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Research Article

Links Between Short-Term Memory and Word Retrieval in Aphasia

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Purpose: This study explored the relationship between anomia and verbal short-term memory (STM) in the context of an interactive activation language processing model.
Method: Twenty-four individuals with aphasia and reduced STM spans (i.e., impaired immediate serial recall of words) completed a picture-naming task and a word pair repetition task (a measure of verbal STM). Correlations between verbal STM and word retrieval errors made on the picture-naming task were examined.
Results: A significant positive correlation between naming accuracy and verbal span length was found. More intricate verbal STM analyses examined the relationship between picture-naming error types (i.e., semantic vs. phonological) and 2 measures of verbal STM: (a) location of errors on the word pair repetition task and (b) imageability and frequency effects on the word pair repetition task. Results indicated that, as phonological word retrieval errors (relative to semantic) increase, bias toward correct repetition of high-imageability words increases.
Conclusions: Results suggest that word retrieval and verbal STM tasks likely rely on a partially shared temporary linguistic activation process.

Aphasia, an acquired language disorder, impacts more than a million stroke and head injury survivors in the United States (National Institute of Neurological Disorders and Stroke, 2015) and affects all linguistic domains, including speaking, understanding, reading, and writing (Rosenbek, LaPointe, & Wertz, 1989). Most aphasiologists agree that aphasia results from impaired access: Linguistic elements are not wholly lost, but access to linguistic representations is disrupted (McNeil, Odell, & Tseng, 1991). Thus, investigations of language breakdown must take into account not only linguistic representations but also the processes that facilitate their access. Theoretically, such investigations will help determine how linguistic representations are activated and selected during language production and comprehension. Clinically, investigations of linguistic processing mechanisms will help move beyond identifying what language tasks are disrupted to understanding why the disruption occurred, thereby helping to inform the development of assessments and treatment programs for people with aphasia.

The current study investigated mechanisms underlying word retrieval impairment (anomia), a ubiquitous and pervasive symptom of aphasia (Benson, 1988). One process that underlies language, including word retrieval, is verbal short-term memory (STM), the temporary activation of linguistic representations (Martin & Saffran, 1997). This definition is consistent with Cowan's embedded processes model (Cowan, 1988), which holds that the storage system that supports linguistic processing must be at least partly language-specific and thus views STM as heightened activation of existing knowledge from long-term memory. Consistent with this claim, neural evidence points to shared networks between tasks classically labeled as STM tasks (i.e., immediate serial recall of a sequence of digits or words) and classic language tasks (Cahana-Amitay & Albert, 2015). Verbal STM is a subcomponent of verbal working memory, which includes the temporary storage system (i.e., STM) and attentional functions that (a) maintain activation of verbal information beyond the temporal limits of verbal STM and (b) manipulate information in verbal STM in the service of a given goal (e.g., repeating a list of words backward requires temporary storage of the linguistic information and an attentional mechanism that enables the numbers

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to be recalled in reverse order; Baddeley & Hitch, 1974; Unsworth & Engle, 2007; Wright & Fergadiotis, 2012). A note must be made on the choice to use the term STM rather than working memory to describe the process of interest in the current study. Though the complete isolation of the temporary storage system (i.e., STM) from the larger concept encompassing this system and additional attentional functions is likely impossible, a number of studies have demonstrated the theoretical and empirical validity for studying STM and working memory as separate constructs (for a review, see Unsworth & Engle, 2007). Every linguistic task likely has at least a minimal attentional component; however, the focus of the present work is to investigate how the fleeting verbal STM process supports language and affects its breakdown in aphasia.

The verbal STM model at the heart of this study, based on principles of Dell et al.'s two-stage interactive activation (IA) model of word retrieval (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997), offers a linguistically specified view of STM. Dell et al.'s model consists of three levels of interactive linguistic nodes: semantic nodes that hold conceptual information, lemma nodes that hold grammatical knowledge, and phonological nodes that hold sound-level information. Nodes at neighboring levels are connected through excitatory, bidirectional connections. Word production occurs in two steps: (a) selection of a lemma node and (b) selection of that node's corresponding phonemes. In the production of *cat*, for example, semantic nodes (e.g., furry, four legs) are activated first, and these units activate the corresponding lemma node and semantically related lemmas (e.g., dog), which in turn activate corresponding phonemes. As soon as activation starts to spread, it begins decaying to baseline but is replenished by feedback from nodes at subsequent levels (phoneme to lexical nodes and lexical to semantic nodes). The most highly activated lemma is selected and sends activation to its phonemes, which are selected in the second stage. In the case of weak activation or overly rapid decay, word retrieval can fail, resulting in the selection of a more strongly activated alternative (e.g., a semantic neighbor such as *dog*, a phonological neighbor such as *mat*, an unrelated real word or nonword) or an omission.

Martin's model is derived from this IA model and views verbal STM as the temporary activation of linguistic knowledge needed to process language (Martin & Saffran, 1997). The goal of this study is to test this model's hypothesis that classic STM tasks (i.e., immediate serial recall) and language tasks (e.g., picture naming) rely on a shared temporary linguistic activation mechanism. This idea conflicts with Baddeley's classic model of working memory, which views verbal STM as a largely phonological process that is not intrinsically connected to language production and comprehension (Baddeley & Hitch, 1974). In Baddeley's model, a phonological store (i.e., verbal STM) temporarily holds verbal information (e.g., a sequence of words) via a phonological code and works with attentional mechanisms to retain and manipulate this information. These STM and attentional mechanisms compose the larger working memory system. A number of recent studies have continued to use Baddeley's phonological store to conceptualize verbal STM (e.g., Lauro, Reis, Cohen, Cecchetto, & Papagno, 2010; Schuchardt, Maehler, & Hasselhorn, 2011). Conversely, Martin's model views STM and language as intricately tied constructs and argues that verbal STM makes use of a variety of linguistic codes (e.g., semantic, lexical, phonological) that are contingent on the needs of a given linguistic task. Though Baddeley (2000) amended the classic model (Baddeley & Hitch, 1974) by including a multimodal temporary storage system capable of integrating various types of information (i.e., episodic buffer), the updated model does not specifically outline a mechanism through which lexical and semantic information is stored in verbal STM.

