Memory function and short-term store as a psychological construct—Implications of a working memory framework—

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It is generally believed that memory stores as psychological constructs are distinguishable from other cognitive mechanisms, such as language processing systems. One such memory system might be a short-term store (STS), which is a putative construct assumed to retain small amounts of information for a short period of time. In this article, I discuss two lines of research in relation to this construct. One indicates that some data in the working memory literature can be explained without postulating a STS, suggesting its redundancy in our cognitive system, and the other suggests the importance of STS in explaining observed phenomena. The first line includes studies on working memory span tests and the second includes those on the role of the phonological loop in long-term learning. I distinguish two situations: one in which retention over the short term is required and one in which we must assume the presence of STS, a dedicated system for temporary storage over the short term.

Key words: working memory, short-term memory, short-term store, working memory span test, phonological loop

"Nature has no particular obligation to honor any taxonomy, so we expect to find cases where our distinctions are blurred. The primary value of this taxonomy is as a conceptual framework for formulating hypotheses about where the major determinants of cognitive behavior may lie" (Elman, Bates, Johnson, Harmiloff-Smith, Prisi, & Plunkett, 1996, p. 24).

A long held belief among psychologists is that memory functions are separate from other human cognitive functions, such as language production, perception, visuospatial processing, and thinking. This assumption that memory systems as psychological constructs are distinguishable from other cognitive systems has dominated memory research to date, and has led to the conception of separate systems of cognitive processing. One of the most widely accepted memory systems of this kind is the short-term store (STS), a putative construct assumed to retain small amounts of information for a short period of time.

I examine two schools of thought in relation to this construct. One suggests the redundancy of the concept of a STS in the human cognitive system, indicating that some of data in the literature on working memory could be explained without postulating a STS. The other line of research asserts the importance of the STS in explaining observed phenomena. The former line includes studies on working memory span tests and the latter contains studies on the role of the phonological loop in long-term learning.

Working memory span tests and STS

Working memory is, by definition, assumed to play a crucial role in many kinds of cognitive activity (Baddeley, 1986; Baddeley & Hitch, 1974; Just & Carpenter, 1992). In other words, working memory function is in the service of complex cognition (Miyake & Shah, 1999). This central feature of the working memory concept is reflected in the direction of working memory research, which uses so-called working memory span tests as a research tool. One of the most important characteristics of these tests is that they impose both storage and processing require-

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ments. For example, in the reading span test (Daneman & Carpenter, 1980), participants are required to read a series of sentences aloud or verify the truthfulness of the sentences (the processing requirement) while trying to remember the last word of each sentence or some other target words for later recall (the storage requirement). Ever since Daneman and Carpenter (1980) demonstrated that this task can predict individual differences in reading comprehension ability better than digit or word span tasks (see Daneman & Merikle, 1996, for a meta-analytic review), the reading span test and its variants (i.e., working memory span tests), such as counting span (Case, Kurland, & Goldberg, 1982), operation span (Turner & Engle, 1989), and spatial span (Shah & Miyake, 1996), have been widely used as indices of working memory capacity (Miyake & Shah, 1999).

Until recently, theoretical accounts of working memory span tests have been dominated by the concept of resource sharing. According to this type of hypothesis (e.g., the resource sharing hypothesis proposed by Daneman & Carpenter, 1980), a working memory span test measures the functional capacity of resources that can be flexibly allocated between processing and storage activities. For example, if an individual is skilled at language processing, performing the concurrent processing requirement of the reading span test consumes a small amount of resources, enabling him or her to allocate a large amount of the leftover resources for the maintenance of target words. In contrast, if a person is not skilled at language processing, performing a language processing task consumes a lot of resources and leaves only a small amount available to support the storage of target words. Thus, working memory span performance has been assumed to reflect the amount of resources one has available after all the processing requirements are met.

