Chapter 3
Working Memory as a Basis of Consciousness

Mariko Osaka

Abstract 'Working memory' refers to the capacity-constrained active memory in which information is temporarily maintained and concurrently processed for the use in an ongoing goal-directed activity. The neural mechanisms responsible for consciousness are located in certain brain regions, such as the DLPFC, PPC TPJ and ACC, and these brain regions are coupled with a network that includes the central executive of working memory. In this chapter, we explore the nature of the neural basis of working memory and try to explain the mechanisms of working memory. In order to understand the neural basis of active consciousness, we also investigate how information is controlled by the neural basis of working memory. We use reading span test (RST), which measures the working memory capacity to memorize the target words of sentences during reading, to measure individual differences in working memory capacity.

Keywords Working memory • Consciousness • Capacity • Awareness • Dual process • Central executive system • Phonological loop • Visuospatial sketchpad • Episodic buffer • Reading span test (RST) • Language comprehension • Inhibitory control • Focusing attention • DLPFC • ACC • Individual differences • Superior parietal lobule • Posterior parietal cortex (PPC) • Recursive-consciousness

3.1 Neural Basis of Consciousness and Working Memory

Consciousness plays an essential role in human cognitive functions, such as language comprehension, self- and other-recognition, complex reasoning, and problem solving. Neuroimaging techniques like functional magnetic resonance imaging (fMRI) are recently coupled with psychological methods for studying consciousness and its neural basis. Neuroimaging study has promoted the understanding of consciousness by gradually revealing the complex neural networks that dynamically connect the areas of the brain that are involved in high-level cognition.

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Current evidence from cognitive neuroscience and computational neurobiology indicates that the neural mechanisms responsible for consciousness are located in different regions, including the dorsolateral and ventrolateral prefrontal cortex (DLPFC and VLPFC), the posterior parietal cortex (PPC), the medial PFC coupled with the superior temporal sulcus (STS) and temporo-parieal junction area (TPJ), the anterior cingulate cortex (ACC), and the orbitofrontal cortex. Consciousness has two aspects by its nature: one is the passive aspect which perceives the surrounding world and the other is the active aspect which plans to act to adjust to the surrounding current world.

Recently, it has been shown that working memory is essential for understanding consciousness (Osaka 1997, 1998). 'Working memory' refers to the capacity-constrained active memory in which information is temporarily maintained and concurrently processed for the use in an ongoing goal-directed activity. The active aspect of working memory involves conscious tasks, such as rehearsal, inner speech, visual imagery, and verbal report. These tasks are similar to the tasks performed by active consciousness, which people use in order to adjust themselves to the current world.

The executive function of working memory is regarded to be essential for the relationship between consciousness and working memory. It depends on the central system of working memory and a flexible attention control system for performing cognitive tasks. Awareness arises when the resources of working memory are divided to perform dual tasks. A possible hypothesis is that active consciousness is a portion of working memory that is activated by the cognitive control of the executive function of working memory. The brain regions mentioned above in which consciousness is located are coupled with a network that includes the central executive of working memory. In the present chapter, we explore the nature of the neural basis of working memory and try to explain the mechanisms of working memory. In order to understand the neural basis of active consciousness, we also investigate how information is controlled by the neural basis of working memory.

3.2 Working Memory

Our daily activities often require the dual process of storing and processing information over a short time. When we are driving to the store, for example, we must observe the traffic signals on the street, while keeping in mind what we have to buy. Working memory serves to store and process information simultaneously (Baddeley 1986). Higher cognitive brain functions require the dual process like this. This means that working memory supports a wide range of functions that are needed for complex cognitive activities, such as reading texts or talking with people.

3.2.1 Baddeley's Model of Working Memory

Traditionally, human memory was regarded to be composed of two main storage components: STM (short term memory) and LTM (long term memory) (Atkinson and Shiffrin 1968). Patient studies later revealed that the two memory types were dissociated; a lesion in the left temporo-parietal lobe was found to impair only STM (Shallice and Warrington 1970), and pure amnesic patients were observed to perform well STM-associated tasks, despite their grossly impaired LTM (Baddeley and Warrington 1970). On the basis of these findings, Baddeley and Hitch (1974) replaced the concept of a single short-term store with that of a three-component system. The three-component system, as they conceptualized it, is comprised of an attentional controller (also known as the central executive system) and two subsidiary systems: the phonological loop and the visuospatial sketchpad. The phonological loop processes and articulates vocal and subvocal information, and the visuospatial sketchpad stores visual and spatial information.

