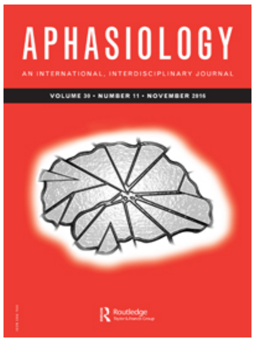

Aphasiology

ISSN: 0268-7038 (Print) 1464-5041 (Online) Journal homepage: http://www.tandfonline.com/loi/paph20

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APHASIOLOGY, 2016
VOL. 30, NO. 11, 1264–1282
http://dx.doi.org/10.1080/02687038.2015.1135867

Lexical access in non-fluent aphasia: a bit more on reduced processing

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ABSTRACT

Background: Lexical access problems of inflected verbs are common in aphasia. Previous research addressed these problems either in purely linguistic terms (e.g., verb movement) or in terms of lexical characteristics (e.g., frequency). We propose a new measure of verb complexity, which combines linguistic and lexical characteristics and is formulated in terms of Shannon's information theory.

Aims: We aim to explore the complexity of individual verbs and verb paradigms and its effect on lexical access, both in unimpaired people and people with aphasia (PWA). We apply information theory to investigate the impact of verb complexity on reaction time (RT) for lexical decision.

Methods & Procedures: 20 non-fluent aphasic subjects and 11 age-matched and education-matched peers performed an auditory lexical decision task containing 286 real and 286 phonotactically legal non-word past tense forms (regulars and irregulars). RTs and error rates were measured. Two information-theoretic measures were calculated: inflectional entropy (reflecting probabilistic variability of forms within a given verbal family) and information load (*I*) (reflecting complexity of an individual verb form). The effect for these and other more traditional measures on RT were measured.

Outcomes & Results: Linear mixed model analyses to the data for each group with participant and verb as crossed random effects were performed. Results show that for all groups inflectional entropy had a facilitatory effect on RT. There was a group effect for inflectional entropy indicating that for the patients with aphasia the effect of inflectional entropy was less pronounced. At the same time, *I* did correlate with latencies for healthy adults but not for individuals with aphasia.

Conclusions: Our results demonstrate that the decrease in lexical processing capacity characteristic for PWA has a measurable effect that can be calculated using information theoretical means. According to our model, these individuals have particular difficulties with processing lexical items of higher complexity, as measured by individual *I*, and benefit less from the support normally provided (in comprehension) by other members of the corresponding lexical network. Finally, the proposed information-theoretic complexity measures, which encompass both frequency effects and linguistic parameters, provide a superior measure of lexical access, and have a better explanatory power for the analyses of access problems found in non-fluent aphasia, compared to analyses based on frequency only.

ARTICLE HISTORY
Received 8 January 2015
Accepted 15 December 2015

KEYWORDS
Aphasia; information theory; lexical access; inflectional entropy

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Introduction

Difficulty accessing words in the lexicon is the most common and one of the most frustrating characteristics of aphasia. It is evident in all forms of aphasia, although different forms of aphasia may have specific difficulties with particular classes of words. Within the group of content words, verbs are known to be particularly difficult for many patients. The current study adopts a new method based on information theory that provides the possibility to quantify complexity of lexical items and, as a result, to make predictions about the performance of aphasic patients within a reduced processing capacity framework. This allows us to make specific predictions about the performance of aphasic individuals who, as often suggested, suffer from a reduced processing capacity. We first discuss literature on lexical access and reduced activation and cognitive control in aphasia and then briefly touch upon research that shows that processing capacity is reduced in aphasia. We then describe the most important notions from information theory and how these can inform research on lexical access in aphasia. Next, we discuss several information-theoretic measures used to calculate verb complexity and present the results of an auditory lexical decision experiment using these measures as predicting factors for reaction time (RT) in non-fluent aphasia. We argue that the main problem for people with non-fluent aphasia is related to processing higher information loads (*I*) associated with some verbs, while the organisation of the lexical network is intact, although weakened.

Lexical access and reduced activation

Lexical access in aphasia has been a much-studied topic. Several explanations have been proposed in the literature for lexical processing impairments that have to do with the levels of activation in the lexicon. In non-fluent aphasia activation has been suggested to be reduced (Blumstein & Milberg, 2000; Janse, 2006; Yee, Blumstein, & Sedivy, 2008) or delayed or slowed, leading to a later-than-normal rise time (Prather, Zurif, Stern, & Rosen, 1992; Swinney, Prather, & Love, 2000). Others suggest issues with working memory to be responsible for difficulties with lexical access. People with aphasia (PWA) are claimed to have difficulty maintaining the activation of lexical representations in working memory, which leads to a failure in lexical access (Martin, Breedin, & Damian, 1999). A third explanation has to do with cognitive control; PWA are claimed to have difficulties selecting a target between competing alternatives and therefore be unable to overcome lexical competition (Utman, Blumstein, & Sullivan, 2001).

Although these theories have been described as independent accounts of lexical access difficulties in (non-fluent) aphasia, recent research indicates that it is difficult, if not impossible to distinguish between them. Utman et al. (2001) for example set out to investigate reduced activation in non-fluent aphasia using a semantic priming paradigm. They manipulated acoustic features within the prime word to create good and poor exemplars. In healthy adults it has been shown that words containing poorer phonetic exemplars produce less semantic facilitation. Results for a group of PWA showed that, like for healthy adults, semantic priming decreased in words containing poor phonetic exemplars. However, in healthy adults this reduction is short-lived and is not influenced by the presence or absence of a lexical competitor. For the PWA however, semantic priming *was* influenced by competition. The authors argue that this is the result of lowered activation levels overall: poor phonetic exemplars lead to low activation levels in both the target and competitors (due to spreading of activation in the network). As activation is very low to begin with, the system fails to distinguish the target from its competitors. Although the authors set out to investigate activation levels in aphasia, they acknowledge that these results could also be explained by an impairment in selection of a target amongst competitors. This account is further supported by the fact that most of their participating aphasic patients had damage to the left inferior frontal gyrus, an area implicated in conflict resolution in the presence of competing representations (cf. Novick, Trueswell, & Thompson-Schill, 2005). Of course, it is plausible that a combination of reduced activation and an impairment in selecting an item from competing entries leads to difficulties with lexical access and retrieval. Alternatively, it can be that reduced activation in the lexical network *causes* conflict resolution difficulties.

Frequency effects have been taken to be indicative of ease of retrieval of items from the mental lexicon. All other things being equal, frequent words are more readily perceived than rarer forms (Baayen, Feldman, & Schreuder, 2006; Howes & Solomon, 1951). It is argued that high-frequency words have a higher rest activation, and need less extra activation to exceed the threshold value for recognition than low-frequency words (Dell, 1990).

