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Cognitive effort during a short-term memory (STM) task in individuals with aphasia

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A B S T R A C T

People with aphasia (PWA) have been shown to demonstrate limited short-term memory (STM) span capacity, but little is known about the degree of cognitive effort PWA expend when completing STM tasks. For decades, researchers have used task-evoked pupillary responses (TEPRs) to infer cognitive effort; pupil size increases as the difficulty of a task increases. The purpose of this study was to examine TEPRs while PWA and healthy control participants completed a STM picture span task. Sixteen PWA and 16 demographically matched control participants completed paper-based and computer-based versions of a picture span task. Measures of pupil size were collected using an eye-tracking system during the computer-based task. Both PWA and control participants demonstrated increased pupil size as STM demands increased. The two groups did not differ in pupil size across different span levels; however, PWA performed significantly poorer than matched controls in terms of behavioural accuracy scores. This suggests that although PWA exerted similar amounts of effort to control participants as task demands increased, they did not show a corresponding increase in accuracy. These data provide support for the feasibility of using TEPRs to investigate cognitive effort in PWA. In conjunction with behavioural performance measures, measures of cognitive effort may provide a holistic picture of cognitive and linguistic functioning in PWA.

1. Introduction

Aphasia is an acquired communication disorder that is most commonly caused by stroke, and can impair an individual's ability to speak, understand, read and write (National Aphasia Association, 2015). In addition to the frank language impairments that characterize aphasia, a growing body of evidence also documents impairments in several cognitive domains in people with aphasia (PWA), including attention (Hula & McNeil, 2008; Murray, 2012), short-term memory (Beeson, Bayles, Rubens, & Kaszniak, 1993; Francis, Clark, & Humphreys, 2003; Laures-Gore, Marshall, & Verner, 2011) and working memory (Wright & Fergadiotis, 2012; Wright & Shisler, 2005).

Working memory (WM) refers to a cognitive system that keeps goal-relevant information in an accessible state, so that it is available for further processing (Becker & Morris, 1999). Seminal WM model of Baddeley and Hitch (1974) has served as a foundational model for further research in this area (Baddeley, 1986, 1992, 2000), and comprises two modality-specific components, the *visuospatial sketch pad* and *phonological loop,* which are regulated by a *central executive* that adjusts the allocation of attentional resources. The most recent iteration of Baddeley's WM model (2000) also includes the *episodic buffer*, which aids in maintenance by

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coordinating information between long-term memory and working memory. The visuospatial sketch pad and the phonological loop involve storage of visual and auditory information, respectively, and therefore overlap with the construct of short-term memory (STM).

STM refers to the storage component of the WM system, and is typically measured by 'simple' span tasks, where individuals recall increasing numbers of items (e.g., digits, words, pictures) in the order they were presented. Individuals with aphasia have been shown to have difficulty with a variety of STM tasks, including digit span, word span and picture span (DeDe, Ricca, Knilans, & Trubl, 2014; Friedmann & Gvion, 2003; Laures-Gore et al., 2011; Martin & Ayala, 2004; Pluth, Bogdanova, White, Lundgren, & Albert, 2003; Ronnberg et al., 1996). The smaller span capacities observed in PWA – particularly with verbal stimuli – have been attributed to deficits in phonological processing affecting rehearsal via the phonological loop, and several investigators have demonstrated a link between the integrity of phonological/lexical-semantic processes and the degree of short-term memory impairment (Gvion & Friedmann, 2012; Laures-Gore et al., 2011; Martin & Ayala, 2004; Vallar, di Betta & Silveri, 1997). However, others have also shown that PWA demonstrate smaller span capacities with nonverbal tasks as well (De Renzi & Nichelli, 1975; Martin & Ayala, 2004; Potagas, Kasselimis, & Evdokimidis, 2011), suggesting STM capacity deficits may reflect a general cognitive deficit not specific to linguistic information.

