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Pankaj Dwivedi
Lecturer cum Junior Research Officer, Central Institute of Indian Languages, Mysore, Karnataka, India

Correspondence
Pankaj Dwivedi
Lecturer cum Junior Research Officer, Central Institute of Indian Languages, Mysore, Karnataka, India

A linguistic review of working memory model

Pankaj Dwivedi

Abstract
There seems to be an obvious relation between working memory and language processing. But how they relate is the question that has intrigued the scholars over the centuries. Psychologists, cognitive scientists, linguists etc. have been coming up with their own models and theories to account for the involved underlying neuro-cognitive processes. In 1974 Alan Baddley and Graham Hitch proposed a multi-component working memory model. His model introduced a component, the phonological loop, to account for the relation between the processing of language and memory.
This paper introduces you to Baddley and Hitch's (1974) multi-component working memory model in its recent form with all four components: central executive (CE); phonological loop (PL); visuospatial sketch pad, and episodic buffer. It critically analyzes the language component, the phonological loop. The paper also evaluates the model's recent claims regarding the relationship between memory and language by presenting counterevidence from studies in the core areas of linguistics such as phonetics, semantics, and syntax.

Keywords: Working memory model, language processing, language and memory

Introduction
Memory involves the manipulation and storage of the information necessary for the higher level of cognitive processes such as language processing and decision making. Memory is mainly of two types: Long-term memory (LTM) and Short-term memory (STM). Long-term memory is the memory which holds the unlimited (as is possible in the case of any healthy individual) amount of the information for a longer period. In contrast, short-term memory, in its active state, holds a small amount of information for a shorter period. Apart from these two types, one more type is considered; Working Memory (WM). Working memory specifically refers to the structures and processes used for the active storage and manipulation of information for a very short period. However, the term 'working memory' has evolved from the concept of short-term memory itself and is often used in place of short-term memory. The term 'working memory' was coined by Miller, Galanter, and Pribram in the 1950s (Miller, Galanter and Pribram, 1960) [7] and further used by Atkinson and Shiffrin (1968) [1] (Atkinson and Shiffrin, 1968) [1].
The language closely relates to memory. In fact, work on finding the exact the relations between language, information, and memory approximately dates back over 100 years back since the time of Hitzig (1839-1907) and Ferrier's (1843-1928) ablation experiments on the frontal and prefrontal lobes (Wozniak and Ferrier, 1876)**.** Of late, of all three types of memories, 'working memory' and its relation to language has been one of the prime areas of research interest among linguists, neuro-psychologists, psychologists, and all those interested in computational modelling of the brain/mind. Across various disciplines, many theories have been proposed to work out the relation. However, none of them seems to completely fill in the explanatory gap.
This paper briefly reviews Baddeley's model of working memory while taking inputs from some other works along similar lines. Since most of the experiments conducted by Baddeley and his associates involved language in one way or the other, so we will review the relevance of the interpretation of their findings mainly from the perspective of the studies done in language processing rather than memory. We will concentrate on some experimental issues such as chunking, type and nature of traces, trace decay, order of recalling, word length effect, and phonological similarity. Thereafter, we will discuss Baddeley's interpretation of the findings from the perspective of the language. Since, in Baddeley's model, the 'phonological loop' is thought to be responsible for the linguistic processing, specifically 'phonological processing of the language', we will review this component in more detail than others and will see how this component fits in with a recently proposed component

'episodic Buffer' and with the overall structure of the model.

Baddeley's model of working memory

Following many ambiguities and unclear explanations of Atkinson & Shiffrin's multi-store memory model (1968), Baddeley and Hitch (1974) [2] proposed their own tripartite model of working memory. They named it a model of 'working memory'. Like other models on memory, this model was also an attempt to throw some light on functions that short-term memory plays in describing the various cognitive tasks such as reading, listening, calculating recognizing, and differentiating. The original model consists of three components:

