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Published version

PILKINGTON, Emma, KEIDEL, James, KENDRICK, Luke, SADDY, Doug, SAGE, Karen and ROBSON, Holly (2017). Sources of phoneme errors in repetition: perseverative, neologistic and lesion patterns in jargon aphasia. *Frontiers in Human Neuroscience*, 11, p. 225.

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1 **Sources of Phoneme Errors in Repetition: Perseverative,**
2 **Neologistic and Lesion Patterns in Jargon aphasia**

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12

13 **Keywords: Repetition₁, Aphasia₂, Neologisms₃, Perseveration₄, Voxel-Lesion Symptom**
14 **Mappings₅, Jargon aphasia₆. (Min.5-Max. 8)**

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16 Word Count: 6089

17 Number of Figures: 5

18 Number of Tables: 6

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34 **Abstract**

35 This study examined patterns of neologistic and perseverative errors during word repetition
36 in fluent Jargon aphasia. The principal hypotheses accounting for Jargon production indicate
37 that poor activation of a target stimulus leads to weakly activated target phoneme segments,
38 which are outcompeted at the phonological encoding level. Voxel-lesion symptom mapping
39 studies of word repetition errors suggest a breakdown in the translation from auditory-
40 phonological analysis to motor activation. Behavioural analyses of repetition data were used
41 to analyse the target relatedness (Phonological Overlap Index: POI) of neologistic errors and
42 patterns of perseveration in 25 individuals with Jargon aphasia. Lesion-symptom analyses
43 explored the relationship between neurological damage and jargon repetition in a group of 38
44 aphasia participants. Behavioural results showed that neologisms produced by 23 jargon
45 individuals contained greater degrees of target lexico-phonological information than
46 predicted by chance and that neologistic and perseverative production were closely
47 associated. A significant relationship between jargon production and lesions to
48 temporoparietal regions was identified. Region of interest regression analyses suggested that
49 damage the posterior superior temporal gyrus and superior temporal sulcus in combination
50 was best predictive of a Jargon aphasia profile. Taken together these results suggest that poor
51 phonological encoding secondary to impairment in sensory-motor integration alongside
52 impairments in self-monitoring result in jargon repetition. Insights for clinical management
53 and future directions are discussed.

54

55 **Introduction**

56 Neologistic Jargon aphasia is an acquired language disorder characterised by severely
57 distorted speech output. Production in Jargon aphasia is fluent but underspecified and
58 contains numerous nonword errors, rendering it hard to comprehend. Prognosis in Jargon
59 aphasia is poor, with reports of declining vocabulary size and mixed therapeutic outcomes
60 (e.g., Bose, 2013; Eaton et al., 2011; Panzeri et al., 1987; Robson et al., 1998a; 1998b).
61 Perseveration, repeated patterns of phonological distortion, frequently co-occurs with Jargon
62 aphasia and is particularly evident during elicitation tasks such as serial repetition.

63

64 Neurobiologically, the repetition of a word requires the transformation of sensory
65 information into motor activation. Traditional neurological accounts of impaired repetition
66 posit damage to the white matter tracts—particularly the arcuate fasciculus—connecting
67 posterior and anterior language areas as the source of breakdown (Geschwind, 1965). Recent
68 neuroimaging and stimulation work has expanded this dorsal network to include cortical
69 regions; namely the inferior supramarginal gyrus (SMG) and posterior superior temporal
70 gyrus (pSTG) (Anderson et al., 1999; Quigg & Fountain, 1999) including area Spt at the
71 boundary of the inferior parietal and superior temporal lobes, which includes portions of the
72 planum temporale (Hickok et al., 2003; 2009; Hickok & Poeppel, 2004). In repetition, the
73 pSTG plays a perceptual role analysing phonetic and phonemic information in the speech
74 stream (Buchsbaum et al., 2001; Deschamps & Tremblay, 2014; McGettigan et al., 2010).
75 This phonological information is transformed into motor responses for articulatory processes,
76 a function proposed to be supported by area Spt (Buchsbaum et al., 2011; Hickok, 2009;
77 Hickok et al., 2011; Hickok & Poeppel, 2004; Warren et al., 2005). Area Spt has direct
78 structural connectivity with motor and frontal regions, including the pars opercularis and
79 premotor cortex which are associated with the articulatory components of speech production
80 (Basilakos et al., 2015; Isenberg et al., 2012; Itabashi et al., 2016). The SMG is also proposed
81 to support encoding for production (Mesgarani et al., 2014; Ravizza et al., 2004; Trébuchon
82 et al., 2013) but is more prominently associated with auditory short-term memory/working

83 memory functions (Henson et al., 2000; Paulesu et al., 1993) which support the temporary
84 maintenance of phonological information during the repetition process.

85

86 Convergent with the neurobiological account, cognitive neuropsychological and
87 psycholinguistic models highlight a phonological pathway for repetition. In addition, many
88 models allow a further repetition route via a semantic pathway (Dell et al., 2007; Hanley et
89 al., 2004; Hanley & Kay, 1997; Hillis & Caramazza, 1991; McCarthy & Warrington, 1984;
90 Nozari et al., 2010). Word repetition is commonly impaired in aphasia, and has classically
91 been used as a diagnostic screening test (Kaplan, 1983). However, repetition errors do not
92 occur in all aphasic conditions. For example, individuals with isolated semantic impairment
93 such as those with transcortical sensory aphasia or semantic dementia have preserved
94 repetition abilities (Boatman et al., 2000; Hodges et al., 2008; Jefferies & Lambon Ralph,
95 2006). Where repetition errors do occur they tend to be phonological in nature, with a
96 comparative scarcity of purely semantic errors (Hanley et al., 2002; Martin, 1996; Martin et
97 al., 1994). These behavioural patterns are consistent with a neurobiological mechanism
98 predominantly engaging sensory-motor integration functions with relatively less weight on
99 semantic processes (Moritz-Gasser & Duffau, 2013). Nonwords are one form of phonological
100 repetition error which are particularly frequent in individuals with Jargon aphasia. Nonwords
101 can range from mild phonemic substitutions of acoustically or articulatory similar phonemes
102 (e.g. village - /vilti:/), typically referred to as phonological paraphasias, to severe distortions
103 which bear little resemblance to target phonology (e.g. rocket - /waɪæpəl/), typically referred
104 to as neologisms. Perseverative errors, the repeated intrusion of phoneme strings or syllabic
105 patterns, have been noted to occur alongside neologistic production in Jargon aphasia
106 (Buckingham et al., 1978; Moses et al., 2004). A fourth type of error commonly observed is
107 referred to as a formal error, which occurs when an alteration in the phonological structure of
108 a word results in a real word error (e.g. cot - /kəʊt/). There has been considerable research
109 into the underlying causes of nonword and perseverative errors in repetition and other
110 production modalities. Much evidence points to a single impairment source for paraphasias,
111 neologisms, and perseverative errors, with different error types reflecting a range of severity
112 (Buckingham & Buckingham, 2011; Dell et al., 1997; Martin & Dell, 2007; Olson et al.,
113 2007; 2015; Schwartz et al., 2004). The predominant hypothesis indicates a disruption in
114 lexical and phonological processes, during which weak and aberrantly spreading activation
115 can result in non-target phonology being selected for production. Nonword production is
116 modulated by word length and word frequency, suggestive of a single lexico-phonological
117 source generating errors with a range of severity (Nozari et al., 2010; Olson et al., 2007;
118 2015). Nonword accuracy range adheres to a normal distribution, thereby suggesting that a
119 single underlying source generates errors of varying severity (Olson et al., 2007). An
120 alternative hypothesis is that paraphasic and neologistic nonwords are independent error
121 types whereby neologisms are produced when lexical retrieval fails, and a random or
122 idiosyncratic phoneme string is generated for output (Buckingham, 1990; Butterworth, 1979;
123 Eaton et al., 2010; Moses et al., 2004). Such production would give rise to two separate error
124 populations; one with very limited target relatedness and the other with high target overlap,
125 thereby conforming to a bimodal distribution.

126

127 The source of perseveration errors is also controversial. The predominant hypothesis states
128 that weak target activation or phonological encoding allows recently used, and therefore the
129 most active representations, to override the current target (Ackerman & Ellis, 2007;
130 Buckingham & Buckingham, 2011; Eaton et al., 2010; Hirsh, 1998; Moses et al., 2007a). As
131 such, perseverative, paraphasic and neologistic errors are hypothesised to have a common
132 source. The co-occurrence of perseverative and non-perseverative nonword errors supports

133 this hypothesis (Martin & Dell, 2007; Moses et al., 2007b). An alternative hypothesis posits
134 that errors arise from disruption of inhibitory processes, and a failure of post-activation
135 suppression (Papagno & Basso, 1996; Sandson & Albert, 1984; Santo Pietro & Rigrodsky,
136 1986; Stark, 2007; Yamadori, 1981). Concurrent inhibition and encoding deficits have been
137 identified in some dysgraphic individuals indicating that these mechanisms are not mutually
138 exclusive (Fischer-Baum & Rapp, 2012). However, it is unclear whether such inhibitory
139 mechanisms are a specific feature of the phonological encoding system or a domain-general
140 cognitive function, and whether different mechanisms operate more strongly in different
141 subtypes of aphasia. A significant challenge in distinguishing between nonword error and
142 perseveration hypotheses within the neologistic Jargon aphasia population comes from the
143 relative rarity of the condition, which has resulted in small scale case-series investigations or
144 single case studies. This results in difficulty applying psycholinguistic patterns to the wider
145 Jargon aphasia population.