STM: Method of Study and Pertinent Research

In an immediate serial recall task, an individual hears a sequence of digits or words and repeats them in the same order (see Madigan, 1980, for a review). The capacity limit for recall of verbal information in typical speakers hovers around seven, give or take two items (Mathy & Feldman, 2012; Miller, 1956). The tendency to better remember the first few (primacy bias) and last few (recency bias) items than items in the middle of a list has repeatedly been observed, and Baddeley and Hitch (1974) attributed recency to enhanced availability of the last few items in the phonological store and primacy to subvocal rehearsal of the first few items. Martin and Saffran (1997) later amended these assumptions by incorporating lexical–semantic in addition to phonological knowledge as a partial explanation for these biases. The idea that lexical–semantic information facilitates the storage of verbal information in STM is supported by various findings, including the better recall of words over nonwords (Hulme, Maughan, & Brown, 1991), digits over words (Brener, 1940), high- over low-imageability words (Bourassa & Besner, 1994), high- over low-frequency words (Allen & Hulme, 2006; Roodenrys, Hulme, Lethbridge, Hinton, & Nimmo, 2002), concrete over abstract words (Allen & Hulme, 2006; Brener, 1940), and content over function words (Bourassa & Besner, 1994; Brener, 1940).

Studies have consistently demonstrated reduced verbal spans in individuals with aphasia relative to neurologically healthy individuals (e.g., Albert, 1976; De Renzi & Nichelli, 1975; Martin & Ayala, 2004; Martin & Saffran, 1997; Potagas, Kasselimis, & Evdokimidis, 2011) and individuals with brain damage without aphasia (Lang & Quitz, 2012; Laures-Gore, Marshall, & Verner, 2011; Kasselimis et al., 2013). In addition, correlational studies have demonstrated that, as verbal STM span length increases, so does performance on classic language tasks, such as word-to-picture matching and phoneme discrimination (Martin & Ayala, 2004; Martin & Gupta, 2004; Potagas et al., 2011). Together, these findings demonstrate that verbal STM impairments in individuals with aphasia are not simply the result of generalized slow processing but that verbal STM and language are likely subserved by overlapping neural networks.

Beyond Span Length: Mechanisms Underlying the STM–Language Link

Several studies of individuals with aphasia have made connections between error location (i.e., primacy and recency effects in repetition) and language processing. This notion was most strongly supported by a study of 15 individuals with aphasia by Martin and Saffran (1997), who predicted that individuals with aphasia who demonstrate greater impairments on phonological input processing tasks (e.g., phoneme discrimination) relative to lexical–semantic processing should be more accurate in retrieving earlier segments during a word span task (primacy bias). This prediction was rooted in an IA model: The earlier segments' activation has more time to spread to semantics before recall. However, those who demonstrated greater impairment on semantic input-processing tasks (e.g., synonymy judgments) should be more accurate in retrieving later segments, which are supported via phonological activation but have not yet built up strong semantic activation (recency bias). Correlations between error location (primacy/recency biases) and language processing–impairment type (lexical–semantic vs. phonological) were consistent with the predictions, and similar results were found in a later study (Martin, Ayala, & Saffran, 2002). In addition, Martin and Saffran (1997) predicted that individuals with greater impairments in phonological processing should demonstrate typical word imageability effects (believed to be tied to semantic processing; e.g., Martín-Loeches, Hinojosa, Fernández-Frías, & Rubia, 2001; Nickels & Howard, 1994) and frequency effects (believed to be tied to lexical processing; e.g., Goldrick & Rapp, 2007; Schilling, 1998) on the word span task because they would likely rely heavily on lexical–semantic processing to complete the task. These effects should, however, be diminished in individuals with greater lexical–semantic impairments who are likely relying primarily on phonology during the word span task. Correlations between word imageability/frequency biases and language impairment type were consistent with the predictions, though the correlation between frequency bias and language impairment type did not reach significance.

More recently, Wilshire, Keall, and O'Donnell (2010) conducted a case study of two patients demonstrating that the aforementioned findings may extend to word production. Patient TV demonstrated primarily phonological nonword naming errors, a primacy effect in serial recall tasks, and an imageability effect on serial recall. Patient NP demonstrated primarily semantic naming errors, a recency effect on serial recall, and no imageability effect. These results warrant further investigation of the relationship between word production and verbal STM breakdown.

Extant literature supports the idea that the STM system that supports language is domain-specific, meaning that it does not support the recall of nonverbal information. The use of a Corsi block span task (De Renzi & Nichelli, 1975), a spatial STM task that requires individuals to replicate sequences of blocks by pointing to them in order of presentation, with individuals with aphasia has revealed conflicting findings regarding domain specificity of STM. Though many individuals demonstrate stronger spatial span performance relative to verbal span, some individuals still show reduced spatial span in comparison with neurologically healthy controls (Martin & Ayala, 2004) and adults with left-hemisphere brain damage but without aphasia (Kasselimis et al., 2013). Potagas et al. (2011) argued for a domain-independent STM on the basis of a correlation between the Corsi block task and classic language tests, but the concurrent finding that digit span length also correlated with the language tests but not with the Corsi block task is problematic for this view. Martin and Ayala (2004) also demonstrated equivocal results. Digit and word repetition spans correlated positively with the Corsi block task in a group of individuals with aphasia, whereas pointing versions of the digit and word span tasks that require participants to point to numbers or pictures corresponding to the sequence they heard did not significantly correlate with the Corsi block task. Additional investigations are needed to determine whether and to what extent a domain-specific STM mechanism supports language.