Norman and Shallice (1986) proposed the Supervisory Attentional System (SAS), and Baddeley (1986) adopted it as a model for the central executive component of working memory. Baddeley proposed that the central executive had four roles: to focus attention, to divide attention across different subsystems, to switch attention between tasks, and to use attention to link working memory with LTM (Baddeley 1996).

However, the three-component system fails to explain the crucial phenomenon of chunking in which one's existing knowledge is used to increase the STM span (Miller 1956). Baddeley, then, added a fourth component: the episodic buffer. It was assumed to be a limited capacity attentional storage system based on multidimensional information, and is controlled by the central executive (Baddeley 2000). The episodic buffer binds together different sources of information into chunks, a process that is assumed to be central to conscious awareness in learning and performing complex tasks. A recent model Baddeley offers for the flow of information from perception to working memory is shown in Fig. 3.1 (Baddeley 2012).

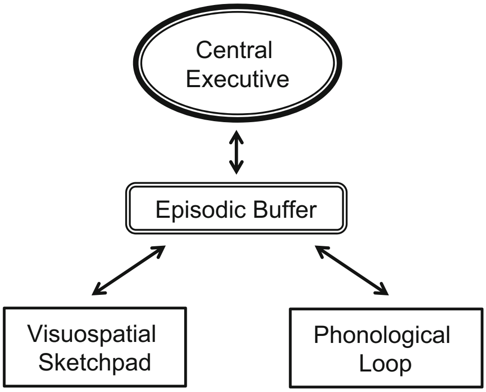

Fig. 3.1 Baddeley's model (Baddeley 2012)

3.3 Individual Differences in Working Memory

Working memory plays an important role in language comprehension, learning, and reasoning (Baddeley 1986; Just and Carpenter 1992). It also plays a particularly critical role in text reading. While reading text, incoming information is decoded perceptually, reorganized, and integrated with a contextual interpretation, and the constituent products of each of these processes are stored for a short period of time (Kintsch and Van Dijk 1978; Daneman and Carpenter 1980). Working memory is important for storing the intermediate and final products of successive data, allowing for integrating text contents and putting words into context.

Because the resources of working memory are limited, an individual must selectively maintain representations that are most needed for current task goals. At the same time, the individual must allocate the resources appropriately to perform current tasks. The central executive serves as an attention controller, and assigns and coordinates the limited resources for storage and processing (Baddeley 1996; Baddeley and Logie 1999; Engle et al. 1999).

The resources available for working memory to maintain and process information are finite. Individuals show differences in working memory, and their differences consist in how they allocate the resources to task goals (Daneman and Carpenter 1980; La Pointe and Engle 1990; Turner and Engle 1989). The differences can account for different performances in cognitive functions, such as language comprehension (Just and Carpenter 1992).

3.3.1 Reading Span Test (RST)

The reading span test (RST) was developed to measure behavioral differences between individuals in verbal working memory capacity during reading sentences (Daneman and Carpenter 1980). In the RST, participants read a few sentences aloud and memorize the last word of each sentence. According to the resource sharing model for working memory proposed by Daneman and Carpenter, mental resources available during reading a sentence and memorizing the target word of each sentence are limited. Thus, participants must allocate portions of working memory resources to different tasks, such as processing information and memorizing information for a short time.

The RST measures the working memory capacity to memorize the target words of sentences during reading, and the contents measured by the RST are similar to the functions of the central executive control processes and not to those of the subsystems, such as the phonological loop (Baddeley 1992; Just and Carpenter 1992). Therefore, resource allocation in the RST must be controlled by the executive control system which serves as an attention controller. It allocates and coordinates attentional resources when one reads and maintains the representations of the target words.

