Cognition 154 (2016) 69–80

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Original Articles

Serial position encoding of signs

Michele Miozzo [a,b,*], Anna Petrova [c], Simon Fischer-Baum [d], Francesca Peressotti [c]

[a] The New School, United States
[b] Johns Hopkins University, United States
[c] Universita' di Padova, Italy
[d] Rice University, United States

ARTICLE INFO

Article history:
Received 4 September 2014
Revised 29 April 2016
Accepted 15 May 2016

Keywords:
Sign language
Deafness
Short-term memory

ABSTRACT

Reduced short-term memory (STM) capacity has been reported for sign as compared to speech when items have to be recalled in a specific order. This difference has been attributed to a more precise and efficient serial position encoding in verbal STM (used for speech) than visuo-spatial STM (used for sign). We tested in the present investigation whether the reduced STM capacity with signs stems from a lack of positional encoding available in verbal STM. Error analyses reported in prior studies have revealed that positions are defined in verbal STM by distance from both the start and the end of the sequence (both-edges positional encoding scheme). Our analyses of the errors made by deaf participants with finger-spelled letters revealed that the both-edges positional encoding scheme underlies the STM representation of signs. These results indicate that the cause of the STM disadvantage is not the type of positional encoding but rather the difficulties in binding an item in visuo-spatial STM to its specific position in the sequence. Both-edges positional encoding scheme could be specific of sign, since it has not been found in visuo-spatial STM tasks conducted with hearing participants.

1. Introduction

The short-term memory (STM) span, which corresponds to the longest sequence of items correctly recalled in a specific order, represents a widely used measure of STM capacity. STM span is shorter with signers as compared to speakers, a robust finding that has been documented in different languages and populations using a variety of experimental paradigms. Reduced STM capacity has in fact been reported in American Sign Language (e.g., Bellugi, Klima, & Siple, 1975), Auslan (Logan, Mayberry, & Fletcher, 1996), British Sign Language (Conrad, 1970; MacSwinney, Campbell, & Donlan, 1996), Italian Sign Language (Geraci, Gozzi, Papagno, & Cecchetto, 2008), Israeli Sign Language (Miller, 2007), and Swedish Sign Language (Rönnberg, Rudner, & Ingvar, 2004). Shorter STM spans were observed with signs produced both by deaf signers and hearing individuals proficient in sign language (Boutla, Supalla, Newport, & Bavelier, 2004; Hall & Bavelier, 2011). Differences in STM capacities were demonstrated with stimuli as diverse as printed digits, letters and words (e.g., Belmont, Karchmer, & Pilkonis, 1976; Pintner & Paterson, 1917; Wallace & Corballis, 1973), as well as their corresponding signs (e.g., Bonvillain, Rea, Orlansky, & Slade, 1987; Krakow & Hanson, 1985; Liben & Drury, 1977). Furthermore, span differences persisted despite variations in the responses (written vs. signed; e.g., Hamilton & Holzman, 1989; Lichtenstein, 1998; Shand, 1982) or order of recall (forward vs. backward; Bavelier, Newport, Hall, Supalla, & Boutla, 2008). As highlighted by several researchers, these differences in STM span are especially puzzling in light of other findings revealing striking similarities in the processes supporting immediate recall of sign vs. speech (Wilson, 2001). For example, span reduces as duration of stimuli increases both with spoken words (Baddeley, Thomson, & Buchanan, 1975) and signs (Wilson & Emmorey, 1998), possibly reflecting the limited capacity of STM buffer or the functioning of rehearsal mechanisms (Baddeley, 2007). Researchers have long recognized that understanding what causes such discrepancies in STM span is of potential relevance for defining STM mechanisms and how language and specific language modalities affect STM processing. Notwithstanding the relevance of this question, the causes have remained elusive.

Attempts to characterize the source of modality-specific variations in STM span have been primarily of two types. Some accounts have drawn attention to structural differences between signs and verbal stimuli (Marschark & Mayer, 1998; Wilson, 2001; Wilson & Emmorey, 1997), chiefly the fact that signs tend to be longer in

* Corresponding author at: Department of Psychology, 80 5th Avenue, New York, NY 10011, United States.
E-mail address: mm1150@columbia.edu (M. Miozzo).

http://dx.doi.org/10.1016/j.cognition.2016.05.008
0010-0277/

duration (Bellugi & Fischer, 1972). While a few results lent support to accounts assuming differences in duration (Wilson & Emmorey, 2006), findings showing that shorter STM spans persisted even when signs were carefully matched to verbal stimuli in duration (Bavelier, Newport, Hall, Supalla, & Boutla, 2006; Bavelier et al., 2008; Boutla et al., 2004; Geraci et al., 2008) weaken accounts that identify structural differences as a primary cause of the disadvantage observed with signs.