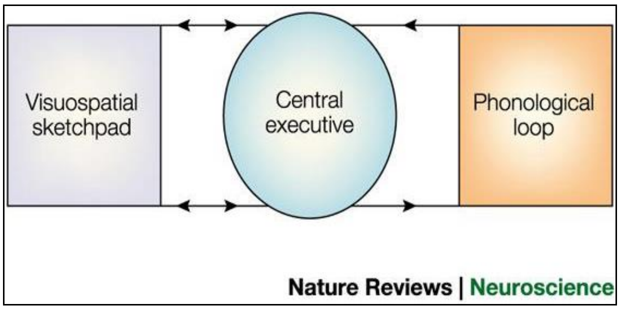


Fig 1: Original model (adopted from Nature Reviews: Neuroscience, 2003)

Central executive (CE)

Central executive is also referred to as master component. Unlike the other theories which mainly focused on the role of attention in perception, the main role of the 'central executive', in Baddeley's model, was the attentional control of the action (Baddeley and Hitch, 1974), i.e., control over the slave components: Phonological Loop (PL) and Visuospatial sketch pad (VSSP). The explanation of the functioning of the 'central executive' was largely influenced by an article published by Norman and Shallice (Baddeley, 2012; Norman and Shallice 1986) [4, 8]. However, how it really functioned, i.e., kept control over the working of slave components, was not very clear. Interestingly, Baddeley himself mentioned that it mainly works for the attentional control of the slave systems; he himself denied that attention plays any major role in the functioning of working memory.

Phonological loop

Phonological loop is a modular component. It includes a brief store together with a means of maintaining information by vocal and sub-vocal rehearsal (Baddeley and Hitch 1974) [2]. In fact, 'phonological loop' was the first system to be investigated given the findings along the lines of previous research on short-term memory. It has been the most investigated component of the model since its introduction in comparison with other components.

Visuospatial sketch pad

This component was assumed to process visuospatial information. However, whether it held visual or spatial or both visual and spatial information was not explained well. The same was admitted by Baddeley in his following studies and in a recently published review paper (Baddeley 2012) [4]. After finding pieces of evidence from other research on STM/WM, it was assumed that the phonological loop not only relates to the visuospatial sketch pad but also plays a significant role in the learning of new phonological structures. Therefore, it is believed that the phonological loop should also be directly interconnected with the long-term memory in some way. The same is believed to be for granted for the visuospatial sketch pad. One more modification that was brought to the model was dividing it into two parts: fluid and crystallized. The temporary storage, e.g., WM, part was referred was the fluid part whereas more permanent storage, e.g., LTM was referred to as the crystallized part. However, this classification did not intend to bring any drastic change or modification from the previous line of thought of the model. Thereafter, following strong pieces of evidence of a correlation between the working memory span and reading comprehension (dual task-based studies), Baddeley added one more component to the model. He named it 'episodic buffer'.

Episodic buffer

He proposed this component in the revised model in the year 2000. This is also a slave component. Like the other component, it is also limited in its storage capacity. The component is assumed to hold the integrated multidimensional episodes/chunks in some kind of multidimensional codes. But how the chunks from different loops get integrated over a very short period of time and then get separated for their respective output requirements is not clear.

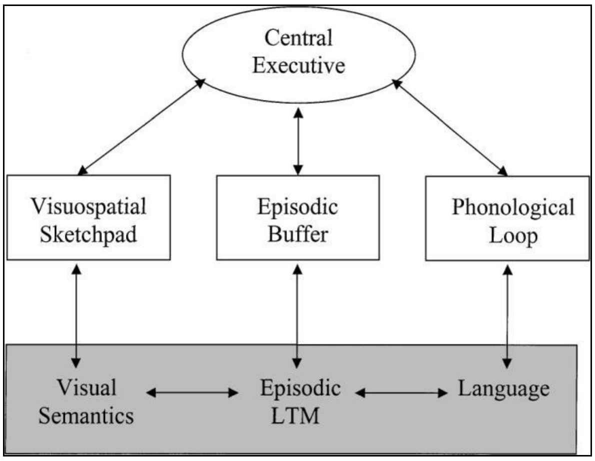


Fig 2: A revised model of working memory (Baddeley 2000)

Phonological loop: An overview

We will now focus on the functional characteristics of the 'phonological loop', the component mainly responsible for linguistic processing, as described by the working memory model. The phonological loop is also referred to as the inner voice. It is concerned with verbal and acoustic information. It is a modular system of limited storage. It is assumed to be made up of two components: phonological store and articulatory rehearsal process system. The main job of the phonological store is to maintain the memory traces for a very short time (about 2 seconds) before they fade, whereas the articulatory rehearsal process system helps with the retrieval of memory traces. The articulatory system maintains the remembrance of the information with the help of vocal and sub-vocal rehearsal. Both these components hold due importance as working memory is believed to have a very limited span.