3.3.2 RST and Language Comprehension

By measuring the processing and storage during reading, the RST can account for various aspects of language comprehension (Daneman and Carpenter 1980; Just and Carpenter 1992; Daneman and Merikle 1996). Although the correlation between short term memory and reading comprehension is low, (Perfetti and Goldman 1976), the RST estimates show a higher correlation with reading comprehension (Masson and Miller 1983; Baddeley et al. 1985). In fact, Daneman and Carpenter (1980) have found that participants with high working memory capacity (high-span participants in the RST) are more successful at remembering target words than are participants with low working memory capacity (low-span participants in the RST). Furthermore, high-span participants are more successful at interpreting the meaning of an ambiguous word when it appears separately from the words necessary for clarifying its meaning. Other span tasks, such as the listening span test (LST) and operation span test (OST), also show that there is a high correlation between working memory capacity and language comprehension scores (Turner and Engle 1989). These results indicate that the correlation is independent of the stimulus modality (reading or listening) or the task (reading or arithmetic).

3.3.3 Japanese RST

There are different versions of the RST that correspond to different languages. For example, in the Japanese version of the RST, a target word can be selected from one word in a sentence (Osaka and Osaka 1992, 1994, see Table 3.1), whereas in the English RST, a target word is always the last word of a sentence (Daneman and Carpenter 1980). In Japanese, the last word of a sentence is usually a verb, and it is rarely a noun. In addition, as a feature of Japanese syntactic mechanisms, the last word of a Japanese sentence is rarely a focus word (Kuno 1978), whereas in English it is (Bolinger 1986). The Japanese RST requires the variability of target words; because the target word occupies different positions in different sentences, it needs to be underlined in each sentence (Osaka et al. 2002). Despite the differences between Japanese and English, the scores of the Japanese RST and English RST show a strong correlation (Osaka and Osaka 1992). Just as in the English RST, span scores are strongly correlated with reading comprehension cores in the Japanese RST (Osaka and Osaka 1994).

Table 3.1 Japanese reading span test. Three sentence condition

- 水泳教室に通っているためか、母は最近とても元気である。

(Lately, my mother is well because she goes to swimming school.)

- 熱帯の植物なので、その花は寒さには弱い。

(Tropical plants are vulnerable to cold weather.)

- 雷のため、電車の切符販売機が故障した。

(Thunder caused the ticket machine at the train station to break down.)

3.3.4 What Does RST Measure?

In order to explain what kinds of processes are involved in sentence comprehension, several hypotheses have been proposed. The resource-sharing model provides an interpretation of different performances on the RST in terms of capacity differences. Daneman and Carpenter (1983) suggest that the semantic processing of sentence comprehension is attributable to differences in capacity. High-span participants devote fewer resources to the semantic processing of a sentence, and therefore they retain sufficient resources to remember words. Another suggestion is that high-span participants make greater use of various strategies (Carpenter and Just 1989). Meta-analysis of studies on working memory span tasks show that passive storage measures, such as STM measures, correlate less with reading skills than working memory span measures do (Daneman and Merikle 1996).

The inhibitory control is also important. When one performs poorly on working memory tasks, one often has a deficit in inhibiting irrelevant information and performs poorly on the RST as well. For this reason, it has been proposed that successful performance on the RST requires good inhibitory mechanism (Conway and Engle 1994; Engle et al. 1995; De Beni et al. 1998; May et al. 1999).

Another interpretation of the RST is based on a task switching difference. Towse et al. (1998) report that sentence processing and word storage do not compete for working memory resources during the RST. They conclude that high span participants utilize a task-switching strategy, and they alternate easily reading a sentence and holding the last word of it (Towse et al. 2000).

Osaka (2002) reports that RST participants often use strategies like a rehearsal using the phonological loop. Participants who show good performance employ several strategies. They change strategies during the RST. This suggests that they can tell whether the adopted strategy is effective or not. Self-monitoring influences performance on the RST. Consistent with this observation, an earlier study shows that high-span participants are likely to use more strategies than low-span participants do (Osaka and Nishizaki 2000). Thus, high-span participants can monitor their performance and change strategies more effectively than low span participants.