Research Questions and Predictions

The goal of the current study was to investigate the relationship between verbal STM and word retrieval impairment type in individuals with aphasia through an analysis of errors occurring in word pair repetition and picture naming. The research questions were the following:

1. Is verbal STM span length associated with (a) word retrieval accuracy and (b) a nonlinguistic (i.e., spatial) STM task? Predictions: Verbal STM span length will positively correlate with word retrieval accuracy but will not significantly correlate with spatial STM span length.
2. Is word retrieval impairment type associated with primacy/recency biases observed in a verbal STM task? Prediction: As phonological nonword naming errors relative to semantic errors increase, primacy bias will increase.
3. Is word retrieval impairment type associated with imageability and frequency biases observed in a verbal STM task? Prediction: As phonological nonword naming errors relative to semantic errors increase, imageability and frequency biases will increase.

Method

This project was approved by the University of Washington Institutional Review Board (#48385), and informed consent was obtained from each participant.

Inclusionary Criteria

Twenty-four individuals with aphasia participated in this study (Table 1). All participants had left-hemisphere

Table 1. Participant demographic characteristics.

ID	Gender	Age	MPO	Lang 1	Hand	Edu	Etiology	AOS characteristics
1	M	70	107	Eng	L	19	Remote left temporofrontal infarct with associated encephalomalacia	None
2	F	64	120	Eng	R	18	Left frontal, temporal, parietal infarct, before aneurysm clipping of left MCA (hemorrhage, craniotomy × 2)	None
3	M	54	74	Eng	R	16	Small, left, cortical lateral frontal infarct	None
4	M	68	36	Eng	R	12	Left MCA infarct temporal lobe, insula, frontal and parietal lobes affected	None
5	F	71	125	Eng	R	14	Left MCA infarct involving basal ganglia and cortical gray matter	None
6	F	60	70	Eng	R	12	Large left infarct with involvement of temporal pole and frontal lobe (extending from orbitofrontal cortex to Broca's area and to superior frontal sulcus)	None
7	M	61	77	Eng	R	16	Left hemorrhage with involvement of basal ganglia, posterior frontal, temporal, and parietal lobes	None
8	F	45	10	Eng	R	16	Left MCA infarct involving insula, operculum, modest extent of superior temporal gyrus, and extensive frontal cortex	None
9	F	54	54	Eng	R	14	Left MCA aneurysmal subarachnoid hemorrhage	Moderate. Slowed rate, segmented speech, increased difficulty on consonant clusters; presence of schwas and distorted substitutions.
10	M	66	60	Eng	R	16	Left MCA involving anterior left parietal lobe extending to the level of the Sylvian fissure with question of component of extension into the left temporal lobe. Mild effacement upon the left lateral ventricle.	None
11	F	59	51	Eng	R	20	Decompressive craniotomy after large left CVA. Left internal carotid occlusion (likely a very large ischemic infarct s/p decompressive craniotomy).	None
12	M	72	64	Eng	R	23	Left hemorrhagic CVA with involvement of basal ganglia, adjacent insular cortex, left corona radiata, with ischemic damage to frontal lobe	Mild. Slightly abnormal rate; mild disruption to prosody and articulation.
13	F	51	69	Gujarati	R	12	Left basal ganglia hemorrhagic infarct, with ischemic damage to overlying perisylvian cortex	None

(*table continues*)

Table 1. *(Continued).*

ID	Gender	Age	MPO	Lang 1	Hand	Edu	Etiology	AOS characteristics
14	M	61	116	Eng	R	19	Left MCA infarct, large territory hypodensity involving the left cerebral hemisphere in the frontal, temporal, and parietal lobes	Moderate. Distorted substitutions, errors increase with increasing word length, abnormal prosody.
15	F	71	41	Eng	R	14	Surgery to “tie off” aneurysm led to bleeding that required a second surgery Distal left M1 embolic event. Infarct involves part of putamen, insula, operculum (though minimal frontal), and extensive temporal and parietal lobes.	None
16	F	70	85	Eng	R	12	History of two strokes (or one stroke and one TIA). Left MCA territory infarcts including the temporoparietal junction, coronal radiata, and subinsular region (ischemic).	None
17	M	62	42	Eng	R	13	Distal L M1 event with extensive infarction of temporal lobe and insula and modest infarction of frontal and parietal operculum	None
18	M	57	128	Eng	L	18	Large, left MCA infarct with involvement in head of the caudate, most of the left lenticular nucleus, the insular cortex, and posterior half of the left frontal lobe extending into the anterior portion of the left parietal lobe	None
19	F	64	42	Eng	R	17	Large, left basal ganglia hemorrhage with intraventricular extension	None
20	M	60	32	Eng	R	16	Large, left basal ganglia hemorrhage	None
21	M	70	59	Eng	R	16	Suggestion of subtle loss of gray–white matter differentiation in the left basal ganglia. Occlusive thrombosis within proximal aspect of the left middle CVA.	None
22	F	72	34	Eng	R	16	Left M2 region infarct with loss of left insular ribbon, loss of gray–white differentiation in the left frontal operculum and left parietotemporal lobes (ischemic)	Mild. Distorted substitutions, segmented syllables, increase in errors with increasing word length, slowed speech rate.
23	F	56	17	Eng	R	12	Left MCA ischemic event. Infarct extending deep from lateral left frontal pole.	None
24	M	46	86	Eng	L	13	Massive left MCA infarct with subsequent surgical decompression. Left hemisphere is gone, expect for ACA and PCA territories.	None
M		61.83	66.63			15.56		
SD		8.04	33.77			2.95		

Note. AOS = apraxia of speech; CVA = cerebrovascular accident; Edu = years of education; F = female; Lang 1 = native language; M = male; MPO = months after left CVA onset; Eng = English; L = left; R = right; MCA = middle cerebral artery; s/p = status post; TIA = transient ischemic attack; M1 = primary motor cortex; M2 = supplementary motor cortex; ACA = anterior cerebral artery; PCA = posterior cerebral artery.

damage due to a cerebrovascular accident (CVA), which was confirmed through a computed tomography or magnetic resonance imaging scan and interpreted by a radiologist or behavioral neurologist. Individuals with multiple left-hemisphere strokes were included. Other inclusionary criteria were as follows: ≥ 6 months after CVA, ≥ 12 years of schooling, and between the ages of 30 and 75 years. All participants had to be native speakers or use English as their predominant language after stroke, confirmed by a short interview with participants and their caregivers. Whereas right handedness was preferred, left-handed individuals who presented with aphasia were included.

