COGNITIVE SPARE CAPACITY AS A MEASURE OF LISTENING EFFORT

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Abstract

There has been a recent interest in listening effort as a factor to be taken into account in the audiological clinic. However, the term "listening effort" is poorly determined and needs to be defined before it can be used as a clinical or research tool. One way of understanding listening effort is in terms of the cognitive resources expended during listening. Cognitive capacity is finite and thus if cognitive capacity is used up during the act of listening to speech there will be fewer cognitive resources left to process the content of the message conveyed. We have introduced the term Cognitive Spare Capacity (CSC) to refer to residual cognitive capacity once successful listening has taken place. This extended abstract describes the work we have carried out to date on measures of CSC for research and clinical use. In the course of this work we have developed tests to assess the role of memory load, executive function and audiovisual integration in CSC under challenging conditions. When these tests are fully developed, our aim is that they should allow objective individual assessment of listening effort in cognitive terms. Results to date indicate that under challenging conditions, CSC is an arena for executive processing of temporarily stored information; it is related to individual working memory capacity and can be enhanced by hearing aid signal processing.

Key words: hearing impairment • cognition • cognitive spare capacity • memory load • executive function

Background

Persons with hearing impairment often describe listening in noise as effortful and fatiguing (Pichora-Fuller, 2006). Many studies have shown that listening under challenging conditions including hearing impairment and competing background noise is cognitively taxing (Foo et al., 2007; Gatehouse et al., 2003; 2006; Lunner, 2003; Lunner & Sundewall-Thorén, 2007; Rudner et al., 2008; 2009; 2011). However, it has proved elusive to pin down the relationship between subjectively rated effort and cognitive engagement. This might be because the degree of effort experienced while listening under challenging conditions is more closely related to the depletion of cognitive resources that occurs in this situation than to independently measured individual cognitive capacity. We have introduced the term Cognitive spare capacity (CSC) to refer to residual cognitive capacity once successful listening has taken place. In a set of studies we are adopting an approach which involves measuring the quantity and quality of residual cognitive capacity once successful listening has taken place.

This work is inspired by the notion that language understanding proceeds effortlessly and unconsciously under optimal listening conditions, but that when a situation arises in which mismatch occurs between the incoming language signal and representations stored in semantic long-term memory, listening becomes effortful and conscious. This relationship is described by the working memory model of Ease of Language Understanding (ELU; Rönnberg et al., 2008; 2010), which postulates an episodic buffer (Baddeley, 2000) whose function is Rapid Automatic Multimodal Binding of PHOnology. This function earns the buffer the acronym RAMBPHO, see Figure 1. When mismatch occurs as a result of the incoming language signal being degraded or distorted at source, by background noise, by hearing aid signal processing or a damaged cochlea, explicit cognitive processing takes place to resolve the mismatch and generate understanding. We postulate that this explicit cognitive processing takes place in working memory where phonological representations are stored temporarily and processed. Working memory processing may include different varieties of executive processing, such as shifting, updating and inhibition (Miyake et al., 2000). Different executive functions may be more or less salient under different sets of challenging conditions (Rudner et al., 2011).

We are currently developing three different measures of CSC for research and clinical use: (1) a free recall task using audio recordings of the Swedish version of the Hearing In Noise Test sentences (HINT; Hällgren et al., 2006; Nilsson, Soli & Sullivan, 1994), which are everyday Swedish sentences; (2) the Auditory Inference Span Test (AIST) using audio recordings of the Hagerman sentences (Hagerman & Kinnefors, 1995), which are Swedish matrix-type sentences with stereotypical structure; and (3) the Cognitive Spare Capacity Test (CSCT) using audiovisual recordings of two-digit numbers.

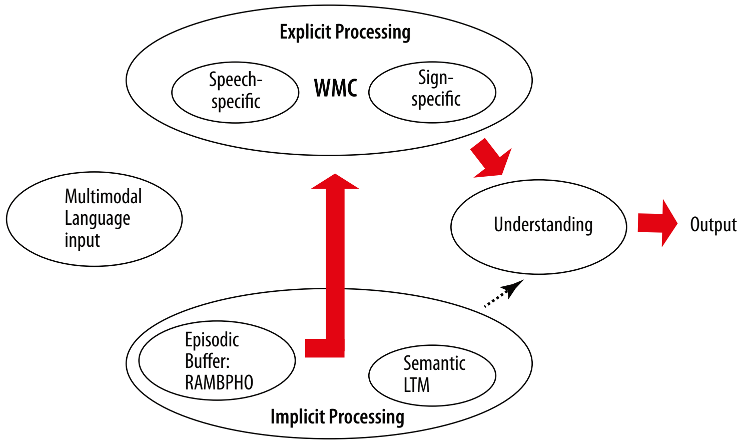

Figure 1. The Working Memory Model for Ease of Language Understanding (ELU) describes the role of explicit processing in language understanding under challenging conditions when the incoming language signal is distorted or degraded at source, due to noise or by a damaged cochlea.

Study 1

Materials and methods

In a study using the free recall task (Ng et al., under review); sets of eight HINT sentences were presented in quiet or in background noise, with and without noise reduction (Wang et al., 2009). Final words were repeated after each sentence and recalled after each set (c.f. Sarampalis et al., 2009).

Results

The performance of listeners with mild-to-moderate hearing impairment showed more successful recall of sentence final words that occurred near either the beginning or the end of each list, than for sentence final words in mid list positions. This phenomenon is known as the serial position curve (SPC) and is a classic effect of list recall (Murdock, 1974). Participants with better cognitive speed were able to correctly recall more words in both noise and silence. Participants with better working memory capacity were able to correctly recall more words in noise and they also benefitted in terms of enhanced recall of words from near the end of lists when hearing aid noise reduction was used.

Study 2

Materials and methods

In a study using a version of the AIST similar to that reported in Rönnberg et al. (2011), Hagerman sentences were presented in sets of three in steady state noise at three different signal-to-noise ratios (SNRs). The ability to recall the content of the sentences was tested at three different levels of cognitive load, represented by three different types of questions about the content of the sentences. At level 1 answering the question involved remembering one item; at level 2, two items and at level 3, remembering and processing several items. In all cases the participants responded by indicating which of three alternatives was correct.

Results

Listeners with normal hearing showed decreasing accuracy with increasing cognitive load and their responses were slower at maximum cognitive load. Interestingly, SNR did not influence speed or accuracy, and thus no relation between SNR and cognitive spare capacity could be established in this study.

Study 3

Materials and methods

In the CSCT (Mishra et al., 2010), Swedish two-digit numbers were presented audiovisually (AV) or as audio only (A) in sets of 13 and recalled in accordance with instructions inducing differential memory and executive load. The experimental design was 2×2×2 with the factors: Memory load (High, Low); Executive function (Updating inhibition); Modality (AV, A). Thus there were eight experimental conditions.

Results

Listeners with normal hearing performed worse on high load than low load conditions, even when adjustment was made for the number of items to be recalled. They performed worse in updating than in inhibition conditions and worse in AV than in A conditions. Although the finding of worse performance in AV than in A was unexpected (e.g. Bernstein & Grant, 2009), recent work has shown that a demanding cognitive task may reverse this effect (Fraser et al., 2010).

Discussion

Together, these findings show that it is possible to measure CSC in persons with and without hearing impairment and that the properties of CSC can be understood in terms of cognitive function. All three tests will be further developed as tools for understanding listening effort as a function of cognitive spare capacity.

Acknowledgements

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