The main goal of the phonological loop is to facilitate the language acquisition and learning process. It is claimed that the acquisition of the native vocabulary of the children is well predicted by non-word repetition, the capacity to hear and repeat an unfamiliar pseudo-word, which depends on the phonological loop (Norman and Shallice 1986) [8]. So, the phonological loop has evolved to master new words, comprising unfamiliar sequences of phonemes. There is enough evidence for it from the studies of the patients suffering from various speech disorders. Investigation revealed that their speech suffered due to some or other kind of deficit in the phonological loop (Baddeley, 2003) [3]. However, against all these claims, Kuhl, Williams, Lacerda, Stevens, and Lindblom, 1992 [6] in his paper claim that acquisition of language phoneme inventory starts from as early as 2 months and an infant establishes the prototypes for the vowel phoneme by 6 months but starts to lose sensitivity to non-native vowel phonemes after that (Khul, Williams, Lacerda, Stevens, & Lindblom 1992) [6]. Similar claims have also been made by Polka and Werker (Polka and Worker 1994) [9]. Polka and Werker state that by the end of the first year, infants start losing the capacity to discriminate against nonnative consonantal contrasts too (Polka and Worker 1994) [9]. If we consider the above two claims then how much weight we should give to the claims of Baddeley *et al*. regarding the main goal of the phonological loop considering the fact that his most of the experiments involved either adult learners or people suffering some speech disorder. In none of the two cases, we get the true picture of language acquisition.

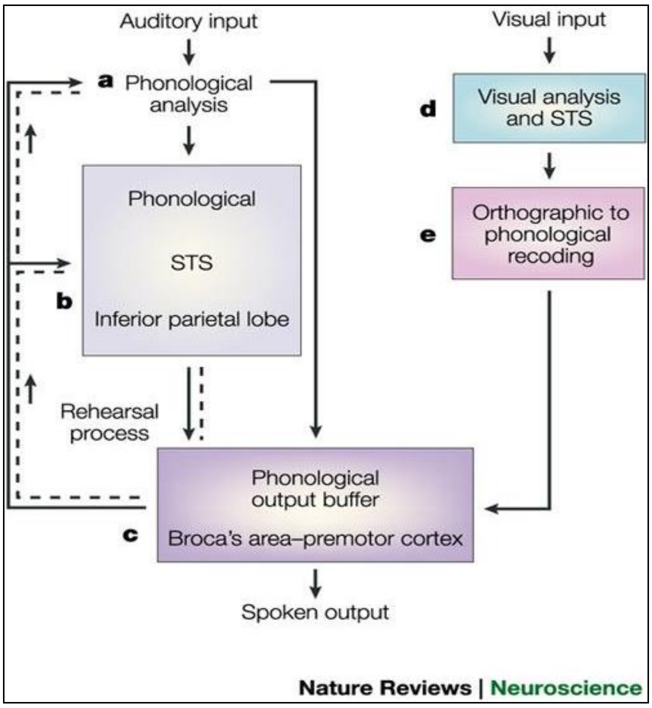


Fig 3: Functional model of the phonological loop (adopted form Nature Reviews: Neuroscience, 2003)

Baddeley's model: Problems and issues

The main loophole of Baddeley's model is that, in most of the experiments, it uses natural language in one way or the other. But neither in the design nor in the interpretation of the results of the experiments do the authors take the linguistic properties such as word order, rate of speech, and phonological properties into account. According to several research studies, language can heavily influence your overall cognitive development, competence, and performance. Apart from intelligence, perception, and attention, memory is also one of those cognitive faculties. It is confirmed by a number of research studies that the development of language, memory, attention, and intelligence are directly connected with one another. However, which of these influences which of them in what way is yet to be clearly ascertained. So, Baddeley's model takes the process of recalling into account without giving due consideration to other factors such as attention, unique linguistic properties of the language being used, or language habits of the subjects.