3.4 Focusing Attention

Focusing attention is important for language comprehension in reading and listening (Carpenter and Just 1977; Blutner and Sommer 1988; Osaka et al. 2002). When one reads a sentence, one initially directs one's attention to the focus word in a sentence (Carpenter and Just 1977). The focus word in a sentence is a critical word for text integration, and it is considered to play an important role in comprehending text reading. It has been reported that focusing on a word enhances memory (Birch and Garnsey 1995). They proposed that the focus word in a sentence facilitates the process of integrating information in sentences, and it is critical for creating a coherent understanding.

Focusing attention is important for attentional control systems in the central executive (Cowan 2001). The central executive is responsible for the control and selection of the currently relevant parts of long term memory representations. The activated parts of long term memory are regarded to work under the surveillance of attention (Cowan 1999, 2001). Cowan (2001) suggests that the focus of attention represents a capacity-limited part of working memory that constitutes approximately four independent units and holds a restricted set of items. As was stated in the last section, low-span-participants have a deficit in inhibiting irrelevant information for the task (Conway and Engle 1994; Engle et al. 1995; May et al. 1999). In addition, it is difficult for low-span participants to inhibit information on which they have previously focused attention (De Beni et al. 1998).

3.4.1 Focused RST vs Non-focused RST

In order to confirm the importance of focusing attention in the span task, Osaka et al. (2002) have developed two versions of the RST: the focused-RST (F-RST) and the non-focused RST (NF-RST). While the NF-RST does not, the F-RST uses the focus word in each sentence as the target word, i.e., the word to be remembered.

The focus word in a sentence is defined as the word most critical for understanding the sentence (Birch and Garnsey 1995). To identify the focus word, a preliminary survey has been conducted among students who do not participate in the experiments. They are asked to identify which word of a sentence is most important and critical for understanding it. When a word is chosen by more than 70 % of the students, it is selected as the focus word in that sentence. (Osaka et al. 2002).

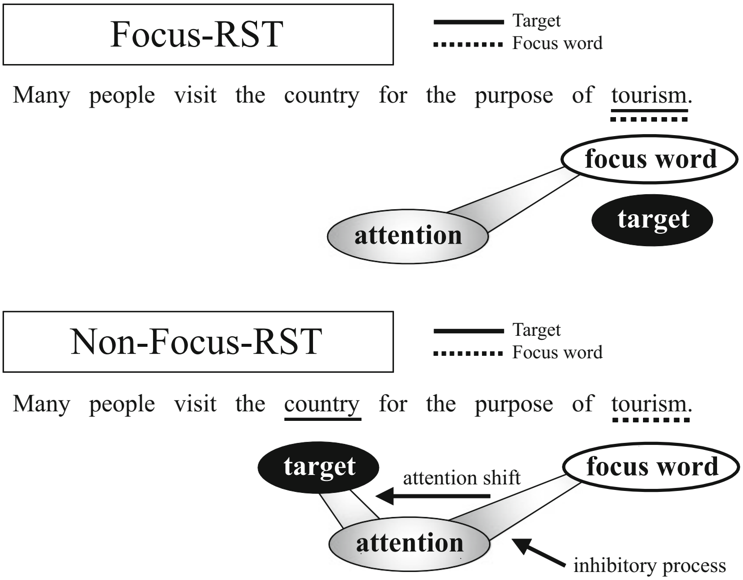

Fig. 3.2 Sample sentences of the F-RST and NF- RST

Figure 3.2 shows sample sentences used in both the F- RST and the NF- RST. In the sentence "Many people visit the country for the purpose of tourism," the word "tourism" was chosen as the focus word by a preliminary estimate. The F-RST then uses "tourism" as the target word, and the NF-RST uses other words like "country."

3.4.2 *Focusing Attention and Inhibitory Processes in the NF-RST*

When the target word coincides with the focus word in a sentence, it should be easier to memorize the target word because attention is easily focused on the target word. When the focus word in a sentence is not the target word, participants have to shift their attention from the focus word to the target word.

In the F-RST, the focus word is the target word, but not in the NF-RST. In the NF-RST, it is required for participants to inhibit attention on the focus word in a sentence, because their task goal is to remember the target word.