146
147 Despite this, evidence from lesion-symptom mapping is currently consistent with the
148 proposed impairment in phonological encoding put forward by computational modelling and
149 neuropsychological investigations. Repetition errors in chronic aphasia have been associated
150 with lesions affecting the left inferior parietal lobe (Fridriksson et al., 2010), the left posterior
151 temporo-parietal cortex (Baldo et al., 2012), and area Spt (Rogalsky et al., 2015) similarly
152 interpreted as a disruption to sensory-motor integration (including phonological encoding).
153 However, lesion-symptom mapping, modelling and neuropsychological evidence is not
154 currently directly comparable. Lesion-symptom mapping repetition studies currently contain
155 few or no individuals with jargon-type repetition impairments, and predominantly include
156 those with conduction-like repetition deficits (Baldo et al., 2012; Rogalsky et al., 2015),
157 reducing the applicability of these results to the jargon population. As such the possibility
158 remains that more “peripheral” aspects of the repetition system, such as perceptual auditory-
159 phonological or articulatory processing, may contribute to jargon repetition. An impairment
160 in perceptual analysis is consistent with the majority of individuals with Jargon aphasia also
161 displaying Wernicke’s-type aphasia associated with auditory-phonological processing
162 impairments (Robson et al., 2012; 2013; 2014) and the association of neologistic production
163 and impairments in self-monitoring (Kinsbourne & Warrington, 1963; Maher et al., 1994;
164 Marshall et al., 1998). Perceptual and articulatory processes are also not captured in
165 computational modelling which focuses on core linguistic components of semantic, lexical
166 and phonological processing. A further possibility is that no single process or neural region
167 results in the deficit. Rather, jargon repetition may occur following damage to multiple
168 components of the repetition network, resulting in the severe distortions observed in the
169 condition. Investigating the lesion profiles associated with nonword and perseverative errors
170 in a large cohort is required to explore these hypotheses.

171
172 In the current study we use a combination of psycholinguistic and lesion-symptom mapping
173 analyses to explore the cognitive and neurobiological underpinnings of jargon repetition
174 deficits. The target relatedness and distribution of nonword errors are analysed to distinguish
175 the default generation and phonological encoding hypotheses. Patterns of perseveration are
176 examined, and the co-occurrence of perseveration and non-perseveration errors is explored to
177 determine whether these error types share a common source. Whole brain and region of
178 interest lesion-symptom mapping analyses are used to explore the contribution of the wider
179 dorsal repetition network to neologistic Jargon aphasia.

180
181 **Method**

182 Ethical approval for the current study was given by the Multicenter NHS Research Ethics
 183 Committee, the NHS East of England Research Ethics Committee and the University of
 184 Reading School of Psychology Research Ethics Committee.

185

186 **Participants**

187 We report data from 46 individuals with aphasia (female n=15), mean age 69.7 years ($\sigma =$
 188 12.24; range = 31-93), mean time post onset 35 months ($\sigma = 47.63$; range = 5-204), see Table
 189 1. Aphasia profile was assessed with the Boston Diagnostic Aphasia Examination – Short
 190 Form (Goodglass et al., 2001). Percentile scores for auditory comprehension, repetition (word
 191 and sentence) and fluency subtests are presented in Table 1. Twenty individuals presented
 192 with Wernicke’s aphasia, four with conduction aphasia, four with anomic aphasia, and two
 193 with transcortical sensory aphasia. In the nonfluent categories, four participants were
 194 classified as Broca’s type aphasia, with one individual classified as transcortical motor
 195 aphasia. Four individuals were classified as mixed aphasic, and the remaining six were
 196 unable to be classified as the necessary BDAE data were unavailable. Different individuals
 197 were entered into behavioural and neuroimaging analyses based on analysis criteria discussed
 198 below.

199

200 **Neuroimaging**

201 Neuroimaging data were available for 38 participants (see Table 1). 3T T1w research MRI
 202 scans were collected for 27 individuals. Scans were collected across different studies and, as
 203 a result, protocols varied. Clinical imaging scans were available for the remaining 11
 204 participants. Only scans which were carried out after 24 hours post stroke onset were
 205 included in the analysis to avoid significant underestimation of the extent of the stroke.
 206 Lesions were manually delineated by lesion drawing in native space. The native lesion masks
 207 were used for cost-function masking during normalisation. Normalisation was implemented
 208 in the SPM Clinical toolbox (Rorden et al., 2012). Normalisation parameters were applied to
 209 the native lesion masks which were subsequently manually checked for normalisation
 210 accuracy. Lesion overlap maps for the whole aphasia group and for the Jargon aphasia
 211 subgroup are presented in Figure 1A & 1B. Lesions were observed throughout the entire left
 212 MCA territory in the aphasia group as a whole with peak lesion overlap in the
 213 temporoparietal junction including the superior temporal gyrus and sulcus and supramarginal
 214 gyrus, in both the whole group and Jargon subgroup.

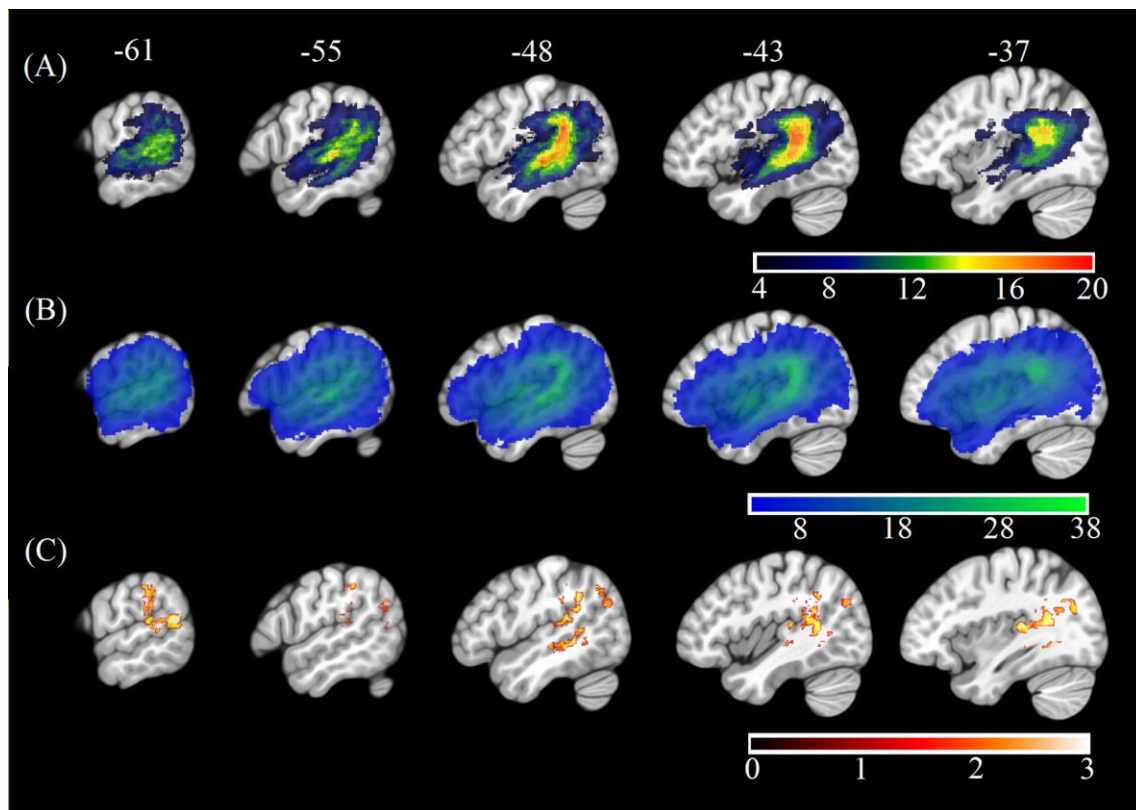
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217 *Table 1: Demographic, imaging and BDAE information*

Pt code	Age (years)	Time post stroke (months)	Gender	Imaging	BDAE centiles		
					Comprehension	Fluency	Repetition
1	55	24	M	3T	n/a	n/a	n/a
2	70	96	M	3T	n/a	n/a	n/a
3	80	8	F	Clinical CT	30	n/a	n/a
4	54	145	F	n/a	38	n/a	45
5	56	22	M	3T	77	n/a	15
6	75	132	F	3T	58	7	60
7	63	144	M	3T	48	13	40
8	31	15	M	n/a	48	20	20
9	68	108	M	3T	87	30	65

10	81	8	M	Clinical CT	15	30	25
11	59	14	M	3T	10	38	13
12	68	24	M	3T	9	42	7
13	65	108	F	3T	50	48	45
14	74	6	M	n/a	12	51	13
15	69	15	F	n/a	33	55	10
16	72	204	M	3T	100	62	60
17	73	6	M	3T	3	63	<1
18	62	84	M	3T	n/a	63	n/a
19	78	72	F	3T	5	68	10
20	53	7	M	n/a	15	68	<1
21	64	6	M	n/a	10	68	15
22	66	10	M	3T	5	70	25
23	49	24	F	3T	70	70	60
24	81	7	F	Clinical CT	18	75	15
25	85	9	F	n/a	<1	75	<1
26	86	13	M	3T	10	80	7.5
27	88	9	M	Clinical MRI	42	80	65
28	73	13	F	3T	10	83	10
29	60	5	M	3T	7	84	8
30	77	24	M	3T	40	90	25
31	71	72	M	3T	7	90	1
32	70	42	M	3T	45	100	28
33	59	6	M	3T	17	100	20
34	75	12	M	Clinical MRI	28	100	5
35	78	9	F	3T	73	100	80
36	83	9	F	Clinical CT	48	100	60
37	93	9	F	Clinical CT	67	100	80
38	68	9	M	Clinical CT	55	100	50
39	80	9	F	n/a	25	100	20
40	71	9	M	Clinical MRI	50	100	80
41	82	9	M	Clinical MRI	64	100	30
42	76	14	M	3T	13	100	1
43	74	9	M	3T	57	100	50
44	57	9	M	3T	15	100	10
45	86	13	F	Clinical CT	3	100	15
46	49	5	M	3T	67	100	60



219
220 *Figure 1: Lesion Overlap Maps and VLSM Results*

221
222 **Repetition tasks**

223 All participants completed an 80 item word repetition task. Sixteen participants completed
224 the word repetition test from the PALPA (Psycholinguistic Assessment of Language
225 Processing in Aphasia, subtest 9; Kay et al., 1996) and 30 participants completed an in-house
226 80 item repetition test. The 80 items were administered either continuously or in shorter
227 blocks if a participant was perceived to require a break. The experimenter provided
228 repetitions when requested.

