Published in final edited form as:
Aphasiology. 2011 January 14; 25(1): 43–56. doi:10.1080/02687031003714426.

Performance of Individuals with Left-Hemisphere Stroke and Aphasia and Individuals with Right Brain Damage on Forward and Backward Digit Span Tasks

Jacqueline Laures-Gore,
Communication Disorders Program, Georgia State University

Rebecca Shisler Marshall, and
Communication Sciences & Special Education, University of Georgia

Erin Verner
Communication Disorders Program, Georgia State University

Abstract

Background—Working memory (WM) limitations have been suggested as a significant source of the linguistic processing deficits observed in individuals with aphasia (IWA). Digits forward (DF) and digits backward (DB) span tasks are frequently used to study WM in both healthy and clinical populations. Unfortunately, only a handful of studies have explored digit span in IWA.

Aims—The purpose of the current study is to measure the DF and DB spans of IWA and compare their digit spans to a group with right brain damage, but no aphasia (RBD). Additionally, DF and DB span is compared within each group to determine if there is indeed a performance differential that may support the idea that DB is a more difficult WM task in these populations.

Methods and Procedures—Seventeen IWA and 14 individuals with RBD participated in a DF and DB span task. Modifications to the span tasks were implemented to accommodate language deficits. A series of two digits were orally presented to each participant continuing to a maximum of eight digits. There were seven trials per digit series. Participants were asked to point to the correct order of digits on a written 1–9 digit list provided on individual note cards or verbally repeat the numbers if the participant was able to do so.

Outcomes and Results—IWA demonstrated shorter digit spans than the RBD group. Both groups performed worse on the DB span tasks than the DF span tasks.

Conclusions—The results are consistent with previous studies suggesting that DB span is shorter than DF span in other populations and that there are differences in performance on digit span tasks between the two groups. The differences between RBD group and IWA may be explained by decreased attentional capacity or inefficient resource allocation in IWA, or alternatively, a deficient phonological loop. Future studies should explore these possibilities.

Many have argued that working memory (WM) is critical for the processing of language (Caspari, Parkinson, LaPointe, & Katz, 1998; Friedmann & Gvion, 2003; Wright, Newhoff, Downey & Austermann, 2003). Indeed, a number of studies have linked measures of verbal WM with expressive language skills and sentence comprehension skills in individuals with aphasia (IWA; e.g., Caspari et al., 1998; Tompkins, Bloise, Timko, & Baumgaertner, 1994; Heilman, Scholes, & Watson, 1976; Rothi & Hutchinson, 1981), as well as discourse

---

Send correspondence to: Jacqueline S. Laures-Gore, Ph.D., Department of Educational Psychology and Special Education, Communication Disorders Program, Georgia State University, P.O. Box 3979, Atlanta, Georgia 30303, jlaures@gsu.edu, Tel: (404)413-8299, Fax: (404)413-8043.

production in individuals with right brain damage (RBD; Beeman, 1998; Brownell & Martino, 1998) and comprehension in RBD (Blake 2009a, 2009b; Lehman-Blake & Tompkins, 2001; Tompkins, Baumgaertner, Lehman, & Fassbinder, 2000; Tompkins et al., 1994; Tompkins, Lehman-Blake, Baumgaertner, & Fassbinder, 2001; Tompkins et al., 2002; Tompkins, Meigh, Scott, & Lederer, 2009; Tompkins, Scharp, Meigh, & Fassbinder, 2008c). Working memory limitations have been suggested as a significant source of deficits in linguistic processing observed in IWA (Caspari, Parkinson, LaPointe, & Katz, 1998; Conner, MacKay, & White, 2000; Dick et al., 2001; Friedmann & Gvion, 2003; Martin, 2000; Murray, 2004; Wright, Newhoff, Downey, & Austermann, 2003; Yasuda & Nakamura, 2000), and RBD (Lehman & Tompkins, 1998; Tompkins et al., 1994). The idea that WM skills and language impairments are related emerged from the development of several models describing the relation between WM and language (Baddeley, 1986; Caplan & Waters, 1999; Just & Carpenter, 1992).

Typical descriptions of WM include components of temporary storage and manipulation utilized for cognitive processes such as language (Baddeley, 2003). Baddeley (1986) suggested a single resource model with a multicomponent makeup that works to store and manipulate information. The single resource model theory refers to the idea that a single or central processor is responsible for all language processing. Essential to this model is the idea of a phonological loop and visuospatial sketchpad, which are slave systems to the limited capacity attentional control system called the central executive. Alternatively, Caplan and Waters (1999) offered a dual resource model that focuses on a limited resource pool for either automatic tasks or more conscious processing of language. Relatedly, Just and Carpenter (1992) proposed that a limited capacity variation in working memory leads to comprehension discrepancies and individual differences. Although there are differences in each model, each commits to the idea of simultaneous processing and manipulating language for the definition of working memory (Wright & Shisler, 2005). For the purposes of this paper, WM is defined as a process that uses a central executive as an attentional control system to briefly store and manipulate information in the phonological loop and visuospatial sketchpad (Baddeley, 1996; Baddeley, 2000).

Past research has suggested that the right hemisphere is important for only spatial WM and the left hemisphere is dominant for verbal WM (Jonides et al., 1993; Smith, Jonides & Koeppe, 1996; Paulesu, Frith, & Frackowiak, 1993; Kapur et al., 1994). However, more recent evidence from brain imaging and behavioral studies suggests that both the right and left hemispheres are involved in verbal WM skills (D'Esposito et al., 1998; Philipose, Alphs, Prabhakaran, & Hillis, 2007; Prabhakaran, Narayanan, Zhao, Gabrieli, 2000; Rypma & D'Esposito, 2000). Individuals with RBD have demonstrated decreased verbal working memory when compared to neurologically intact controls (Tompkins et al., 1994; Tompkins, Lehman, & Baumgaertner, 1999; Tompkins et al., 2008b; Tompkins et al., 2008c), which appears to be related to discourse-level linguistic performance for this population. For example, in RBD, WM appears to be related to discourse comprehension (Tompkins et al., 1999; Tompkins et al., 2000; Tompkins et al., 2009), inferencing related tasks (Lehman-Blake & Tompkins, 2001; Blake, 2009b; Tompkins et al., 1999), reaction times in lexical decision tasks (Tompkins et al., 2008a), and may even be used to predict performance on tasks that require increased information processing (Tompkins et al., 1994). Research regarding the role of the two hemispheres in WM and the association of WM deficits and linguistic processing deficits in the two hemispheres reveals a need for further inquiry into WM skills in IWA and RBD patients. Therefore, the current study explores digit span, a common index of WM, in IWA and individuals with RBD in an effort to further understand the relation between WM and language performance in these two populations.