Not surprisingly, it has been reported that participant's performance is significantly higher in the F-RST than in the NF-RST (Osaka et al. 2002). In particular, the number of intrusion errors is significantly higher in the NF-RST than in the F-RST. Most intrusion errors in the NF-RST are focus intrusion errors: participants recall the focus word rather than the target word. The prevalence of focus-intrusion errors in the NF-RST suggests that it is difficult for participants to inhibit the word on which they have previously focused their attention.

Moreover, the frequency of intrusion errors, including focus intrusion errors, is higher in low-span participants than in high-span participants in the NF-RST. These findings indicate that low-span participants have deficits in their abilities to shift attention to the target and to inhibit the irrelevant words. They have more difficulty in inhibiting irrelevant information after they pay attention to it.

3.5 Neural Basis of Working Memory

Recent brain-imaging studies have attempted to identify the brain anatomy underlying the working memory systems. On the basis of Baddeley's original model (Baddeley 1986), two types of working memory processes are distinguished: the central executive system and modality-specific buffers, such as the phonological loop and the visuo-spatial sketchpad. The phonological loop is responsible for the retention of verbal information. Verbal information activates the left ventrolateral prefrontal cortex (VLPFC), while visuo-spatial information activates the right homologues (Jonides et al. 1993; Paulesu et al. 1993; Awh et al. 1996; Smith et al. 1996; Courtney et al. 1998; Owen et al. 1998).

Positron emission tomography (PET) has revealed the frontal lobe activities during episodic memory encoding and retrieval. The right PFC during episodic retrieval typically shows that the VLPFC (Broadman Area; BA 45) and the anterior extent of the PFC (BA 10) are involved (the latter is also known as the frontopolar cortex) (Shallice et al. 1994; Tulving et al. 1994). The ACC (BA 24/32) is found to be activated during episodic retrieval tasks (Nyberg 1998).

The central executive system serves as an attention controller, and allocates and coordinates attentional resources in performing cognitive tasks (Baddeley 1996; Baddeley and Logie 1999; Engle et al. 1999). Neuroimaging studies have explored the neural basis of this executive attention control system, and suggested that the system is located in the prefrontal cortex, and mainly in the DLPFC (BA9/46) and ACC (D'Esposito et al. 1995, 1998, 1999; Owen et al. 1996; Cohen et al. 1997; Smith and Jonides 1999; Bunge et al. 2000; Smith et al. 2001; Kane and Engle 2003; Osaka et al. 2003, 2004; Linden 2007).

Brain activities in the DLPFC increase as working memory task demands increase (Braver et al. 1997; Rypma et al. 1999; Bunge et al. 2000). D'Esposito et al. (1995) have found that DLPFC activation increases only during a dual task; it does not increase during a single task, regardless of how difficult it is. Rypma et al. (1999) report on the relationship between activation in the DLPFC and remembering digits. Although the DLPFC is not activated when participants remember one to three digits, activities in the DLPFC increase when participants remember six digits. It is within the capacity limitation to remember three digits, whereas it exceeds the capacity to remember six digits (Cowan 2001). In order to remember six digits, participants need the aid of the executive attention control, which increases activities in the DLPFC.

3.5.1 Attention Control in DLPFC vs ACC

It is important for working memory performance to dissociate the DLPFC and ACC. MacDonald et al. (2000) dissociate them using the Stroop paradigm (Stroop 1935): activation in the DLPFC is observed in congruent color-word trials, and activation in the ACC occurs when participants engage in incongruent color-naming trials (but not in congruent trials). MacDonald et al. conclude that the DLPFC plays a role in providing top-down support for attention maintenance in task-appropriate behaviors. On the other hand, they regard the ACC to be subserved by the attention control system when attention is strongly controlled in incongruent color-naming trials. Smith and Jonides (1999) propose that both the DLPFC and ACC play an executive role in working memory tasks. The ACC mediates the inhibition of a preprogrammed response, such as word reading, and inhibition occurs automatically in incongruent color-naming trials so as to release any conflict.