229
230 **Recording and error coding**

231 All response data were transcribed into broad phonemic transcription. When multiple
232 responses were given per item, the final stressed response was accepted. All transcriptions
233 were then converted into DISC symbols (1:1 phoneme: symbol correspondence, e.g. IPA =
234 [i:], DISC = [i]); to enable automated data extraction via Microsoft excel and MATLAB.
235 Responses were categorised following criteria used by Moses, Nickels, and Sheard (2004).
236 Non-lexical responses were classified as nonwords. Lexical errors were labelled according to
237 their target relationship, and were classed as either formal (either identical first phoneme or
238 fifty percent phonology overlap with target), semantic (semantically related to target), mixed
239 (semantically and phonologically related to target word form), unrelated (real word error that
240 did not share an obvious relationship to target), no response (individual indicated they could
241 not provide an answer or did not respond); or circumlocution (individual provides
242 information about the item by talking around it but not naming it).

243
244 **Analysis summary**

245 Four different analyses were undertaken to explore behavioural patterns in jargon production.
246 Phonological accuracy of nonwords was explored using the Phonological Overlap Index
247 measure (POI: Schwartz et al., 2004), and nonword accuracy distributions were examined

248 using the Kolmogorov-Smirnov test. Perseverative patterns were analysed using the Intrusion
249 Perseveration Probability (IPP) measure, adapted from Cohen and Dehaene (1998), and the
250 relationship between perseverative and non-perseverative nonwords was explored, using a
251 correlation analysis. Voxel-lesion symptom mapping and follow-up region-of-interest (ROI)
252 analyses were used to investigate the relationship between jargon production and lesion
253 profiles.

254

255 **Phonological accuracy in neologistic Jargon**

256 The degree to which neologistic errors are produced with reference to target phonology was
257 investigated using the POI measure (Bose, 2013; Schwartz et al., 2004). The POI for each
258 non-word repetition response was calculated using the formula:

259

260 $POI =$

261 $(n \text{ phonemes shared between target and response}) \times 2 /$

262 $(n \text{ phonemes in target} + n \text{ phonemes in response}).$

263

264 A value of 0 indicates no overlap with target phonology and a value of 1 indicates complete
265 overlap between the target and response. Non-word responses were then assigned to a
266 paraphasic (>0.51 POI) or neologism (≤ 0.5 POI) error category (Schwartz et al., 2004). The
267 target relatedness of neologistic errors was compared to a chance rate derived from null
268 distributions. In each null distribution, all non-word errors from all participants were
269 randomly reassigned to a new target and a new POI calculated. To statistically compare
270 individual and chance accuracy an equal number of resampled responses as neologistic errors
271 were randomly extracted for each participant. The observed POI mean was compared against
272 each resampled POI mean to derive a level of significance.

273

274 **Nonword accuracy distributions**

275 The accuracy (POI) distribution of both nonword error types (paraphasias and neologisms)
276 was examined using the one sample Kolmogorov-Smirnov (KS) test of normality, in order to
277 examine whether distributions adhered to a normal curve and conformed to the single source
278 hypothesis.

279

280 **Perseveration**

281 The Intrusion Perseveration Probability (IPP) measure, adapted from Cohen and Dehaene
282 (1998), calculates how often a phonological error occurs in each of the previous ten
283 responses. To calculate it, every intruded/erroneous phoneme was identified. Then, how often
284 each of these intruded phonemes was present (matched) in each of the previous ten responses
285 was measured. The probability was calculated by dividing the number of matched phonemes
286 at each lag by the total number of intruded phonemes. The average IPP across the ten lags
287 was calculated so as to assign each individual with a perseveration value, representative of
288 persistent patterns of phoneme intrusions. To account for breaks in administration, data were
289 split into blocks of twenty responses, and only responses eleven to twenty were analysed in
290 relation to the previous ten responses. This method provided 40 trials per individual for
291 analysis. Both correct and incorrect responses were included in the analysis. Six individuals
292 (4, 12, 26, 41, 43, 44) were excluded from this analysis because their data could not be split
293 into blocks of twenty.

294

295 **Chance perseveration**

296 To interpret the prevalence of perseveration within the Jargon aphasia group, observed IPP
297 values were compared against a chance rate. In the current study, all responses from all

298 participants were randomly reassigned to a new target to create a null distribution, and forty
299 trials were randomly selected to undergo IPP analysis. This process was repeated 1000 times.
300 The observed IPP score was compared against each resampled IPP score to derive a level of
301 significance.

302

303 **Relationship between perseverative and non-perseverative nonwords**

304 For individuals who presented with fluent Jargon aphasia, the number of perseverative
305 nonword errors was calculated using criteria from Martin and Dell (2007). A nonword was
306 identified as a perseveration when a phoneme error was present in the previous response.
307 Otherwise, the nonword was labelled as a non-perseveration. To accommodate administration
308 breaks, the initial response in each subset was discounted. The association between
309 perseverative and non-perseverative nonwords was examined using Spearman's rank
310 correlation.

311

312 **Voxel-lesion symptom mapping**

313 All participants with an available clinical or 3T T1w image were included in an exploratory
314 voxel-lesion symptom mapping analysis implemented in the vlsfm2 matlab toolbox (version
315 2.3; Bates, et al., 2003). This analysis uses a mass univariate general linear model approach
316 to determine the relationship between the presence of lesion and behaviour at each voxel
317 while accounting for total lesion volume. The analysis was constrained to the left hemisphere
318 grey and white matter regions. Results were obtained at thresholds of 0.05 and 0.01 and
319 compared to those obtained from 1000 permutations/null distributions. The VLSM analysis
320 was extended using an ROI analysis. VLSM clusters significant at $p < 0.05$ and greater than
321 200 voxels were identified and the percentage lesion overlap with each cluster was extracted
322 in each participant. ROI data were used to identify the consistency of lesion-behaviour
323 associations and the strongest predictors of jargon repetition.

324

325 **Results**

326 **Overall accuracy and error patterns**

327 All but 4 individuals (participants 7; 38; 40; 46) displayed a repetition impairment ($\bar{x} = 35$ σ
328 $= 23.24$, range = 1-73; see Table 2). Individuals with anomic aphasia were the most accurate
329 as a group ($\bar{x} = 54$; $\sigma = 28.62$), followed by those with Broca's aphasia ($\bar{x} = 49.7$; $\sigma = 19.40$),
330 then conduction aphasia ($\bar{x} = 43.3$; $\sigma = 25.16$). Those with Wernicke's aphasia were the least
331 accurate as a group ($\bar{x} = 21.45$; $\sigma = 16.30$). Across all participants, the predominant error
332 types were nonwords (1288, 35%) and formal errors (304, 8%). The remaining four error
333 categories (unrelated, semantic, circumlocution, no response) contributed just over 7% of the
334 overall response rate. POI analysis indicated roughly equal numbers of neologistic and
335 paraphasic errors (medians; paraphasias = 14; neologisms = 8.5; Mann Whitney U = 875.5; p
336 $= .153$). Participants who presented with fluent speech and produced 5 or more neologistic
337 errors during repetition were considered to present with neologistic Jargon aphasia; 25
338 participants met these criteria.

339

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348 *Table 2: Number of each response type on single word repetition task.*

Pt code	Test	Nonwords					No response	Other
		Correct	Paraphasia	Neologism	Formal	Unrelated		
17	Palpa	1	8	71	0	0	0	1
44	DV	3	12	59	3	3	0	0
45	DV	4	20	38	8	8	1	2
20	Palpa	6	18	44	4	6	2	2
21	Palpa	6	17	51	1	4	1	2
19	Palpa	8	25	30	3	6	7	0
22	Palpa	8	38	22	7	3	2	0
26	Palpa	8	19	33	9	11	0	1
12	DV	10	21	28	12	9	0	1
28	Palpa	16	18	32	9	1	2	2
11	Palpa	17	19	19	7	3	15	2
31	DV	19	8	1	7	1	43	1
42	DV	19	15	23	13	9	0	1
41	DV	20	30	16	11	2	0	0
25	Palpa	21	34	17	5	1	0	0
34	DV	23	10	30	13	4	0	0
10	DV	25	16	18	16	4	0	0
30	Palpa	25	26	17	6	4	0	0
29	Palpa	26	9	14	6	6	18	0
5	DV	33	30	6	6	4	0	0
9	DV	36	25	9	7	3	0	0
6	DV	37	14	4	21	0	3	0
14	Palpa	37	21	9	7	3	1	1
15	DV	39	15	9	16	1	0	0
8	DV	40	6	0	3	2	29	1
32	Palpa	40	21	8	6	3	1	1
43	DV	40	14	11	11	1	1	0
3	Palpa	42	19	6	10	2	0	0
33	Palpa	42	14	5	2	1	15	0
39	DV	49	17	1	11	1	0	1
24	Palpa	50	12	13	3	0	0	0
27	DV	60	8	0	11	1	0	0
1	DV	61	8	2	8	0	0	0
4	DV	62	11	0	6	1	0	0
2	DV	66	5	1	6	0	0	1
13	DV	67	7	0	4	1	1	2

35	DV	69	4	1	4	2	0	0
23	DV	70	7	0	2	1	0	0
36	DV	71	4	1	4	0	0	1
16	DV	72	4	0	3	0	1	1
37	DV	72	2	1	5	0	0	0
18	DV	73	3	1	3	0	0	1
40	DV	76	1	0	3	0	0	0
7	DV	78	2	0	0	0	0	2
38	DV	78	0	0	2	0	0	1
46	DV	80	0	0	0	0	0	0
Total (#)		1805	637	651	304	112	143	28
1288								

Ordered by fewest correct responses

349

350

351 **Phonemic content of neologisms**

352 Chance POI was calculated as 0.18 (± 0.01) independent of the number of samples extracted
 353 from each null distribution (see methods). The mean POI of neologisms produced by 23
 354 Jargon individuals was greater than the chance prediction ($p \leq .007$; see Table 3). Two
 355 individuals (33, 44) could not be differentiated from chance ($p \geq .066$; see Figure 2).