Most of the research on reduced lexical activation in aphasia has focused on nouns. However, research on frequency effects in aphasia shows that disturbances in activation levels could also play an important role in the retrieval of verbs. Stemberger (1984, 1985) suggested that difficulties retrieving verbs and particularly verb inflection errors might be determined by frequency. Research on verb production, for example, by Faroqi-Shah and Thompson (2004) is consistent with this prediction; word form (lexeme) frequency emerged as a significant predictor of both accuracy and substitution errors in their study in which non-fluent PWA were asked to produce inflected verb forms in a picture naming paradigm.

The studies described show that PWA have difficulties with lexical access and retrieval as a result of reduced activation levels, which leads to (or is combined with) a reduced ability to select a target among competing (lexical) entries. Recent research further shows that task and lexical complexity can influence performance, indicating that computational load is an important factor to take into account when investigating lexical access in PWA. Bastiaanse and Bol (2001) and Bastiaanse (2011), for example, show that problems with producing inflected verbs are not due to representational deficits, but rather occur when there is a computational overload in aphasia. Bastiaanse and colleagues looked at the trade-off between verb inflection and verb diversity. In several papers they showed that patients with non-fluent aphasia *can* produce inflected verbs, but that this has an effect on the number of different verbs they produce in a given conversation. Similar support comes from a study using a dual task design (Kok, van Doorn, & Kolk, 2007) in which participants had to produce inflected verbs. The results showed a significant drop in performance on inflection production for a dual task, in which both inflections and word order needed to be produced, in comparison to a task in which verb inflections were produced but word order of the sentence constituents was given.

Summarising the discussed literature so far, it is evident that processing capacity plays an important yet still somewhat undetermined role in verb inflection in aphasia. An increase in cognitive load, be it by presenting participants with a more complex task or unconsciously favouring verb diversity at the cost of verb inflection, leads to profound problems with the production of inflected verbs. Literature on lexical access and retrieval shows that there may be reduced activation in the lexicon in PWA which, combined with difficulties selecting a target, leads to problems activating lexical items in conversation. The current study sets out to combine these two lines of research and to investigate lexical access to verbs in aphasia. A simple task will be presented (auditory lexical decision) in which complexity of the lexical items will be manipulated in a structured way. We will show that complexity of individual verb forms affects lexical access and that a difficulty in selecting a specific verb form from competing alternatives in the inflectional family is present in aphasia. Measures from information theory will be used to calculate complexity of the verbs. The most important notions from information theory are discussed in the following section.

Information theory: measures of complexity

Information theory is a branch of mathematics and engineering that is involved with chaos, uncertainty and the quantification of information. In communication it was first used by Claude Shannon (1948) who was interested in reducing errors and noise when sending signals across technical channels. Unlike previously thought, Shannon discovered that it was not the *speed* at which messages were sent that determined the amount of errors in the output, but the *complexity* of the message. He used a measure from information theory to calculate complexity in bits. He suggested that information of any message can be expressed in bits and that each (technical) channel has a certain maximum channel capacity at which information can be sent in bits per second. If the information of the message sent has a higher value in bits than the channel can cope with, errors start occurring. In information theory the complexity of an item is based on its probability of occurrence. This probability is then transformed by the (base two) logarithm to obtain the I in bits as shown in Equation (1):

$$I_x = -\log_2 p(x) \tag{1}$$

in which I is the amount of information in bits and p the probability of the item occurring. An example often used to explain this formula is the fair coin. If one were to flip a fair coin the probability of heads is ½. The amount of information exchanged upon flipping the coin is $-\log_2$ ½, which equals 1 bit of information. In contrast, when rolling a fair die the information exchanged upon rolling 6 equals $-\log_2 1/6 = 3$. Information of a message thus increases as the probability of that event occurring decreases. A high-level uncertainty regarding the outcome of the event equals a high I.

Since the 1950s, information theory has had myriad applications in psychology, biology, and language sciences. Within psychology and psycholinguistics, it has often been used to investigate processing cost and specifically the balance between maximisation of information transfer and the cost of communication imposed by limitations of the human brain. In psycholinguistics, it has been applied amongst other things for measuring the cognitive cost of semantic processing of lexical items (McDonald & Shillcock, 2001); the structure of the whole lexicon (Ferrer-i-Cancho, 2006); sentence processing (Manika, 2014); article production (van Ewijk & Avrutin, 2010) and inflectional paradigms (Moscoso del Prado Martín, Kostić, & Baayen, 2004).

Although many of the published papers use information-theoretic measures to discuss properties of human language in relation to the cognitive cost of communication, application to populations with possible reduced cognitive processing abilities is sparse. Ferrer-i-Cancho (2006) uses information theory and variations in Zipf's law (a power law natural language follows) to show that young children and individuals with schizophrenia deviate from healthy adults in their ability to overcome cost of communication, as shown by a deviating slope of Zipf's curve for these individuals. He suggests that young children constrained by their brain limitations balance communication towards saving the cost of communication as much as possible. Similar findings have been reported for children with Down's syndrome (Piotrowski, Pashkovskii, & Piotrowski, 1995; Piotrowski & Spivak, 2007). A recent study by van Egmond, van Ewijk, and Avrutin (2015) investigating Zipf's law and reduced processing in aphasia shows very similar findings for four adults with aphasia. A difference was found between the aphasic speakers and their age-matched peers in the slope of this distribution of Zipf's law. This finding is explained as indicative of an unimpaired lexicon and an adaptation to reduced processing capacities.

Morphological processing of nouns and verbs by healthy adults has been extensively researched by Kostiç and colleagues (Baayen et al., 2006; Milin, Filipović Đurđević, & Moscoso del Prado Martín, 2009). They described several measures for the informational complexity of a word both in terms of the amount of information contained by the target word itself (*I*) and the amount of information carried by its nested morphological paradigms (derivational and inflectional entropy). They show that these measures explain variation in RTs in lexical decision tasks for healthy adults. One of the first series of papers published to this effect was by Kostiç and colleagues (Kostić, 1995; Kostić & Katz, 1987). Kostić (1995) investigated token and type-based counts for inflectional processing. Using an information-theoretic approach, Kostiç derived the amount of information for Serbian inflected nouns. Unlike in the situation of a fair coin, the probability of occurrence of inflections in Serbian is not equal. The inflectional exponent −a is far more frequent (and thus has a higher probability of occurrence) than −u. Furthermore, exponents can be used for various grammatical functions, e.g., the exponent −a can be used for nominative singular as well as genitive plural and the exponent −e for genitive singular, nominative plural, and accusative plural (see Table 1). Kostiç adapted Shannon's measure of information and proposed to weight the probabilities for their functions and meanings. By dividing the relative frequency of an inflected form by the number of its functions and meanings, one obtains the average frequency per syntactic function/meaning for a given inflected form. In order to obtain the amount of information carried by an inflected form, this

Table 1. Case & number, frequency, number of functions and meanings (*R*), and *I* of the exponents for Serbian feminine nouns.

Exponent	Case & number	Frequency	*R*	Information
a	Nom sg/ gen pl	12.06	54	1.464
u	Acc sg	5.48	58	2.705
e	Gen sg/nom pl/acc pl	14.20	112	2.280
i	Dat sg/ loc sg	3.80	43	2.803
om	Ins sg	1.94	32	3.346
ama	Dat pl/ loc pl/ins pl	1.69	75	4.773

average probability should be expressed as a proportion relative to the sum of average probabilities per syntactic function/meaning for other inflected forms of a given paradigm as shown in Equation (2).