Chunking

What should be called a chunk? What is the ideal length of a chunk? Do all individuals form chunks of similar length? To provide a common theoretical explanation, there should be some uniform criterion for all. Complexity emerges as natural languages tend to heavily differ in the ways meaning is encoded into words and grammar. On one extreme we have a language like Vietnamese, whose every morpheme independently functions as a lexical word. On the other extreme, we have the aboriginal languages such as that of Eskimos where a word itself is long enough to stand in for a complete sentence.
For example:

Vietnamese (Isolating language)
khi tôi dên nhà ban tôi, chúng tôi bát dâu làm bài.
When I come house friend I Plural I begin do lesson.
When I came to my friend's house, we began to do lessons.

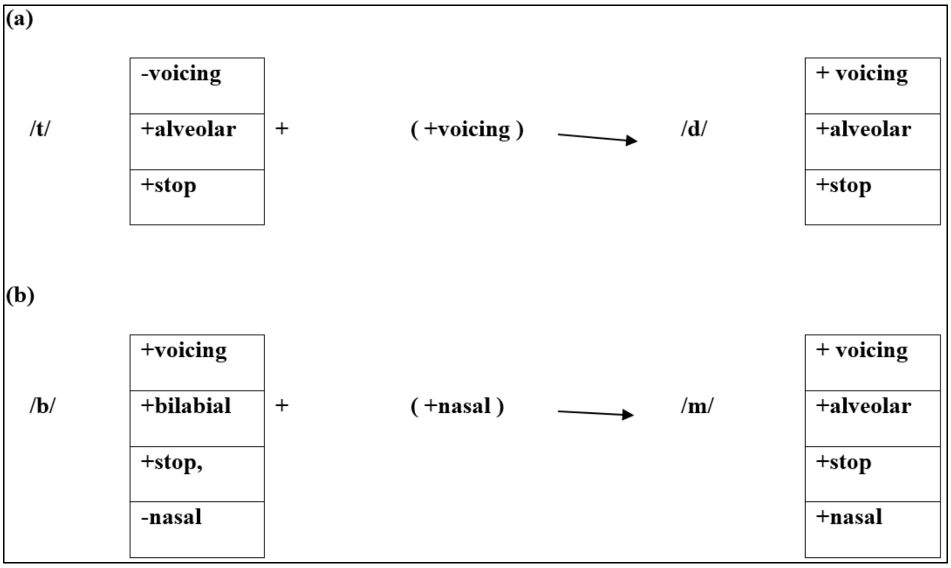
Chukchi (Polysynthetic language)
Təmeyŋəlevtpəɣtərkən.
t-ə-meyŋ-ə-levt-pəɣt-ə-rkən
1. SG.SUBJ-great-head-hurt-PRES.1
'I have a fierce headache. (Skorik 1961: 102)

So, does short-term storage of chunks differ depending on the language being used? If it does not differ, how does it handle so much variation? If WM differs in structures, should results obtained through one or two languages, e.g., English, should be equally applicable to all?

Phonological similarity

Another finding is that items such as letters or words that are similar in sound are harder to remember accurately. That is referred to as the effect of 'phonological similarity'. However, in his own review paper Baddeley (2003) [3] claims that immediate recall of the non-words is better when they are similar in the native language of the person remembering. This indicates that long-term implicit knowledge can be used to aid immediate serial recall (Baddeley 2003) [3]. Chomsky and Halle 1968 [5] proposed that every sound is nothing but a bundle of features (Chomsky and Halle 1968) [5]. These features are mainly of three types: acoustic; articulatory; and auditory. Every phoneme, i.e., the basic unit of sound, is a combinational realization of these features. Therefore, spoken language habits are nothing but native familiarity with these features. Now, if the semantic information is secondary to the phonological one in the process of immediate serial recall, why does the same phonological familiarity disadvantage the meaningful words but not the non-words?