Digits forward (DF) and digits backward (DB) span tasks are a mainstay in psychological assessment and are used to study working memory (WM) in both healthy and clinical populations (Wilde, Strauss, & Tulsky, 2004). These tasks require participants to orally repeat a sequence from 3 to 9 digits in the DF span task and 2 to 8 digits in the DB span task. When the participant fails two consecutive trials the task is discontinued. The span is calculated as the maximum number of digits repeated by the participant. It is presumed that DB span is typically shorter than DF span in adults due to the greater demand on WM skills (The Psychological Corporation, 2002; Wilde et al., 2004). Digits forward has been characterized as a simple span test, and is thought to measure the storage and maintenance components of WM by deemphasizing the manipulation of the material. Digits backward is thought to be a more complex span task which relies more heavily on WM processing because it requires information storage as well as concurrent processing essential to mentally reordering the information (Black & Strub, 1978; The Psychological Corporation, 2002; Wilde et al., 2004*)*. Digit span tasks activate the phonological loop (verbal memory), the sketchpad if information is visualized (Philipose, Alphs, Prabhakaran, & Hillis, 2007), and the central executive depending on the amount of manipulation necessary (Baddeley, 2000; Baddeley & Hitch, 1976; Ostrosky-Solis & Lozano, 2006).

With verbal WM components possibly found in both left and right hemispheres, it becomes important to determine how lesions might influence performance on digit span measures. Over the years a handful of studies have investigated the effect left brain damage (LBD) and RBD has on digit span as a way to determine brain-behavior relations. Overall, the studies have yielded mixed results. Black (1986) found that patients with RBD perform similarly to neurologically intact (NI) controls on DF span tasks, but LBD patients demonstrated a shorter DF span than both groups. Similar results were observed for DB span in that the LBD group demonstrated a shorter digit span than the RBD group. In contrast, Heilbronner, Henry, Buck, Adams, and Fogale (1991) and Philipose et al. (2007) did not find a difference in DF or DB span between RBD and LBD groups. Similarly, Black and Strub (1978) found digit span tasks did not discriminate between right and left hemisphere brain damage. Therefore, it is unclear whether individuals with LBD or RBD perform differentially on DF and DB span tasks between groups or whether there is differential performance on DF and DB span tasks within the groups (Black & Strub, 1978; Costa 1975; McFie, 1969; Newcombe, 1969; Weinberg, Diller, Gerstmann, & Schulman, 1972). Additionally, while Black (1986) did include IWA, he did not separate the results for IWA from individuals with LBD and no aphasia. Eight percent of the LBD participants in the Black and Strub (1978) study were diagnosed with aphasia while the studies by Heilbronner et al. (1991) and Philipose et al. (2007) did not report whether IWA were included in their participant sample. The type of participants (i.e., LBD with or without aphasia, the aphasia profile; lesion size and location of RBD participants, e.g., see Philipose et al., 2007) included in these studies could contribute to the inconsistent results.

In addition to the previous research examining the relation between digit span and brain damage, several studies have explored DF span specifically in IWA. Ronnberg et al. (1996) and Ween et al. (1996) found that IWA have significantly shorter digit spans than NI counterparts, based on an average of one digit difference (Ronnenberg et al., 1996; Ween, Verfaellie, & Alexander, 1996). Ronnberg et al. (1996) studied nine IWA (mild) resulting from subarachnoid hemorrhage (SAH) along with two control groups. One control group consisted of individuals with SAH, but no aphasia while the others consisted of age-matched NI individuals. Requiring recall of digits (not recognition), they found significant differences on DF spans for IWA ($M = 4.78$ digits) as compared to the NI group ($M = 5.89$ digits), but no significant difference for IWA compared to the SAH group ($M = 5.67$ digits). In addition, they also observed deficits on other WM measures that IWA completed in their assessment battery and concluded that the deficits could be due to an inefficient central executive. Similarly, Ween et al. (1996) used digit span with standard recall as the modality. They studied 16 IWA from various etiologies as well as 16 NI controls and similarly found shorter DF spans for IWA and concluded IWA have significant memory deficits.

As part of a larger study investigating sentence comprehension and WM, Friedmann and Gvion (2003) found that during a recognition digit span task participants with conduction aphasia demonstrated an average DF span of 3.2 and the agrammatic group had a DF span of 2.6. Both groups had a much shorter DF span than the healthy control group ($M = 7.25$ digits). Overall, it appears that DF span is shorter in IWA than healthy controls, which provides some information about WM in the IWA population. Finally, a 2003 study by Pluth and colleagues administered visual memory span (VMS) tasks and digit span tasks (DF and DB) to IWA. The results revealed that VMS was longer than DF and DB, and performance on DB was correlated with the degree of language loss (Pluth, Bogdanova, White, Lundgren, & Albert, 2003). This study, however, did not compare digit span performance between IWA and RBD. Therefore, the extent that DS is related to aphasia as a result of left brain damage remains unknown. Given the belief that DB tasks are more demanding of WM skills, exploration of DB span may provide a greater understanding of WM skills specific to IWA.

