2016) as “… enhanced memory for materials that were given unique productions during study relative to materials that were not produced” (p. 89). Indeed, various studies on the production effect have shown that the simple act of producing study materials (e.g., vocalizing) yields significant memory benefits (Forrin et al., 2012; Mama & Icht, 2016b). The current results show a similar pattern using production by the AAC device in a group of individuals with complex communication needs.

The significance of the findings is twofold: First, they contribute to the understanding of the production effect, and extend its boundaries to another type of production and to another special population. Second, and more importantly, they provide insights into verbal long-term memory abilities of individuals with complex communication needs who rely on AAC. Namely, the superior memory performance for produced relative to no-produced words indicates that actively using the AAC system enhances verbal long-term memory performance.

The current findings extend our knowledge of the possible broader gains of AAC techniques, suggesting that an active AAC use may enhance memory performance for individuals with complex communication needs with preserved cognitive abilities. It complements previous studies that showed that AAC use may serve to improve language comprehension and expression in individuals with complex communication needs (e.g., autism spectrum disorder or developmental disabilities; Millar et al., 2006; Roth & Cassatt-James, 1989; Schlosser & Wendt, 2008).

The memory benefit of words produced by the AAC device can be accounted for by several theories. The prevailing encoding distinctiveness account (Bodner & MacLeod, 2016; MacLeod et al., 2010) suggests that the higher distinctiveness of the produced words relative to the backdrop of the no-produced words at the time of encoding underlies their better memorization at the time of test. Having produced some words makes them distinctive by virtue of their having an additional dimension of encoding. Producing words by the AAC device involves various distinct or unique encoding processes: visual scanning of the keyboard, motor action to select the target letters, and auditory process of...
hearing the voice output generated by the device. In contrast, silent reading or listening (no-production conditions) comprise only a single encoding process, visual or auditory, respectively. At the time of test, participants can use retrieval of the fact that they produced a word during study to certify it had appeared before, resulting in enhanced memory for produced words.

Another possible explanation for the production benefit may be related to the high levels of difficulty and effort involved in the act of production, especially as many users are motor impaired. Given these impairments, forming a message through an AAC system by typing or scanning a virtual on-screen keyboard is a complex and cumbersome task (relative to speech), presenting multiple and unique motor and cognitive demands (Kühn & Garbe, 2001; Light & Lindsay, 1991). The desirable difficulties account (Bjork, 1994, 1999) posits that effortful encoding methods, which impose difficulties at the study phase, enhance long-term memory (retention). According to this view, learning that is more demanding and effortful activates encoding and retrieval processes that increase later remembering (Bjork & Bjork, 2011). The current results suggest that the effort of production by the AAC device, which involves locating and selecting appropriate symbols in correct order, pays off, resulting in a deeper memory trace, and better memory performance. (Similar gains have been found for adults with dysarthria; Icht et al., 2019; and for cochlear implant users; Taitelbaum-Sweed et al., 2017).

An alternative suggested explanation for the production effect assumes that attentional processes underlie the memory benefit. Accordingly, during the study, participants allocated higher attention levels to the produced words relative to the no-produced words, resulting in enhanced memory (MacDonald & MacLeod, 1998; Ozubko et al., 2012). Mama and Icht (2019) provide support for this account, assessing memory performance of adults with attention deficit hyperactivity disorder (ADHD) before and after the administration of Methylphenidate (MPH, a stimulant medication used to treat ADHD). The participants showed higher recall rates and a larger production effect following drug administration. Presumably, MPH enabled the participants to successfully shift their attention to the produced words, improving their retrieval rates. This pattern of results stresses the role of attention in the production effect.

Individuals who rely on AAC face significant attention challenges. When the primary communication mode is visual (rather than spoken), attention must alternate between the AAC device (to search and select a symbol) and the communication partner (to make eye contact; Wilkinson & Hennig, 2009). Moreover, social communication requires the speaker to manage joint attention, that is, to coordinate attention among three focal points: partner, self, and object of communication. Using an AAC device adds another element to the equation, increasing the number of focal points from three to four, hence adding joint attention demands (Thistle & Wilkinson, 2013). The current results suggest that focusing attention as well as improves the encoding, storage, and retrieval of verbal information from long-term memory.

Effects of learning modality

Another interesting finding of the present study concerns the effects of learning modality. To allow a successful AAC implementation in the context of learning, a number of variables must be taken into account. First, the AAC systems must be designed to meet the special needs and accommodate the skills of the users. Hence, it is worth considering technical, physical, cognitive and social aspects (Higginbotham, Shane, Russell, & Caves, 2007). Second, the physical-environmental characteristics of the learning setting are of importance (e.g., the classroom setting, the degree of environmental noise and reverberation). Among these variables, learning modality is of special interest. Beyond the personal preferences of the teacher or the student, the learning modality may have an impact on long-term memory performance (the long-term modality effect; Conway & Gathercole, 1987). However, little is known about the effect of learning modality (visual vs. auditory) on memory performance of individuals who rely on AAC.

