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Detecting Cognitive Load during Working Memory Tasks utilizing a Digitizer Tablet

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Abstract

The purpose of this line of research is to determine whether the 'Digitizer' is a reliable and valid way to measure cognitive load during dual working memory-drawing tasks. This quasi-experimental study included seven right-handed healthy adult participants with normal or corrected vision and no reading difficulty. The participants were selected on a volunteer basis. The study required participants to draw circles while continuously performing in three conditions – one baseline and two working memory experimental tasks, administered in counterbalanced order. The baseline task was to read an 8th grade level passage at comfortable speed and loudness level. The working memory tasks were symmetry span and operation span tasks. The operation span task required the participants to remember letters in sequence while simultaneously verifying arithmetic operations presented after each letter. The symmetry span task required participants to remember the position of the highlighted square in a grid in sequence while simultaneously determining the symmetricity of a figure presented afterwards. Both tasks were completed while drawing continuous circles on the 'Digitizer'. A separate repeated measures analysis of variance (ANOVA) was conducted for each measure. A significant omnibus effect was found for the stroke duration measure only. Post-hoc paired tests showed that baseline was higher ($p=.01$) in stroke duration than in operation span task and symmetry span task. In this literature review, the results and elements of the study are described in full to inform future research. It was initially assumed that the working memory load would be significantly less in the baseline task as compared to the two working memory tasks; however, the data alternatively indicated that it taxed working memory more. With reading comprehension as a reference condition, it is logical to conclude that there is evidence of cognitive load in working memory tasks as measured by manual disfluencies. This literature review outlines potential adaptations and highlights primary weaknesses for future study in this area.

Keywords: working memory, cognitive load, digitizer, scriptalizer

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Working memory plays a crucial role in understanding language and reading comprehension, and it refers to the limited set of resources available for the temporary processing and storage of information necessary for a range of cognitive activities (Baddeley 2003). Working memory allows a set number of items to be actively maintained in a readily accessible state (Fukuda, Vogel, Mayr, Awh, 2010). There are multiple models of working memory, but all assume some limitation of processing definite quantities of information simultaneously. Baddeley and Hitch proposed the three component working memory model; which includes the central executive, phonological loop, and visuospatial sketchpad (Figure 1.1). The system that is responsible for the attentional control of working memory is the central executive, which then delegates that information to the phonological loop or visuospatial sketchpad. The phonological loop is a temporary verbal-acoustic storage system responsible for processing phonological characteristics, and the visuospatial sketchpad is the temporary parallel visual subsystem for storage and manipulation of visual information (Baddeley 2001). The idea that the central executive was responsible for attention and storage was omitted, instead proposing an episodic buffer responsible for storage of information from a number of different sources into different chunks or episodes (Baddeley 2003). These chunks of information contribute to the overall cognitive load imposed on each individual.

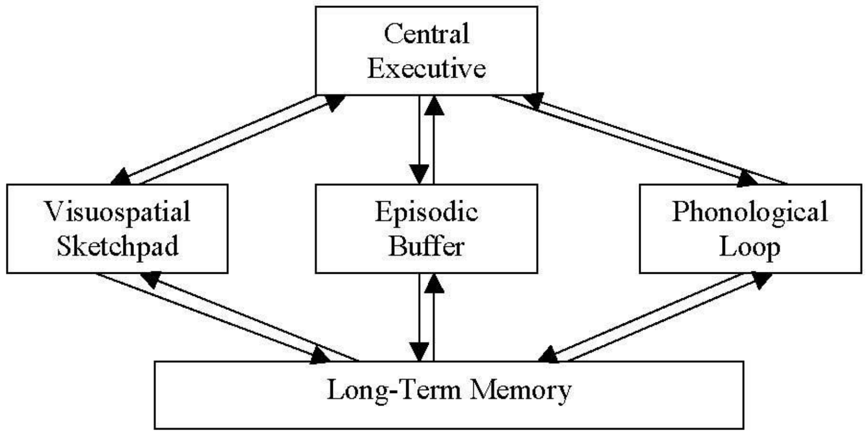

FIGURE 1.1 THE BADDELEY WM MODEL

Working memory can be used to operationalize the theory of cognitive load, meaning that the volume of information being processed in working memory has a direct correlation with the presence of cognitive load (Logie, Cocchini, Delia Sala, & Baddeley, 2004). There are three types of cognitive load: intrinsic, extraneous, and germane, and all refer to the amount of information being processed in working memory at any given time (van Merriënboer & Ayres, 2005). Intrinsic cognitive load depends on the previous experience the individual has had with the information being processed. Extraneous cognitive load can be caused by a multitude of things, such as poor teaching, inappropriate learning environment, or excessive searching for information needed to solve a problem. One example of possible extraneous cognitive load could be e-learning or the comprehension of non-linear, web based text. Finally, germane cognitive load "is associated with processes that are directly relevant to learning, such as schema construction and automation" (van Merriënboer & Ayres, 2005). Germane cognitive load relates to how active the learner is, and the amount of effort they are willing to put forth to process the information or solve the problem. In a scholastic environment, reducing cognitive load as much as possible is vital in order to maximize learning potential. To sum up cognitive load theory, "the main instructional principle…is to decrease extraneous cognitive load and to increase germane cognitive load, within the limits of totally available processing capacity" (van Merriënboer & Ayres, 2005). In other words, the goal should be to prevent cognitive overload in any setting.