It has been reported that the ACC has an executive function and the posterior cingulate cortex has an evaluative function (Vogt et al. 1992). More specifically, the dorsal site and ventral side of the ACC are regarded to be involved in cognitive activity and emotional division, respectively (Bush et al. 1998, 2000). An increase in activation of the ACC is reported to occur in error trials or high-conflict trials, such as go/no-go trials, oddball trials, and two-alternative forced-choice selections (Barch et al. 1997; Bush et al. 1998; Carter et al. 1998; Braver et al. 2001).

3.5.2 Neural Correlates of Span Tasks

The functions or processes measured in span tasks are considered similar to those for which the executive control of the working memory system is responsible (Baddeley 1992; Just and Carpenter 1992). Given this, it is plausible that resource allocation is controlled by the executive control system when one takes the RST. fMRI studies give evidence for this claim by showing that increases in activation in the frontal regions are associated with task demands in the RST. For example, Just et al. (1996) have found that activation in the left frontal and temporal language areas increases during the RST, but not during the single reading task. Bunge et al. (2000) have found that activation in the PFC increases during the RST. This suggests that the increase in activation in the frontal region is affected by dual task demands. Activation in the left DLPFC increases during the OST as well (Smith et al. 2001). This increase occurs only in poor performers, and also depends on the level of the task demand.

These studies lead to further questions concerning the neural bases of working memory that explain the differences between high-span and low-span participants in span tasks, and in particular the activation differences in the frontal region, such as the DLPFC.

3.5.3 Neural Basis of Individual Differences

Osaka et al. (2003) investigated the neural substrates to which the differences between high-span and low-span participants are attributable. An fMRI study showed that a significant increase in activation of the left DLPFC and ACC occurred during the LST, but not in single task conditions. While a significant increase in activation of the DLPFC has been found in both high-span and low-span participants, an increase in the ACC is significant only in high-span participants.

Figure 3.3 (left) shows fMRI images of the brain areas in high-span and low-span participants that are activated in the LST condition (Osaka et al. 2003). Figure 3.3 (right) compares activations in the ACC regions between the high and low span participants. In both, the DLPFC shows an increase in activation. An increase in activation of the ACC, however, is confirmed only in the group of high-span participants.

In Fig. 3.4, fMRI shows that there are significant increases in activation mainly in three regions in the RST: the ACC, left PFC, and superior parietal lobule (SPL) (Osaka et al. 2004). A group difference in activation is observed in these three regions: the increases are higher in high-span participants than in low-span participants.

3.5.4 Functional Connectivity Between DLPFC and ACC

The possible functional connectivity between the DLPFC and ACC was compared between high-span and low-span groups by computing the average time courses of the activated voxels of fMRI data (Osaka et al. 2003, 2004). The correlation coefficient (a measure of the similarity in voxel activation between the DLPFC and ACC) is higher in the high-span group for both the LST and RST (Osaka et al. 2003, 2004). Higher correlations between different cortical areas throughout the activation time course are taken to indicate an increase in functional connectivity (Diwadkar et al. 2000).

Structural equation modeling (SEM) has been used to investigate the network connectivity between the DLPFC and ACC in the OST (Kondo et al. 2004a). As with the RST and LST, signal changes in the ACC are greater in the high-span group during the OST. The SEM result indicates that the effective connectivity from the ACC to the left DLPFC is positive and high in the high-span group, and it is negative and low in the low-span group. A significant positive correlation