The purpose of the current study is to measure the DF and DB span of IWA and compare their digit spans to a group with RBD, but no aphasia. RBD was chosen as a comparison group in order to effectively isolate linguistically-based language disorders characteristic of aphasia as much as possible. This comparison of RBD and IWA is important due to the conflicting reports of digit span between LBD and RBD individuals, and the regularity with which digit span tasks are clinically administered to stroke populations. Additionally, DF and DB span is compared within each group to determine if there is indeed a performance differential that may support the idea that DB is a more difficult WM task. It is predicted that IWA will demonstrate a shorter DF and DB span than the RBD group given the suggested association between diminished WM and decreased language processing (Caspari et al., 1998; Miyake, Carpenter, & Just, 1994; Murray, 2004). As mentioned earlier, some research has suggested that individuals with RBD demonstrate decreased verbal WM and decreases in discourse-level abilities (Blake, 2009b; Lehman-Blake & Tompkins, 2001; Tompkins et al., 1994; Tompkins et al., 1999; Tompkins et al., 2000; Tompkins et al., 2008a Tompkins et al., 2008b, Tompkins et al., 2008c; Tompkins et al., 2009). While individuals with RBD may have compromised communication, the extent and type of the linguistic impairments differ from those with left brain damage and aphasia (Archibald & Wepman, 1968; Deal, Deal, Wertz, Kitselman, & Dwyer, 1979; Eisenson, 1962, Myers & Lehman Blake, 2008). Due to the findings in previous research regarding both right and left hemisphere involvement in verbal WM (D’Esposito et al., 1998; Prabhakaran, Narayanan, Zhao, & Gabrieli, 2000; Rypma & D’Esposito, 2000), and that executive functioning is necessary for WM tasks and relies on activity and interactions between multiple regions of the brain (for review, see Collette & Van der Linden, 2001), it is also predicted that both groups will demonstrate a much shorter DB span than DF span given the increased WM demands required to manipulate information active in the phonological loop and processed in the central executive.

Method

Participants

Post-stroke patients were recruited through speech-language pathology departments in hospitals located in a large urban area in the Southeastern United States. Participants were paid for their involvement. A total of 36 individuals (22 IWA; 14 individuals with RBD) between 40 and 74 years of age were recruited to participate in this study. Five IWA were excluded from the study due to their inability to give any response during the experimental task (*WAB AQ*'s of the excluded participants were 7.9, 14.15, 15, 27.2, and 35.8). Clinical data for IWA and the RBD groups are listed in Tables 1 and 2. Mean age was 53.14 years (*SD* = 7.93) for IWA and 61.21 years (*SD* = 8.85) for the RBD group. A significant group difference for age was found [t (29) = −2.68, $p < .05$]. The IWA group ages ranged from 40–66 years and the RBD group ages ranged from 43–74 years. Mean recovery time from the stroke was 1.89 months for the IWA and 2.28 months for the RBD group. No significant difference between the groups was found for months post-onset [t(29) = 1.51, $p > .05$]. Mean years of education was 14 (*SD* = 2.69) for IWA and 13 (*SD* = 3.55) for the RBD group. No significant difference between the groups was found for years of education [t(29) = .25, $p > .05$]. All participants had a premorbid history of normal speech and language as determined by self/family report. Participants all passed a hearing screening at 45 dB bilaterally at 500, 2K, and 4K Hz unaided.

The participants with aphasia ranged from mild to severe aphasia according to the Western Aphasia Battery (*WAB*; Kertesz, 1982). Average *WAB* Aphasia Quotient (*WAB AQ*) for the IWA was 65.67 (*SD* = 27.2). Participants in the RBD group ranged in severity from mild to moderate-severe right brain deficits. The average stanine score for the Mini-Inventory for Right Brain Injury-2 (*MIRBI-2*; Pimental & Knight, 2000) for the RBD group was 5.71(*SD* = 1.23). Stanine scores for *MIRBI-2* can range from 1–9. The current group demonstrate a rather narrow range of stanine scores from 4–7.

Procedures

As part of a larger study investigating the relation between salivary cortisol and language and memory recovery following stroke, all participants completed a DF span task followed by a DB digit span task described below. The IWA group was administered the *WAB* during the same session as the experimental task. The RBD group was given the *MIRBI-2* during the same session as the experimental task. Modifications to the span tasks, such as altering the response modality to include either verbal or gestural responses, were implemented to accommodate language deficits. Such modifications have been conducted in previous studies (Friedmann & Gvion, 2003; Sakurai et al., 1998). Participants from both groups were provided this modification.

Digits forward

The DF span task was modeled after Friedmann and Gvion (2003). The task begins with a series of two digits orally presented to each participant continuing to a maximum of eight digits. There were seven trials per digit series. Participants were asked to point to the correct order of digits on a written 1–9 digit list provided on individual note cards (one number per note card) or verbally repeat the numbers if the participant was able to do so. Note cards were placed on the table in front of all participants; however, the response mode was selected by the participant. Span was defined as the maximum level at which 3 trials out of 7 were accurate. An additional half point was given if 2 trials out of 7 were accurate. The task was discontinued when only 2 trials out of 7 were accurate. Digits were presented at 1 per second. The examiner provided one repetition of a trial if requested by the participant.

Digits backward

The DB task followed the same procedure as described with the DF task. The same digit sequences used during the DF task were used for this task. All sequences were orally presented to the participant. The participant then verbally repeated the numbers or pointed to the numbers written on individual note cards in reverse order. A criterion for maximum level of DB was the same as for DF.

Results

See Figure 1 for average DF and DB span for each group. A multivariate analysis of variance (MANOVA) was used to analyze between group effects and two-tailed paired samples *t*- tests with alpha set at .05 were conducted to explore differences within groups and tasks. A significant group effect was found for the DF span, $F(1, 29) = 7.05$, $p = .01$, $r^2 = .2$, and the DB span, $F(1, 29) = 5.31$, $p = .03$, $r^2 = .16$. The IWA group performance was significantly lower on the DF span ($M = 4.38$, $SD = 1.96$) than the RBD group ($M = 5.96$, $SD = 1.17$). Similarly, the IWA group performance was significantly lower on the DB span ($M = 2.03$, $SD = 1.39$) than the RBD group ($M = 3.43$, $SD = 1.99$). Analysis of within group performance between tasks revealed both groups had significantly decreased performance on the DB span than the DF span [IWA, $t(16) = 5.47$, $p = .00$; RBD, $t(13) = 5.23$, $p = .00$].

