Developing a standardized measure of short-term memory and syntactic complexity: results from subtests of the CRTT-R

Background

According to a prominent view, sentence comprehension deficits in individuals with aphasia arise due to a reduction in working memory (WM) or processing resources necessary to conduct the operations for decoding and integrating lexical, syntactic, semantic, prosodic and discourse information (e.g., Caplan et al., 2007; Haarmann, Carpenter, & Just, 1997). In its original formulation by Baddeley and Hitch (1974), WM is a system that supports both the temporary storage as well as current computations necessary to accomplish a task. A central executive component provides attentional control over the system.

While any task requires the use of both short-term memory (STM) and computational/executive components of WM, tasks differ in the extent they draw on each component (Engle et al, 1999). Results from several studies suggest that the contribution of STM and complexity/executive aspects of working memory can be distinguished (e.g., Conway et al, 2002; Engle et al.,1999). It follows that for both theoretical and clinical purposes it is important to delineate differential effects of reduced capacity in STM and the computational/executive components of WM on deficits in sentence comprehension. This study investigates if effects of STM and WM in sentence comprehension can be measured with an adapted version of the CRTT-R (McNeil et al., 2010).

Most studies of sentence comprehension deficits in aphasia have focused on varying the complexity of syntax. A hierarchy of difficulty for various syntactic structures is fairly well established, both theoretically and experimentally (e.g., Caplan, Baker, & Dehaut, 1985). Therefore manipulation of syntactic complexity can be considered a reliable approach to study working memory effects for linguistic computations, and was chosen for this study.

STM was taxed by adding additional words that do not affect syntactic complexit.. Such padding increases the distance between sentence areas that induce syntactic complexity effects (e.g., the verb in passive sentences), and add lexical information that needs to be integrated. While padding reliably reduces comprehension performance in unimpaired individuals, results for individuals with aphasia have been mixed (see Sung et al., 2011) However, the implementation of padding in the CRTT has been shown to affect off-line and on-line measures in both unimpaired individuals and individuals with aphasia (McNeil & Prescott, 1978; Sung et al., 2011), and was therefore chosen for this study.

Methods

Fifty-four individuals (29 control participants (CP) , 25 participants with aphasia (PWA)) participated in the study (see Table 1 and 2 for demographic and selection data for CPs and PWAs, respectively). CPs had no history of brain injury, normal language development (self-report), and/or performed at or above 13.86 on the overall score of the PICA (Duffy & Keith, 1980). PWAs met McNeil and Pratt's (2001) definition and criteria for aphasia, assessed with the *Porch Index of Communicative Ability* (*PICA*) (Porch, 2001) or *WAB* (Kertesz, 2001). 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).

All stimuli were based on subtests from the CRTT-R battery (see McNeil et al., 2010, for details about stimuli, task structure, and dependent measures). Effects of syntactic complexity (SC) were investigated in two sets of contrasted sentence structures (see Table 3 for stimulus examples): (1) imperative sentences in which two NPs are conjoined by “and” versus connected by a preposition; (2) declarative active versus passive sentences. Padding was manipulated by adding a size adjective (“little”, “big”) to the NP. Participants read each sentence in a computer-presented word-by-word self-paced reading paradigm.

Analysis

Effects of SC and padding were investigated for sentence-based off-line measures (CRTT-R Score, efficiency score, response time, and sentence reading time) as well as local word-based effects for color adjective and shape noun (accuracy and reading time) in the second NP, that is, after the preposition or verb that induces the SC effect.

A three-way repeated-measure general linear model analysis was carried out for each dependent measure with SC (imperative-conjoined, imperative-prepositional, declarative-active, declarative-passive) and Padding (1 vs. 2 adjective) as within-subject, and Group (CP vs. PWA) as between-subject factors. Significant interactions were investigated with post-hoc contrasts, Bonferroni-adjusted to a cumulative alpha-level of $p < .05$).

Results

This section reports only significant findings (alpha-level of $p <.05$). Because of the space limitations for this abstract, p-values are reported in Table 3.

All measures showed an effect of group, that is, CPs performed better than PWAs on all tasks. The CRTT-R score and efficiency score showed main effects for SC and Padding, reflecting that performance was better on imperative-conjoined than on imperative-prepositional, better on actives than on passives, and on unpadded versus padded sentences. Response time showed main effects for SC and Padding, but the Padding main effect was qualified by a Group x Padding interaction. These results reflected that response times were faster on the imperative-conjoined than on all other conditions. Furthermore, only PWA showed a length effect.