356

357 **Nonword accuracy distributions**

358 The POI of all nonwords (paraphasias and neologisms) produced by 20 neologistic
 359 individuals adhered to a normal distribution ($p \geq .067$). Nonword POI distributions exhibited
 360 by individuals 41, 30, 22, 12, and 44, violated the normal distribution ($0.124 \leq KS \leq 0.211$; p
 361 $\leq .05$; see Table 3). Individual 12 produced a bimodal distribution and individual 44
 362 exhibited a left skew (see supplementary materials). Histograms for these five individuals are
 363 presented in supplementary materials.

364

365

366

367 *Table 3: Test statistics for Phonological Overlap Index (POI) and distribution analyses*

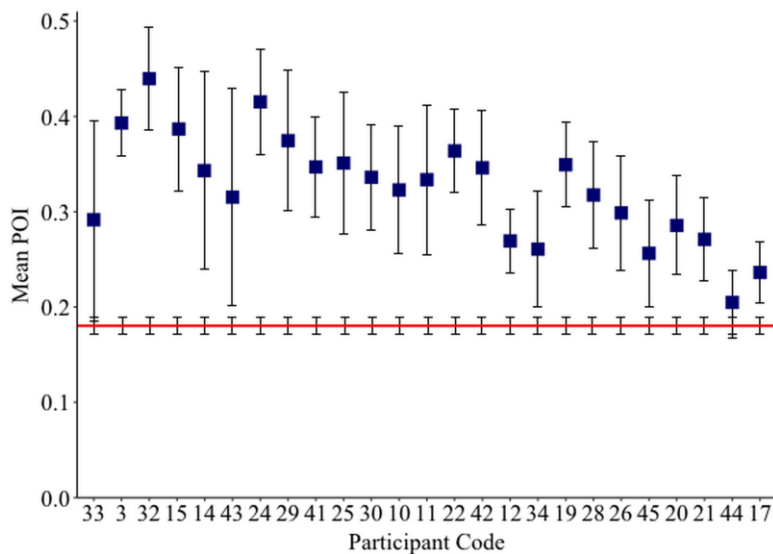
Pt code	Mean POI	p value	KS stat ^a
33	0.29	0.066	0.148
3	0.39	≤ 0.001	0.146
32	0.44	≤ 0.001	0.154
14	0.34	≤ 0.001	0.154
15	0.39	≤ 0.001	0.127
43	0.32	0.007	0.149
24	0.42	≤ 0.001	0.18
29	0.37	≤ 0.001	0.16
41	0.35	≤ 0.001	0.211***
25	0.34	≤ 0.001	0.109
30	0.35	≤ 0.001	0.163**

10	0.32	0.002	0.102
11	0.33	≤0.001	0.12
22	0.36	≤0.001	0.124*
42	0.35	≤0.001	0.121
12	0.27	0.003	0.212***
19	0.35	≤0.001	0.12
34	0.26	0.006	0.096
28	0.32	≤0.001	0.09
26	0.30	≤0.001	0.09
45	0.26	0.004	0.11
20	0.29	≤0.001	0.093
21	0.27	≤0.001	0.072
44	0.20	0.149	0.159***
17	0.24	≤0.001	0.09

368 Note. * = $p \leq .05$; ** = $p \leq .01$; *** = $p \leq .001$.

369 ^aKolmogorov-Smirnov test statistic

370
371
372
373



374
375 Figure 2: Mean neologism Phonological Overlap Index (POI) score per Jargon individual
376 (squares), and the mean chance POI estimate (red line). Error bars show 95% confidence
377 intervals.

378
379

380 Perseveration results

381 The IPP measure quantifies how frequently intruded phonemes occur over the previous ten
382 responses. This analysis was applied to individuals with fluent Jargon aphasia for whom
383 suitable data were available (n=25). The perseveration probability scores observed across
384 lags one to ten were averaged to derive a single IPP (perseveration) score. Individual IPP
385 scores were compared against the null chance distributions. Thirteen individuals (3, 28, 39,
386 22, 20, 25, 34, 30, 42, 45, 19, 21, 17) produced perseveration at significantly greater rates

387 than the chance prediction ($p \leq 0.039$; see Table 4). The remaining twelve individuals did not
 388 persevere at above the chance prediction ($p \geq 0.054$; see Figure 3).

389

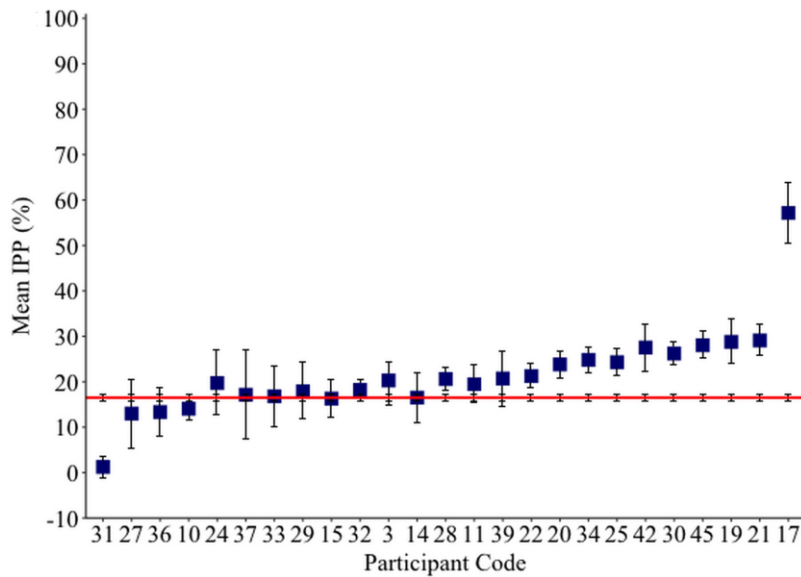
390 *Table 4: Test statistics for Intrusion Perseveration Probability (IPP) analysis.*

Pt code	IPP mean	<i>p</i> value
31	0.01	1
27	0.13	0.963
36	0.13	0.949
10	0.14	0.905
15	0.16	0.527
14	0.17	0.467
33	0.17	0.395
37	0.17	0.337
29	0.18	0.269
32	0.18	0.219
11	0.19	0.068
24	0.20	0.054
3	0.20	0.039
28	0.21	0.029
39	0.21	0.028
22	0.21	0.007
20	0.24	≤ 0.001
25	0.24	≤ 0.001
34	0.25	≤ 0.001
30	0.26	≤ 0.001
42	0.28	≤ 0.001
45	0.28	≤ 0.001
19	0.29	≤ 0.001
21	0.29	≤ 0.001
17	0.57	≤ 0.001

391

392

393



394
 395 *Figure 3: Mean Intrusion Perseveration Probability (IPP) score per Jargon individual*
 396 *(square), and IPP chance estimate (red line). Error bars show 95% confidence intervals.*

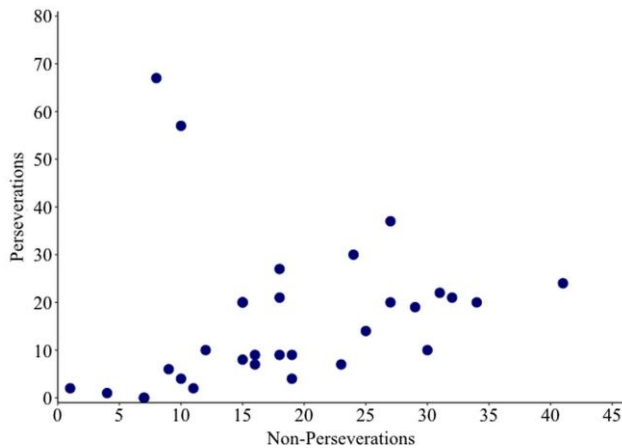
397

398 **Relationship between perseverative and non-perseverative nonwords**

399 Nonword errors were coded as a perseveration if an intruded phoneme was present in the
 400 previous response. Remaining nonwords were coded as non-perseverative errors. A
 401 correlation analysis revealed a significant positive relationship between rates of perseverative
 402 and non-perseverative nonwords ($\rho = 0.557, p = .001$; see Figure 4). The size of this effect
 403 increased from moderate to large when the two outlying individuals (17 and 44) were
 404 removed ($\rho = 0.749, p \leq .001$).

405

406



407
 408 *Figure 4: Scatter plot showing the relationship between numbers of perseverative and non-*
 409 *perseverative nonwords.*

410

411

412 **Lesion-Symptom mapping**

413 The Jargon aphasia group were combined with a wider aphasia group for whom
 414 neuroimaging data were available to explore the relationship between lesion and jargon
 415 repetition. All but four participants (7; 38; 40; 46) in the wider aphasia group displayed a
 416 degree of repetition impairment; however, these impairments were only considered Jargon in

417 25 participants. As well as the significant relationship between perseverative and non-
 418 perseverative errors, Pearson correlation analyses displayed strong to medium relationships
 419 between overall repetition accuracy, number of neologistic errors, number of paraphasic
 420 errors and total number of intruded phonemes, see Table 5. Principal component analysis was
 421 used to derive a summary score representing number of neologisms, paraphasias and intruded
 422 phonemes (jargon score) which was entered into the VLSM analysis as the continuous
 423 dependent variable.

424
 425 VLSM analysis identified lesion clusters associated with the jargon score in the posterior
 426 temporal and inferior parietal lobe, Figure 1C. These regions included the grey and white
 427 matter of the posterior superior temporal gyrus (STG), including areas Spt, the posterior
 428 superior temporal sulcus (STS), grey matter of the inferior parietal lobe (IPL) including the
 429 supramarginal gyrus (SMG) and white matter at the temporal-parietal boarder. These clusters
 430 remained significant at $p = .01$, (see Table 5), however did not survive permutation
 431 correction.

