INTRODUCTION

Impaired comprehension of language (both listening and reading) is a common feature in the performance of persons with aphasia (PWA) (Kertesz, 1982), or essential for its diagnosis (McNeil & Pratt, 2001). Dysfunction in one or more of three mechanisms have been proposed to account for this impairment; *linguistic* (e.g. Grodzinsky, 2000), *memorial* (e.g. Martin, Kohen, & Kalinyak-Fliszar, 2008) and *attentional* (e.g. McNeil, 1982). One construct that unites these three mechanisms and licenses their interaction is that of working memory (WM). In its original and most basic formulation (Baddeley & Hitch, 1974), WM is a mechanism whereby information from various cognitive sources (e.g., linguistic) is held in a limited capacity short term memory (STM) buffer, were subordinate representations are integrated, or in some fashion computed, in order to yield a product greater or different from its component parts. These linguistic computations (LC) in STM are limited, enabled and guided by an executive attentional system (EA). Since its original introduction and subsequent acceptance, it has undergone considerable investigation (Cf: Miyake and Shah, 1999; Cowan, 2011). The work of Engle, Tuholski, Laughlin, & Conway (1999) has elucidated the essential nature of EA, perhaps the most elusive, controversial but important component of WM. Engle and colleagues have, through factor analysis, highlighted the critical role of EA in the model and made the strong claim that “goal maintenance” and “conflict resolution” form the bases of EA as applied to verbal WM (VWM) and accounts for the majority of its variance.

Sentence comprehension, evaluated within the framework of VWM, offers a rich platform for exploring the mechanisms subtending their impairments. While several measures of VWM have been developed, none has found acceptance, especially for the assessment of PWA. Furthermore, the measures that have been developed, without exception, do not afford a fractionation of the three components (LC, STM & EA). The typical VWM tasks developed by Caplan and Waters (1999), Gaulin and Campbell (1994), Tompkins, Bloise, Timko, & Baumgaertner (1994), Water and Caplan (1996, 1999, 2004) and Wright and Shisler (2005) manipulate LC and STM but do not attempt to manipulate and quantify the independent demands or impairments of EA. Furthermore, when individual components of VWM have been explored (e.g. Engle, Tuholski, Laughlin & Conway, 1999) the tasks used to assess each of the components make vastly different cognitive demands by varying the stimuli, computations and responses across tasks. Indeed, it seems beneficial and perhaps imperative to develop a measure whose task requirements can be manipulated parametrically– holding all components constant while manipulating one variable at a time so that the individual and interactional demands of LC, STM and EA can be evaluated. Additionally, the tool must be calibrated in difficulty for PWA. One tool that may be particularly well suited to this purpose is the Computerized Revised Token Test (CRTT). The CRTT maintains the same task and response stimuli and scoring system across all subtests. It systematically manipulates STM by adjectival padding (adding and deleting size adjectives) and phrasal number (simple versus compound). LC is manipulated by comparing imperative, prepositional or active/passive sentence types. EA is manipulated by requiring Stroop-like comprehension of color words printed and read in regular font (“red” printed and responded to as the lexical word) versus colored font (“red” printed and responded to in the font color). With these parametric manipulations, it may be possible to evaluate the independent and interactional components of VWM in sentence comprehension.

METHODS

It was the purpose of this investigation to evaluate the main effects and interactions among LC and EA (controlling STM) across two on-line (reading times for Color Words and

Nouns) and off-line (OA reading time, OA response time, CRTT-R Score, CRTT-R Efficiency Score, Color and Noun word Errors), measures for the CRTT-R (reading version) and CRTT-R-Stroop, comparing normal controls (NC) and PWA. To accomplish this, the CRTT-R and CRTT-R-$_{\text{Stroop-100\%-Incongruent}}$ (taxing goal maintenance and conflict resolution) versions of the battery (described by McNeil, et al, 2010) were administered to 30 NC and 25 PWA. After eliminating missing data, errors in some conditions and outliers, 29 NC and 22 PWA were included.

The PWA met the definition and criteria for aphasia specified by McNeil and Pratt (2001) as evidenced by their performance on the *Porch Index of Communicative Ability* (*PICA*) (Porch, 2001) or *WAB* (Kertesz, 2001). The NA group had no history of brain injury, a self-report of normal language development and/or PICA overall performance at or above the range established for normal adults (13.86) (Duffy & Keith, 1980). All participants were administered the Digit span test from the Wechsler Memory Scale (Wechsler, 1981), and the Trail Making Test, Parts A and B (Reitan, 1958). Demographic and selection data for the full group are summarized for the PWA in Table 1 and the NC in Table 2.