Let R_e denote the number of functions and meanings carried by exponent *e* and *F* the frequency of that exponent. Then the weighted amount of information I_e can be expressed as follows:

$$I_e = -\log_2\left(\frac{F_e/R_e}{\sum_e F_e/R_e}\right) \tag{2}$$

The obtained value provides a measure for the complexity of each exponent: the higher the information, the higher the complexity of that form. Kostiç calculated the information load of each inflectional class for Serbian feminine nouns. Table 1 provides the frequency, number of functions and meanings, and amount of information carried by the exponents for Serbian feminine nouns.

Kostiç then used these values as predicting factor in a series of visual lexical decision experiments and showed that mean latencies had a strong positive correlation with *I*, far stronger than frequency count alone. Complexity as measured by *I* thus predicts processing cost. It is argued that low information words have a higher rest activation, and need less extra activation to exceed the threshold value for recognition than high information words.

van Ewijk (2013) adopted Kostiç' *I* measure to calculate complexity of Dutch verbs. Frequency and linguistic information were used, by calculating the number of functions and meanings a specific verb form has. Functions and meanings were based on the number of grammatical roles a verb form could have. The verb form *helpt* (*help or helps*), for example, has two functions and meanings in Dutch (2nd & 3rd pres sg).

The second application of information theory to word retrieval involves nested inflectional paradigms (Baayen et al., 2006; Milin et al., 2009). These studies assume, in line with word and paradigm morphology (Blevins, 2003), that inflected forms exist side by side, stored in memory in so-called inflectional paradigms. An inflectional paradigm of a word (the conjugation) consists of the stem, the basic unit of the word, and its inflected forms. *Inflectional entropy* has been suggested to capture the amount of information carried by a word's inflectional paradigm. In the original measure suggested by Moscoso del Prado Martín et al. (2004), the syntactic functions/meanings parameter *R* was not included. We will follow Kostiç (and van Ewijk, 2013) in defining inflectional entropy and incorporate frequency and linguistic considerations as included by the term *R* and propose it is captured by Equation (3):

$$H = -\sum p \log p \tag{3}$$

in which *p* equals

$$p = \frac{F_e/R_e}{\sum F_e/R_e} \tag{4}$$

Here F_e represents the probability of a verb form within its inflectional paradigm and *R* the number of functions that verb form can fulfil. This measure captures the relative probability distribution of all inflected verb forms of a particular lemma. It is a description of the organisation of a single paradigm within the lexicon. Low inflectional entropy indicates that the memory traces of the inflected verb types are unevenly distributed within a paradigm. Some forms within the paradigm carry more information than others. High inflectional entropy reflects a more even distribution of the memory traces within one paradigm (see Figure 1). The calculation of *I* and Inflectional Entropy is exemplified for the verbs *help* (helpen in Dutch) and *praise* (prijzen in Dutch) in Table 2.

Similar to *I*, Inflectional entropy is related to processing cost. The direction of the effect of this measure depends on the type of task that participants perform. In

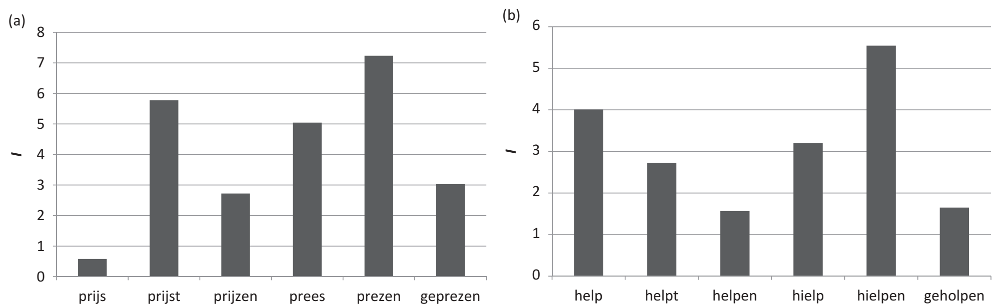

Figure 1. Distribution of a paradigm with (a) low inflectional entropy (1.476 bits for the Dutch verb *prijzen* “to praise”) and (b) high inflectional entropy (2.183 bits for the Dutch verb *helpen* “to help”). Bars represent the information load (*I*) of each verb form of the paradigm.

Table 2. Calculation of Information load (*I*) and Inflection entropy (*H*) for the verbs *helpen* “to help” and *prijzen* “to praise”.

	Help	Helpt	Helpen	Hielp	Hielpen	Geholpen
F	583	1420	6336	1533	302	1496
R	2	2	4	3	3	1
F/R	291.5	710	1584	511	100,7	1496
$p = \frac{F_e/R_e}{\sum F_e/R_e}$	.062	.151	.338	.109	.021	.319
$I_e = -\log_2\left(\frac{F_e/R_e}{\sum_e F_e/R_e}\right)$	4.009	2.725	1.567	3.199	5.543	1.65
$H = -\sum p \log p$						2.183
	Prijs	Prijst	Prijzen	Prees	Prezen	geprezen
F	3230	88	1458	219	48	295
R	2	2	4	3	3	1
F/R	1615	44	364,5	73	16	295
$p = \frac{F_e/R_e}{\sum F_e/R_e}$	.671	.018	.151	.030	.007	.123
$I_e = -\log_2\left(\frac{F_e/R_e}{\sum_e F_e/R_e}\right)$	.576	5.774	2.724	5.043	7.233	3.029
$H = -\sum p \log p$						1.476

F represents form frequency, *R* the number of functions and meanings, and *p* the probability of each inflected form (a function of the ratio of the relative frequency (*F*) of the inflected form to the syntactic functions and meanings (*R*) of that inflected form).

production tasks, this measure has an inhibitory effect on latencies (Baayen et al., 2006; Tabak, Schreuder, & Baayen, 2010), whereas in comprehension tasks it has a facilitatory effect (Tabak et al., 2010). Tabak suggests that in production tasks the inhibitory effect of this measure captures the effect of lexical competition. In comprehension, she argues, the effect is facilitatory due to the support provided to the target by other activated members of the network.

In summary, information theory has provided us with a quantitative measure of complexity of linguistic material. Morphological processing and the role of individual *I* and inflectional families have been well documented in normal language processing. An increase in information corresponds to an increase in processing load. In healthy adults these findings are subtle and only show up in experimental settings. Studies on aphasia suggest that PWA may have reduced lexical activation and specific difficulties selecting targets amongst competitors. Furthermore, verb retrieval has been shown to be particularly difficult for these people and susceptible to changes in processing load. The current study therefore set out to investigate the effect of complexity of verb forms, as measured by the information-theoretic measure of information load and inflectional entropy in aphasia. It provides us with the unique possibility to make quantitative predictions about the performance in aphasia and relate the findings to those in previous studies. Our research questions are as follows:

(1) What is the effect of *I* of individual lexemes on lexical processing in adults with aphasia?
(2) What is the effect of the inflectional entropy on lexical processing in aphasia?