432
 433 *Table 5: Correlations coefficients displaying medium-strong relationships between jargon*
 434 *score components*

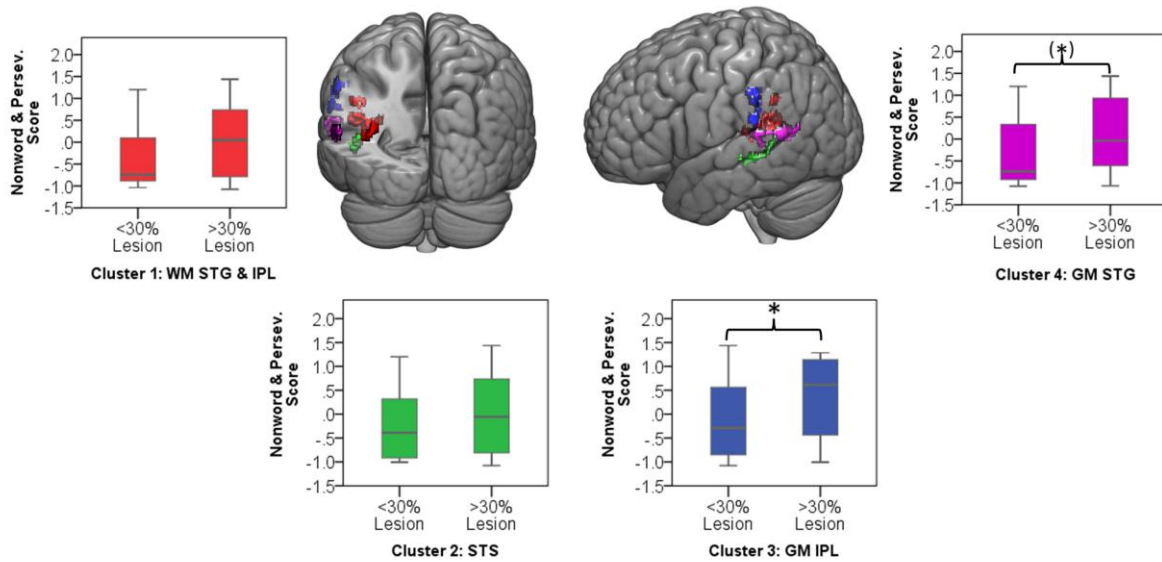
		Number Neologisms	Number Paraphasias	Total Intruded Phonemes
Repetition Accuracy	r value	-0.799	-0.709	-0.671
	p value	<0.001	<0.001	<0.001
Number Neologisms	r value		0.363	0.851
	p value		.023	<0.001
Number Paraphasias	r value			0.324
	p value			.044

435
 436
 437

438 *Table 6: Peak VLSM results, threshold ≤ 0.01*

Region	MNI Coordinate
Posterior Superior Temporal Gyrus	-42 -50 15
	-50 -36 17
	-58 -57 16
Superior Temporal/Inferior Parietal Lobe	-33 -37 15
Supramarginal Gyrus	-50 -46 33

439 Significant clusters occurred in regions of high lesion overlap, (see Figure 1B). Therefore,
 440 follow-up ROI analyses were used to explore consistency of the VLSM results across the
 441 aphasia group. Four neuroanatomically constrained clusters were identified from the VLSM
 442 analyses: 1) White matter of the STG and IPL; 2) STS; 3) Grey matter of IPL including SMG
 443 and 4) Grey matter of the STG, (see Figure 5). The number of lesion voxels in each ROI was
 444 identified for each participant and participants were separated into low overlap (<30% ROI
 445 voxels lesioned) or high overlap (>30% ROI voxels lesioned). T-tests were used to compare
 446 the jargon score between the high and low overlap groups in each ROI. There was no
 447 significant difference in jargon score for clusters 1 and 2. There was a significant difference
 448 in jargon scores between the high and low overlap groups in cluster 3, IPL ($t_{(36)} = 2.0, p =$
 449 $.049$), and a borderline significant difference in cluster 4, STG grey matter ($t_{(36)} = 1.77, p =$
 450 $.085$), (see Figure 5).
 451



452
 453 *Figure 5: Colour areas display four regions of interest derived from VLSM clusters. Graphs*
 454 *indicate jargon score for low and high lesion overlap group in each ROI. Ceiling*
 455 *performance on jargon score = -1.07. * = significant group difference; (*) = borderline*
 456 *significant group difference. WM = white matter; GM = grey matter; STG = superior*
 457 *temporal gyrus; IPL = inferior parietal lobe; STS = superior temporal sulcus.*

458
 459 A regression analysis was performed to investigate whether a combination of lesions was
 460 most predictive of jargon production. The centred percentage lesion overlap of each ROI and
 461 the two-way interaction between ROIs were added as predictor variables alongside age, time
 462 post onset at testing and total lesion volume into a linear regression; jargon score was the
 463 dependent variable. Interaction terms were calculated by multiplying percentage of lesion in
 464 each cluster e.g. percentage overlap in cluster 1 x percentage overlap in cluster 2. Predictors
 465 in the model displayed sufficient collinearity tolerance; the minimum tolerance value outside
 466 interaction predictors was 0.2. The regression returned a borderline significant model ($F_{12,25}$
 467 $= 2.05, \text{adjusted } R^2 = 0.253, p = .063$). Time post onset was a significant predictor ($t = -2.3, p$
 468 $= .03$) indicating that the greater time post onset the less jargon production. Lesions in
 469 isolated clusters did not significantly contribute to the model, however the interaction
 470 between cluster 2 (STS GM) and cluster 4 (STG GM) was a significant predictor ($t = 2.3, p =$
 471 $.03$) indicating that jargon was more severe when lesions affected both the STS and STG.

472

473 **Discussion**

474 The aim of the current study was to explore, side by side, the behavioural and neurological
475 patterns associated with repetition deficits in Jargon aphasia. Behavioural analyses identified
476 the target relatedness of phonological distortions, and explored the effect of phoneme
477 perseveration in Jargon repetition. Correlation analyses exposed the relationship between
478 perseverative and non-perseverative errors. Lesion analyses were used to identify
479 neurological regions and patterns of damage associated with jargon repetition. Results
480 support the hypothesis that weak activation of target phonology results in neologistic
481 production. Individuals with increasingly severe production deficits showed greater degrees
482 of perseveration, and there was a clear association between the occurrence of perseverative
483 and non-perseverative nonwords, suggesting that both error types arise from a common
484 mechanism. Lesion analyses converge with this interpretation and, additionally, implicate a
485 contribution of impairments in analysis and maintenance of auditory information to jargon
486 repetition.

487

488 Psycholinguistic models account for nonword errors in Jargon aphasia through a breakdown
489 in phonological encoding, whereby activation is not effectively transferred from the lexical to
490 the phonological level (Dell, 2014; Marshall, 2006; Olson et al., 2007; 2015; Schwartz et al.,
491 2004). Therefore, phonological and neologistic errors are accounted for by the same
492 mechanism with differing degrees of breakdown severity. However, some evidence has
493 pointed towards a random or default phonological activation pattern for some individuals,
494 hypothesised to arise when lexical retrieval fails, (Butterworth, 1979; Eaton et al., 2010;
495 Moses et al., 2004). Phonological Overlap Index (POI) analysis of the neologisms produced
496 by the 25 participants with neologistic Jargon aphasia in the current study is largely
497 consistent with the phonological encoding hypothesis and does not provide direct support for
498 the default phonology hypothesis. The phonological overlap between neologisms and targets,
499 although by definition low, was significantly above chance for 23 of the 25 neologistic
500 Jargon aphasia participants, indicating a post-lexical retrieval breakdown. However, a large
501 cluster of nonword errors with very limited target overlap occurring alongside errors with
502 greater target relatedness would provide evidence for an additional lexical retrieval failure
503 and default phonological production source. To investigate this hypothesis, the POI
504 distribution across all nonword errors was analysed. Only five individuals violated the normal
505 distribution and only one of these participants (individual 12) displayed evidence of a
506 separate cluster of nonword errors with limited target overlap, thus conforming to the two
507 deficit account. However, caution must be taken in this interpretation in that the pattern could
508 be accounted for by a large number of perseverative responses which were not distinguished
509 within the POI or accuracy distribution analyses. For example, individual 44 exhibited a left
510 skew indicating that most of their nonwords had very limited target overlap, and the POI
511 analysis identified the accuracy of individual 44 as at chance. However, the correlation
512 analysis indicated that individual 44 was highly perseverative, thus it is probable that their
513 skewed POI distribution and neologistic accuracy is contaminated by perseveration.

514

515 A perseveration error is thought to occur when poor activation of target phonology allows
516 recently used segments to compete and intrude. Therefore, perseveration errors are proposed
517 to share a source with other nonword jargon errors (Buckingham & Buckingham, 2011;
518 Martin & Dell, 2007). In the current study 25 individuals with Jargon aphasia had suitable
519 data for IPP perseveration analysis. Thirteen of these individuals displayed perseveration at a
520 significantly greater level than the chance prediction, demonstrating that perseveration was a
521 common but not universal feature of Jargon aphasia. Correlation analysis conformed to

522 previous data (e.g. Martin & Dell, 2007) showing that nonword perseverative and non-
523 perseverative error rates are strongly associated, indicating a common error source. Taken
524 together, these results illustrate that perseverative errors occur at moderate to severe levels of
525 phonological encoding impairment. One interpretation is that when phonological encoding is
526 sufficiently impaired, a dearth of target activation results in the availability of only previously
527 active phonological units. These results do not, however, preclude a breakdown of within-
528 network inhibitory processes contributing to perseverative error production. Indeed, if the
529 existence of both excitatory and inhibitory processes are presumed to occur within a
530 cognitive system, it would be highly unlikely that one is impaired and the other spared.