To determine whether severity of deficits and digit span were related, a post-hoc correlation analysis was performed. Pearson's *r* correlation coefficient revealed DF and DB span were strongly correlated with severity in the IWA group as measured by *WAB AQ* (forward, $r = .62$, $p = .01$; backward, $r = .66$, $p = .00$). A strong correlation between *MIRBI-2* and DB span was found ($r = .61$, $p = .03$), but no correlation was found between *MIRBI* scores and DF span ($r = -.05$, $p = .88$).

Discussion

Working memory in IWA was studied by comparing performance on DF and DB span tasks. Similar to some of the findings in the literature (e.g., Black, 1986), IWA demonstrated decreased performance on DB (i.e., a shorter span) in comparison to DF. In addition, performance on these two tasks was compared between IWA and a RBD group without aphasia. IWA also presented with a shorter DF and DB span in comparison to RBD participants. This finding is consistent with previous work indicating that digit span tasks are more affected in LBD than RBD (Black, 1986). Performance for DF in IWA was also similar to Ronnberg et al.'s (1996) findings. However, the results do conflict with other reports suggesting there is no difference between LBD and RBD digit span (Black & Strub, 1978; Heilbronner et al., 1991, Philipose et al., 2007). The present study included only IWA in the LBD group, whereas, the other studies did not specify presence of aphasia in their LBD participants (Heilbronner et al., 1991; Philipose et al., 2007) or included only a few IWA in their participant samples (Black, 1986; Black & Strub, 1978).

It could be argued that language impairments for IWA may be due to deficits in the phonological loop and therefore observed as shortened DF and DB span. In fact, past research has demonstrated that IWA have phonological loop deficits (Heilman, Scholes & Watson, 1976; Martin, 1987; Rothi & Hutchinson, 1981) and that phonological loop deficits are related to comprehension deficits in IWA (Caramazza, Basili, Koller & Berndt, 1981; Ostrin & Schwartz, 1986; Saffran & Martin, 1975; Vallar & Baddeley, 1984). The phonological loop is a prime component of the WM system. If an IWA has decreased WM due to a deficient phonological loop, this could influence language learning and performance (Baddeley, 2003; Murray, 2004). This would suggest that WM deficits (which are potentially deficiencies in the phonological loop) contribute to the linguistic deficits observed in IWA. Yet, it is unclear from this study alone whether it is indeed a deficient phonological loop or rather another possibility. Other authors may argue that language impairments could result from capacity limitations of the central executive (eg., Beeson, Bayles, Rubens, & Kaszniak,1993) and/or inefficient resource allocation (Murray et al, 1997; Tseng, McNeil, & Milenkovic, 1993). Again, further study of the components of WM in IWA would be necessary to answer this particular question.

Subsequent studies could include a LBD control group with no aphasia to make firmer conclusions about the interaction of brain damage, language and digit span performance. Some would argue that the inability to replicate previous findings could be due the individual differences in WM (Engle, Kane, & Tuholski, 1999; Turner & Engle, 1989) and could account for the differences seen in IWA. Future research could compare DS with other measures of WM (especially those with linguistic components) that have been used in the past (Caspari et al., 1998; Tompkins et al., 1994). This comparison becomes increasingly important since studies have found a correlation with WM scores and language abilities (Caspari et al., 1998; Conner et al., 2000; Dick et al., 2001; Friedmann & Gvion, 2003; Martin, 2000; Murray, 2004; Wright et al., 2003).

Furthermore, both groups demonstrated a shorter DB than DF span, consistent with digit span performance in healthy populations. According to a standardization sample from the Wechsler Memory Scales - III (The Psychological Corporation, 2002) average digit spans (DF, DB) for healthy adults are as follows: 6.57, 4.79 (45–54 years); 6.35, 4.55 (55–64 years); 6.28, 4.48 (65–69); and, 6.14, 4.4 (70–74 years). Participants included in the current study fall within the previous age ranges (IWA group M = 53.14 years; RBD group M = 61.21 years). A shorter DB span within both clinical groups included in the current study is consistent with the idea that DB is a more challenging task and may demand more WM capacity, and therefore, taps into the central executive (Rypma, Prabhakaran, Desmond, Glover, & Gabrieli, 1999). However, this does not explain why IWA demonstrate a shorter DB span than RBD individuals. One possibility is that IWA may be exhibiting decreased performance on DB relative to those with RBD due to the above-mentioned deficits in the phonological loop or potential capacity limitations of the central executive (Beeson et al., 1993). An alternative explanation may be made regarding resource allocation deficits to explain the performance of IWA in the current study. The inability to allocate sufficient resources to a task will result in decreased performance (Kahneman, 1973; Murray, 2004; Norman & Shallice, 1986) and it has been found that IWA have decreased resource allocation (McNeil, Odell, & Tseng, 1991; Murray, Holland, & Beeson, 1997; Slansky & McNeil, 1997). With previous literature demonstrating decreased resource allocation for IWA (Murray et al, 1997; Tseng, McNeil, & Milenkovic, 1993) as well as decreased WM capacity for both RBD and IWA (Capsari et al., 1998; Tompkins et al., 1994; Tompkins, Lehman, & Baumgaertner, 1999; Tompkins et al., 2008b; Tompkins et al., 2008c; Wright et al., 2003), it is interesting that DB span is shorter in IWA than the RBD group. It could be argued that IWA have greater resource allocation deficits than individuals with RBD (Murray, 2000). Alternatively, although individuals with RBD demonstrate limitations in the central executive (Mecklinger, von Cramon, Springer, & Matthes-von Cramon, 1999), they may not have similar deficits in the phonological loop (Gainotti, Cappa, Perri, & Silveri, 1994; Hanley, Young, & Pearson, 1991).