Addressing this issue, the current study compared verbal long-term memory performance following a unimodal presentation of the study material, visual or auditory. This procedure was applied in order to remove modality-based effects (Penney, 1989), gaining a clear picture of verbal memory operations in each modality. The results indicate similar memory performance in both the visual and the auditory tasks. That is, studying visually or aurally presented words by vocal production or by no-production (silently reading or listening) results in a comparable long-term memory benefit. These findings ran contrary to the hypothesis that the participants would show better visual memory performance (Laws, 2002), given their greater experience with visual material, as many aided AAC systems (communication boards, manual signs, or gaze communication) rely on the visual modality (Wilkinson & McIlvane, 2013).

It is important to note that in the current study, memory performance was assessed using a visual test (recognizing visually presented words). Reviewing the pertinent production effect literature, visual testing is the common procedure, using either written free recall tests (Icht, Mama, & Algom, 2014) or visually presented recognition tests (Forrin et al., 2012; MacLeod et al., 2010). Therefore, a visual recognition test was employed in the present study. Interestingly, auditory recognition memory performance has been found to be markedly inferior to visual recognition memory on various tasks (Cohen, Horowitz, & Wolfe, 2009) suggesting an asymmetry between auditory and visual processing. However, as Mama and Icht (2016b) have demonstrated that retrieval mode (written or aloud) may influence the production effect, future studies may evaluate memory functioning of individuals who rely on AAC using aurally presented tests.

Returning to the present study, while a superior learning modality was not identified, the visual and auditory perceptual needs of individuals with complex communication needs
should be noted (Higginbotham et al., 2007). Many of these individuals demonstrate visual problems and/or hearing impairments, and thus may have limited access to visually or aurally presented study material. For example, while studying visually presented material (textbooks, flashcards), educators should take into consideration features such as the size, shape, color, contrast, complexity, position and illumination of the study information. Studying by auditory modality (e.g., an aurally presented lecture), speech rate, intelligibility and intensity may play a significant role. Clearly, the presentation of the learning material should be adapted to better meet the perceptual needs of individuals who rely on AAC. Considering such factors is important to ensuring effective intervention and successful learning.

**Clinical implications**

In many cases, the intervention process for individuals with complex communication needs who rely on AAC may be complicated by the presence of additional developmental and physical disabilities. Identifying and understanding their strengths are important for careful design of intervention programs that are sensitive to their needs and abilities. The current results, namely, production benefits and relatively high recognition rates (similar to that found in the literature; MacLeod et al., 2010), suggest that long-term verbal memory abilities of individuals who rely on AAC (with intact cognitive abilities) may be preserved, providing this special subgroup with an important strength. This finding is of special interest, as other memory domains may be impaired in individuals with complex communication needs (e.g., phonological working memory seems to be vulnerable to constraints arising from lack of availability of sub-vocal rehearsal; Smith, 2003).

The results of this study support the use of active production of the study material by the AAC device as an effective mnemonic technique. Although such production procedure may be difficult (relative to speech), it yields significant memory gains. Interestingly, Foley and Pollatsek (1999), who tested phonological coding in memory in adults with dysarthria or anarthria, concluded that articulatory ability is helpful but not a prerequisite for using phonological coding in memory. The current results support this notion. From a clinical perspective, it is recommended that an AAC user produce the to-be-remembered portion of study material, regardless of the learning modality utilized (visual, such as reading from a written text; auditory, such as listening to a lecture). This mnemonic device can be used in educational contexts (e.g., when studying second-language vocabulary) as well as in daily situations (e.g., listening to a doctor recommending a medication protocol).

**Limitations and future directions**

This study provides evidence for the preserved visual and auditory verbal long-term memory function of individuals who rely on AAC. However, all participants used SGDs, while many AAC users rely on AAC tools that do not include voice output (like printed communication boards or printed symbols). Future studies are needed to ascertain whether the current findings will be found in those AAC users. In addition, the current sample size was small, with a wide age range, and different communication functioning levels. Participants’ cognitive level was not directly assessed due to the lack of appropriate tools in Hebrew. We note that the small sample size may attribute to the lack of main effect for learning modality (although the group was large enough to reveal the main production effect). Future studies may test a larger and less heterogeneous group of participants.

Several limitations of the experimental procedure also warrant mention. First, accuracy of silent reading could not be verified for the no-production visual condition. However, it can be assumed that the random allocation of study words across the different study lists and learning conditions allowed us to control for possible biases. Second, visually presented yes/no recognition test was used to assess memory performance. Since the literature indicates that memory performance may be affected by the test modality (visual vs. auditory; Mama & Icht, 2016b), future studies may wish to use aurally presented tests that may be especially suitable for individual with visual impairments.

Testing long-term verbal memory for more complex materials (e.g., text) is also called for, as well as assessing possible effects of learning modality on other aspects of memory performance (e.g., phonological memory), and the effect of multi-modal presentation of the study material (visual and auditory), thus better reflecting many daily situations. From the clinical perspective, further work is required to identify other effective mnemonics for AAC users. Future studies should also focus on reconciling the theoretical models of the production effect (distinctiveness, effortful encoding, and attention).

**Conclusion**

The results of this study stress the role of an active production of words by the AAC system as a memory strategy that can effectively be used by individuals who rely on AAC, regardless of the learning modality (visual or auditory). The findings provide initial evidence of the preserved visual and auditory verbal long-term memory abilities of this population. Active production of words via the AAC system may be used in educational as well as therapeutic settings to enhance memory and learning.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

**References**