A 3-way (group X condition X linguistic contrast (imperative versus left/right prepositional sentences) - RM-ANOVA was computed for each of the dependent measures. We recognize the limitations in conducting these analyses independently for each dependent measure, however, we find it justified and superior as an exploratory analysis for determining the most relevant combination of factors within the CRTT-R for fractionating sentence-level VWM.

SUMMARY OF RESULTS

Table 3 summarizes the results. Those significant contrasts are summarized below.

Main Effects:

Group The PWA performed significantly ($p<.05$) slower, with lower scores and more errors compared the age-matched controls on each of the eight dependent measure.

Condition The Stroop-100% incongruent condition yielded significantly longer reading times (on-line measure) and more errors for color word reading (locally determined off-line measure) than the normal reading condition. Unexpected longer response times and more shape errors were found for the fade, compared to the Stroop condition.

Language Complexity The off-line measures of Overall CRTT-R Score and Efficiency, Response Time and Sentence Reading Time each showed a significantly poorer performance on the prepositional compared to the imperative sentences.

***Interaction Effects*:**

Group by Condition While both groups demonstrated significantly longer response times on the Stroop condition, the PWA demonstrated an over-additive effect compared to the NC group.

Language Complexity by Group While the prepositional phrases yielded significantly longer response times for the PWA, their times were over-additive compared to the NC group.

Language Complexity by Condition While the PWA produced significantly longer response times than the NC group, significantly longer response times on the fade than the Stroop condition produced a significant LC by condition interaction.

Language Complexity by Condition by Group This interaction is accounted for by a group, by condition by sentence length effect; A comparison not of interest in this investigation.

DISCUSSION

These findings are interpreted as providing qualified support for the CRTT-R-$_{\text{fade}}$ and CRTT-R-$_{\text{Stroop-100\%-Incongruent}}$ tasks for the capture of the LC and EA components of VWM in both NC and PWA. Each of the dependent measures demonstrated the expected performance pattern for PWA relative to NC. Only the on-line color word reading times and errors captured the Stroop effects. The primary off-line measures captured the linguistic complexity effects. The overall response time yielded the expected PWA by Stroop and PWA by linguistic complexity interaction effects. Additional research will address the STM component of VWM relative to the CRTT-R tests as well as other sentence type challenges offered by the active/passive sentences.

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Table1. Demographic and descriptive measures for the Persons With Aphasia

PWA Group	Age (Years)	Education (Years)	Gender	PICA-%ile / WAB –AQ*	MPO	Digit Span - Forward	Digit Span - Backward	TMT - A	TMT - B
1	55	16	F	81	362	7	4	33	114
2	75	14	F	79	369	8	5	56	143
3	47	14	F	72	36	2	4	26	103
4	50	18	F	90	19	4	4	64	128
5	58	17	M	71	57	7	4	52	144
6	42	18	M	66	37	4	2	27	157
7	63	16	M	69	48	4	2	40	247
8	71	10	F	71	48	2	2	99	257
9	67	13	F	74	492	6	4	142	468
10	64	15	M	75	73	5	5	34	193
11	54	18	F	30	22	8	4	41	55
12	37	16	M	38	76	2	2	233	>300
13	59	18	M	62	20	1	1	191	>300
14	54	14	M	60	154	1	2	85	282
15	57	14	M	52	24	0	2	120	>300
16	52	15	M	88*	-	7**	**	31	81
17	66	21	M	86.8*	-	0**	**	76	176
18	71	25	M	32.7*	-	0**	**	61	122
19	59	17	M	79.3*	-	6**	**	62	132
20	66	17	M	80.8*	-	27**	**	37	123
21	60	16	M	19.16*	-	0**	**	31	65
22	72	18	M	77.4*	-	0**	**	40	124
23	47	12	M	92.8*	-	31**	**	52	61
24	51	16	M	92.4*	-	70**	**	35	76
25	68	20+	M	91*	-	40**	**	43	137
Mean	59	16	F:7/M:18	PICA: 66 *WAB: 74	122	4.1 18.1**	3.1	68	172
SD	10	3			154	2.7 23.6**	1.3	52	100

PICA=Porch index of Communicative Ability (Porch, 2001); MPO=Months Post Onset; M=Male; F=Female; TMT=Trail Making Test (Reitan, 1958); Digit Span=maximum recalled items; *=WAB (Western Aphasia Battery Aphasia Quotient); **=WAIS-III digit span score - memory scale form 1.