Articulatory suppression
Linguists believe that every sound is composed of three types of features: acoustic; articulatory; and auditory. Quite a few of Baddeley's findings are based on the effect of the articulatory suppression, i.e., some kind of sound sequences are forced over the input or output of chunks in the recalling process. Now, these sound sequences in place of affecting the memory can also affect the quality of the phonological chunks being received or produced. Therefore, there can be a total change in the sounds being perceived and produced without having to do anything with memory. For example:



Primacy: phonological processing vs. semantic processing
Working Memory model has consistently emphasized on the primacy of the phonological information over semantic information in working memory. The model also makes it very clear that the same stands true for all phenomena including language learning/acquisition. However, pictographic languages like classical Chinese and sign language do not always seem to confirm the claim. Classical Chinese does not have any definite phonological or orthographical alphabet for its speaker to master. Speakers have to master each word separately for its meaning as well as pronunciation. Interestingly, native speakers believe that they remember the words more with the help of the meanings than their respective pronunciations. That is to say, the native speakers' claim is just the opposite of what Baddeley's model claims, i.e., grapheme-to-phoneme conversion without any intervention of meaning from long-term memory. How does Baddeley's model accommodate their claims, as language intuitions of the natives hold the maximum importance in any end of the language? Meaning also holds more importance than pronunciation for sign language. In the absence of the phonological loop, will their working memory be also affected? So, how would the WM working of these differently-able people fit in Baddeley's model of working memory?

Type and nature of traces
Baddeley talks about the role of 'traces' in the process of recalling. But he only talks about the 'phonological traces'. Is it possible that we may have some other different types of traces depending on all sensory information available, as phonological traces cannot account for all types of information held by our short-term or long-term memory? In fact, phonological traces don't even seem to do well in explaining the linguistic behaviour of some artificial linguistic solutions like Sign and Braille for deaf and blind people respectively. Is it not possible for sign language users to have developed some sort of 'visual traces' and/or Braille language users to have developed some sort of 'tactile traces' to facilitate the immediate recall phenomenon?

Trace decay
In the serial recall phenomenon, Baddeley claims that subjects tend to forget the words as traces left by the words decay over time. The estimated time for a trace to decay is about 2 seconds. However, the articulatory rehearsal system tries to rehearse /refresh the traces to recall the chunks. The process of refreshing the traces can roughly be equated with the process of sub-vocalization.

As per Baddeley's explanation of forgetfulness/errors i.e., temporal decay of traces of the chunks, the chunks presented in the first few places should be prone to be erred /lost. However, this is almost never the case. The chunks presented in the first places are recalled as well as the ones presented in the last places. In fact, there is hardly any difference between them in terms of the intensity of the remembrance. It shows that there should be something more than temporal decay. Some other experiments on similar lines have confirmed that the so-called trace-decay should not be directly related to increasing time.

I believe that every language has its own different natural rate of speech to understand or speak. Too much deviation from it to any end i.e., too slow or too fast, should cause the so-called 'trace-decay' problem. None of Baddeley's experiments has so far considered this line of thought in the interpretation of the results. Even if, some trace-decay process affects the serial recall order, it must definitely be not directly related just to the passage of time. It might be related to the deviation from the natural rate of speech than other factors.

Serial order recalls
In the multi-component model, serial order recalling is one of the main issues. The order of recalling is dependent on

the relative positions of the chunks. That is to say, an item is accepted to be correctly recalled if its order of occurrence with respect to the preceding and following chunks is correct. Baddeley's many findings are based on this test using natural language chunks. There is one point which can significantly influence the findings but has not been taken into account while interpreting the results, i.e. word order. Language habit significantly influences our thought process at all levels of cognition. Some languages like Hindi, and, Sanskrit are free word-order languages while others like English and, French are restricted word-order languages. A native speaker of the free word-order language will be more automatic in the habit of transposing the chunks, at least when chunks are of some natural language than a native of the restricted word-order language. Therefore, the nature and chances of the serial order errors can be relatively fore-grounded in the word-order habit of the speaker than memory span.

Conclusion

Baddeley's multicomponent model of working memory is considered the most successful model of working memory. It too has invited no less amount of controversy. Almost all studies in the area of brain and language processing agree with the intertwining nature of language with the major cognitive functions of the brain such as attention, perception, and intelligence. A closer look from the perspective of language processing can provide rich insights into the phenomenon of working memory. In fact, it becomes essential when it is difficult to avoid the intervention of the language in the design of the experiments.

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