531
532 Failure of inhibition as a dominant impairment is hypothesised to result in a qualitatively
533 different error pattern than impairments in activating new target information, with consistent
534 perseverative responses occurring without a correspondingly high level of non-perseverative
535 nonword errors (Fischer-Baum & Rapp, 2012). Two individuals in the current study
536 (participants 17 and 44) displayed this pattern, producing extremely high proportions of
537 errors classified as perseverative with a comparatively low number of errors classified as
538 non-perseverative nonword responses. This may indicate a greater contribution of inhibitory
539 breakdown in these two individuals. Again, however, caution must be taken in this
540 interpretation. The perseverative errors produced by these two individuals were blended
541 perseverations in which responses contained both perseverated phonemes and non-
542 perseverated phonemes. Non-perseverated phonemes were, for the most part, not related to
543 the target item, suggestive of additional phonological encoding breakdown. Extreme
544 breakdown in phonological encoding would cause consistent failure of target phonology
545 activation and an over-reliance on previously encoded phonology resulting in the majority of
546 responses being identified as perseverative. This would also account for the error patterns
547 produced by participants 17 and 44. Further testing of dissociating individuals would provide
548 useful information on the nature and consistency of production patterns, and is crucial for
549 better understanding Jargon aphasia and the heterogeneity within the population (Nickels et
550 al., 2011).

551
552 Voxel-lesion symptom mapping (VLSM) analyses were used to explore the relationship
553 between lesion distribution and a sensitive measure of jargon repetition. Results parallel those
554 obtained in previous VLSM studies and revealed a significant relationship between jargon
555 production and lesion in the posterior temporoparietal region. Four significant clusters were
556 identified in the grey matter of the posterior superior temporal gyrus (pSTG), supramarginal
557 gyrus (SMG) and superior temporal sulcus (pSTS) and the white matter at the border of the
558 superior temporal and inferior parietal lobes. These regions are commonly observed to
559 activate during functional imaging studies of speech production and repetition, although the
560 precise roles remain under discussion. The pSTG region identified included area Spt at the
561 border between the temporal and parietal lobe. Area Spt is proposed to be a hub region
562 supporting the translation of auditory into motor information (Buchsbaum et al., 2011;
563 Hickok et al., 2011; Hickok & Poeppel, 2004; Warren et al., 2005). These posterior auditory
564 and phonological processes are thought to interact with frontal motor and articulatory
565 processes via dorsal stream white matter tracts associated with the regions of white matter
566 lesion identified in the current study. This finding converges with the phonological encoding
567 impairment interpretation from the current and previous psycholinguistic analyses in that, in
568 the context of repetition, phonological encoding requires the translation of auditory
569 information into phonological patterns that can interface with articulatory processes. The
570 SMG and pSTS regions identified in the VLSM analysis are associated with other processes.
571 The SMG is frequently found to be active during tasks which require the temporary storage

572 of phonological information, leading to the interpretation of this area as a phonological short
573 term memory store. An impairment in phonological short term memory is likely to
574 exacerbate difficulties with phonological encoding through a difficulty in maintaining
575 phonological strings during production and, indeed, those with a greater degree of lesion in
576 the SMG region displayed significantly more severe jargon repetition (Figure 5). The pSTS
577 may play a role in maintaining auditory targets during repetition (Markiewicz & Bohland,
578 2016; Tourville et al., 2008). This converges with traditional hypotheses which implicate an
579 impairment in self-monitoring in Jargon aphasia (Kinsbourne & Warrington, 1963; Maher et
580 al., 1994); difficulties in holding auditory targets may result in limited information with
581 which to monitor production. The VLSM analysis did not identify regions associated with
582 articulatory processes, therefore indicating limited involvement of articulatory impairment in
583 jargon repetition.

584
585 ROI analyses were used to explore whether combinations of lesions across the posterior
586 temporal-parietal region were predictive of jargon repetition. Regression analysis found that
587 combined lesions to the STG and STS region were associated with jargon production. This
588 indicates that jargon is more likely to occur when impairments in phonological encoding and
589 self-monitoring occur in combination. The STG and STS clusters were proximal and
590 consequently there was a medium correlation between percentage lesion overlap in these
591 clusters across the group ($r = 0.54$). However, over 1/3 of the group displayed high lesion
592 overlap in the STG or STS but not in the other region, therefore this pattern is not fully
593 accounted for by a lesion to a single region.

594
595 The VLSM analyses in the current study converge with previous lesion studies undertaken
596 with a smaller proportion of severely impaired individuals. Therefore, these results indicate
597 that jargon repetition may be a more severe manifestation of milder conduction-like
598 repetition deficits. However, ROI analyses in the current study found that individuals with
599 mild or no impairments still presented with lesions in regions identified by the VLSM
600 analysis. These individual differences may be a consequence of post-stroke reorganisation,
601 which was also a significant predictor of jargon production, and are of interest for
602 neuroscientific studies of stroke recovery. These results should, however, be treated as
603 exploratory. Although the results parallel previous VLSM studies of repetition in aphasia
604 (Baldo et al., 2012; Fridriksson et al., 2010; Rogalsky et al., 2015), the results did not remain
605 significant following permutation testing. This is likely to be a consequence of high lesion
606 overlap in the aphasia group as a whole and the high prevalence of repetition impairment,
607 Figure 1, Table 1. Additionally, caution must be taken in interpreting mass-univariate lesion-
608 symptom mapping analyses which suffer from spatial distortion because of constraints of the
609 vascular architecture (Mah et al., 2014) and do not account for regions which have limited
610 functional capacity but remain structurally intact (Robson et al., 2016).

611 **Insights for therapy**

612 Current findings highlight several possible therapeutic strategies that may aid clinical
613 management of Jargon aphasia. Weak activation of target segments at the phonological
614 encoding level dictates that therapy and management should maximise the degree of
615 activation feeding through to the phonological level. According to cognitive-
616 neuropsychological models of word repetition, this is achieved via two converging avenues;
617 lexical (via semantics) and sub-lexical (auditory-phonological analysis and translation into
618 motor instructions). To fully utilise and maximise activation via lexical and sub lexical
619 avenues, clinical tasks should include stimuli in multiple modalities, administering a written
620 and verbal model of the stimuli, and imagery where possible. Phonological awareness
621

622 training could be adapted to include post phonological processing tasks – an area of
623 comparative strength in this patient population (Romani & Galluzzi, 2005; Romani et al.,
624 2002). Jargon aphasia therapy studies are scarce and further research is crucial to enhance
625 understanding of the Jargon impairment, and thus support development of targeted
626 treatments.

627

628 **Conclusions**

629 This study explored behavioural and neurological patterns associated with neologistic and
630 perseverative word repetition errors in Jargon aphasia. Results from the behavioural and
631 lesion analyses converge and support an impairment in encoding target phonology, possibly
632 secondary to impairments in sensory-motor integration. Region of interest lesion analysis
633 extended behavioural findings by indicating that impairments in maintaining auditory
634 information in combination with phonological encoding impairments are particularly
635 detrimental for repetition and were the most predictive of jargon responses in the current
636 study. Behavioural analysis found that nonword and perseverative production are for the most
637 part closely associated, paralleling previous psycholinguistic investigations and supporting
638 the interpretation that perseverative and nonword errors can be accounted for by the same
639 impairment source. These results imply that strengthening auditory-phonological integration
640 and supporting self-monitoring would support speech production in Jargon aphasia.

641

642

643 **References**

644 Ackerman, T., & Ellis, A. W. (2007). Case study: Where do aphasic perseverations come
645 from? *Aphasiology*, 21(10-11), 1018-1038. doi: 10.1080/02687030701198361

646 Anderson, J. M., Gilmore, R., Roper, S., Crosson, B., Bauer, R. M., Nadeau, S., . . . Heilman,
647 K. M. (1999). Conduction aphasia and the arcuate fasciculus: A reexamination of the
648 Wernicke-Geschwind model. *Brain and Language*, 70(1), 1-12. doi: 10.1006/brln.1999.2135

649 Baldo, J. V., Katseff, S., & Dronkers, N. F. (2012). Brain regions underlying repetition and
650 auditory-verbal short-term memory deficits in aphasia: Evidence from voxel-based lesion
651 symptom mapping. *Aphasiology*, 26(3-4), 338-354. doi:10.1080/02687038.2011.602391

652 Basilakos, A., Rorden, C., Bonilha, L., Moser, D., & Fridriksson, J. (2015). Patterns of
653 Poststroke Brain Damage That Predict Speech Production Errors in Apraxia of Speech and
654 Aphasia Dissociate. *Stroke*. 46:1561-1566.

655 <https://doi.org/10.1161/STROKEAHA.115.009211>

656 Boatman, D., Gordon, B., Hart, J., Selnes, O., Miglioretti, D., & Lenz, F. (2000).
657 Transcortical sensory aphasia: revisited and revised. *Brain*, 123(8), 1634-1642.
658 doi:10.1093/brain/123.8.1634

659 Bose, A. (2013). Phonological therapy in Jargon aphasia: effects on naming and neologisms.
660 *International Journal of Language & Communication Disorders*, 48(5), 582-595. doi:
661 10.1111/1460-6984.12038

662 Buchsbaum, B. R., Baldo, J., Okada, K., Berman, K. F., Dronkers, N., D'Esposito, M., &
663 Hickok, G. (2011). Conduction aphasia, sensory-motor integration, and phonological short-
664 term memory – An aggregate analysis of lesion and fMRI data. *Brain and Language*, 119(3),
665 119-128. doi:http://dx.doi.org/10.1016/j.bandl.2010.12.001

666 Buchsbaum, B. R., Hickok, G., & Humphries, C. (2001). Role of left posterior superior
667 temporal gyrus in phonological processing for speech perception and production. *Cognitive*
668 *Science*, 25(5), 663-678. doi:http://dx.doi.org/10.1016/S0364-0213(01)00048-9