Additionally, it is understood that healthy aging negatively affects both DF and DB span (Hester, Kinsella, & Ong, 2004; Myerson, Emery, White & Hale, 2003; Wilde et al., 2004) with some indication that DB span is affected more by age than is DF (Babcock & Salthouse, 1990; Lezak, 1995). In the current study the IWA were younger than the RBD group. Nevertheless, because there is only a small difference between standardized DS scores for the participants' respective age groups (e.g., 6.57 vs. 6.35 for DF; 4.93 vs. 4.55 for DB), age should not be considered a significant factor when considering the differences in DS between the two groups. While it is also acknowledged that education influences digit span in healthy populations (Ostrosky-Solis & Lozano, 2006), the amount of education for both groups did not differ significantly and therefore is not a likely factor in the results.

The current study also revealed a significant relationship between severity scores of the *WAB* and *MIRBI* and digit span. While only the DB task strongly correlated with the *MIRBI* scores, both DF and DB did correlate with performance on the *WAB AQ*. This provides further support that WM may be associated with the severity of cognitive and language deficits (Tompkins et al., 1994). Other studies have found correlations between performance on the *WAB* and WM capacity (Caspari et al., 1998) and have suggested that simple span tasks (such as DF) do not predict language performance. The significant correlation between the digit spans and *WAB AQ* found in the current study does not support that idea. As Caspari et al. (1998) discussed as well, the significant correlations may simply be driven by overall severity.

Alternatively, the correlations of *WAB AQ* with DF and DB in IWA could be interpreted as support for phonological loop deficits in IWA leading to decreased span scores, both forward and backward. In comparison, *MIRBI* scores (RBD) correlating only with DB may suggest a more general central executive processing deficit. This is further supported by the findings that DF was longer in RBD than IWA in the current study. With the two groups' linguistic performance differences, it is possible that performance on DS tasks for these two populations can be attributed to different aspects of the WM system. Without other measures of WM to compare for the current study, this is only a provisional suggestion and requires further study.

Potentially, the findings of the current study could be influenced by task modifications used in order to compensate for language deficits in the brain damaged groups, which is similar to what previous studies have done (Friedmann & Gvion, 2003; Sakurai et al., 1998). This modification, while necessary to allow participants with language deficits the opportunity to participate, may have altered the sensitivity of DF and DB span tasks. It is known that recognition is easier than recall in such tasks (e.g., Flexser & Tulving, 1978); however, all participants were presented with numbered cards and the modification affected response modality, not recall. Participants were able to use the cards if they believed it aided their communication of the digits. Although data regarding the number of participants from each group who chose to use the cards was not collected, anecdotal evidence showed that individuals from the RBD group as a whole did not use the cards. Some IWA did choose to use them and yet the IWA group performed worse than the RBD group. Subsequent studies should compare digit span performance with and without the use of cards. Furthermore, all participants were exposed to the digit sequences twice, once during the DF task and then during the DB span task. Although there is a chance that a practice effect for DB span may be present, all participants experienced this exposure. Therefore, group differences in DB span cannot be explained by a practice effect. It is possible, however, that DB spans of both groups may be shorter if they received new sequences. Additionally, because the DB task was always presented following the DF task the DB span may be influenced by fatigue effects. Future studies will need to implement a method of counter-balancing span assessment to avoid the potential confound of fatigue.

Overall, the current study suggests that IWA have shorter DF and DB spans than do individuals with RBD and no aphasia. Consistent with previous studies in healthy populations, the current study also found that DB is shorter than DF in IWA. Both findings have implications for our understanding of IWA performance on digit span tasks and measurement of WM. IWA will show decreased WM performance even on simple DF span tasks. Further, while participants with RBD demonstrated shorter DB than DF, the performance differential on digit span tasks between RBD and IWA suggests that language deficits are associated with digit span performance, with various potential explanations. Shorter digit spans could indicate that WM skills are decreased in IWA as compared to the RBD group. Based on the limited exploration of digit span in IWA, future research examining the relationship of WM and language in IWA and performance on digit span tasks should continue.

Acknowledgments

This study was supported by NIH R03 DC006177. The authors would like to thank the following speech-language pathologists for their aid in participant recruitment: Winn Hill, Scott Russell, Julie Bonner, Michelle Cooper, Amy Dryver, Amy Samuelson, Cheryl Stewart, and Tracey Wallace. Additional gratitude is extended to the participants. We are also appreciative of the time and work of the reviewers and Alexandra Basilakos in the revision process.

References

Archibald TM, Wepman JM. Language disturbances and nonverbal cognitive performance in eight patients following injury to the right hemisphere. Brain. 1968; 91:117–130. [PubMed: 5643280]

Babcock RL, Salthouse TA. Effects of increased processing demands on age differences in working memory. Psychology and Aging. 1990; 5:421–428. [PubMed: 2242246]

Baddeley, AD. Working Memory. Oxford, England: Oxford University Press; 1986.

Baddeley A. Working memory. Science. 1992; 255(5044):556–559. [PubMed: 1736359]

Baddeley A. Exploring the central executive. The Quarterly Journal of Experimental Psychology. 1996; 49A(1):5–28.

Baddeley AD. The episodic buffer: A new component of working memory? Trends in Cognitive Sciences. 2000; 4:417–423. [PubMed: 11058819]

Baddeley A. Working memory and language: An overview. Journal of Communication Disorders. 2003; 36:189–208. [PubMed: 12742667]

Baddeley, AD.; Hitch, GJ. Working memory. In: Bower, GH., editor. The psychology of learning and motivation: Advances in research and theory. New York: Academic Press; 1974. p. 647-667.

Beeman, M. Coarse semantic coding and discourse comprehension. In: Beeman, M.; Chiarelio, C., editors. Right hemisphere language comprehension: Perspectives from cognitive neuroscience. Mahwah, NJ: Erlbaum; 1998. p. 255-284.