Although not our primary focus in this study, we have also calculated the more traditional lexical parameters such as frequency and the number of synsets in order to investigate whether the proposed information-theoretic measure is superior in predicting the experimental outcome and whether the proposed conclusions are consistent with those based on these more traditional measures.

Regarding (1), our prediction is that there will be an inhibitory effect for both unimpaired adults and PWA, although the effect could be more drastic for PWA due to their overall decrease in processing capacity. This prediction is based on the fact that the individual *I* is an index of the strength of the memory trace associated with a given lexical item (the higher the *I*, the lower the strength). Thus, the effort necessary to bring the item to the threshold of recognition should be reversely proportional to the individual *I*. Given the general decrease of processing capacity in PWA, the effect should be even more drastic.

Regarding (2), our prediction is that there will be a facilitatory effect for both populations, although the effect can be less pronounced for PWA. This prediction is based on the fact that the inflectional entropy is an index of the homogeneity of the lexical network and, as previous studies demonstrated, activated members of a higher homogeneous network provide stronger support to other members in comprehension experiments. For PWA, however, the effect can be decreased due to the overall decrease of the activation of the network, hence weaker support.

Materials and method

Participants

Two groups of adults participated in this experiment. Twenty aphasic participants were recruited via local rehabilitation—and aphasia centres. All participants were monolingual, had Dutch as their native language and had no prior history of dementia or other memory deficits. None had a significant history of other neurological or psychiatric illness or drug/alcohol abuse. All participants had normal or corrected to normal hearing and most suffered a unilateral lesion resulting from a cerebrovascular accident. One patient had suffered multiple infarcts and one patient suffered from meningitis. As this study did not set out to find neural correlates for behavioural data, it was decided to include these subjects. Onset of aphasia was at least 6 months prior to testing for all participants. All participants had normal or corrected to normal vision and no known oculomotor deficits. One participant was excluded from the analysis as she had pre-morbid (developmental) dyslexia. Two participants were excluded because they were unable to perform the auditory lexical decision task. The remaining 17 participants were able to understand the experimental task and performed well above change on the six practice trials. The token test (part of the Dutch AAT (Graetz, De Bleser, & Willmes, 1992)) was administered to determine the presence of aphasia. As suggested by Heesbeen (2001) a cut-off score of 7 errors was used for the diagnosis of aphasia. Fewer than 7 errors indicate no or residual aphasia. With scores of 13 errors or more the token test is 100% sensitive at identifying aphasia. We chose not to use the diagnostic tool AAT as strong evidence has been published suggesting this tool is unreliable in classifying aphasia (Günter, Hofman, & Promes, 2009). Instead, the diagnosis of non-fluent aphasia was provided by the local speech and language therapist and confirmed by the first author and an independent aphasia therapist by analysis of short narrative samples. The participants were asked to place five pictures in the correct order and to provide a short narrative. Non-fluency was defined as: presence of word finding difficulties AND difficulties producing verbs and/or inflecting verbs AND slow and effortful speech. Auditory comprehension was not formally assessed; ability to participate in the series of experiments (and perform above change) was taken as an indication that auditory comprehension was not severely disrupted. The Ruff Figural Fluency task (Ruff, Light, & Evans, 1987) was administered to control for non-verbal initiation, planning, and divergent reasoning. All participants performed within normal limits on this task. Further information about these participants can be found in Table 3.

Ten healthy elderly participants were recruited via local choirs. All participants had normal levels of hearing, were right-handed and monolingual native speakers of Dutch. Each participant received 5 euros for their participation. Participants were matched to the aphasic participants on age and years of education. Mean age for the elderly groups was 62 years (*SD* = 9.1 years), and mean age for the group of aphasic participants was 58 years (*SD* = 10.7 years). *t*-Test revealed no significant difference between the two groups.

Table 3. Information on aphasic participants.

	Gender	Age	Onset	Aetiology	Profession/level of education	Ruff FF (%)	Token (50–0)
AD	Female	61	1998	iCVA-left	Secretary	54	28
BL	Male	64	2009	iCVA-left	Representative	22	13
HA	Male	33	2008	Meningitis	Civil engineer	50	37
TV	Male	77	1996	iCVA-left	Technical director	24	33
JJ	Female	63	2004	iCVA-left	Taxi driver	84	24
JH	Female	36	2003	Multi-infarct	Social worker	5	9
JL	Male	60	1999	iCVA-left	HBS	40	29
LV	Female	58	2006	iCVA-left	Administration	30	7
LiV	Female	55	2008	iCVA-left	Salesperson	46	17
MN	Male	48	2009	iCVA-left	Accountant	35	48
SB	Male	61	1995/2004	Bleed left	Minister	24	33
SS	Male	57	2002	iCVA-left	Skipper	58	10
SK	Female	65	2005	Aneurism left	Translator	34	8
SV	Male	42	2005	iCVA-left	Civil engineer	38	8
DO	Male	64	2006	iCVA-left	Administration	46	41
MK	Female	42	2009	iCVA-left	BA	61	36
PG	Female	46	2008	iCVA-left	Unknown	54	27

Stimulus materials

Two hundred and eighty-six simple verbs were used; 143 regular and 143 irregular verbs. Lemma frequencies were matched for regular and irregular verbs. The list consisted of past tense forms only. Two hundred and eighty-six phonotactically legal pseudoverbs were pair wise matched to the real verbs. The pseudoverbs had the same distribution of first phoneme, started with CV, and had the same number of syllables as the verb form they were matched to. The list was then read out by a female native speaker of standard Dutch with a clear speaking style and recorded on digital audiotape with a Sennheiser microphone. The samples were fed as digital input into the computer, and down-sampled to 32 kHz. Each word was cut and stored as a separate sound file using PRAAT (Boersma & Weenink, 2001). In addition to the test items, 6 practice items (3 verbs that were not part of the list and 3 pseudoverbs) were recorded to familiarise the participants with the speaker's voice and with the task of lexical decision.

Procedure

The software package FEP (http://www.hum.uu.nl/uilots/lab/resources.php) was used to create an experimental script to control stimulus presentation and data acquisition. This experimental script automatically randomised the order of presentation of the verbs and pseudoverbs. Participants were seated at a table, wearing closed earphones through which the auditory stimuli were presented. They were asked to indicate whether a presented word was a real word or a non-word by pressing one of two buttons labelled YES and NO on a button box with their hand of preference. The auditory stimuli were presented at a comfortable loudness level. Each stimulus was preceded by a beep and 150 ms silence. After each stimulus the participant had 3000 ms to respond; 500 ms after the response the next stimulus was presented. If the participant failed to respond within 3000 ms the next stimulus was presented. RTs were measured from target offset until the button press. Accuracy was automatically recorded. During the practice session, meant to familiarise participants with the task, each participant's performance was monitored. After the practice items participants were given the opportunity to ask questions. Participants were told that they could not correct their response once given. The experiment was split up into two sessions, each lasted about 20 minutes. Participants were given a short break halfway through in both sessions. There was not more than 1 week in between Session 1 and Session 2. If participants preferred to participate in both sessions on the same day, they were given at least an hour's break in between sessions.