All inclusionary and descriptive language and verbal STM test scores are listed in Table 2. To confirm presence of aphasia, Comprehension of Spoken Language and Naming modality subscores of the Comprehensive Aphasia Test (CAT; Swinburn, Porter, & Howard, 2004) were calculated. Individuals who were below the cutoff scores (≤ 56/66 on Comprehension of Spoken Language and ≤ 69 on the Naming Subtest) met the language criteria. In addition, individuals who did not meet one or both cutoff scores but demonstrated marked production and comprehension difficulties in conversation, during discourse testing (as measured by the CAT picture description), and during the rest of the language battery (including the repetition subtest of the CAT), as confirmed by a certified speech-language pathologist, were also included. The seven participants who did not meet the standard cutoffs all demonstrated marked anomia and slow, halting, effortful speech in conversation and in the CAT picture description test as well as slowed speed on formal and informal language comprehension tasks.

To confirm presence of verbal STM impairment, participants had to demonstrate impaired performance on a word pointing span task (Martin, 2012), which was selected over the repetition version because it does not require a verbal response and may thus be a purer STM measure. Participants listened to a sequence of words and pointed to corresponding pictures in serial order. Each span length included 10 trials, and span length was calculated as follows: list length at which at least 50% of lists were reproduced correctly + 0.50 of the proportion of lists recalled at the next list length (Shelton, Martin, & Yaffee, 1992). Individuals with span lengths ≤ 4.0 met the verbal STM impairment criteria. In addition, participants who achieved a score ≥ 4.1 (i.e., no more than 2/10 items correct on the five-item list length) and a marked increase in difficulty at the four-item list length (e.g., verbal report of increased effort/fatigue, significantly slowed response time, and/or a significant increase in omission of list items) were also included.

Exclusionary Criteria

Individuals with a history of right CVA, degenerative neurological illnesses, and/or currently untreated psychiatric

Table 2. Inclusionary and descriptive short-term memory and language test scores.

				CAT naming				CAT spoken comprehension				CAT repetition						CAT PD
ID	Word span	Corsi block	RPM	Fluency	Obj.	Act.	Total	Words	Sent.	Par.	Total	Words	CW	NW	DS	Sent.	Total	Total
1	2.10	4	35	8	16	1	25	28	18	4	50	25	2	2	6	0	35	6.0
2	2.00	5	32	18	34	0	52	26	17	4	47	32	4	8	6	6	56	13.5
3	2.15	5	33	19	44	4	67	27	28	4	59	31	6	4	12	8	61	49.0
4	3.20	4	29	23	44	5	72	26	26	3	55	32	6	6	10	10	64	51.0
5	2.20	4	33	19	37	3	59	29	23	3	55	24	4	0	8	6	42	26.0
6	1.15	5	29	13	21	0	34	21	9	0	30	26	3	5	6	6	46	19.5
7	3.10	3	32	20	43	7	70	23	26	3	52	31	6	10	10	8	65	44.0
8	4.00	5	36	11	36	10	57	30	27	4	61	32	6	10	8	12	68	27.0
9	2.10	4	29	13	35	6	54	26	11	4	41	30	6	9	8	6	59	10.0
10	1.10	4	30	0	0	1	1	17	20	1	38	19	0	5	2	0	26	16.0
11	2.10	4	35	8	40	2	50	23	13	3	49	28	6	8	8	6	56	17.5
12	3.05	5	33	16	46	10	72	29	30	4	63	28	6	9	10	12	65	23.0
13	4.05	4	33	20	39	2	61	26	25	2	53	32	6	10	10	12	70	32.5
14	2.10	5	33	14	34	2	50	29	20	4	53	20	0	0	8	6	34	7.5
15	3.05	5	34	20	40	9	69	27	25	4	56	30	4	6	8	6	54	53.0
16	1.00	3	23	3	3	0	6	22	16	3	41	27	1	2	4	6	40	11.0
17	2.05	4	35	11	32	0	43	24	25	4	53	28	6	2	4	6	46	15.5
18	2.00	3	25	4	27	1	32	22	19	3	44	32	4	4	6	6	52	6.0
19	4.00	3	30	7	36	10	53	29	28	2	59	32	6	10	12	12	72	64.5
20	2.00	5	32	8	5	1	14	26	27	3	56	14	0	0	4	0	18	3.5
21	3.20	5	32	7	33	0	40	26	27	3	56	32	6	10	10	12	70	35.0
22	4.00	3	34	13	45	9	67	28	30	4	62	32	6	8	10	12	68	30.5
23	2.20	4	27	4	42	8	54	29	24	2	55	32	6	10	6	8	62	26.0
24	1.05	3	31	2	12	0	14	22	16	0	38	30	4	8	0	6	48	2.0
M	2.46	4.13	31.46	11.71	31	3.79	46.50	25.63	22.08	2.96	51.08	28.29	4.33	6.08	7.33	7.17	53.21	24.56
SD	0.96	0.80	3.23	6.66	13.98	3.80	21.46	3.25	6.04	1.23	8.54	4.86	2.20	3.59	3.05	3.73	14.82	17.42

Note. CAT = Comprehensive Aphasia Test; CW = complex words; DS = digit strings; NW = nonwords; PD = picture description; RPM = Raven's Progressive Matrices; Obj. = object; Act. = action; Sent. = sentence; Par. = paragraph.

illness were excluded. Individuals with a score below 23 on Raven's Progressive Matrices (Raven, Raven, & Court, 1998), a measure of nonlinguistic processing impairments, were excluded. In addition, individuals with visual impairment, as defined by failure to read the second-to-bottom line of the Tumbling E eye chart at a distance of 20 ft (Chang, 1995), and/or a hearing impairment, as defined by failure to pass an audiometric pure-tone, air-conduction screening at 35 dB HL at 500 Hz and 1 and 2 kHz for at least one ear, were excluded. A line bisection task was used to screen for visual neglect. Individuals with a severe apraxia of speech, as judged by assessments of videos of participants' performance on repetition, picture description, and other tasks from the CAT, were excluded. Three certified speech-language pathologists evaluated the videos, and consensus judgments for the following behaviors were used: slow rate, prolonged segment durations and intersegment durations (including intrusive schwa), distortions, and prosodic abnormalities.