Several recent theoretical proposals have provided alternative accounts of working memory span performance that do not necessarily invoke the idea of resource sharing (e.g., Engle, Kane, & Tuholski, 1999; MacDonald & Christiansen, 2002; Maehara & Saito, 2006; Saito & Miyake, 2004; Stoltzfus, Hasher, & Zacks, 1996; Towse & Hitch, 1995; Towse, Hitch, & Hutton, 1998, 2000; Waters & Caplan, 1996). Most of them, however, are still based on a core assumption, which is also at the root of the resource sharing hypothesis, that memory items are "actively" maintained during performance on working memory span tests. It has been assumed that in the reading span test, for example, memory items presented earlier in the span list are successfully recalled only when those items are constantly in an active state during reading of the later sentences in the span list (Figure 1); in other words, when those items are in working memory. Thus, the notion of "active" maintenance of memory items is a central tenet in theories of working memory span tests.

A recent study by Cowan et al. (2003), in which a response-time analysis was conducted on working memory span performance in children, has cast doubt on this assumption. They found that recall response times were longer in sentence-based span tests, such as reading and listening span tests, than in other span tests (i.e., counting span and digit span test).

Figure 1. A schematic illustration of an active maintenance view of working memory span performance; an example of 3-sentence condition of the reading span test. According to this view, memory items presented earlier in the span list are successfully recalled only when those items are constantly in an active state during reading of the later sentences in the span list.
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Figure 2. A schematic illustration of a retrieval-based account of working memory span performance; an example of 3-sentence condition of the reading span test. According to this view, participants forget some of target memory items during reading of sentences and then retrieve those items in the recall period, suggesting that they might not continuously maintain all target items in an active state during reading span performance.

tests). This suggests that participants might not continuously maintain all target items in an active state during, for example, reading span performance. Rather, they might "forget" some of the target memory items during reading of the sentences and then "retrieve" those items in the recall period (Figure 2). Cowan et al. (2003) suggested that participants use the sentences presented during the processing phase of the task as retrieval cues to recall the target words. This idea has been supported by other data showing that participants make intrusion errors by recalling nontarget words from processing sentences within a list (e.g., Chiappe, Hasher, & Siegel, 2000; De Beni, Palladino, Pazzaglia, & Cornoldi, 1998; Friedman & Miyake, 2004).

Saito & Ishii (2004) proposed a similar idea; they examined individual differences in performance on cued recall tests and language comprehension. In their study, participants were required to perform a language comprehension test, a reading span test, a word span test, and two types of cued recall test. One type of cued recall test, developed by Haarmann, Davelaar, & Usher (2003), used a semantic category cue. The other type of test was newly developed and used a color cue to recall a list of words. Saito & Ishii (2004) found that the reading span scores were correlated more strongly than the word span scores with the language comprehension scores, replicating findings from previous studies (Daneman & Merikle, 1996, for a review). Furthermore, recall scores on a category-cue test and those on a color-cue test were both significantly correlated with reading span and language comprehension scores. Partial correlation analyses revealed that a lot of variances were shared among reading span scores, the category-cue test scores, and the color-cue test scores and that these variances could predict the language comprehension scores. From these data, they proposed the retrieval-based account of working memory span performance, which assumes that individual differences in working memory span are partly driven by individual differences in efficiency when retrieving memory items from long-term memory. Miyake & Friedman (2004) also emphasized the importance of retrieval abilities in performing working memory span tests.

The retrieval-based account of working memory span is similar to the long-term working memory hypothesis (Ericsson & Kintsch, 1995) in the sense that efficient retrieval of memory items from long-term memory contributes to working memory span performance (see Kintsch, 1998). However, they differ in two ways. First, while the long-term working memory hypothesis assumes domain specificity in the ability of efficient retrieval, the retrieval-based account does not include such an assumption (Miyake & Friedman, 2004, provided evidence for the domain generality of retrieval ability). Second, the long-term working memory framework still holds the concept of a "short-term" working memory, which can retain retrieval cues over the short term, but the retrieval-based account does not need to assume the presence of a short-term retention system.
(i.e., a STS).

Although further empirical evidence is needed for the retrieval-based account on working memory span performance, a possibility exists that it is not necessary to postulate the existence of a STS to explain working memory span performance.

The phonological loop, STS, and long-term learning

It is ironic that advances in working memory research have indicated the redundancy of the STS rather than the importance of its involvement in working memory span tests, in which short-term retention of information is required. An equally paradoxical line of reasoning has been occurring in studies of the phonological loop, a subsystem in a working memory model (Baddeley, 1986; Baddeley & Hitch, 1974), which is assumed to be a short-term retention system for verbal material.

