Does research provide evidence for a short-term store for complex sounds (speech), and what does it tell us about its properties?

by Patricia Karsten

Speech comprehension makes heavy use of memory, as words must be recognized and their meaning retrieved. A sequence of words has to be kept in mind until everything belonging to a unit of meaning has been captured and short-term information has been integrated with prior knowledge to achieve comprehension. This corresponds to an understanding of memory separated in short- and long-term memory, where the short-term component is seen as 'working memory', instead of a passive storage unit. Research found evidence for a 'phonological loop' as specialized component of working memory serving to process spoken language. To explain properties and internal structure of the phonological loop, evidence for the two-component model will be presented. It will be shown that the phonological loop plays a vital role in vocabulary acquisition and verbal communication.

In their research on working memory, Baddeley and Hitch (1974; as cited in Hitch, 2005) found that irrelevant short-term memory loads, like repeating random digit sequences, affected cognitive processing, in line with their idea of working memory consisting of a small phonological store and a second component for cognitive control. Dual-task studies indicated that visuo-spatial tasks interfered only mildly with verbal tasks, suggesting separate resource pools. The tripartite model (Baddeley 1983; 1986; as cited in Hitch, 2005) integrated these findings, proposing that working memory in itself is not unitary, but consists of three main components: A central executive responsible for control and coordination, the visuo-spatial scratchpad and a so-called articulatory loop responsible for auditory processing and storage. This auditory component is now referred to as 'phonological loop'. Its existence and structure was inferred from observations of two important effects in the processing of auditory stimuli, the word length effect and the phonemic similarity effect.

The word length effect denotes a quasi-perfect negative correlation between word length and subsequent recall of words. With increasing number of syllables, research participants recalled a continuously decreasing number of words correctly. The number of correctly recalled words was determined by the time it took to speak them out loud, with 2 seconds being the typical time limit for correct recall. Consistently, participants with higher speech rates were able to recall more words correctly (Baddeley et al. 1975; as cited in Hitch, 2005). The word length effect was explained with a 'rehearsal loop', serving to refresh decaying memory traces of auditory stimuli in a limited capacity phonological memory buffer.

The phonemic similarity effect consists in poorer recall for similar sounding items, for example for the words *can, cad, cat, cap, mad*, compared to performance for dissimilar sounding items like *cow, day, bar, few, hot* (Baddeley, Lewis and Vallar 1984). In dual-task studies employing articulatory suppression, for example requiring participants to say the word 'the' repeatedly, the phonemic similarity effect disappeared for visually presented stimuli, but remained for auditory material. Baddeley, Lewis and Vallar (ibid.) interpreted this as evidence for a two-component model of the phonological loop, with a phonological store and an articulatory rehearsal process: Auditory material enters the phonological store directly, whereas visual material has to be recoded through an articulation process. Consequently, suppressing articulation hinders visual material from entering the phonological store, and the phonemic similarity effect disappears.

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Further evidence for a distinction between phonological store and rehearsal process within the phonological loop came from neuropsychological studies. Patient PV suffered severe, but selective short-term memory impairment after a stroke which damaged her left parietal cortex: While she retained fluent speech, her auditory digit span was reduced to only two items. Her memory was poorer for similar sounding words (phonemic similarity effect), but she showed no word length effect, leading to the conclusion that her phonological store must have been damaged, rendering the subvocal rehearsal process ineffective (Baddeley and Vallar 1984; as cited in Hitch 2005). In a later PET study, Paulesu et al. (1993; as cited in Hitch 2005) compared brain activation for different task types (verbal memory and rhyme judgement) selectively involving phonological storage and rehearsal. Using a subtraction logic, they located activation of left supramarginal gyrus related to phonological storage tasks, and activation in Broca's area for rehearsal processes. The phonological storage area they identified corresponded to the area which was damaged in patient PV (Hitch 2005).

To shed more light on the function of the phonological store, Baddeley, Papagno and Vallar (1988) conducted a detailed experimental study which further explored the nature of patient PV's impairments. They found that when compared to controls, PV showed equal performance on learning associations between known words, but completely lacked the ability to learn novel polysyllabic nonwords when they were presented auditorily. At the same time, PV showed no impairment on phonological processing, as she had perfect immediate recall of novel nonwords if they did not exceed her memory span.