Classification of Word Retrieval and STM Impairments

The Philadelphia Naming Test (PNT; Roach, Schwartz, Martin, Grewal, & Brecher, 1996) was administered to determine word retrieval severity and the relative contributions of semantics and phonology to each individual's word retrieval impairment. The test is composed of 175 nouns and provides thorough error-coding guidelines based on Dell et al.'s IA model of word retrieval (Dell et al., 1997). The PNT was presented on a computer with Microsoft PowerPoint 2010, and participants were instructed to name each black and white line drawing immediately using one word, with a limit of 30 s per picture. Participants' responses were audio recorded and scored offline by the first author or a research assistant trained in broad phonetic transcription. The first complete attempt, as defined by PNT instructions, was scored correct or incorrect, and incorrect responses were coded for error type according to PNT guidelines. The following distorted substitutions were scored correct in the four participants identified as mildly–moderately apraxic: substitutions of voiced consonants for unvoiced, and vice versa, if place and manner were preserved, and substitutions of stop for nasal consonants, and vice versa, if place and voicing were preserved. Schwa insertions were also scored correct. These decisions were based on the literature that argues that these errors are most likely motoric (Ballard, Granier, & Robin, 2000; Itoh, Sasanuma, & Ushijima, 1979; Mauszycki, Dromey, & Wambaugh, 2007; Odell, McNeil, Rosenbek, & Hunter, 1990). To classify word production impairment, a relative phonologic-to-semantic (P–S) index was calculated as follows: total number of phonologically related nonword errors (P score) – total number of semantic errors (S score). To assess reliability, 15% of each participant's responses were randomly selected and coded by the same research assistant and another research assistant, and Cohen's kappa (Landis & Koch, 1977) was calculated.

To quantify the nature of verbal STM impairment, 240 two- and three-syllable nouns were selected, and four lists of 60 words were created from this corpus: high frequency–high imageability, low frequency–high imageability, high frequency–low imageability, and low frequency–low imageability. Words were considered high frequency if they occurred more than 40 times per million and low frequency if they occurred less than 25 times per million (based on ratings from SUBTLEX-US database; Brysbaert & New, 2009). Words were considered high imageability if the imageability rating was greater than 497 and low imageability if the imageability rating was less than 497 (based on ratings from MRC psycholinguistic database; Coltheart, 1981; Martin & Saffran, 1997). With the alpha criterion set at .05, the subsets of high- and low-imageability words did not differ in frequency, $t(238) = 0.031$, $p = .976$, and the subsets of high- and low-frequency words did not differ in imageability, $t(238) = 0.469$, $p = .640$. Phonotactic probability ratings were obtained from the Irvine Phonotactic Online Dictionary (Vaden, Halpin, & Hickok, 2009) to assure that high- and low-imageability words, $t(237) = -1.89$, $p = .060$, and high- and low-frequency words did not differ in phonotactic probability, $t(237) = 0.902$, $p = .368$.

Thirty word pairs were created from each of the four lists (120 total pairs). Words in each pair were matched for syllable length and were not semantically related. Words were recorded by a native male English speaker with a Marantz Professional Solid State Recorder (D&M Holdings), and recordings were spliced into word pairs separated by a silent 1-s interval. Word pairs were administered in two sets that contained the same pairs of items in a different order, with a short break between sets. The order of the sets and the word pairs within each set was randomized for each participant. Participants were instructed to repeat each word pair in serial order immediately after hearing it, and their responses were audio recorded with an Olympus Digital Voice Recorder. Recordings were transcribed by the first author or a research assistant, and each word was scored for whole-word accuracy. Only first responses were scored, and responses initiated more than 5 s after the target was presented were not scored. All phonemes had to be produced accurately, and the word had to be produced in the correct serial position to be considered correct. If participants consistently repeated only the second word, it was considered to occur in the correct serial position, due to evidence that individuals who did this frequently were aware that they were omitting the first word (e.g., insertion of the word "blank" into the first word's position). Distorted phonemes were scored correct, and modified scoring rules for individuals with apraxia of speech used for the PNT also applied to word pair repetition. Three bias scores were calculated for each participant: a primacy bias score, (number of first words correct/[number of first + second words correct]); an imageability bias score, (number of high-imageability words correct/total words correct); and a frequency bias score, (number of high-frequency words correct/total words correct).

To calculate nonverbal STM span, the Corsi block span task (De Renzi & Nichelli, 1975) was administered.

A participant's nonverbal span was defined as one less than the length at which two consecutive trials (of six total trials) were missed.

Data Analysis

For Research question 1, word pointing span length was correlated with PNT accuracy and nonverbal span length. For Research question 2, P–S scores were correlated with primacy bias scores. For Research question 3, P–S scores were correlated with imageability and frequency bias scores. Correlation effect sizes were as follows: $r = .1$, small; $r = .3$, medium; and $r = .5$, large (Cowan, 1988). Because these main analyses were based on a priori hypotheses and motivated by extant research, the alpha value for each of these analyses was set at .05 (two-tailed test). Contingent on findings of significant associations between bias scores (primacy, imageability, and frequency) and P–S scores, a multiple linear regression with simultaneous entry of bias score predictors was planned to determine whether each bias score was uniquely predictive of P–S score.