Cognitive effort expended during a task may also have an effect on performance during STM tasks. Cognitive effort has been referred to as the "rate of mental resource consumption to support processing or to maintain information in active storage" (Just & Carpenter, 1993, p. 311). Until recently, cognitive effort has not been commonly assessed in PWA during language and memory tasks (Chapman & Hallowell, 2015). Yet, measures of cognitive effort may provide important information about mechanisms underlying performance accuracy and latency. The same task may require different degrees of cognitive effort across individuals – even when these individuals exhibit similar profiles and severity of aphasia. Likewise, the same individual with aphasia can exert different levels of cognitive effort on the same task depending on various other factors such as confidence levels or physical fatigue. These levels of effort may be related to accuracy and latency; thus, exploring cognitive effort may facilitate a more robust understanding of reasons for task outcomes and the nature of the breakdown in STM. One method to assess cognitive effort is pupillometry.

Pupillometry (i.e., the study of changes in diameter of the pupil as a function of cognitive activity) has been of interest to researchers in cognitive science for several decades (Laeng, Sirois, & Gredebäck, 2012; Sirois & Brisson, 2014). Hess and Polt (1964) were the first to report that pupil size increased as the difficulty of mental calculations increased. Similarly, Kahneman and Beatty (1966) observed an incremental increase in pupil size during a digit span task as each digit to-be-remembered was presented, prompting Beatty (1982) to make the following observations regarding this "task-evoked pupillary response" (TEPR):

> They occur at short latencies following the onset of processing and subside quickly once processing is terminated. Perhaps most important, the magnitude of pupillary dilation appears to be a function of processing load or 'mental effort' required to perform the cognitive task (p. 276).

With advances in eye-tracking technology, there has been a recent proliferation in the use of pupillometry to measure TEPRs across a variety of tasks (see Sirois & Brisson, 2014 for a review), but one of the most widely reported is the STM span task (Ahern & Beatty, 1979; Granholm, Asarnow, Sarkin, & Dykes, 1996; Johnson, Singley, Peckham, Johnson, & Bunge, 2014; Piquado, Isaacowitz, & Wingfield, 2010). In these studies, pupil size was shown to increase as the number of items temporarily stored in STM increased, and changes in TEPRs were sensitive to manipulations in processing demands.

The measurement of TEPRs provides an index of processing without requiring a verbal response, making it a potentially useful tool for investigating cognitive effort in individuals with aphasia. To our knowledge, only one study has been published to date investigating TEPRs in aphasia (Chapman & Hallowell, 2015). In this study, PWA and healthy controls listened to single words that varied in semantic complexity (as determined by a combination of psycholinguistic variables). Both groups demonstrated increased TEPRs for words that were more semantically complex. Importantly, no differences in TEPRs were observed between groups, suggesting both PWA and healthy controls exerted similar amounts of cognitive effort during this linguistic processing task. The authors contend that the single word comprehension task used in the study may not have been sufficiently cognitively taxing for healthy controls or PWA. In addition, the task used in this study did not require any active processing by participants (i.e., they were not required to make any response). Pupil size has been shown to be related to task-engagement and levels of alertness (Kristjánsson et al., 2009; Morad, Lemberg, Yofe, & Dagan, 2000; Unsworth & Robison, 2015); therefore measuring pupil size during a task requiring active responding would provide valuable insight into the amount of effort expended during cognitive tasks in PWA.

The purpose of this study was to examine TEPRs as an index of cognitive effort in people with aphasia during a STM task. Healthy control participants have demonstrated increased TEPRs in relation to increased demands on STM capacity. Given that reduced STM capacity has been well documented in PWA, the question of whether or not PWA exert similar degrees of cognitive effort during STM span tasks is of interest from a theoretical standpoint, with potential practical implications for assessment and treatment of aphasia. The following research questions were addressed in the present study:

1. Do PWA and healthy controls differ on accuracy on the STM picture span task?
2. a) Do PWA and healthy controls demonstrate increased TEPRs as STM demands increase? b) Do PWA and healthy controls differ on the size of TEPRs on the STM task?