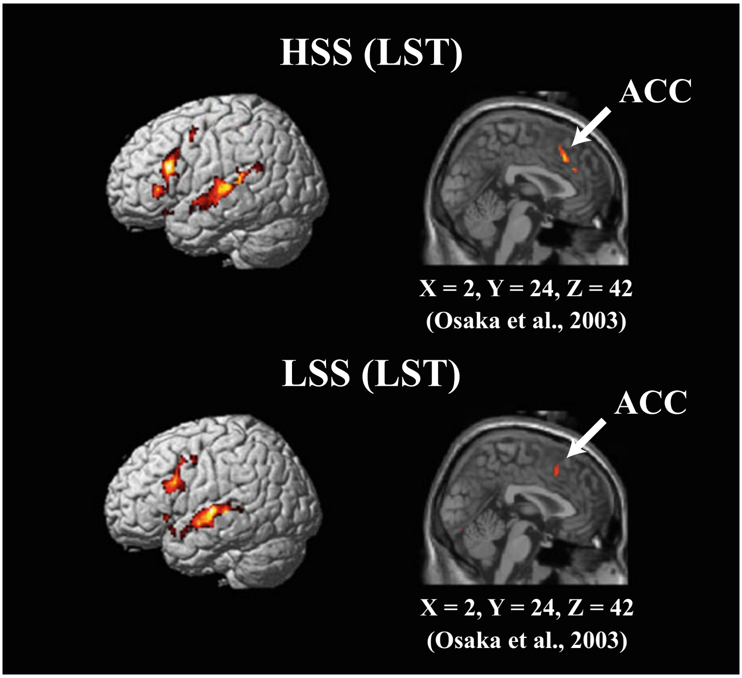

Fig. 3.3 (*Left*) Rendered fMRIimages of activated brain areas of high-span and low-span participants in the LST condition. (*Right*) Activated brain areas in the ACC of high-span and low-span participants in the LST condition. *HSS* high-span participants, *LSS* low-span participants

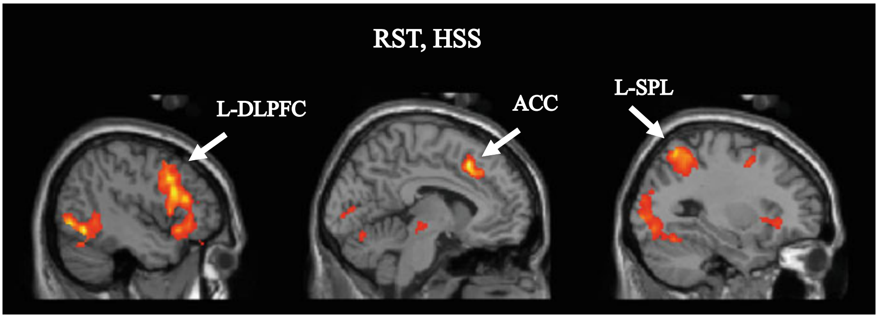

Fig. 3.4 Rendered fMRI images of activated brain areas in the DLPFC, ACC, and SPL of high span participants in the RST condition

between signal changes in the right DLPFC and right ACC is confirmed by using a spatial span task (SST) in which five letters and five arrows were alternately presented and participants verify whether the letters were normal or mirror-imaged while concurrently retaining the orientations of arrows (Kondo et al. 2004b). These results suggest that an effective connection exists between the DLPFC and ACC only in the high-span group.

Osaka et al. (2003, 2004) conclude on the basis of these findings that the ACC subserves the attention control system of working memory; it inhibits irrelevant information and monitors attention control processes in accordance with the DLPFC. Furthermore, Osaka et al. propose that when one performs span tasks, such as the LST and RST, the attention controller of the central executive is regulated by the DLPFC and ACC; the DLPFC maintains attention processes and the ACC inhibits them. As for capacity differences, it has been found that activation differences between low-span and high-span participants can be explained in terms of differences between the DLPFC and ACC. A higher functional connectivity between the DLPFC and ACC is always observed in the high-span group.

3.5.5 Role of the Parietal Cortex

A recent study demonstrates that activity in the inferior parietal lobule (IPL) is associated with the disengagement and reorientation of attention to the relevant target presented outside the current focus of attention (Corbetta et al. 2008). It is consistent with this report that the IPL has a role in the basic attentional process of the central executive. In addition, the SPL involves the lateral intraparietal area and is generally related to attention and saccade-related eye movements (Culham and Kanwisher 2001). RST participants show activation in the left SPL, as well as in the DLPFC and ACC, suggesting that the SPL may contribute to shifting and focusing attention (Osaka et al. 2004). Attention shift may explain the performance difference between high-span and low-span participants. When they perform the F- or NF-RST, activation in the left SPL (BA 7) is found to be enhanced in both groups. However, only the high-span group shows a greater increase in left SPL activation during the NF-RST than during the F-RST (Osaka et al. 2007).