Beeson PM, Bayles KA, Rubens AB, Kaszniak AW. Memory impairment and executive control in individuals with stroke-induced aphasia. Brain and Language. 1993; 45:253–275. [PubMed: 8358599]

Brownell, H.; Martino, G. Deficits in inference and social cognition: The effects of right hemisphere brain damage on discourse. In: Beeman, M.; Chiarelio, C., editors. Right hemisphere language comprehension: Perspectives from cognitive neuroscience. Mahwah, NJ: Erlbaum; 1998. p. 255-284.

Black FW. Digit repetition in brain-damaged adults: Clinical and theoretical implications. Journal of Clinical Psychology. 1986; 42(5):770–782. [PubMed: 3760210]

Black FW, Strub RL. Digit repetition performance in patients with focal brain damage. Cortex. 1978 March; 14(1):12–21. [PubMed: 16295105]

Blake ML. Inferencing processes after right hemisphere brain damage: Maintenance of inferences. Journal of Speech, Language, and Hearing Research. 2009a; 52:359–372.

Blake ML. Inferencing processes after right hemisphere brain damage: Effects of contextual bias. Journal of Speech, Language, and Hearing Research. 2009b; 52(2):373–384.

Caplan D, Waters G. Issues regarding general and domain specific resources. Behavioral Brain Sciences. 1999; 22:114–126.

Caramazza A, Basili AG, Koller JJ, Berndt RS. An investigation of repetition and language processing in a case of conduction aphasia. Brain and Language. 1981; 14:235–275. [PubMed: 7306783]

Caspari I, Parkinson S, LaPointe L, Katz R. Working memory and aphasia. Brain and Cognition. 1998; 37:205–223. [PubMed: 9665743]

Collette F, Van der Linden M. Brain imaging of the central executive component of working memory. Neuroscience and Biobehavioral Reviews. 2001; 26:105–125. [PubMed: 11856556]

Conner L, MacKay A, White D. Working memory: A foundation for executive abilities and higher-order cognitive skills. Seminars in Speech and language. 2000; 21(2):109–119. [PubMed: 10879544]

Costa LD. The relation of visuospatial dysfunction to Digit Span performance in patients with cerebral lesions. Cortex. 1975; 11:31–36. [PubMed: 1149465]

D'Esposito MD, Aguirre GK, Zarahn E, Ballard D, Shin RK, Lease J. Functional MRI studies of spatial and nonspatial working memory. Cognitive Brain Research. 1998; 7(1):1–13. [PubMed: 9714705]

Deal, J.; Deal, R.; Wertz, RW.; Kitselman, K.; Dwyer, C. Right hemisphere PICA percentiles: Some speculations about aphasia. In: Brookshire, RH., editor. Clinical Aphasiology: Conference Proceedings. Minneapolis: BRK; 1979. p. 30-37.

Dick F, Bates E, Wolfec B, Utman JA, Dronkers N, Gernsbacher MA. Language deficits, localization, and grammar: Evidence for a distributive model of language breakdown in aphasic patients and neurologically intact individuals. Psychological Review. 2001; 108(4):759–788. [PubMed: 11699116]

Eisenson J. Language and intellectual modifications associated with right cerebral damage. Language and Speech. 1962; 5:49–53.

Engle, R.; Kane, MJ.; Tuholski, SW. Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence and functions of the prefrontal cortex. In: Miyake, A.; Shah, P., editors. Models of working memory: Mechanisms of active maintenance and executive control. Cambridge, UK: Cambridge University Press; 1999. p. 102-131.

Flexser AJ, Tulving E. Retrieval independence in recognition and recall. Psychological Review. 1978; 85:153–171.

Friedmann N, Gvion A. Sentence comprehension and working memory limitation in aphasia: A dissociation between semantic-syntactic and phonological reactivation. Brain and Language. 2003; 86:23–39. [PubMed: 12821413]

Gainotti G, Cappa A, Perri R, Silveri MC. Disorders of verbal and pictorial memory in right and left brain-damaged patients. International Journal of Neuroscience. 1994; 78(1–2):9–20. [PubMed: 7829295]

Hanley JR, Young AW, Pearson NA. Impairment of the visuo-spatial sketch pad. The Quarterly Journal of Experimental Psychology. 1991; 43A(1):101–125. [PubMed: 2017570]

Heilbronner RL, Henry GK, Buck P, Adams RL, Fogle T. Lateralized Brain Damage and performance on trail making A and B, Digit span forward and backward, and TPT memory and location. Archives of Clinical Neuropsychology. 1991; 6:251–258. [PubMed: 14589517]

Heilman KM, Scholes R, Watson RT. Defects of immediate memory in Broca's and Conduction aphasia. Brain and Language. 1976; 3:201–208. [PubMed: 938927]

Hester RL, Kinsella GJ, Ong B. Effect of age on forward and backward span tasks. Journal of the International Neuropsychological Society. 2004; 10:475–481. [PubMed: 15327726]

Just MA, Carpenter PA. A capacity theory of comprehension: Individual differences in working memory. Psychological Review. 1992; 99:1–27.

Jonides J, Smithe E, Koeppe R, Awh E, Minoshima S, Mintum MA. Spatial working memory in humans as revealed by PET. Nature. 1993; 363:623–625. [PubMed: 8510752]

Kahneman, D. Attention and effort. Englewood Cliffs, NJ: Prentice-Hall; 1973.

Kapur S, Rose R, Liddle PF, Zipursky RB, Brown GM, Stuss D, et al. The role of the left prefrontal cortex in verbal processing: Semantic processing or willed action? Neuroreport. 1994; 5:2193–2196. [PubMed: 7865775]

Kertesz, A. Western Aphasia Battery. New York: Grune and Stratton; 1982.

Lehman MT, Tompkins CA. Reliability and validity of an auditory working memory measure: Data from elderly and right-hemisphere damaged adults. Aphasiology. 1998; 12:771–785.