As stated in the introduction, memory researchers have been basing their theories on the separate-system view, which assumes a distinction between memory and language systems. However, some dichotomies based on this view (e.g., the distinction between long-term store and short-term store or more generally between memory and language systems) have been repeatedly criticized (e.g., MacKay, Burke, & Stewart, 1998; Nairne, 2002). For example, MacKay et al. (1998) who examined the language abilities of H.M., an amnesic patient who had been thought to have "pure" memory deficit, emphasized the importance of an integrated-systems approach as opposed to the separate-system view.

However, MacKay et al. (1998) suggested that an exception to their critique was working memory research, especially studies on the phonological loop. In fact, over four decades, evidence has accumulated for a strong link between the immediate serial recall of verbal material, which is believed to reflect phonological loop functioning, and the processes responsible for speech perception and production. Conrad (1964) observed that the intrusion errors in an immediate serial recall task for visually presented consonants were acoustically similar to the items they replaced, resembling the auditory perceptual errors found when consonants were presented in noise, rather than visual errors. Moreover, Ellis (1980), when analyzing intrusion errors, noted a similarity between errors in immediate serial recall & slips of the tongue. More recently, Saito and Baddeley (2004) reported significant correlations between digit span and experimentally induced speech errors.

These and other related data led to an idea that the phonological loop function might be supported by a "pseudo-memory system," which is developed as a "by-product" of the speech processing system. This pseudo-memory view is compatible with the results of a neuroimaging approach to the phonological loop. A PET (positron emission tomography) study (Paulesu, Frith, & Frackowiak, 1993) indicated that the activities of the phonological loop were localized in the left supramarginal gyrus and in Broca's area. The former area seems to be involved in speech perception, whereas the latter is involved in speech production. Furthermore, another PET approach has directly supported the relationship between the phonological loop and language systems; areas that were activated during the phonological loop action were also working during language comprehension and production (Price, Wise, Watson, Petterson, Howard, & Franckowiak, 1994; Smith & Jonides, 1997 [review]; Vallar, 2006, for a recent review of neuroimaging and neuropsychological studies).

These studies indicated that phonological loop functioning might have emerged, at least partly, due to the actions of language processing systems. The activities of the phonological loop may simply reflect the activation of the processes involved in language processing, representing an incidental feature of a general system rather than the principal function of a specifically dedicated STS. This view is consistent with the result from a neuropsychological study by Allport (1984), which reported subtle deficits in speech processing in a patient who had previously been thought to have a pure phonological short-term memory deficit. Allport (1984) interpreted the data in terms of the proposed link between the mechanisms of speech perception and short-term memory. However, other patients with an equally impaired phonological loop do not appear to have speech perception or production deficits (Shallice, 1988; Vallar...
& Baddeley, 1984; Vallar & Shallice, 1990), while patients with substantial speech perception deficits may have relatively well preserved phonological loop functions (Baddeley & Wilson, 1993). Therefore, a simple identification of the phonological loop within speech processes is probably an oversimplification, although it is likely that considerable overlap occurs in the processes involved, with the result that an increase in knowledge of one area (e.g., language processing) is likely to be of considerable relevance to the other (e.g., short-term/working memory).

One example of this relationship is the impact of long-term linguistic knowledge in both children and adults on their short-term memory task performance. For example, adults typically show better immediate serial recall performance for words than nonwords (Hulme, Maughan, & Brown, 1991). This lexicality effect is believed to partly reflect the long-term phonological knowledge of a native language (Gathercole, Frankish, Pickering, & Peaker, 1999; Thorn & Gathercole, 1999). Similar findings have been reported in developmental studies, which showed for example, that children’s repetition performance of nonwords is better for nonwords with a high wordlikeness value than those with a low wordlikeness value (Gathercole, Willis, Emslie, & Baddeley, 1991; Roodenry & Hinton, 2002). The wordlikeness values of nonwords are believed to reflect adults’ sublexical knowledge of the language; thus, for example, nonwords with a high wordlikeness value have phonological structures that are similar to phonotactic patterns of real words in that language. Therefore, it is assumed that the wordlikeness effect (a difference in memory performance between high wordlike and low wordlike nonwords) represents the extent to which children can rely on their phonological knowledge of the language. In fact, the size of the wordlikeness effect increases with age between 4- and 5-years old, suggesting that the effect reflects knowledge acquired throughout development (Gathercole, 1995; see Yuzawa & Saito, 2006 for recent discussions). These and other data suggest that performance on short-term memory tasks is augmented by long-term knowledge of the phonological structure of the language.