Calculation of statistical measures

As described in the Introduction, two measures from information theory were used, namely *I* and inflectional entropy. In addition, several other factors were taken into consideration in the analyses. Frequency counts were entered into the analyses (both lemma and form frequency) to evaluate whether the proposed information-theoretic measures are more advantageous in predicting the RT. To investigate possible effects of semantic neighbourhood we used a number of synsets (Tabak et al., 2010).

Lemma frequency: the summed frequencies of all inflectional variants of each verb were extracted from CELEX (Baayen, Piepenbrock, & Gullikers, 1995).

Form frequency: for each verb form the form frequency was extracted from CELEX.

Synsets: As described by Tabak, Schreuder, and Baayen (2006) the number of synsets, or synonym set, was calculated for each verb, using EuroWordNet (Vossen, Bloksma, & Boersma, 1999). In wordnet a synset represents one underlying lexical concept. A synset can consist of one single word, or multiple (complex) words. One word can occur in several synsets. In other words the number of synsets of one verb comprises the number of different lexical concepts that verb can represent. An example of the synsets of *lopen* (walk) is presented in Table 4.

Information load

I was then calculated with the formula described in Equation (2) in which *I* equals *I* of verb form (*e*), *F* is the frequency of the verb form, and *R* is the number of grammatical functions the verb form can fulfil. Unlike in previous work, *I* was not averaged for a given exponent, but rather *I* of individual verb forms was calculated.

Table 4. The synsets of lopen, "walk", in the Dutch EuroWordNet. Adopted with permission from Tabak et al. (2010).

1	doorgaan (*go on*), aanhouden (*keep on*), continueren (*continue*), doorlopen (*pass through*), lopen (*walk*), voortduren (*continue*)
2	draaien (*turn*), lopen (*walk*)
3	leiden (*lead*), lopen (*walk*), lopend voeren (*lead along*)
4	lopen (*walk*), gaan (*go*), treden (*tread*)
5	verlopen (*elapse*), gaan (*go*), lopen (*walk*), marcheren (*march*)
6	vloeien (*flow*), lopen (*walk*)
7	volgen (*follow*), doorlopen (*keep on walking*), lopen (*walk*)
8	zitten (*sit*), liggen (*lie*), lopen (*walk*), staan (*stand*)

Inflectional family size: entropy (H)

Inflectional entropy as described in Kostić, Marković, and Baucal (2003) was calculated in the following manner: frequency for each verb form in a paradigm was extracted from CELEX. For each verb form, the number of grammatical functions that specific form can fulfil in Dutch was determined. F/R was then calculated for each inflected form of a given verb. This value (rather than probability of occurrence only) was used to calculate the inflectional entropy for each verb, as described in Equation (3) in which p equals Equation (4), in which F_e represents the probability of a verb form within its inflectional paradigm and R is the number of grammatical functions that verb form can fulfil.

Results

RTs and error rates were measured for all participants. For both groups 1.5% of data were missing, no button was pressed within the allotted time. These items were removed. RTs and error rates for both groups are reported in Table 5.

Mann–Whitney tests revealed significant differences between the groups in RT ($p < 0.01$) and number of errors ($p < 0.01$).

The distribution of the latencies was highly skewed. For further analyses we reduced this skewness by means of a logarithmic transformation, which outperformed the inverse transform. Distributions were checked for normality. Only correct answers were used for further analyses. Each list and group was analysed individually to investigate the effect of our information-theoretic measures in RTs. First correlations between RT and individual factors were plotted. We then performed a linear mixed model analysis to the data with participant and verb as crossed random effects. We investigated all main effects and interactions. For reasons of space Tables 5, 6 and 7 and Figures 2a–d only report those predictors and interactions that reached significance.

For the control group significant correlations to response latencies were found for:

Inflectional entropy ($F(1, 2635) = 14.921$, $p < 0.001$), I ($F(1, 2617) = 4.963$ $p < 0.05$) and number of synsets ($F(1, 2644) = 17.166$, $p < 0.001$).

For the aphasic participants significant correlations were found for: lemma frequency ($F(1, 5064) = 4.177$, $p < 0.05$); number of synsets ($F(1, 5064) = 19.412$, $p < 0.001$); inflectional entropy ($F(1, 5046) = 9.392$, $p < 0.01$).

Significant correlations are displayed in graphs 2.0–2.4 (Figure 2).

We then performed a linear mixed model analysis to the data for each group with participant and verb as crossed random effects. We investigated all main effects and interactions. Tables 6 and 7 display the estimated coefficients of the predictors in the multilevel model fit to response latencies of the lexical decision experiment.

Finally, we combined the result of the aphasic and control groups to investigate possible interactions between the group and other factors. A significant interaction was found for

Table 5. Mean reaction time and percentage correct on the auditory lexical decision task for aphasic and control subjects.

	Mean RT (SD)	*Correct% (SD)*
Aphasia	1146 (520)	84% (7.8%)
Control	798 (400)	94.1% (2.3%)

Table 6. Multilevel analyses on the reaction times for the aphasic subjects.

	Estimate	Std error	Df	*t*	Sig.
Intercept	71.358	0.079	49.672	90.061	.000
Regularity	−.1156	.0190	280.445	−6.083	.000
nSynsets	−.0118	.0033	282.164	−3.501	.001
Infl entropy	−0.050	.0248	280.758	−2.033	.043

Table 7. Multilevel analyses on the reaction for the control subjects.

	Estimate	Std error	Df	*t*	Sig.
Intercept	68.607	.0983	28.167	69.726	.000
Regularity	−.1384	.0240	278.846	−5.748	.000
Infl entropy	−.0869	.0042	275.484	−3.443	.001
nSynsets	−.0146	.0312	276.093	−2.784	.006