Measuring working memory continues to be challenging especially due to its lack of sensitivity in behavioral outcomes to tasks that are likely to tax it. For example, a study completed by Srivastava & Gray (2011) investigated the reading comprehension of adolescents with and without language-learning disabilities on computer based and paper-based texts. The results of their study indicated neither group to be affected by the additional cognitive load imposed by computer based hypertext, although previous studies have shown that individuals with lower working memory capacities produce the best results with traditional text (Lee & Tedder, 2003). The results of this study may be due to insufficient cognitive load differences between the two conditions, however, it is not possible to exclude the alternative explanation that working memory is too difficult to measure relying on behavioral data.

There are several other factors that may contribute to this obstacle in research regarding working memory and cognitive load. As was previously mentioned, working memory resources are limited when dealing with novel information due to intrinsic cognitive load (van Merriënboer & Ayres, 2005). Individuals are capable of holding approximately seven schemas, or models, within their working memory at one time due to the extremely limited capacity (Miller 1956). Schemas heavily reduce working memory load due to their comprehensive nature; however, they also contribute to the difficulty in measuring working memory (van Merriënboer & Ayres, 2005). For example, someone who has never written a scholastic article would have much less working memory capacity available throughout the process than an experienced writer who has pre-existing schemas to organize the information. This could result in a variety of behavioral data and little or no indication of cognitive load and its effect on the writer. Regardless of how difficult the information is; it can be dealt with as one element in working memory if there is an existing schema for it. There is also conflicting research on how and why working memory capacity is limited, which could contribute to the difficulty in quantifying working memory differences in the literature (Oberauer, Farrell, Jarrold, Lewandowsky, 2016). One common method found in various studies to examine the capability of an individual's working memory is the dual-task paradigm.

Dual-task interference paradigms offer a potentially sensitive means of measuring subtle differences in working memory during a reading task that may not be apparent in behavioral data alone (Pashler, 1994). A dual-task paradigm requires an individual to perform two tasks simultaneously, thus increasing cognitive load (Saltuklaroglu, Teulings, & Robbins, 2008). Even the very simplest activities suffer interference when undertaken simultaneously (Pashler 1992). Typically, the more "natural" task is inhibited by the challenging task being performed. Previous studies have utilized a dual task paradigm to measure manual disfluency during circle drawing tasks because of its relative simplicity and inherent nature (Teulings et al., 1997). It has also been demonstrated that dual reading and circle drawing tasks are sensitive to overt disfluencies in both an overt reading (Saltuklaroglu, Teulings, & Robbins, 2008) and a listening task, consistent with an intrinsic link between oral-motor and manual output (Dayalu, Teulings, Bowers, Crawcour, & Saltuklaroglu, 2013). In both of these studies, a Digitizer tablet was utilized to convert hand-drawn images into a readable format for the computer to process. In the first of these two studies, fifteen stuttering and fifteen non-stuttering participants drew circles on the Digitizer under three conditions: silent, reading aloud, and choral reading. According to this research, the control group of non-stuttering participants did not increase manual disfluency under any condition, but the participants who stuttered had increases in manual disfluency that correlated with their increases in speech disfluency. This study supports the theory that circle drawing tasks are sensitive to disruptions in neural processing. The second of these studies supports the same theory, and in addition indicates that there is a link between speech perception and production. In this study, thirteen participants drew circles under five conditions: baseline, reading fluently, reading disfluently, listening to fluent speech, and listening to disfluent speech. In all of the disfluent conditions, manual disfluency was also significantly present. For both studies, the primary way that manual disfluency was measured was by normalized mean squared jerk (NJ), and a link between manual fluency and neural processes was indicated.

Previous research has indicated that working memory and disfluency are associated in addition to the correlation between manual fluency and neural processing (Saltuklaroglu, Tuelings, Robbins, 2008; Eichorn & Marton, 2014). In a study conducted by Van Gemmert, Teulings, and Stelmach, elderly patients with Parkinson's were compared to healthy elderly controls during handwriting exercises on a Digitizer because they often show a reduction in handwriting size as the length of the text increases (2001). The authors concluded that this was due to processing demands, which demonstrates that continuous hand-writing tasks are influenced by cognitive load. There are several means by which the 'Digitizer' is capable of measuring manual disfluency during circle drawing, namely: pen pressure, stroke duration, and normalized jerk. Normalized mean squared jerk could also be called pen stroke disfluency, and it is a measure of change in acceleration over time (Saltuklaroglu, Teulings, Robbins, 2008). Normalized jerk can be used to compare different individuals and tasks because it is unit free, and the calculation is taken across one entire stroke to the next. Normalized jerk is strongly correlated with stroke time, which suggests that manual disfluency is commonly characterized by slower movements. Stroke time is an additional manual kinematic measure that the Digitizer is capable of processing and can indicate manual disfluency. In addition to normalized jerk and stroke time, the Digitizer is also capable of measuring the pen pressure applied during the task. Pen pressure might help characterize manual disfluency because it has been shown to be higher in poor handwriters when compared to good handwriters (De Brina, et. Al., 2008; Dayalu, et. Al., 2013). Thus, simultaneous working memory and continuous manual kinematic tasks may detect subtle differences in cognitive load that are not obvious in behavioral data from reading tasks alone. Considering the promising sensitivity offered by dual-task paradigms, this study aims at determining whether a Digitizer tablet could be utilized to detect cognitive load during working memory tasks.

Considering the promising sensitivity offered by dual-task paradigms, this study aims at determining whether a Digitizer tablet could be utilized to detect cognitive load during working memory tasks. This literature review outlined the major themes behind the rationale of utilizing a Digitizer to illustrate specific effects on neural processes, and future research can be guided by the evidence from the information included.

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