Table2. Demographic and descriptive measures for the Normal Control Participants

NC Group	Age (Years)	Education (Years)	Gender	PICA-%ile WAB – AQ**	Digit Span - Forward	Digit Span - Backward	TMT - A	TMT - B
1	50	16	M	35	10	6	16	43
2	58	13	F	45	11	10	19	36
3	69	12	M	50	11	12	21	51
4	41	12	M	25	10	9	12	40
5	55	14	F	25	7	7	19	49
6	80	14	M	10	11	12	52	100
7	55	16	M	30	8	6	37	97
8	56	16	F	30	9	6	33	87
9	83	16	M	15	10	8	33	69
10	85	18	F	25	8	8	33	81
11	76	12	M	10	6	4	47	108
12	77	18	M	60	11	8	34	85
13	80	12	M	35	8	7	61	81
14	78	12	F	15	8	6	19	54
15	54	16	M	35	7	6	24	59
16	25	14	M	----**	25**	**	21	48
17	42	16	M	----**	30**	**	19	84
18	60	16	F	----**	47**	**	25	66
19	63	16	F	----**	44**	**	19	46
20	69	18	M	----**	28**	**	19	56
21	73	16	F	----**	28**	**	32	80
22	69	16	F	----**	34**	**	33	67
23	54	7	M	----**	76**	**	28	90
24	57	18	F	----**	44**	**	24	70
25	60	18	F	----**	95**	**	34	55
26	61	16	F	----**	56**	**	27	59
27	50	18	F	----**	110**	**	17	30
28	62	18	M	----**	24**	**	18	47
29	64	15	F	----**	57**	**	38	59
Mean	62	15	F;1 M;1	29.7	9/ 49.9**	7.7	28	65
SD	14	3		14.5	1.7/ 25.9**	2.3	11	21

PICA=Porch index of Communicative Ability (Porch, 2001); M=Male; F=Female; TMT=Trail Making Test (Reitan, 1958); Digit Span=maximum recalled items; *=WAB (Western Aphasia Battery Aphasia Quotient); **=WAIS-III digit span score -memory scale form 1.

Table 3. Summary of results for main effects and interactions for independent variable for each dependent measure.

Dependent Measure	**Group** ***NC* Vs. *PWA***	**Condition (EA)** ***Fade* Vs. *Stroop 100% Incongruent***	**Language Complexity (LC)** ***Imperative* Vs. *Prepositional***	**Group X EA**	**LC X Group**	**LC X EA**	**LC X EA X Group**
OA CRTT-R SCORE	Sig. (p<.0001) **PWA<NC**	Nonsig.	Sig. (p<.0001) **Imp.<Prep.**	Nonsig.	Nonsig.	Nonsig.	Nonsig.
OA CRTT-R EFFICIENCY SCORE	Sig. (p<.0001) **PWA<NC**	Nonsig.	Sig. (p<.0001) **Imp.<Prep.**	Nonsig.	Nonsig.	Nonsig.	Nonsig.
OA RESPONSE TIME	Sig. (p<.0001) **PWA>NC**	Sig. (p<.0001) Fade>Stroop	Sig. (p<.0001) **Imp.<Prep.**	Sig. (p<.02) **NC<PWA***	Sig. (p<.0004) **NC<PWA*****	Sig. (p<.0001) NC>PWA[+]	Nonsig.
OA SENTENCE READING TIME	Sig. (p<.0001) **PWA>NC**	Nonsig.	Sig. (p<.0001) **Imp.<Prep.**	Nonsig.	Nonsig.	Nonsig.	Sig. (p<.002)
COLOR (adjective) WORD READING TIME	Sig. **(p<.0001)** **PWA>NC**	Sig. (p<.0001) **Fade<Stroop**	Nonsig.	Sig. (p<.019) Mixed Effects**	Nonsig.	Nonsig.	Nonsig.
COLOR (adjective) WORD ERRORS	Sig. (p<.0001) **PWA>NC**	Sig. (p<.0001) **Fade<Stroop**	Sig. (p<.004) Imp.>Prep.	Nonsig.	Nonsig.	Nonsig.	Nonsig.
SHAPE (noun) WORD READING TIME	Sig. (p<.0005) **PWA>NC**	Nonsig.	Nonsig.	Nonsig.	Nonsig.	Nonsig.	Nonsig.
SHAPE (noun) WORD ERRORS	Sig. (p<.0005) **PWA>NC**	Sig. (p<.035) Fade>Stroop	Nonsig.	Nonsig.	Nonsig.	Nonsig.	Sig. (p<.001)

Predicted results are **bolded**.
*PWA demonstrated an over-additive effect of the Stroop condition compared to the NC
**Mixed effects were found whereby the fade condition produced longer reading times in the imperative sentences compared to the prepositional sentences, however, the Stroop condition produced the expected longer reading times in the prepositional sentences compared to the imperative sentences.
***The PWA produced longer response times that were over-additive relative to the CA participants.
[+] A reversed effect was found whereby the fade condition produced longer OA response times than the Stroop condition.