Baddeley, Papagno and Vallar (ibid.) point out that both Atkinson and Shiffrin's modal model, and Craik and Lockhart's level's of processing framework are at odds with the pattern of PV's impairments. The modal model proposes short-term memory as entry point to build new long-term memories, so that defects in short-term memory will impair long-term memory (Atkinson and Shiffrin 1968; as cited in Baddeley, Papagno and Vallar, ibid.). This model was able to explain why no new word learning occurred for PV, but it was too simplistic to account for PV's unimpaired association learning. On the other hand, Craik and Lockhart's levels of processing framework (1972; as cited in Baddeley, Papagno and Vallar, ibid.) explained PV's association learning, but her inability to learn new words despite normal phonological processing capacities contradicted it in an important aspect. Her perfect performance in immediate recall task showed she was able to process correctly so the framework would not predict impairments on long-term memory.

But PV's impairments were consistent with the two-component model of the phonological loop. Baddeley, Papagno and Vallar (1988) suggested that association learning between known words depends on semantic, not phonological coding and was therefore unaffected. At the same time, the complete inability to learn novel nonwords when they were presented auditorily while retaining normal immediate phonological processing abilities was in line with the presumed specific damage to a phonological store component of the phonological loop, and they pointed to the specific importance and function of the phonological store component for learning new words.

This conclusion was further supported from studies of individual differences regarding vocabulary acquisition. Developmental evidence from children with normal intelligence but delayed language acquisition, who were different from controls with respect to their ability to repeat spoken nonwords, suggested that damage to the phonological store may have played a role in their impairment (Baddeley and Gathercole 1987; as cited in Baddeley, Papagno and Vallar 1988). The capacity of children's phonological store appeared as good predictor for performance in a vocabulary acquisition task (Gathercole et al 1997; as cited in Hitch 2005). The capacity of the phonological loop also seems to play a role in the acquisition of new vocabulary at adult age, as was shown by Papagno and Vallar (1995). They found superior auditory digit span and nonwords repetition in polyglots with fluency in at least three languages, but otherwise equal performance on tests of general intelligence and learning.

On the other hand, it cannot be said that the phonological loop represents a 'single point of failure' in human language acquisition. This can be concluded from substitution mechanisms appearing when auditory processing is impaired. For example, patient PV was able to learn novel words when they were presented visually, suggesting that a visual component of working memory interacts with the auditory component in language acquisition (Baddeley, Papagno and Vallar 1988). This phenomenon is clearly related to the secondary representation of human language through a system of visual signs, and it also shows that a theoretical separation of language processing subsystems leads to the question how the separately processed information is finally integrated to enable conscious experience of understanding. To accommodate for this binding problem, the original tripartite model of working memory was adapted to include an episodic buffer, able to integrate codes from auditory and visual slave systems to feed into the central executive, from where they are thought to be consciously accessible (Baddeley 2000).

To summarize, the above presented evidence strongly supports the idea of a specific auditory component of working memory, which has a specialized function in language processing and vocabulary acquisition. The two-component model of the phonological loop, which posits a phonological store component whose contents are continuously refreshed by a subvocal rehearsal process is able to explain many observations from experimental, neuropsychological and developmental studies. These research results are very much in line with the idea of an evolutionary advantage stemming from brain structures specialized in processing phonological stimuli, when trying to explain why and how human language may have developed.

References

Baddeley, A.D. (2000) 'The episodic buffer: a new component of working memory?, *Trends in Cognitive Sciences*, vol. 4, pp. 417-23.

Baddeley A.D., Lewis, V. and Vallar, G. (1984) 'Exploring the Articulatory Loop', *The Quarterly Journal of Experimental Psychology*, vol. 36A, pp. 233-252.

Baddeley, A.D. and Gathercole, S. (1987) as cited in Baddeley, Papagno and Vallar (1988).

Baddeley, A.D. and Vallar, G. (1984) as cited in Hitch (2005).

Baddeley, A.D., Papagno, C. and Vallar, G. (1988) 'When long-term learning depends on short-term storage', *Journal of Memory and Language*, vol.27, pp.586–96.

Gathercole, S., Hitch, G.J., Martin, A.J. and Service, E. (1997) as cited in Hitch 2005

Hitch G.J. (2005) 'Working memory', in Braisby, N. and Gellatly, A. (eds.) *Cognitive Psychology*, Milton Keynes, The Open University, pp. 307-341.

Paulesu, E., Frith, C.D. and Frackowiack, R.S.J. (1993) as cited in Hitch (2005).

Papagno, C. and Vallar, G. (1995) 'Short-term memory and vocabulary learning in polyglots', *Quarterly Journal of Experimental Psychology*, vol. 48A, pp.98–107.