Short-term memory span in aphasia: Insights from speech-timing measures

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ABSTRACT

Auditory-verbal short-term memory impairments are part and parcel of aphasia and interfere with linguistic processing. To date, the science about short-term memory impairments in aphasia has been generated and dominated by studying measures of accuracy, that is, span length. Because accuracy is expressed through speech, examining the speech-timing characteristics of persons with aphasia as they engage in spoken recall could reveal insights about the manner in which accuracy is achieved.

Six speech-timing measures (e.g., response durations, pause durations) were elicited from the speech waveform of word span tasks from twelve people with aphasia. Speech-timing measures were compared to neuro-typical control participants. Speech-timing performance between erroneous and correct responses in the aphasia group was also examined. Across all measures, people with aphasia produced considerably longer speech-timing patterns in comparison to control participants. Memory load affected some measures in people with aphasia and control participants. Speech-timing in correct response trials was shorter than responses in erroneous trials. Memory span correlated only with one measure, namely, speech time (defined as the sum of each individual word duration in a response). Speech time also correlated with the following measures: Aphasia severity (Aphasia Quotient of the Western Aphasia Battery), spontaneous speech, and language comprehension (also measured by the Western Aphasia Battery).

Some protracted speech-timing patterns in the aphasia group may be explained by a deregulation of activation-decay patterns. However, in the absence of further evidence from people with aphasia, possible issues around the sensitivity of some speech-timing measures limit firmer conclusions. Speech-timing measures are response-time measures, which have not been systematically studied in studies of short-term or working memory in aphasia and as such, can push the current boundaries of knowledge of short-term and working memory impairments in aphasia, not only in stroke related aphasia but also other neurological conditions.

1. Introduction

The links between the integrity of verbal short-term and working memory (STM and WM respectively) and language abilities in aphasia have been attracting considerable interest in both theoretical (Howard & Nickels, 2005; Martin & Allen, 2008; Martin & Ayala, 2004; Martin & Reilly, 2012; Murray, 2012; Wright & Fergadiotis, 2012) and clinical aphasiology (DeDe, Ricca, Knilans, & Trubl, 2014; Minkina, Rosenberg, Kalinyak-Fliszar, & Martin, 2017; Paek & Murray, 2015; Salis, Hwang, Howard, & Lallini, 2017;

Zakariás, Keresztes, Marton, & Wartenburger, 2018). STM and WM impairments co-occur with aphasia and interfere with core linguistic processing at multiple levels, from phonology and word to sentence and discourse (Martin, 2009; Sung et al., 2009). Various theoretical positions about the precise nature of STM and WM impairments and their links to aphasia have been proposed to account for the diverse associative or dissociative patterns of STM and WM functioning (e.g., Majerus, Attout, Artielle, & van der Kaa, 2015; Martin & Allen, 2008; Verhaegen, Piertot, & Poncelet, 2013). For example, Majerus et al. (2015) reported that people with aphasia may present with a range of deficits, affecting particular sub-processes of STM functioning: Selective item deficits, selective order deficits, generalized item deficits, and serial order deficits. Another theoretical position distinguishes phonological vs. semantic STM deficits (Martin & Allen, 2008; Martin & Ayala, 2004).

As a construct, STM pertains to the temporary storage of a limited amount of information in a relatively unprocessed state (Cowan, 2008). Unlike the related construct of WM, STM does not involve manipulation of information, which is the distinguishing feature of WM. In contrast to STM, WM draws heavily upon attention related processes (e.g., updating, inhibiting) responsible for the temporary storage of information while it is being manipulated (Cowan, 2008). Another distinguishing feature in the two constructs is how they are measured. STM measures are considered simple (e.g., serial recall of words), whereas WM measures are considered complex (e.g., alphabet span in which a series of presented words must be rearranged to recall in alphabetical order) (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002). A recent review of standardized STM/WM measures in aphasia research since 1980 has shown that both simple and complex measures are increasing in popularity (Murray, Salis, Martin, & Dralle, 2018).

The present study investigates several measures of STM performance elicited from word span, a simple measure of STM. The method we used involves the temporal analysis of the speech of persons with aphasia and neuro-typical control participants as they recall lists of words serially. Because STM by its very nature is time-limited, speech-timing measures afford precision that more typical measures of accuracy do not. In the remainder of the introduction, we draw from the wider, non-aphasia literature on speech-timing measures of STM and WM as our framework. The consensus of that literature is that speech-timing measures reflect covert processes in STM architecture. We then discuss the relevance of speech-timing measures in terms of levels of activation-decay of STM representations and processing speed.

1.1. Measures of accuracy and speech timing in STM

Measures (standardized or not) are quantified records, which are gathered from testing procedures and enable researchers to describe, quantify and consequently understand constructs, that is, real phenomena of theoretical and clinical interest (Edwards & Bagozzi, 2000). Consequently, measures form the basis of understanding a phenomenon. In STM and WM research in aphasia, accuracy is the prototypical measure that has been used for over a century (Eling, 2015). In STM, accuracy is often defined as the maximum number of words a person can recall correctly from a list, usually in serial manner. This measure of accuracy is often referred to as memory span and is usually demonstrated through speech production. Speech, therefore, is the physical medium through which the abstract, verbal representations held in STM are realised. To date, the science about STM impairments in aphasia has been generated and dominated by studying measures of accuracy (i.e., span size) elicited from spoken production with some evaluation of variation in accuracy, either as a function of items that are being recalled (e.g., number of syllables, frequency, concreteness), or accuracy of recall at various serial positions of a list. Yet, the temporal characteristics of speech output have seldom been scrutinized.

Nevertheless, in literature domains beyond aphasia, researchers have broadened the knowledge of STM (and to a lesser extent WM) by examining directly the temporal characteristics of the speech output as it is produced in real time, when participants recall words. Cowan (1992), who carried out a comprehensive study of speech-timing measures in developmental STM research, provides a list of measures and how they are elicited from a speech sound waveform (see Fig. 1). The most popular measures that have attracted repeated attention across literature domains are word duration, inter-word pauses (pauses hereafter), and preparation time. The literature domains and studies that used speech-timing measures are as follows: *Developmental psychology* (Cowan, 1992, 1999;
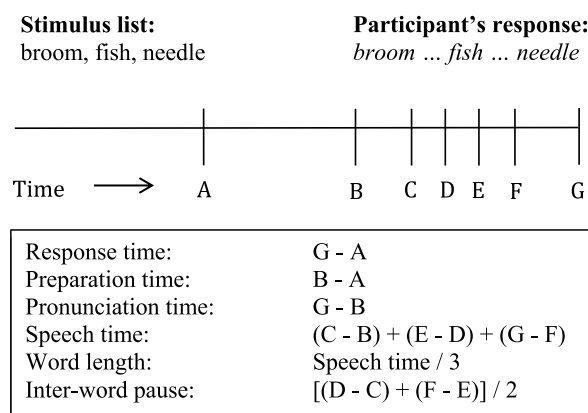

Stimulus list:
broom, fish, needle

Participant's response:
broom … fish … needle

Response time:	G - A
Preparation time:	B - A
Pronunciation time:	G - B
Speech time:	(C - B) + (E - D) + (G - F)
Word length:	Speech time / 3
Inter-word pause:	[(D - C) + (F - E)] / 2

Fig. 1. Illustration of a stimulus list, with an accuracy response (adapted from Cowan, 1992).