It is important to note that the relationship between short-term memory and long-term phonological knowledge is bidirectional; substantial influences of short-term memory capacity occur in language acquisition, while long-term knowledge impacts short-term memory performance. It has already been established that children’s ability to repeat nonwords can predict the speed of vocabulary acquisition, particularly at an earlier stage of development, i.e., around age 4 (e.g., Gathercole & Baddeley, 1990; see also Jarrold, Baddeley, Hewes, Lecke, & Phillips, 2004 for further discussions).

Although a very strong relationship exists between short-term memory and long-term phonological knowledge, it is probably necessary to distinguish between two separate systems that support the short-term and the long-term retention mechanisms, respectively. A critical aspect here is that the acquisition of the long-term knowledge seems to require a separate short-term retention system (i.e., STS) for two reasons: the first one is theoretical, and the second is based on computational and experimental evidence.

It has been widely accepted that memory consolidation mechanisms might be necessary for long-term learning and that some time is required to stabilize long-term storage. During the consolidation period, some retention mechanisms, which must be separated from the long-term storage mechanisms, have to work at temporarily maintaining the information to be consolidated (see Crowder, 1993). This retention can be for the short term (i.e., it is not necessary to retain the information for the long term), and must be achieved very quickly in order to support consolidation. The rapid encoding of new experiences, which is distinct from long-term memory encoding, is postulated in some models of learning and memory (e.g., Baddeley, Gathercole, & Papagno, 1998; Brown & Hulme, 1996; MacClelland, McNaughton, & O'Reilly, 1995) and this retention mechanism could be regarded as a function of the STS.

Computer simulation studies on language acquisition structures have highlighted the advantages of setting a capacity limitation on holding information during the earlier stages of language development.
Several similar ideas have been presented in addition to Elman's (1993) formulation stating "the importance of starting small." They are based on computer simulations and/or behavioral data: the "less is more" hypothesis (Newport, 1990) and the "capacity-based" hypothesis of language acquisition (e.g., Cochrans, McDonald, & Parault, 1999). All of these models emphasize the advantages in restricting the amount of input information to long-term knowledge structures during language acquisition. Such a system, which acts as a gateway to limit input into the long-term memory system and can retain information over the short-term is, by definition, a STS or working memory (e.g., Kareev, 1995; Kareev, Lieberman, & Lev, 1997). Although limiting input into the long-term memory system may not require a STS, postulating a STS seems to be the simplest way to fulfill the capacity limitation in language acquisition processes.

Summary and conclusions

In the first part of this article, I reviewed recent studies on working memory span tests, emphasizing the role of long-term memory retrieval in working memory span tests and suggesting the obscurity of the distinction between short-term store and long-term store. Studies on working memory span have ironically indicated that the STS as a psychological construct might be redundant in our cognitive systems. However, it has also been argued that the STS remains important for explaining phenomena in two research areas: the phonological loop and language acquisition. Although at first glance, the boundary between a short-term store and languages processing systems in the phonological loop literature would seem unclear, some neuropsychological studies have demonstrated the distinction between phonological loop functioning and language processing. Furthermore, it has been theoretically and empirically confirmed that the STS as a psychological construct plays an important role in language acquisition processes.

Two counterintuitive facts have emerged in this review. First, it is not necessary to postulate a STS in order to explain working memory span performance, which intuitively seems to require STS. Second, it is necessary to postulate a limited capacity STS in explaining the acquisition of the language structures, which is essentially a long-term phenomenon that one would not expect to demand a STS. Therefore, it is important to note that two situations must be distinguished, one in which retention over the short term is required and the other assuming the presence of a STS, dedicated system for short-term retention or for other cognitive functions (see Crowder, 1993).

Although cognitive psychologists have been largely successful in separating the human cognitive system into distinct components to better understand it, one must bear in mind that the psychological reality of a construct can only be confirmed through empirical observations of its explanatory value in a theoretical context.

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