Lehman-Blake MT, Tompkins CA. Predictive inferencing in adults with right hemisphere brain damage. Journal of Speech, Language, and Hearing Research. 2001; 44:639–654.

Lezak, MD. Neuropsychological assessment. 3. New York: Oxford University Press; 1995.

Norman, DA.; Shallice, T. Attention to action: Willed and automatic control of behavior. In: Davidson, RJ.; Schwartz, GE.; Shapiro, D., editors. Consciousness and self-regulation. New York: Plenum Press; 1986. p. 1-18.

Martin N. Word processing and verbal short-term memory: How are they connected and why do we want to know? Brain and Language. 2000; 71:149–153. [PubMed: 10716832]

Martin N, Ayala J. Measurements of auditory-verbal STM span in aphasia: effects of item, task, and lexical impairment. Brain and Language. 2004 June; 89(3):464–483. [PubMed: 15120538]

Martin RC. Articulatory and phonological deficits in short-term memory and their relation to syntactic processing. Brain and Language. 1987; 32:159–192. [PubMed: 3651806]

McFie, L. The diagnostic significance of disorders of higher nervous activity. In: Vinken, P.; Bruyn, G., editors. Handbook of clinical neurology. Vol. 4. Amsterdam; North Holland: 1969. p. 1-12.

McNeil MR, Odell K, Tseng CH. Toward the integration of resource allocation into a general theory of aphasia. Clinical Aphasiology. 1991; 20:21–39.

Mecklinger A, von Cramon DY, Springer A, Matthes-von Cramon G. Executive control functions in task switching: Evidence from brain injured patients. Journal of Clinical and Experimental Neuropsychology. 1999; 21(5):606–619. [PubMed: 10572281]

Miyake A, Carpenter PA, Just MC. A capacity approach to syntactic comprehension disorders: Making normal adults perform like aphasic patients. Cognitive Neuropsychology. 1994; 11(6):671–717.

Murray LL, Holland AL, Beeson PM. Auditory processing in individuals with mild aphasia: A study of resource allocation. Journal of Speech, Language, and Hearing Research. 1997; 40:792–808.

Murray LL. Cognitive treatments for aphasia: Should we and can we help attention and working memory problems? Journal of Medical Speech-Language Pathology. 2004; 12(3):xxv–xl.

Myerson J, Emery L, White DA, Hale S. Effects of age, domain, and processing demands on memory span: Evidence for differential decline. Aging Neuropsychology and Cognition. 2003; 10:20–27.

Myers, PS.; Blake, ML. Communication disorders associated with right-hemisphere damage. In: Chapey, R., editor. Language intervention strategies in aphasia and related neurogenic communication disorders. Philadelphia, PA: Wolters Kluwer; 2008. p. 963-987.

Newcombe, F. Missile wounds of the brain. London: Oxford University Press; 1969.

Ostrin RK, Schwartz MF. Reconstructing from a degraded trace: A study of sentence repetition in agrammatism. Brain and Language. 1986; 28:328–345. [PubMed: 3730819]

Ostrosky-Solis F, Lozano A. Digit Span: Effect of education and culture. International Journal of Psychology. 2006; 41(5):331–341.

Paulesu E, Frith CD, Frackowiak RSJ. The neural correlates of the verbal component of working memory. Nature. 1993 March.362:342–345. [PubMed: 8455719]

Philipose LE, Alphs A, Prabhakaran V, Hillis AE. Testing conclusions from functional imaging of working memory with data from acute stroke. Behavioral Neurology. 2007; 18:37–43. [PubMed: 17297218]

Pimental, PA.; Knight, JA. Mini Inventory of Right Brain Injury-II. Austin, TX: Pro-Ed; 2000.

Pluth S, Bogdanova Y, White RF, Lundgren K, Albert ML. Examination of auditory and visual memory spans in an aphasic population. Journal of the International Neuropsychological Society. 2003; 9:135–330. [PubMed: 12701618]

Prabhakaran V, Narayanan K, Zhao Z, Gabrieli JD. Integration of diverse information in working memory within the frontal lobe. Nature Neuroscience. 2000; 3:85–90.

The Psychological Corporation. WAIS-III/WMS-III technical manual: Updated. San Antonio, TX: Author; 2002.

Ronnberg J, Larsson C, Fogelsjoo A, Nilsson LG, Lindberg M, Angquist KA. Memory dysfunction in mild aphasics. Scandinavian Journal of Psychology. 1996; 37(1):46–61. [PubMed: 8900819]

Rothi LJ, Hutchinson EC. Retention of verbal information by rehearsal in relation to the fluency of verbal output in aphasia. Brain and Language. 1981; 12:347–359. [PubMed: 7214134]

Rypma B, D'Esposito M. Isolating the neural mechanisms of age-related changes in human working memory. Nature Neuroscience. 2000; 3:509–515.

Rypma B, Prabhakaran V, Desmond JE, Glover GH, Gabrieli JDE. Load-dependent roles of frontal brain regions in the maintenance of working memory. NeuroImage. 1999; 9:216–226. [PubMed: 9927550]

Saffran EM, Martin OSM. Immediate memory for word lists and sentences in a patient with deficient auditory short-term memory. Brain and Language. 1975; 2:420–433. [PubMed: 1218376]

Sakurai Y, Takeuchi S, Kojima E, Yazawa I, Murayama S, Kaga K, et al. Mechanism of short-term memory and repetition in conduction aphasia and related cognitive disorders: A neuropsychological, audiological and neuroimaging study. Journal of Neurological Sciences. 1998; 154:182–193.

Slansky BL, McNeil MR. Resource allocation in auditory processing of emphatically stressed stimuli in aphasia. Aphasiology. 1997; 11:461–472.

Smith EE, Jonides J, Koeppe RA. Dissociating verbal and spatial working memory using PET. Cerebral Cortex. 1996; 6:11–20. [PubMed: 8670634]

Tompkins CA, Baumgaertner A, Lehman MT, Fassbinder W. Mechanisms of discourse comprehension impairment after right hemisphere brain damage: Suppression and enhancement in lexical ambiguity resolution. Journal of Speech, Language, and Hearing Research. 2000; 43:62–78.