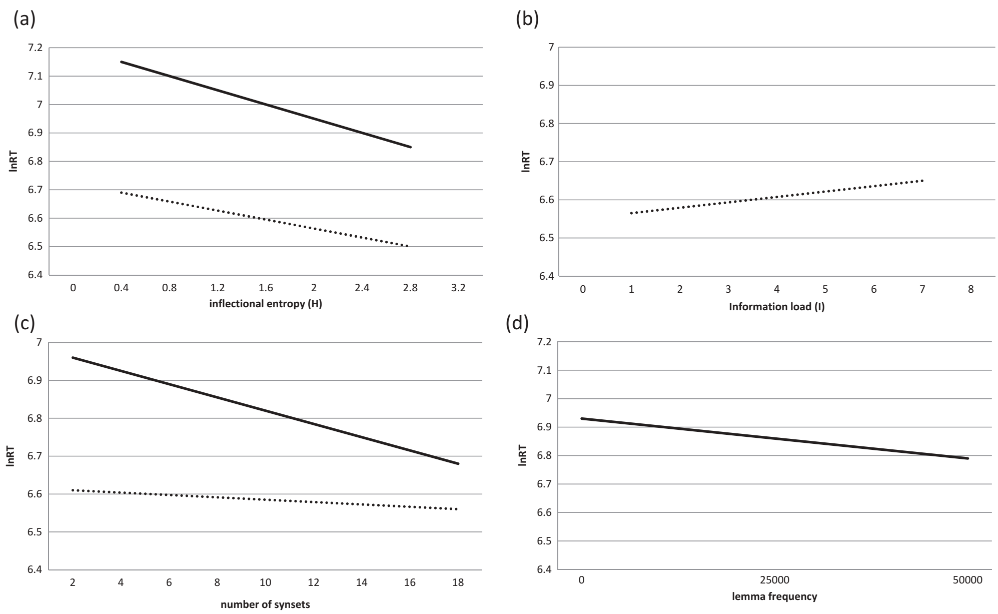

Figure 2. Correlations between lnRT for *I*, number of synsets, inflectional entropy, and lemma frequency. Dotted lines represent control participants, and solid lines the aphasic group. (a) Effect of inflectional entropy (*H*) on lnRT, showing a significant effect for both groups and a significant interaction between groups. (b) Effect of *I* on lnRT, significant only for the control group. (c) Effect of the number of synsets on lnRT, significant for both groups. (d) Effect of lemma frequency on lnRT, significant for the aphasic participants only.

group × inflectional entropy ($F(1, 7545) = 3.648$, $p < 0.05$). The effect of inflectional entropy was stronger for the control group than the group of aphasic participants.

Discussion

The current study investigated lexical access of verbs in aphasia from a reduced processing point of view. Two measures from information theory to calculate the complexity verb forms were used, in addition to more traditional frequency measure. Our prediction is that PWA have less benefit of the support provided by a strong inflectional family and more difficulty with verb with a higher individual complexity load. We will now first discuss the results of the auditory lexical decision experiment after which we will turn to the implications for theories of lexical access difficulties in aphasia.

Lemma frequency was a significant predictor for response latencies for the PWA, but not for the control group. It is somewhat surprising that lemma frequency did not show a significant effect for the control group. One explanation could be that the PWA treat the inflected verbs as decomposed whole words, whilst the control participants do not. This finding would be in line with research that suggests that PWA have weakened morphological decomposition (cf. Tsapkini, Peristeri, Tsimpli, & Jarema, 2014). However, no differences were found between regular and irregular verbs for either groups, which makes this interpretation less plausible. Furthermore, if the PWA treated the inflected verbs as decomposed whole words, form frequency should influence RT even more than lemma frequency. Form frequency did not significantly correlate to latencies for either group. Importantly, the frequency effects were outperformed by the information-theoretic measure of inflectional entropy in the multilevel analyses, indicating that the information-theoretic measure is a stronger predictor of processing time.

Since language processing is sensitive to interference effects, that is, effects arising from neighbourhood elements, it is not surprising that inflectional entropy significantly influenced latencies in both PWA and the control group. This provides evidence that memory traces are present for all inflected verb forms and that there are tight connections between members of inflectional paradigms. In aphasia these connections are still present, but processing of information (expressed in bits) is less efficient, as indicated by the interaction between group and inflectional entropy present in the multilevel analyses. In this lexical access experiment, it has a facilitatory effect. In other words, verbs with an inflectional entropy that have an even distribution of probabilities of the individual inflected forms are accessed faster than those that have an uneven distribution with the paradigm. This finding is in line with earlier studies on perception (for English: Baayen et al., 2006; Baayen & Moscoso Del Prado Martín, 2005; Milin, Kuperman, Kostiç, & Baayen, 2009, for SerBoCroation: Kostić & Havelka, 2002; for Dutch: Tabak et al., 2010). During comprehension inflectional entropy measure can be seen as an index of the amount of "support" a verb form receives from its neighbours. Increased inflectional entropy actually facilitates lexical access, though it will hamper retrieval for production.

In our (reception) study, the PWA showed less benefit of the support of the inflectional paradigm than the control group. This was expected since, as we hypothesised, the reduced activation in the lexical network of PWA should result in a less pronounced effect of changes in the inflectional entropy. Informally, making an already difficult task somewhat more difficult (e.g., decreasing H for PWA) has less effect than making a relatively easy task more difficult (e.g., decreasing H for healthy adults). Strong (facilitatory) effects in healthy processing therefore flatten in processing in aphasia.

I is a measure of individual complexity. It is based on frequency of the verb form and the number of grammatical functions that form can fulfil. It can be viewed as an index of the strength of a memory trace. Research in healthy young and elderly participants has shown that words with high *I* are processed slower than those with low *I* (Kostiç & Katz, 1987). Our results for the healthy controls support this: verb forms with high *I* have longer RTs. Complexity as measured by our *I* measure reflects the process of bringing the target to the threshold of activation. We therefore predicted that due to reduced processing capabilities and difficulties in selectivity in aphasia, our aphasic participants would show a strong effect of *I*. However, our results show that information load is not a predicting factor in the RT data of our aphasic participants.

Although we cannot confirm or reject our hypothesis, the finding that there is no correlation between RT and *I* for our patients is interesting as this correlation was found for the healthy controls. Combined with the finding that inflectional entropy did affect RTs, but to a lesser degree than in the healthy subjects, we suspect that the lack of an effect of *I* is due to a floor effect. This can be explained by looking at the possible shape of the curve of the effect of *I* on RT. *I* is unlikely to have a completely linear effect on RT. Instead, we suggest the curve is logistic. For the healthy individuals, this experiment captures performance at the seemingly linear part of the curve. If we were to compare performance on very low or high *I* items only, we would probably not find any effect as the slope of the curve is near to zero at those points. We pose that, due to reduced lexical activation, processing of information in bits in aphasia is reduced and that performance of the aphasic patients on this experiment is captured by the last part of a logistic curve (a flat line). Processing even the items with relatively low *I* is already difficult for PWA (Figure 3).

Our results cannot provide a definitive answer whether the process of lexical access is disturbed top down (by less processing capacity) or bottom up (by weakened lexical activation or reduced levels of activation), or by a combination of the two. However, support for the first hypothesis comes from the finding that this group of patients showed similar detrimental effects of complexity on RTs on a non-verbal visual search task (van Ewijk, 2013). Even for non-linguistic material, these PWA have difficulties distinguishing a target between its neighbours.