Results

Research Question 1: Word Retrieval, Word Pointing Span, and Spatial Span

Research question 1 investigated the domain specificity of verbal STM by testing the relationship between word pointing span and (a) word retrieval accuracy and (b) nonverbal (spatial) span. Raw PNT accuracy scores are listed in Table 3. Pearson's r was computed to assess both relationships, and a large significant positive correlation consistent with the predictions was found between word pointing span length and word retrieval accuracy, $r(22) = .732$, $p < .001$, consistent with extant literature (Martin & Gupta, 2004). A post hoc correlation between the Corsi block task and PNT accuracy was also performed, and no significant correlation was found, $r(22) = .13$, $p = .53$. Together, these findings demonstrate that verbal STM and word retrieval are strongly associated and that this association is domain specific.

Research Question 2: Primacy/Recency Bias and Word Retrieval Breakdown

Research question 2 explored the relationship between error location in word pair repetition and word retrieval error type. Reliability calculations (Cohen's kappa; Landis & Koch, 1977) on the PNT and word pair repetition responses demonstrated that these measures were highly reliable. A kappa coefficient of 0.840 (almost perfect agreement) was found for intrarater naming error coding; and a kappa of 0.958 (almost perfect agreement), for intrarater word pair repetition coding. A coefficient of 0.795 (substantial agreement) was found for interrater naming error coding; and a coefficient of 0.919 (almost perfect agreement), for interrater word pair repetition coding. Individual word retrieval type and primacy bias scores are listed in Table 3. In addition to the correlation of P–S score with primacy, P and S scores were correlated with primacy bias because these raw scores provide information about error frequency (Table 4). No significant correlation was found between P score and primacy, $r(22) = -.367$, $p = .078$, though a trend in the opposite of the predicted direction was observed. That is, as P score increased, primacy bias decreased. No significant correlation was found between S score and primacy or between P–S score and primacy.

Research Question 3: Imageability/Frequency Bias and Word Retrieval Breakdown

Research question 3 explored the relationship between frequency and imageability biases in a word pair repetition task and word retrieval error type. In addition to the correlation of P–S scores with frequency scores, P and S scores were correlated with frequency bias score (Table 5). A significant positive correlation was found between P score and frequency bias, $r(22) = .406$, $p = .049$ (medium correlation): As P score (raw number of phonological errors) increased, frequency bias increased. No other relationships of interest were significant. In addition to the correlation of P–S scores with imageability scores, P and S scores were correlated with imageability bias score (Table 5). Consistent with the predictions, a significant positive correlation was found between P–S score and imageability bias, $r(22) = .429$, $p = .036$ (medium correlation): As the number of phonologically related nonword errors relative to semantically related errors increased, imageability bias increased. No other relationships of interest were significant.

Discussion

The purpose of this study was to determine whether a linguistically specified STM system supports word retrieval. The findings are interpreted in the context of a temporary linguistic activation process that partly underlies both verbal STM and word retrieval.

Domain Specificity of STM in Word Retrieval

The large positive correlation between word pointing span length and PNT accuracy, along with nonsignificant associations between the Corsi block task and both (a) word pointing span and (b) PNT accuracy, demonstrated a domain-specific relationship between verbal STM and word retrieval. Because a relatively pure verbal STM task (i.e., word pointing span) was used, this result was not influenced by both tasks requiring a verbal output. These results warrant careful investigation of the nature of the STM mechanism that supports word retrieval.

Primacy Bias and Word Retrieval Impairment Type

The lack of a positive correlation between primacy bias and word retrieval impairment type differs from the significant positive association between primacy bias and receptive language impairment type shown by Martin and Saffran (1997). In interpreting this discrepancy, the difference in

Table 3. Individual data: verbal STM bias (primacy, imageability, and frequency) and word retrieval type scores.

	Word pair repetition					Picture naming (PNT)			
ID	Word 1 raw #	Word 2 raw #	Primacy bias	Image. bias	Freq. bias	Raw #	P score	S score	P–S score
1	9	141	0.06	0.55	0.57	98	32	4	28
2	98	97	0.50	0.55	0.54	125	2	15	−13
3	171	93	0.65	0.60	0.56	160	4	9	−5
4	230	229	0.50	0.51	0.51	161	1	4	−3
5	100	62	0.62	0.71	0.58	152	7	3	4
6	138	5	0.97	0.54	0.53	68	18	14	4
7	198	185	0.52	0.54	0.55	143	5	16	−11
8	190	194	0.49	0.53	0.48	165	0	6	−6
9	156	171	0.48	0.60	0.50	154	6	5	1
10	20	13	0.61	0.67	0.58	5	2	5	−3
11	179	162	0.52	0.56	0.55	127	4	17	−13
12	202	209	0.49	0.51	0.51	160	3	6	−3
13	225	231	0.49	0.50	0.50	136	1	13	−12
14	51	25	0.67	0.87	0.63	110	27	6	21
15	195	83	0.70	0.58	0.54	159	5	1	4
16	4	142	0.03	0.53	0.51	30	4	16	−12
17	112	63	0.64	0.56	0.53	115	3	20	−17
18	166	203	0.45	0.54	0.53	103	6	10	−4
19	227	225	0.50	0.50	0.50	151	0	5	−5
20	0	28	0	0.61	0.54	39	46	7	39
21	219	215	0.50	0.51	0.52	116	3	11	−8
22	218	225	0.49	0.50	0.50	155	6	6	0
23	211	216	0.49	0.49	0.51	140	10	7	3
24	16	117	0.12	0.53	0.56	52	6	27	−21
M	138.96	138.92	0.48	0.57	0.53	117.67	8.38	9.71	−1.33
SD	81.69	77.21	0.22	0.08	0.03	46.65	11.30	6.32	13.88

Note. Freq. = frequency; Image. = imageability; P = phonological; PNT = Philadelphia Naming Test; S = semantic; STM = short-term memory.