Because of different sentence length, sentence reading times are not a good measure of SC or padding. However, the analysis was included to verify that reading times reflected expected sentence-length effects. The analysis revealed that on declarative sentences, reading times on actives were slower than on passives, even for words before the verb that induces the complexity difference. Therefore this effect was considered an artifact, and reading time investigation for words was limited to the imperative sentences.

Errors for the color adjective and shape noun showed main effects for Group and SC. The SC effect was qualified by a Group/SC interaction, which revealed that only PWA showed an effect of SC, making more errors on passives than on the other sentence structures. Reading times for both words in the imperative conditions showed main effects for Group.

Discussion

All tasks were sensitive to the presence of aphasia. CRTT-R score and Efficiency score clearly captured the manipulation of STM and linguistic complexity in this study, validating the basic approach. The pattern of response times could reflect the intended manipulations, but might also reflect task differences (touch vs. move, and motor difficulties for PWA on the more complex response array).

This initial exploratory analysis was not designed to test for the separability of SC and STM, because the established main effects could equally derive from a single-component account of working memory, where each level of combined SC and STM reflects an increase in complexity (Haarmann et al., 1997). The surprising lack of an interaction between SC and STM in all measures is certainly consistent with the assumption that SC and STM are separable effects in this task. Of course, as a null effect it has to be interpreted with caution.

Another surprising result is the lack of an expected overadditive effect for SC on individuals with aphasia, which has been documented frequently (e.g., Caplan et al., 1985, Caplan et al., 2007; Sung et al., 2011). However, the interaction present in the error scores for words suggest a similar effect. The higher error rate for PWAs after the passive verbs compared to the other sentence structures suggests that for PWA with assumed lower processing resources, the difficulty of processing passives resulted in a spill-over effects for subsequent words, reflecting an additional reduction of resources at this point.

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Table1. Demographic and descriptive measures for the 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;14/ M;15	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 2. Demographic and descriptive measures for Participants With Aphasia

NC Group	Age (Years)	Education (Years)	Gender	PICA-%ile WAB – AQ**	Digit Span - Forward	Digit Span - Backward	TMT -A	TMT - B	NC Group
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.

Table 3. Examples of sentence structures in all conditions

Imperative		
	Conjoined/unpad[1]	Touch the red square and the green circle
	Conoinedj/pad[2]	Touch the big red square and the little green circle
	Prepositional/unpad	Put the red square above the green circle
	Prepositional/pad	Put the big red square above the little green circle
Declarative		
	Active/unpad	The red square has touched the green circle
	Active/pad	The bid red square has touched the little green circle
	Passive/unpad	The big red square has touched the little green circle
	Passive/pad	The big red square was touched by the little green circle

1 = unpadded, 2 = padded

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

Dependent Measure	**Group** *NC Vs. PWA*	**Padding** *Unpadded* **Vs.** *Padded*	**Language Complexity (LC)** *Imp/Conj vs. Imp/Prep vs. Decl/Act vs. Decl/Passive*	**Group X Padding**	**Group X LC**	**Padding X LC**	**LC X EA X Group**
CRTT-R SCORE	Sig. ($p<.001$)	Sig. ($p < .05$)	Sig. ($p<.001$)	Nonsig.	Nonsig.	Nonsig.	Nonsig.
EFFICIENCY SCORE	Sig. ($p<.001$)	Sig. ($p<.001$)	Sig. ($p<.001$)	Nonsig.	Nonsig.	Nonsig.	Nonsig.
RESPONSE TIME	Sig. ($p<.001$)	Sig. ($p<.001$)	Sig. ($p<.001$)	Sig ($p< .01$)	Nonsig.	Nonsig.	Nonsig.
SENTENCE READING TIME	Sig. ($p<.001$)	Sig. ($p<.001$)	Sig. ($p<.001$)	Nonsig.	Sig. ($p<.01$)	Sig. ($p<.001$)	Sig. ($p<.037$)
COLOR (adjective) READING TIME	Sig. ($p<.005$)	Nonsig.	Sig. ($p<.001$)	Nonsig.	Sig. ($p<.001$)	Nonsig.	Nonsig.
COLOR (adjective) WORD ERRORS	Sig. ($p<.001$)	Nonsig.	Sig. ($p<.001$)	Nonsig.	Sig. ($p<.001$)	Nonsig	Nonsig.
SHAPE (noun) WORD READING TIME	Sig. ($p<.001$)	Nonsig.	Sig. ($p<.001$)	Nonsig.	Nonsig.	Sig. ($p<.008$)	Nonsig.
SHAPE (noun) WORD ERRORS	Sig. ($p<.001$)	Nonsig.	Sig. ($p<.001$)	Nonsig.	Sig. ($p<.001$)	Nonsig.	Nonsig