An important facilitatory factor in lexical access for both groups was the number of synsets. This measure is semantic in nature and as described by Tabak et al. (2010) estimates how many distinct meanings one verb has. One synset in WordNet represents one underlying lexical concept and can usually be expressed by multiple verbs. Moreover, one verb may occur in multiple synsets, indicating it has several distinct meanings. Semantic associations have been found to be a predictor in processing for both healthy and aphasic individuals before (cf. Buchanan, Westbury, & Burgess, 2001; Mirman & Magnuson, 2008; Mirman, Yee, Blumstein, & Magnuson, 2011). In line with this

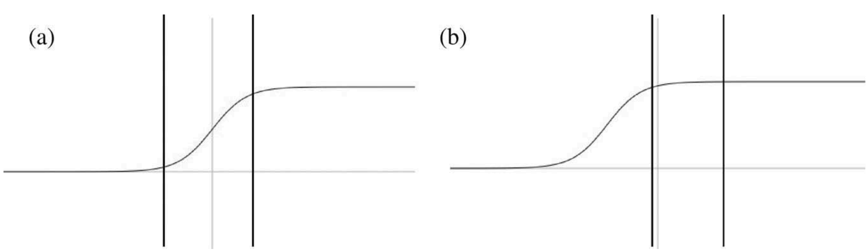

Figure 3. Proposed shape of curve of effect of *I* on reaction time in healthy adults (a) and PWA (b), with RTs in our experiment captured between the two vertical lines.

research, we found that a higher number of synsets has a facilitatory effect on processing; RTs decrease for verbs with high synset scores. This effect is independent of frequency, even though it is the case that verbs with more synsets are often also more frequent.

Following the reasoning of Tabak et al. (2010), we hypothesise that the increase in the number of synsets strengthens the support that members of a semantic network provide to each during activation of one member. In a sense, elements that are involved in a more distributed semantic network are activated (but not necessarily accessed) more often. One can view this as some kind of network training, which eventually allows for a faster activation of an individual member. Given that performance was similar in aphasia and healthy controls. We hypothesise that this indicates that the (semantic) structure of the lexicon does not differ for PWA and healthy controls. This finding is in line with van Egmond et al. (2015) who investigated the organisation of the lexicon in aphasic and healthy adults using Zipf's law (a power law used to describe frequency distributions) and found that aphasic speech conforms to Zipf's law suggesting that the basic organisation of the lexicon is the same for both groups.

In summary, this study set out to investigate lexical access in PWA using quantitative measures from information theory in addition to more traditional frequency measures. Information theory provides tools to quantify distinguishability between distractors and targets in (verb) paradigms. This has been related to processing cost in healthy adults. Reduced processing ability in aphasia has been suggested as a possible factor in difficulties with lexical access. Our results support the view that processing is reduced in aphasia but we take this proposal further: our work demonstrates that it is the capacity to process (lexical) information (as measured by information-theoretical means) that suffers in aphasia. For our aphasic participants, facilitatory effects of inflectional entropy were reduced and *I* did not predict RTs. We therefore pose that the qualitative nature of the underlying lexical network in aphasia remains intact, but the capacity to activate units of this network is decreased, in a quantitative way measurable by information theoretical tools.

Finally, we demonstrate that the analyses of lexical processing based on the information-theoretic measures have better predictive power than those based on frequency only. Of course, frequency *is* a relevant parameter but it is not the only one. Measures that take into account *both* frequency *and* linguistic characteristics (e.g., the number of function and meanings, as originally proposed by Kostić, 1995) appear to be a better predictor for measuring complexity of lexical processing, both for unimpaired subjects and PWA. This so because, as we argue, human processing system is sensitive to *information*, which, in turn, is a function of both frequency and linguistic characteristics.

Acknowledgements

Data on lemma frequency, form frequency, and number of synsets were kindly supplied by Wieke Tabak, MPI Nijmegen, the Netherlands. We would like to thank all the participants and the SLTs that were involved in recruitment, as well as the two anonymous reviewers for their helpful comments and suggestions to improve the paper.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Baayen, R. H., Feldman, L., & Schreuder, R. (2006). Morphological influences on the recognition of monosyllabic monomorphemic words. *Journal of Memory and Language*, *53*, 496–512.

Baayen, R. H., & Moscoso del Prado Martín, F. (2005). Semantic density and past-tense formation in three Germanic languages. *Language*, *81*, 666–698. doi:10.1353/lan.2005.0112

Baayen, R. H., Piepenbrock, R., & Gullikers, L. (1995). *The CELEX lexical database* (CD-ROM). Linguistic Data Consortium. Philadelphia, PA: University of Pennsylvania.

Bastiaanse, R. (2011). The retrieval and inflection of verbs in the spontaneous speech of fluent aphasic speakers. *Journal of Neurolinguistics*, *24*, 163–172. doi:10.1016/j.jneuroling.2010.02.006

Bastiaanse, R., & Bol, G. (2001). Verb inflection and verb diversity in three populations: Agrammatic speakers, normally developing children, and children with specific language impairment (SLI). *Brain and Language*, *64*, 165–181. doi:10.1006/brln.1998.1972

Blevins, J. P. (2003). Stems and paradigms. *Language*, *79*, 737–767. doi:10.1353/lan.2003.0206

Blumstein, S. E., & Milberg, W. P. (2000). Language deficits in Broca's and Wernicke's aphasia: A singular impairment. In Y. Grodzinsky, L. Shapiro, & D. Swinney (Eds.), *Language and the brain: Representation and processing*. New York, NY: Academic Press.

Boersma, P., & Weenink, D. (2001). Praat, a system for doing phonetics by computer. *Glot International*, *5*, 341–345.

Buchanan, L., Westbury, C., & Burgess, C. (2001). Characterizing semantic space: Neighborhood effects in word recognition. *Psychonomic Bulletin & Review*, *8*, 531–544. doi:10.3758/BF03196189

Dell, G. S. (1990). Effects of frequency and vocabulary type on phonological speech errors. *Language and Cognitive Processes*, *5*, 313–349. doi:10.1080/01690969008407066

Faroqi-Shah, Y., & Thompson, C. K. (2004). Semantic, lexical, and phonological influences on the production of verb inflections in agrammatic aphasia. *Brain and Language*, *89*, 484–498. doi:10.1016/j.bandl.2003.12.006

Ferrer-i-Cancho, R. (2006). When language breaks into pieces. A conflict between communication through isolated signals and language. *Biosystems*, *84*, 242–253. doi:10.1016/j.biosystems.2005.12.001

Graetz, P., De Bleser, R., & Willmes, K. (1992). *Akense Afasie Test, Nederlandse versie*. Lisse: Swets & Zeitlinger.

Günter, T., Hofman, M., & Promes, M. (2009). Afasiesyndromen: Twijfels over de klassieke taxonomie [Aphasia syndromes: Questioning the classic taxonomy]. *Logopedie en Foniatrie*, *5*, 148–152.

Heesbeen, I. M. E. (2001). *Diagnostiek en Herstelmeting van Taalproblemen na niet aangeboren hersenletsel* (Ph.D. dissertation). Utrecht: Universiteit van Utrecht.

