Verb retrieval in non-fluent aphasia: an information-theoretic approach

Lizet van Ewijk and Sergey Avrutin

UiL-OTS, Universiteit Utrecht, The Netherlands

1. Introduction

Non-fluent aphasia in a nutshell:

- Acquired language disorder
- Difficulties with closed class words
- Difficulties with **verbs**

Traditionally these difficulties were explained using linguistic theory. However, theories of competence struggle to explain:

- variation between patients
- variation within patients

Kolk: "inconsistency is the hallmark of aphasic behavior"

Therefore aphasia might be (partly) due to **reduced processing capacity** and therefore a difficulty of these patients to process complex materials.

Problem: how do we measure complexity or processing capacity?

2. Information Theory

First used in communication by Claude Shannon (1948).
His research focused on sending signals over technical channels.

"The fundamental problem of communication, is that of reproducing at one point a message selected at another point"

Shannon discovered that it is not the speed but the complexity of the message that determines errors.
Each message has a certain **entropy**: a complexity measure based on a statistical measure of probability, so that each message has a stated probability of occurrence, or entropy, expressed in bits.

$$H(X) = -\sum p(x) \log p(x)$$

H(X) thus consists of the sum of the informative values of the single elements of the message, in which each of these values is weighed for its share in the total frequency.

Resolving uncertainty / entropy requires energy.

There is a link between the availability of processing resources and the capacity to process information expressed in bits.

3. Methods

Auditory lexical decision

16 people with non-fluent aphasia: (average age 58 (11); token test >13 errors; Figural Fluency within normal limits; single LH stroke, >6m post-stroke)

10 healthy adults (matched on age & level of education)

Verbs (PT): 143 regular, 143 irregular + 286 pseudowords

4. Proposed measures

Two information theoretic measures

Information load of individual forms

$$I_m = \left[-\log_2 \left(\frac{\frac{F_m}{R_m}}{\sum_{j=1}^{k} \frac{F_{m_j}}{R_{m_j}}} \right) \right]$$

In which I equals information load of verb form (m), F the frequency of the verb form and R the number of grammatical functions the verb form can fulfil.

Verb form	*Form frequency*	*Pr*	*R*	*Pr/R*	*I*
Speel	301	0.019	2 (1st & 2nd pres sg)	0.001	6.66
Speelt	2866	0.182	2 (2nd & 3rd pres sg)	0.091	3.45
Spelen	7028	0.447	4 (1st, 2nd, 3rd pl & infinitive)	0.111	3.15
Speelde	2732	0.174	3 (1st, 2nd, 3rd past sg)	0.058	4.10
Speelden	893	0.056	3 (1st, 2nd, 3rd past pl)	0.019	5.72
Gespeeld	1870	0.119	1 (past participle)	0.119	3.07

Entropy of the inflectional paradigm

$$H = -\sum {F_e}/{R_e} \log_2 {F_e}/{R_e}$$

In which F_e represents the probability of a verb form within its inflectional paradigm and R the number of functions that verb form can fulfil. The inflectional entropy measure provides the amount of information carried by a verb's inflectional paradigm, in bits.
So for the verb spelen (to play) the entropy is 1.447.

5. Results

Linear mixed model analyses (participants & verb) on lnRT and errors

Factors: information load, entropy and others (form freq; lemma freq; nSynsets)

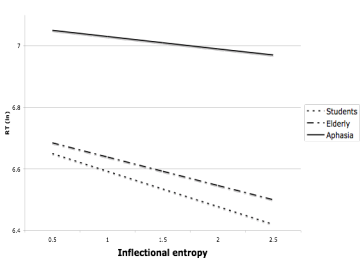
Healthy elderly: 94% correct, 798msec (400)
PWA: 84% correct, 1146msec (520)

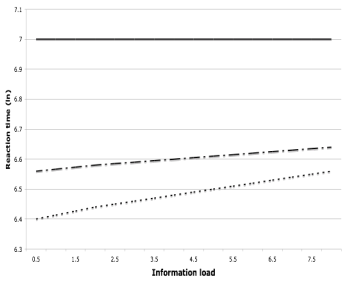
Both groups:
Regulars faster than irregulars
Facilitatory effect of entropy

Interaction:

Group x entropy

Group x information theory





6. Conclusions

- Faster processing times for regulars for both groups
- Information theoretic measures good predictors of RT (outperform simple frequency measures
- Prediction factors same in aphasia and healthy adults

But processing of information different in both groups;
Facilitation effect of entropy in aphasia less pronounced
Floor effect of information load in aphasia

Processing of information expressed in bits thus difficult in aphasia

Information theory provides us with tools to quantify complexity and measure processing deficits.