A second type of accounts hinges on the hypothesis that the reduced span is an effect of modality, stemming from greater STM capacity for encoding *serial information* in auditory STM as compared to visuo-spatial STM (Boutla et al., 2004; Conrad, 1970; Hamilton & Holzman, 1989; Hanson, 1982; Koo, Crain, LaSasso, & Eden, 2008; Lichtenstein, 1988; Miller, 2007). The critical role these accounts assign to the encoding of temporal order information is justified by findings showing that as soon as instructions of recalling items in a specific order were lifted and items could be recalled in any order, comparable spans appeared across modalities (Bavelier et al., 2008; Hanson, 1982; Krakow & Hanson, 1985; Rudner, Davidsson, & Rönnberg, 2010; Rudner & Rönnberg, 2008). While findings from free order recall demonstrate comparable encoding of sign and speech, disadvantages for signs restricted to serial order recall lend support to hypotheses linking the reduced capacity with signs to temporal order information. Further converging evidence was obtained by Bavelier et al. (2008). Even when instructions allow free order recall, order of presentation is often preserved at recall, as in the example ABCDE → ECDBA where C and D appear next to each other both in the stimulus and the response. Bavelier et al. (2008) found that relative order was more likely to be preserved in speech than sign, a result confirming difficulties in encoding serial order with visually presented signs as compared to auditorily presented speech stimuli (see Gmeindl, Walsh, & Courtney, 2011 for a similar result comparing verbal and spatial STM).

The present study aims to contribute to the investigation of the temporal order hypothesis that associates the reduced span of sign to limitations of visuo-spatial STM processes in encoding temporal sequences. Research has shed light on the representation of serial order used in verbal STM, revealing that positions are encoded with respect to both start and end positions (Farrell & Lelièvre, 2009; Fischer-Baum & McCloskey, 2015; Henson, 1998). For example, the position of D in the sequence ABCDE is represented by specifying its distance from the beginning of the list (fourth-from-the-start position; S+4) as well as from the end of the list (second-from-the-end position; E−2). However, Fischer-Baum (2011) found that some spatial STM tasks, like the Matrix Span and Corsi Block Tasks, rely on a different representation of serial order in which position is encoded only relative to the start of the sequence.[1] We investigated whether both-edges positional encoding scheme are computed in the immediate ordered recall of signs, or instead whether position is represented by a start-anchored only scheme. Evidence that favors the start-anchored only scheme over the both-edges scheme would reveal that memory for signs lacks a key component. Such evidence would further indicate that the serial positions of signs are specified as with other visuo-spatial stimuli, for which evidence of both-edges positional encoding was similarly lacking. By contrast, evidence favoring the both-edges positional encoding in sign ordered recall would establish that discrepancies in STM capacity between sign and speech do not reflect differences in the representation of item position within a sequence.

[1] Results reported in Fischer-Baum (2011) indicate that the spatial locations hearing speakers memorized in the Matrix span task were not encoded as part of path-like representations. These results suggest instead that each location was encoded as a distinct unit. In this respect, representations of spatial locations are discrete similar to encoding linguistic elements, such as words and signs.

Critical evidence on the encoding of temporal sequences in verbal STM was garnered from intrusion errors. Intrusion errors arise when an item not included in the original sequence appears in the recalled list. For example, F intrudes in the response ABCDFE produced for the sequence ABCDE. Intruded items were often produced in immediately preceding responses (Conrad, 1960; Estes, 1991; Werner, 1947; Wickelgren, 1966), for example when the intruding letter F in ABCDFE appeared in the immediately preceding response MXBFT. In other words, some of the intrusions appear to be *perseverations* from prior responses. The positions in which intruded items occur would be informative for accounts on serial position encoding if they reflect the positions taken in prior responses rather than being determined by chance. Perseverations produced in verbal serial recall tasks not only differed from distributions expected by chance, but they also conformed to predictions of accounts positing start- and end-anchored positional encoding (Fischer-Baum & McCloskey, 2015; Henson, 1999). Here, we examined the perseverations that signers of Italian Sign Language produced in an immediate serial recall task involving finger-spelled letters (see examples in Fig. 1). Perseverations were analyzed to determine whether their occurrences reflected the encoding of serial positions with respect to both edges that characterizes verbal STM.

1.1. Both-edges positional encoding scheme

Let us suppose that F intruded in the response ABCDFE (hereafter called the *perseveration response*) and appeared in a previous response MBFT (hereafter called the *source response*). Does the intruded F appear in the same position in both responses? The answer to that question differs depending on the underlying scheme used to represent serial position (see examples in Fig. 2). According to a start-anchored scheme, F does not match position between the perseveration and the source response, as it appears in position S+5 in the perseveration response and S+3 in the source response. It does, however, match position according to the end-anchored scheme, appearing in position E−2 in both responses. Alternatively, let us consider the perseveration error ABFCDE with the source response MBFT. Here, the perseveration error matches position by the start-anchored scheme (F is in position S+3 in both responses) but not by the end-anchored scheme (F is in position E−4 in the perseveration response, and E−2 in the source response). The hypothesis that a positional encoding scheme that is both start- and end-anchored underlies the STM representation of signs makes the following two predictions: (1) sign perseveration errors should match position defined by the start-anchored position encoding scheme but not the end-anchored position encoding scheme significantly more often than would be expected by chance, and (2) perseveration errors should match position defined by the end-anchored position encoding scheme but not the start-anchored position encoding scheme significantly more often than would be expected by chance. The second prediction is particularly critical for determining whether the representation scheme used to encode position in this task patterns with the scheme used by hearing participants to encode position in verbal STM (both-edges) or visuo-spatial STM (start-anchored only). To test these predictions, we applied methods developed in earlier work, which used perseverations in reading and writing to evaluate theories of letter position representation (Fischer-Baum, McCloskey, & Rapp, 2010; McCloskey, Fischer-Baum, & Schubert, 2013; McCloskey, Macaruso, & Rapp, 2006).

The logic of these methods have a similar rationale to the analyses reported in Henson (1999) on position representation in immediate serial recall, but with a clear advantage over the earlier