Tompkins CA, Bloise CGR, Timko ML, Baumgaertner A. Working memory and inference revision in brain-damaged and normally aging adults. Journal of Speech and Hearing Research. 1994; 37:896–912. [PubMed: 7967574]

Tompkins CA, Fassbinder W, Scharp VL, Meigh KM. Activation and maintenance of peripheral semantic features of unambiguous words after right hemisphere brain damage in adults. Aphasiology. 2008a; 22:119–138. [PubMed: 20011607]

Tompkins CA, Lehman MT, Baumgaertner A. Suppression and inference revision in right brain-damaged and non-brain damaged adults. Aphasiology. 1999; 13(9–11):725–742.

Tompkins CA, Lehman-Blake MT, Baumgaertner A, Fassbinder W. Mechanisms of discourse comprehension impairment after right hemisphere brain damage: Suppression in inferential ambiguity resolution. Journal of Speech, Language, and Hearing Research. 2001; 44:400–415.

Tompkins CA, Lehman-Blake MT, Baumgaertner A, Fassbinder W. Characterising comprehension difficulties after right brain damage: Attentional demands of suppression function. Aphasiology. 2002; 16(4/5/6):559–572.

Tompkins CA, Scharp VL, Fassbinder W, Meigh KM, Armstrong EM. A different story on “theory of mind” deficit in adults with right hemisphere brain damage. Aphasiology. 2008b; 22:1–20.

Tompkins CA, Scharp VL, Meigh KM, Fassbinder W. Coarse coding and discourse comprehension in adults with right hemisphere brain damage. Aphasiology. 2008c; 22:204–223. [PubMed: 20037670]

Tompkins CA, Meigh K, Scott AG, Lederer LG. Can high-level inferencing be predicted by Discourse Comprehension Test performance in adults with right hemisphere brain damage? Aphasiology. 2009; 23(7–8):1016–1027. [PubMed: 19960072]

Tseng C, McNeil MR, Milenkovick P. An investigation of attention allocation deficits in aphasia. Brain and Language. 1993; 45(2):276–296. [PubMed: 8358600]

Turner ML, Engle RW. Is working memory capacity task dependent? Journal of Memory and Language. 1989; 28:127–154.

Vallar G, Baddeley AD. Phonological short term store: Phonological processing and sentence comprehension: A neuropsychological case study. Cognitive Neuropsychology. 1984; 1:121–141.

Ween JE, Verfaellie M, Alexander M. Verbal memory function in mild aphasia. Neurology. 1996; 47:795–801. [PubMed: 8797482]

Weinberg J, Diller L, Gerstmann L, Schulman P. Digit span in right and left hemiplegics. Journal of Clinical Psychology. 1972; 28:361. [PubMed: 5038003]

Wilde NJ, Strauss E, Tulsky DS. Memory span on the Wechsler scales. Journal of Clinical and Experimental Neuropsychology. 2004; 26(4):539–549. [PubMed: 15512941]

Wright HH, Newhoff M, Downey R, Austermann S. Additional data on working memory in aphasia. Journal of International Neuropsychological Society. 2003; 9:302.

Wright HH, Shisler RJ. Working memory in aphasia: Theory, measures, and clinical implications. American Journal of Speech-Language Pathology. 2005; 14:107–118. [PubMed: 15989386]

Yasuda K, Nakamura T. Comprehension and storage of four serially presented radio news stories by mild aphasic subjects. Brain and Language. 2000; 75:399–415. [PubMed: 11112294]

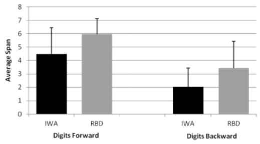

Figure 1.

The means of DF and DB for each group. Bars represent standard deviations.

Table 1

Summary of descriptive data for IWA.

Participant	Age (Years)	Months Post Onset	Area of Lesion	WABAQ	Aphasia Type	Education (Years)
L1	60	1	Left MCA	85.5	Anomic	16
L2	53	1	Left MCA	86.3	Anomic	11
L3	56	1	Left parietal	77.3	Anomic	18
L4	41	2	Left MCA	63.5	TranSensory	16
L5	52	< 1	Left MCA	34.2	Broca’s	12
L6	52	2	Left ACA/MCA	22.4	Broca’s	18
L7	40	< 1	Left MCA	88.6	Anomic	12
L8	56	2	Left MCA	89.6	Anomic	13
L9	66	< 1	Left posterior parietal	59.4	Broca’s	15
L10	47	1	Left MCA	82.6	Anomic	14
L11	63	1	Left MCA	68.5	Broca’s	12
L12	62	2	Left ICA	84.8	Anomic	13
L13	41	2	Left MCA/PCA	11.8	Broca’s	16
L14	46	3	Left MCA	54.7	Broca’s	16
L15	60	5	Left temp/occipital	77.3	Anomic	8
L16	51	4	Left ICA	87.6	Anomic	12
L17	56	5	Left ICA	93.0	Anomic	16

MCA=Middle Cerebral Artery, ACA=Anterior Cerebral Artery, ICA=Internal Cerebral Artery

Table 2

Summary of descriptive data for RBD.

Participant	Age (Years)	Months Post Onset	Area of Lesion	MIRBI	Education (Years)
R1	67	2	right frontal/occipital	4	12
R2	48	1	right watershed MCA	4	12
R3	62	1	right MCA/ACA	6	12
R4	57	2	right MCA/ACA	6	15
R5	62	1	right MCA	7	16
R6	60	1	right MCA/PCA	4	10
R7	63	1	right MCA/ACA	6	12
R8	54	6	right MCA	4	12
R9	71	1	right MCA	6	14
R10	43	4	right pontine	7	16
R11	60	6	right MCA	6	16
R12	73	< 1	right MCA	7	16
R13	63	1	right MCA	7	16
R14	74	2	right MCA	6	3