Howes, D. H., & Solomon, R. L. (1951). Visual duration threshold as a function of word probability. *Journal of Experimental Psychology*, *41*, 401–410. doi:10.1037/h0056020

Janse, E. (2006). Lexical competition effects in aphasia: Deactivation of lexical candidates in spoken word processing. *Brain and Language*, *97*, 1–11. doi:10.1016/j.bandl.2005.06.011

Kok, P., van Doorn, A., & Kolk, H. (2007). Inflection and computational load in agrammatic speech. *Brain and Language*, *102*, 273–283. doi:10.1016/j.bandl.2007.03.001

Kostić, A. (1995). Informational load constraints on processing inflected morphology. In L. B. Feldman (Ed.), *Morphological aspects of language processing*. Hillsdale, NJ: Erlbaum.

Kostić, A., & Havelka, J. (2002). Processing of verb tense. *Psihologija*, *35*, 299–316. doi:10.2298/PSI0203299K

Kostić, A., & Katz, L. (1987). Processing differences between nouns, adjectives and verbs. *Psychological Research*, *49*, 229–236. doi:10.1007/BF00309031

Kostić, A., Marković, T., & Baucal, A. (2003). Inflectional morphology and word meaning: Orthogonal or co-implicative domains? In R. H. Baayen & R. Schreuder (Eds.), *Morphological structure in language processing* (pp. 1–44). Berlin: Mouton de Gruyter.

Manika, S. (2014). *Understanding bit by bit: Information theory and the role of inflections in sentence processing* (LOT Dissertation Series). Utrecht: LOT.

Martin, R. C., Breedin, S. D., & Damian, M. F. (1999). The relation of phoneme discrimination, lexical access, and short-term memory: A case study and interactive activation account. *Brain and Language*, *70*, 437–482. doi:10.1006/brln.1999.2184

McDonald, S. A., & Shillcock, R. C. (2001). Rethinking the word frequency effect: The neglected role of distributional information in lexical processing. *Language & Speech*, *44*, 295–322. doi:10.1177/00238309010440030101

Milin, P., Filipović Đurđević, D., & Moscoso del Prado Martín, F. (2009). The simultaneous effects of inflectional paradigms and classes on lexical recognition: Evidence from Serbian. *Journal of Memory and Language*, *60*, 50–64. doi:10.1016/j.jml.2008.08.007

Milin, P., Kuperman, V., Kostiç, A., and Baayen, R. H. (2009). Paradigms bit by bit: an information theoretic approach to the processing of paradigmatic structure in inflection and derivation. In J. P. Blevins & J. Blevins (Eds.), *Analogy in grammar: Form and acquisition* (pp. 214–252). Oxford: Oxford University Press.

Mirman, D., & Magnuson, J. S. (2008). Attractor dynamics and semantic neighborhood density: Processing is slowed by near neighbors and speeded by distant neighbors. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *34*, 65–79.

Mirman, D., Yee, E., Blumstein, S. E., & Magnuson, J. S. (2011). Theories of spoken word recognition deficits in aphasia: Evidence from eye-tracking and computational modeling. *Brain and Language*, *117*, 53–68. doi:10.1016/j.bandl.2011.01.004

Moscoso del Prado Martín, F., Kostić, A., & Baayen, R. H. (2004). Putting the bits together: An information theoretical perspective on morphological processing. *Cognition*, *94*, 1–18. doi:10.1016/j.cognition.2003.10.015

Novick, J. M., Trueswell, J. C., & Thompson-Schill, S. L. (2005). Cognitive control and parsing: Reexamining the role of Broca's area in sentence comprehension. *Cognitive, Affective, & Behavioral Neuroscience*, *5*, 263–281. doi:10.3758/CABN.5.3.263

Piotrowski, R. G., Pashkovskii, V. E., & Piotrowski, V. R. (1995). Psychiatric linguistics and automatic text processing. *Automatic Document Mathematical Linguistics*, *28*, 28–35. First published in Naucno-Techniceskaja Informatisija, Serija 2, 28, 21–25, 1994.

Piotrowski, R. G., & Spivak, D. L. (2007). Linguistic disorders and pathologies: Synergetic aspects. In P. Grzybek & R. Köhler (Eds.), *Exact methods in the study of language and text*. In honour of Gabriel Altmann (pp. 545–554). Berlin: Walter de Gruyter.

Prather, P., Zurif, E. B., Stern, C., & Rosen, J. T. (1992). Slowed lexical access in non-fluent aphasia: A case study. *Brain and Language*, *43*, 336–348. doi:10.1016/0093-934X(92)90134-Z

Ruff, R. M., Light, R., & Evans, R. (1987). The Ruff Figural Fluency Test: A normative study with adults. *Developmental Neuropsychology*, *3*, 37–51. doi:10.1080/87565648709540362

Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal*, *27*, 379–423. doi:10.1002/bltj.1948.27.issue-3

Stemberger, J. P. (1984). Structural errors in normal and agrammatic speech. *Cognitive Neuropsychology*, *1*, 281–313. doi:10.1080/02643298408252855

Stemberger, J. P. (1985). Bound morpheme loss errors in normal and agrammatic speech: One mechanism or two? *Brain and Language*, *50*, 225–239.

Swinney, D., Prather, P., & Love, T. (2000). The time-course of lexical access and the role of context: Converging evidence from normal and aphasic processing. In Y. Grodzinsky, L. P. Shapiro, & D. Swinney (Eds.), *Language and the brain: Representation and processing* (pp. 273–292). New York, NY: Academic Press.

Tabak, W., Schreuder, R., & Baayen, R. H. (2006). Nonderivational inflection. Manuscript, Max Planck Institute for Psycholinguistics.

Tabak, W., Schreuder, R., & Baayen, R. H. (2010). Producing inflected verbs: A picture naming study. *The Mental Lexicon*, *5*, 22–46. doi:10.1075/ml.5.1

Tsapkini, K., Peristeri, E., Tsimpli, I. M., & Jarema, G. (2014). Morphological decomposition in Broca's aphasia. *Aphasiology*, *28*, 296–319. doi:10.1080/02687038.2013.853022

Utman, J. A., Blumstein, S. E., & Sullivan, K. (2001). Mapping from sound to meaning: Reduced lexical activation in Broca's aphasics. *Brain and Language*, *79*, 444–472. doi:10.1006/brln.2001.2500

van Egmond, M., van Ewijk, L., & Avrutin, S. (2015). Zipf's law in non-fluent Aphasia. *Journal of Quantitative Linguistics*, *22*, 233–249. doi:10.1080/09296174.2015.1037158

van Ewijk, L. (2013). *Word retrieval in acquired and developmental language disorders: A bit more on processing* (LOT Dissertation Series). Utrecht: LOT.

van Ewijk, L., & Avrutin, S. (2010). Article omission in Dutch children with SLI: A processing approach. *Entropy*, *12*, 798–817. doi:10.3390/e12040798

Vossen, P., Bloksma, L., & Boersma, P. (1999). *The Dutch Wordnet*. Amsterdam: University of Amsterdam.

Yee, E., Blumstein, S., & Sedivy, J. C. (2008). Lexical–semantic activation in Broca's and Wernicke's aphasia: Evidence from eye movements. *Journal of Cognitive Neuroscience*, *20*, 592–612. doi:10.1162/jocn.2008.20056