timing between the receptive tasks, during which auditory input must be processed quickly (e.g., hearing two words and making a rhyme judgment), and the word retrieval task used in this study must be considered. As in verbal STM tasks, where an immediate response is required, performance on receptive language tasks likely requires rapid spread of linguistic activation. In this study's naming task, where participants had 30 s to respond, linguistic timing is likely much more flexible. In the allotted response window, error detection mechanisms that slowed or reinitiated the activation stream could have been in play. There is a possibility then that both word retrieval and verbal STM tasks depend on the same linguistic spreading activation process, but they operate on different time courses. The intricately timed word pair repetition task likely required much more rapid linguistic activation, leading to subtle differences in the activation of the first word (more strongly supported by semantic activation) and the second word (more strongly supported by phonological activation). Conversely, the word retrieval (PNT) task did not require participants to respond quickly, so the activation speed of semantic, lexical, and phonological features necessary to correctly name each picture likely varied within and between participants. Thus, the insignificant correlation between primacy bias and word retrieval impairment type may be partially explained by timing differences between the verbal STM (word pair repetition) and word retrieval (PNT) tasks.

A related issue is the question of the time course over which primacy/recency effects might be observed in individuals with aphasia. Though this study derived primacy scores from word pair repetition, Martin and colleagues (2002) later demonstrated a notable association

Table 4. Pearson correlation table: primacy bias and word retrieval impairment type.

Outcome measure	*M*	*SD*	*n*	P score	S score	P–S score	Primacy
P score	8.38	11.30	24	–	−0.18	0.89**	−0.37
S score	9.71	6.32	24	−0.18	–	−0.60**	−0.17
P–S score	−1.33	13.88	24	0.89**	−0.60**	–	−0.22
Primacy bias	0.48	0.22	24	−0.37	−0.17	−0.22	–

Note. *n* = number of participants; P = phonological; S = semantic.

**$p < .01$.

Table 5. Pearson correlations: frequency, imageability, and word retrieval impairment type.

Outcome measure	*M*	*SD*	*n*	P score	S score	P–S score	Freq.	Image.
1. P score	8.38	11.30	24	–	–.18	.89**	.41*	.39
2. S score	9.71	6.32	24	–.18	–	–.60**	.02	–.25
3. P–S score	–1.33	13.88	24	.89**	–.60**	–	.32	.43*
4. Freq. bias	0.53	0.03	24	.41*	.02	.32	–	.82**
5. Image. bias	0.57	0.08	24	.39	–.25	.43*	.82**	–

Note. Freq. = frequency; Image. = imageability; *n* = number of participants; P = phonological; S = semantic.
$^{*}p < .05$. $^{**}p < .01$.

between primacy bias in a four-word string repetition task and receptive language impairment, a finding that was contingent on participants' span size (individuals with spans of 3.5 or lower did not show this association). Individual differences in word pointing span length (ranging from 1 to 4.05, mean = 2.46, *SD* = 0.096) may thus have contributed to the null results. Though most individuals demonstrated a serial position bias on the word pair repetition task, individuals with word pointing span length scores below 3 (*n* = 15, span length ranging from 1 to 2.2) tended to demonstrate larger serial position effects on the word pair repetition task than individuals with word pointing span length scores above 3 (*n* = 9, span length ranging from 3.2 to 4.05). Eleven of the 15 individuals with lower span length scores had a primacy bias greater than 5% above or below 50% (a score of 50% indicates no serial position bias), whereas only one of the nine individuals with higher span length scores demonstrated a serial position bias of more than 5%. Thus, though individuals with word pointing span length scores above three items may have demonstrated serial position effects in a verbal STM task involving the repetition of three or more words, the repetition of word pairs may have been too simple to elicit these effects.

Along with individual differences in word pointing span length, individual differences in the dependence on lexical–semantics during the word pair repetition task must be considered. Though extant work has demonstrated potent influences of lexical–semantic processing on repetition, the task can nevertheless be accomplished solely through phonological activation. Even if an individual demonstrates a marked impairment in phonological relative to semantic processing (i.e., high P–S score), he or she may still not be able to access semantics efficiently enough to compensate for the phonological impairment. In this case, the predicted positive correlation between primacy bias and P–S score would not be expected. If individuals are relying mostly on phonological processing to complete the repetition task, the second word should be easier to repeat (recency bias) because its phonemes are activated closest to the time of recall, a prediction that is consistent with the observed trend toward a negative correlation between primacy bias and P score.

Though the issues discussed above could have affected the results, based on the findings as a whole, verbal STM and word retrieval, at least as measured in this study, do not appear to be supported by shared linguistic activation timing. Despite this conclusion, verbal STM and word retrieval may be subserved by shared linguistic nodes that differ in their activation timing depending on the task. The discussion turns to Research question 3 to explore this possibility.

Imageability and Frequency Biases and Word Retrieval Impairment

Although the observation of a primacy bias in word pair repetition likely depends on intricate activation timing, which creates differential activation patterns between the first and second words to be repeated, imageability and frequency biases likely arise due to a word's overall activation strength. According to the IA model, linguistic nodes rest at varying activation levels. Lexical nodes' resting levels depend on the number of previous encounters with their corresponding words (frequency), whereas semantic nodes' resting activation levels depend on the number of semantic features connected to a word (imageability; Dell et al., 1997; Nickels & Howard, 1994). The higher a node's resting activation level, the longer it can be kept active and the more efficiently it can activate nodes at neighboring levels (Martin & Saffran, 1992, as cited by Nickels & Howard, 1994). The analysis of associations between frequency/imageability biases and word retrieval yielded mixed results. The positive significant correlation between imageability bias and P–S score is consistent with the study's predictions, whereas the insignificant correlation between frequency bias and P–S score is not (though, notably, the significant positive correlation between frequency bias and P score is consistent with the predictions).