- 669 Buckingham Jr, H. W., Avakian-Whitaker, H., & Whitaker, H. A. (1978). Alliteration and
670 Assonance in Neologistic Jargon Aphasia. *Cortex*, 14(3), 365-380.
671 doi:http://dx.doi.org/10.1016/S0010-9452(78)80063-X
- 672 Buckingham, H. W. (1990). Abstruse Neologisms, Retrieval Deficits and the Random
673 Generator. *J. Neurolinguistics*, 5(2/3), 215-235. doi:http://dx.doi.org/10.1016/0911-
674 6044(90)90012-N
- 675 Buckingham, H. W., & Buckingham, S. S. (2011). Is recurrent perseveration a product of
676 deafferented functional systems with otherwise normal post-activation decay rates? *Clin*
677 *Linguist Phon*, 25(11-12), 1066-1073. doi:10.3109/02699206.2011.616982
- 678 Butterworth, B. (1979). Hesitation and the production of verbal paraphasias and neologisms
679 in Jargon aphasia. *Brain and Language*, 8(2), 133-161. doi: http://dx.doi.org/10.1016/0093-
680 934X(79)90046-4
- 681 Cohen, L., & Dehaene, S. (1998). Competition between past and present. Assessment and
682 interpretation of verbal perseverations. *Brain*, 121(9), 1641-1659.
- 683 Dell, G. S. (2014). Phonemes and Production. *Lang Cogn Process*, 29(1), 30-32. doi:
684 10.1080/01690965.2013.851795
- 685 Dell, G. S., Martin, N., & Schwartz, M. F. (2007). A case-series test of the interactive two-
686 step model of lexical access: Predicting word repetition from picture naming. *Journal of*
687 *Memory and Language*, 56(4), 490-520. doi: http://dx.doi.org/10.1016/j.jml.2006.05.007
- 688 Dell, G. S., Schwartz, M. F., Martin, N., Saffran, E. M., & Gagnon, D. A. (1997). Lexical
689 access in aphasic and nonaphasic speakers. *Psychol Rev*, 104(4), 801-838.
- 690 Deschamps, I., & Tremblay, P. (2014). Sequencing at the syllabic and supra-syllabic levels
691 during speech perception: an fMRI study. *Frontiers in human neuroscience*, 8(492).
692 doi:10.3389/fnhum.2014.00492
- 693 Eaton, E., Marshall, J., & Pring, T. (2010). Like deja vu all over again: Patterns of
694 perseveration in two people with Jargon aphasia. *Aphasiology*, 24(9), 1017-1031. doi: Pii
695 918865637
- 696 Eaton, E., Marshall, J., & Pring, T. (2011). Mechanisms of change in the evolution of Jargon
697 aphasia. *Aphasiology*, 25(12), 1543-1561. doi: 10.1080/02687038.2011.624584
- 698 Fischer-Baum, S., & Rapp, B. (2012). Underlying cause(s) of letter perseveration errors.
699 *Neuropsychologia*, 50(2), 305-318. doi:
700 http://dx.doi.org/10.1016/j.neuropsychologia.2011.12.001
- 701 Fridriksson, J., Kjartansson, O., Morgan, P. S., Hjaltason, H., Magnusdottir, S., Bonilha, L.,
702 & Rorden, C. (2010). Impaired Speech Repetition and Left Parietal Lobe Damage. *The*
703 *Journal of Neuroscience*, 30(33), 11057-11061. doi:10.1523/jneurosci.1120-10.2010
- 704 Geschwind, N. N. (1965). Disconnexion syndromes in animals and man. II. *Brain* (London,
705 England: 1878), 88(3), 585.
- 706 Goodglass, H., Kaplan, E., & Barresi, B. (2001). The Boston Diagnostic Aphasia
707 Examination: BDAE-3. Philadelphia, Pa.: Lippincott Williams & Wilkins.
- 708 Hanley, J. R., & Kay, J. (1997). An effect of imageability on the production of phonological
709 errors in auditory repetition. *Cognitive Neuropsychology*, 14(8), 1065-1084. doi:
710 10.1080/026432997381277

711 Hanley, J. R., Dell, G. S., Kay, J., & Baron, R. (2004). Evidence for the involvement of a
712 nonlexical route in the repetition of familiar words: A comparison of single and dual route
713 models of auditory repetition. *Cognitive Neuropsychology*, 21(2), 147-158. doi:
714 10.1080/02643290342000339

715 Hanley, J. R., Kay, J., & Edwards, M. (2002). Imageability effects, phonological errors, and
716 the relationship between auditory repetition and picture naming: Implications for models of
717 auditory repetition. *Cognitive Neuropsychology*, 19(3), 193-206. doi:
718 10.1080/02643290143000132

719 Henson, R. N., Burgess, N., & Frith, C. D. (2000). Recoding, storage, rehearsal and grouping
720 in verbal short-term memory: an fMRI study. *Neuropsychologia*, 38(4), 426-440.

721 Hickok, G. (2009). The functional neuroanatomy of language. *Physics of Life Reviews*, 6(3),
722 121-143. doi:http://dx.doi.org/10.1016/j.pprev.2009.06.001

723 Hickok, G., & Poeppel, D. (2004). Dorsal and ventral streams: a framework for
724 understanding aspects of the functional anatomy of language. *Cognition*, 92(1-2), 67-99. doi:
725 10.1016/j.cognition.2003.10.011

726 Hickok, G., Buchsbaum, B., Humphries, C., & Muftuler, T. (2003). Auditory–Motor
727 Interaction Revealed by fMRI: Speech, Music, and Working Memory in Area Spt. *Journal of*
728 *Cognitive Neuroscience*, 15(5), 673-682. doi:10.1162/jocn.2003.15.5.673

729 Hickok, G., Houde, J., & Rong, F. (2011). Sensorimotor Integration in Speech Processing:
730 Computational Basis and Neural Organization. *Neuron*, 69(3), 407-422.
731 doi:http://dx.doi.org/10.1016/j.neuron.2011.01.019

732 Hickok, G., Okada, K., & Serences, J. T. (2009). Area Spt in the Human Planum Temporale
733 Supports Sensory-Motor Integration for Speech Processing. *Journal of Neurophysiology*,
734 101(5), 2725.

735 Hillis, A. E., & Caramazza, A. (1991). Mechanisms for accessing lexical representations for
736 output: Evidence from a category-specific semantic deficit. *Brain and Language*, 40(1), 106-
737 144. doi: http://dx.doi.org/10.1016/0093-934X(91)90119-L

738 Hirsh, K. W. (1998). Perseveration and Activation in Aphasic Speech Production. *Cognitive*
739 *Neuropsychology*, 15(4), 377-388. doi: 10.1080/026432998381140

740 Hodges, J. R., Martinos, M., Woollams, A. M., Patterson, K., & Adlam, A.-L. R. (2008).
741 Repeat and Point: Differentiating semantic dementia from progressive non-fluent aphasia.
742 *Cortex*, 44(9), 1265-1270. doi:http://dx.doi.org/10.1016/j.cortex.2007.08.018

743 Isenberg, A. L., Vaden, K. I., Saberi, K., Muftuler, L. T., & Hickok, G. (2012). Functionally
744 distinct regions for spatial processing and sensory motor integration in the planum temporale.
745 *Human brain mapping*, 33(10), 2453-2463. doi:10.1002/hbm.21373

746 Itabashi, R., Nishio, Y., Kataoka, Y., Yazawa, Y., Furui, E., Matsudaand M., & Mori, E.
747 (2016). Damage to the Left Precentral Gyrus Is Associated With Apraxia of Speech in Acute
748 *Stroke*. 47:31-36 https://doi.org/10.1161/STROKEAHA.115.010402

749 Jefferies, E., & Lambon Ralph, M. A. (2006). Semantic impairment in stroke aphasia versus
750 semantic dementia: a case-series comparison. *Brain*, 129(8), 2132-2147.
751 doi:10.1093/brain/awl153

752 Kaplan, E. (1983). The assessment of aphasia and related disorders (Vol. 2): Lippincott
753 Williams & Wilkins.

- 754 Kay, J., Lesser, R., & Coltheart, M. (1996). Psycholinguistic assessments of language
755 processing in aphasia (PALPA): An introduction. *Aphasiology*, 10(2), 159-180.
- 756 Kinsbourne, M., & Warrington, E. K. (1963). Jargon aphasia. *Neuropsychologia*, 1(1), 27-37.
757 doi: [http://dx.doi.org.idpproxy.reading.ac.uk/10.1016/0028-3932\(63\)90010-1](http://dx.doi.org.idpproxy.reading.ac.uk/10.1016/0028-3932(63)90010-1)
- 758 Mah, Y.-H., Husain, M., Rees, G., & Nachev, P. (2014). Human brain lesion-deficit inference
759 remapped. *Brain*, 137(9), 2522-2531. doi:10.1093/brain/awu164
- 760 Maher, L. M., Rothi, L. J. G., & Heilman, K. M. (1994). Lack of Error Awareness in an
761 Aphasic Patient with Relatively Preserved Auditory Comprehension. *Brain and Language*,
762 46(3), 402-418. doi: <http://dx.doi.org/10.1006/brln.1994.1022>
- 763 Markiewicz, C. J., & Bohland, J. W. (2016). Mapping the cortical representation of speech
764 sounds in a syllable repetition task. *Neuroimage*, 1;141:174-90. doi:
765 10.1016/j.neuroimage.2016.07.023
- 766 Marshall, J. (2006). Jargon aphasia: What have we learned? *Aphasiology*, 20(5), 387-410.
767 doi: 10.1080/02687030500489946
- 768 Marshall, J., Robson, J., Pring, T., & Chiat, S. (1998). Why Does Monitoring Fail in Jargon
769 aphasia? Comprehension, Judgment, and Therapy Evidence. *Brain and Language*, 63(1), 79-
770 107. doi: <http://dx.doi.org/10.1006/brln.1997.1936>
- 771 Martin, N. (1996). Models of deep dysphasia. *Neurocase*, 2(1), 73-80. doi:
772 10.1080/13554799608402391
- 773 Martin, N., & Dell, G. S. (2007). Common mechanisms underlying perseverative and non-
774 perseverative sound and word substitutions. *Aphasiology*, 21(10-11), 1002-1017.
775 doi:10.1080/02687030701198346
- 776 Martin, N., Dell, G. S., Saffran, E. M., & Schwartz, M. F. (1994). Origins of paraphasias in
777 deep dysphasia: testing the consequences of a decay impairment to an interactive spreading
778 activation model of lexical retrieval. *Brain and Language*, 47(4), 609-660. doi:
779 10.1006/brln.1994.1061
- 780 McCarthy, R., & Warrington, E. K. (1984). A two-route model of speech production. *Brain*,
781 107(2), 463.
- 782 McGettigan, C., Warren, J. E., Eisner, F., Marshall, C. R., Shanmugalingam, P., & Scott, S.
783 K. (2010). Neural Correlates of Sublexical Processing in Phonological Working Memory.
784 *Journal of Cognitive Neuroscience*, 23(4), 961-977. doi:10.1162/jocn.2010.21491
- 785 Mesgarani, N., Cheung, C., Johnson, K., & Chang, E. (2014). Phonetic Feature Encoding in
786 Human Superior Temporal Gyrus. *Science*, 343(6174), 1006-1010.
787 doi:10.1126/science.1245994
- 788 Moritz-Gasser, S., & Duffau, H. (2013). The anatomo-functional connectivity of word
789 repetition: insights provided by awake brain tumor surgery. *Frontiers in Human*
790 *Neuroscience*, 7, 405. doi: 10.3389/fnhum.2013.00405
- 791 Moses, M. S., Nickels, L. A., & Sheard, C. (2004). Disentangling the web: Neologistic
792 perseverative errors in Jargon aphasia. *Neurocase*, 10(6), 452-461. doi:
793 10.1080/13554790490894057
- 794 Moses, M. S., Nickels, L. A., & Sheard, C. (2007a). Chips, cheeks and carols: A review of
795 recurrent perseveration in speech production, *Aphasiology*, 21:10-11, 960-974, DOI:
796 10.1080/02687030701198254