To interpret the lack of a positive correlation between frequency and P–S score, it is important to consider that, although word frequency has typically been thought to influence the first step of word retrieval (lexical selection; Dell et al., 1997), studies have demonstrated that individuals with aphasia make significantly fewer semantic *and* phonological errors on high- than low-frequency words (Kittredge, Dell, Verkuilen, & Schwartz, 2008). This finding has been explained by a holistic influence of frequency on linguistic (i.e., both lexical and phonological) activation (Bastiaanse, Wieling, & Wolthuis, 2015), which may explain the modest associations between frequency and language impairment type found by Martin and Saffran (1997) and in the current study. The imageability manipulation, conversely, works specifically at the semantic level, reflecting a word's semantic richness (i.e., how many semantic features are associated with that word; Martin & Saffran, 1992; Nickels & Howard, 1994). The significant positive correlation between P–S score and imageability bias suggests that verbal STM and word retrieval may share a common underlying process related to overall linguistic activation strength. Perhaps, temporary activation of the same linguistic representations subserves both types of tasks. For example, individuals who make predominately semantic errors in naming and demonstrate no evidence of an imageability bias on word span tasks might do so in part due to diminished semantic activation strength. Taken together with the results of Research questions 1 and 2, the findings reveal that the STM system that supports word retrieval is, at least in large part, language-specific and that it is likely the overall strength of linguistic activation rather than the timing of activation transmission that governs this link. The results are inconsistent with models that view the temporary retention of verbal information as an isolated process completely separate from language processing and supportive of a partial dependence of word retrieval and verbal STM on a shared temporary interactive linguistic activation process.

In addition to the aforementioned interpretations, the lack of significant correlations between S score and imageability/frequency biases deserves mention. One methodological factor is that, in naming tasks, semantic activation is boosted by the picture, which may cause the raw number of semantic errors to be lower than if the word was produced in conversation. Another possible confound involves visual confusions during naming. For example, some participants called the picture whose target was *bowl* a *cup* (a possible visual confusion due to the somewhat ambiguous picture representing the word *bowl*), an error that would be coded as semantic in accordance with PNT rules. The raw number of semantic errors could thus have been overestimated, a difficult issue to avoid even in thoroughly normed naming tests.

General Discussion

The results as a whole suggest that word production, as measured by picture naming, is more dependent on overall representational strength than on intricate spreading activation timing. The same linguistic representations may support both word retrieval and word pair repetition but, perhaps, the spread of linguistic activation follows different time courses in these two tasks.

Clinical Implications

The analysis of speech errors can reveal important insights about the linguistic level(s) at which a linguistic impairment lies; however, it is also a time-consuming and elusive process. The results suggest that imageability bias on verbal STM tasks may be a window into an individual's word retrieval impairment type (i.e., the greater the imageability bias, the more phonological the impairment, relative to semantic). Although replication and extension of this work are necessary to determine whether imageability bias can accurately predict word retrieval impairment type, the possibility of a more efficient way to get at the nature of an individual's word retrieval impairment is a compelling one.

Limitations and Future Directions

Several theoretical and methodological issues deserve mention, the first of which is the limitation of using a repetition-based task to measure verbal STM. The IA model of verbal STM focuses on the pattern of temporary linguistic activation during the intermediate step between hearing a word pair and producing it; however, the model does not account for the complex interactions between this moment of relatively pure temporary storage and the input and output demands of this task (i.e., auditory comprehension and spoken production). Although it may be possible to make the word pair task purer with the use of a picture pointing response, this would be very challenging given the open set of words used and the low imageability of some words. Nevertheless, the limitations of using a repetition task to test verbal STM should always be considered. On the other hand, the use of a word pointing span as the measure of verbal STM can be argued to be problematic as well. Because participants must match word sequences to pictures, such a task can be argued to require a considerable amount of attentional resources and thus may not be a pure verbal STM measure. Including both pointing and repetition spans in future studies may compensate for the shortcomings of each task and provide a more complete picture of verbal STM capacity.

In addition, several modifications to the word retrieval and word pair repetition tasks should be considered. Two changes could be made to make the word retrieval task more in-line with the rapid activation timing requirements of word retrieval in natural settings: (a) limiting the amount of time the picture is present on the screen and (b) limiting the allotted response time. Allowing the picture to be present only for a brief period (Martin, 2012) would require more active generation of features at the conceptual–semantic processing level, whereas limiting the response time would better approximate the rapid spread of activation required to produce a word in conversation. Furthermore, a reanalysis of existing data to determine how many word pair repetition trials must be administered to estimate imageability and frequency biases may maximize the clinical applicability of this work. Although the current 240-trial task is not clinically feasible, a reanalysis may show that fewer trials yield similar imageability and frequency bias scores, thus increasing the task's potential diagnostic utility. In addition, looking at imageability and serial position biases in verbal STM tasks requiring the repetition of three or more words as they relate to word retrieval impairment type might reveal further insights, particularly in individuals with relatively high word span length scores.

Last but not least, though this study was not an investigation of the extent to which language production and comprehension rely on a shared verbal STM process, comparisons of the current results with that of Martin and Saffran (1997) provide a window into the possible partial reliance of the two domains on the same temporary interactive linguistic activation process. In the future, administration of word retrieval, comprehension, and verbal STM measures to the same group of participants would elucidate the extent to which these linguistic domains share a common temporary storage (i.e., verbal STM) process. This investigation would be clinically significant, in that identifying processes that are shared by language production and comprehension tasks and understanding their breakdown can help hone in on what to treat to maximize treatment generalization across language domains.

Conclusion

This study demonstrated notable associations between word retrieval impairment type (i.e., relatively more semantic or phonological) and word pair repetition (i.e., a measure of verbal STM), which at least partly supports a linguistically specified STM system underlying the retrieval of words. The results are problematic for models that view STM as a domain separate from language and supportive of the IA model of STM at the heart of this study. Perhaps, it is time to rethink the classic distinction between language and STM, to investigate further the idea that access to linguistic representations in word retrieval is dependent on a linguistically specified temporary activation process, and to let go of the idea that an STM system exists that is wholly separable from the process it supports. The continued investigation of clinically driven processes (e.g., STM and attention) that aid access to language representations has the potential to inform and influence clinical practice, eventually leading to the creation of impairment-driven and generalizable treatments for aphasia.

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