797 Moses, M. S., Sheard, C., & Nickels, L. A. (2007b). Insights into recurrent perseverative
798 errors in aphasia: A case series approach, *Aphasiology*, 21:10-11, 975-1001,
799 DOI:10.1080/02687030701198312

800 Nickels, L., Howard, D., & Best, W. (2011). On the use of different methodologies in
801 cognitive neuropsychology: Drink deep and from several sources. *Cognitive*
802 *Neuropsychology*, 28(7), 475-485. 10.1080/02643294.2012.672406

803 Nozari, N., Kittredge, A. K., Dell, G. S., & Schwartz, M. F. (2010). Naming and repetition in
804 aphasia: Steps, routes, and frequency effects. *Journal of Memory and Language*, 63(4), 541-
805 559. doi:10.1016/j.jml.2010.08.001

806 Olson, A. C., Romani, C., & Halloran, L. (2007). Localizing the deficit in a case of jargon
807 aphasia. *Cognitive Neuropsychology*, 24(2), 211-238. doi: 10.1080/02643290601137017

808 Olson, A., Halloran, E., & Romani, C. (2015). Target/error overlap in jargon aphasia: The
809 case for a one-source model, lexical and non-lexical summation, and the special status of
810 correct responses. *Cortex*, 73, 158-179. doi:http://dx.doi.org/10.1016/j.cortex.2015.06.028

811 Panzeri, M., Semenza, C., & Butterworth, B. (1987). Compensatory processes in the
812 evolution of severe Jargon aphasia. *Neuropsychologia*, 25(6), 919-933. doi:
813 http://dx.doi.org/10.1016/0028-3932(87)90096-0

814 Papagno, C., & Basso, A. (1996). Perseveration in Two Aphasic Patients. *Cortex*, 32(1), 67-
815 82. doi:10.1016/s0010-9452(96)80017-7

816 Paulesu, E., Frith, C. D., & Frackowiak, R. S. (1993). The neural correlates of the verbal
817 component of working memory. *Nature*, 362(6418), 342-345.

818 Quigg, M., & Fountain, N. B. (1999). Conduction aphasia elicited by stimulation of the left
819 posterior superior temporal gyrus. *J Neurol Neurosurg Psychiatry*, 66(3), 393-396.

820 Ravizza, S. M., Delgado, M. R., Chein, J. M., Becker, J. T., & Fiez, J. A. (2004). Functional
821 dissociations within the inferior parietal cortex in verbal working memory. *Neuroimage*,
822 22(2), 562-573. doi:http://dx.doi.org/10.1016/j.neuroimage.2004.01.039

823 Robson, H., Cloutman, L., Keidel, J. L., Sage, K., Drakesmith, M., & Welbourne, S. (2014).
824 Mismatch negativity (MMN) reveals inefficient auditory ventral stream function in chronic
825 auditory comprehension impairments. *Cortex*, 59, 113-125. doi:10.1016/j.cortex.2014.07.009

826 Robson, H., Grube, M., Lambon Ralph, M. A., Griffiths, T. D., & Sage, K. (2013).
827 Fundamental deficits of auditory perception in Wernicke's aphasia. *Cortex*, 49(7), 1808-1822.
828 doi:10.1016/j.cortex.2012.11.012

829 Robson, H., Keidel, J. L., Ralph, M. A., & Sage, K. (2012). Revealing and quantifying the
830 impaired phonological analysis underpinning impaired comprehension in Wernicke's aphasia.
831 *Neuropsychologia*, 50(2), 276-288. doi:10.1016/j.neuropsychologia.2011.11.022

832 Robson, H., Specht, K., Beaumont, H., Parkes, L. M., Sage, K., Lambon Ralph, M. A., &
833 Zahn, R. (2016). Arterial spin labelling shows functional depression of non-lesion tissue in
834 chronic Wernicke's aphasia. *Cortex*. doi:http://dx.doi.org/10.1016/j.cortex.2016.11.002

835 Robson, J. O., Marshall, J., Pring, T. I. M., & Chiat, S. (1998a). Phonological naming therapy
836 in Jargon aphasia: Positive but paradoxical effects. *Journal of the International*
837 *Neuropsychological Society*, 4(06), 675-686.

838 Robson, J. O., Pring, T., Marhsall, J., Morrison, S., & Chiat, S. (1998b). Written
839 communication in undifferentiated Jargon aphasia: a therapy study. *International Journal of*
840 *Language & Communication Disorders*, 33(3), 305. doi: 10.1080/136828298247767

841 Rogalsky, C., Poppa, T., Chen, K.-H., Anderson, S. W., Damasio, H., Love, T., & Hickok, G.
842 (2015). Speech repetition as a window on the neurobiology of auditory–motor integration for
843 speech: A voxel-based lesion symptom mapping study. *Neuropsychologia*, 71, 18-27.
844 doi:<http://dx.doi.org/10.1016/j.neuropsychologia.2015.03.012>

845 Romani, C., & Galluzzi, C. (2005). Effects of syllabic complexity in predicting accuracy of
846 repetition and direction of errors in patients with articulatory and phonological difficulties.
847 *Cognitive Neuropsychology*, 22(7), 817-850. doi:10.1080/02643290442000365

848 Romani, C., Olson, A., Semenza, C., & Grana, A. (2002). Patterns of phonological errors as a
849 function of a phonological versus an articulatory locus of impairment. *Cortex*, 38(4), 541-
850 567.

851 Rorden, C., Bonilha, L., Fridriksson, J., Bender, B., & Karnath, H.-O. (2012). Age-specific
852 CT and MRI templates for spatial normalization. *Neuroimage*, 61(4), 957-965.
853 doi:10.1016/j.neuroimage.2012.03.020

854 Sandson, J., & Albert, M. L. (1984). Varieties of perseveration. *Neuropsychologia*, 22(6),
855 715-732.

856 Santo Pietro, M. J., & Rigrodsky, S. (1986). Patterns of oral-verbal perseveration in adult
857 aphasics. *Brain and Language*, 29(1), 1-17.

858 Schwartz, M. F., Wilshire, C. E., Gagnon, D. A., & Polansky, M. (2004). Origins of nonword
859 phonological errors in aphasic naming. *Cognitive Neuropsychology*, 21(2-4), 159-186. doi:
860 10.1080/02643290342000519

861 Stark, J. (2007). A review of classical accounts of verbal perseveration and their modern-day
862 relevance. *Aphasiology*, 21(10-11), 928-959. doi: 10.1080/02687030701198239

863 Tourville, J. A., Reilly, K. J., & Guenther, F. H. (2008). Neural mechanisms underlying
864 auditory feedback control of speech. *Neuroimage*, 39(3): 1429–1443. doi:
865 10.1016/j.neuroimage.2007.09.054

866 Trébuchon, A., Démonet, J., Chauvel, P., & Liégeois-Chauvel, C. Ventral and dorsal
867 pathways of speech perception: An intracerebral ERP study. *Brain*, 127(2), 273–283
868 doi:<http://dx.doi.org/10.1016/j.bandl.2013.04.007>

869 Warren, J. E., Wise, R. J. S., & Warren, J. D. (2005). Sounds do-able: auditory–motor
870 transformations and the posterior temporal plane. *Trends in Neurosciences*, 28(12), 636-643.
871 doi:<http://dx.doi.org/10.1016/j.tins.2005.09.010>

872 Yamadori, A. (1981). Verbal perseveration in aphasia. *Neuropsychologia*, 19(4), 591-594.
873 doi:[http://dx.doi.org/10.1016/0028-3932\(81\)90026-9](http://dx.doi.org/10.1016/0028-3932(81)90026-9)

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923 difference. WM = white matter; GM = grey matter; STG = superior temporal gyrus; IPL =
924 inferior parietal lobe; STS = superior temporal sulcus.

925

926 **Conflict of Interest**

927 *The authors declare that the research was conducted in the absence of any commercial or*
928 *financial relationships that could be construed as a potential conflict of interest.*

929

930 **Funding**

931 This research was funded by a Stroke Association Postgraduate Fellowship awarded to
932 Emma Pilkington (TSA PGF 2015-02), and a Stroke Association Senior Research Training
933 Fellowship awarded to Dr Holly Robson (TSA SRTF 2012/2).

934

935 **Acknowledgements**

936 We would like to thank the participants who were involved in the current study.