Because low-span participants receive less aid from the SPL in N F-RST, it is difficult for them to shift attention from the focus word to the target word. This difficulty results in strong conflicts and confusions regarding the goals of the task. Thus, the differences between the low-span and high-span groups in their efficiency of shifting and focusing attention may depend on the SPL and the aid from the DLPFC and ACC network.

3.6 Neural Model of Executive Function of Working Memory

It may be supposed on the basis of the span task results that conflict perception may strengthen the executive control system that is mediated by the ACC, DLPFC and posterior parietal cortex (PPC) including the SPL or IPL. Once a conflict is detected, the executive control mechanism strengthens focusing of attention onto the task relevant stimulus and filters out information from irrelevant stimuli. The attentional system, if thus enhanced, seems to coordinate attention in working memory better.

The model in Fig. 3.5 proposes a distributed network that is structured around the central executive systems in the PFC, ACC and PPC. They contribute to control attention by maintaining, inhibiting, and focusing attention with the aids of the occipital, temporal, and parietal cortices. When a participant performs working memory tasks like the RST and LST, she must focus attention on a certain word and establish a mental representation of it. Her performance depends on how well she can allocate attention or shift the mental focus.

In the network proposed here, it is easy to control attention for self-monitoring both consciously and unconsciously in working memory tasks.

3.6.1 Working Memory and Consciousness Revisited

It has gradually become clear that active consciousness and working memory share some common neural representations. Active consciousness functions on the basis

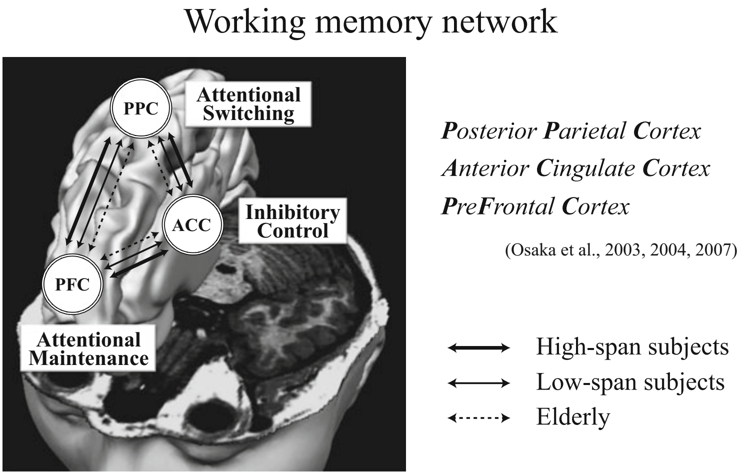

Fig. 3.5 Working memory network model of high-span and low-span participants

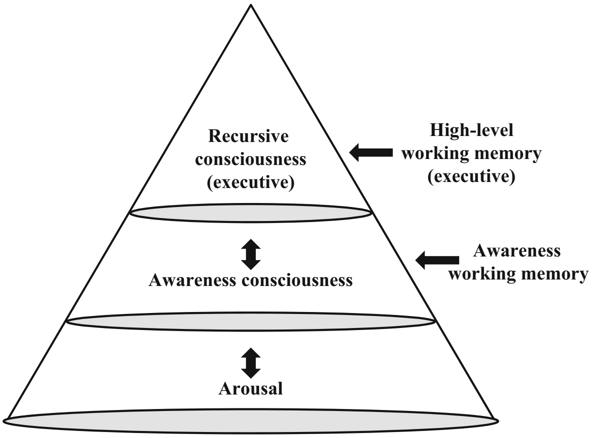

Fig. 3.6 Layered model of active consciousness and working memory

of a capacity-constrained and goal-directed neural system, and it is very similar to the central executive system of working memory. Osaka (2000) proposes a layered model that connects the two systems. Figure 3.6 shows a three-layered model of consciousness: it includes arousal-, awareness-, and recursive-consciousness, and recursive-consciousness is top-down controlled.

These layers correspond to arousal-, awareness-, and recursive-consciousness, and interact with each other in a bidirectional manner. The first level of consciousness is shaped by the arousal system generated by reticular formation of the brain. A biologically-driven arousal system is boosted by the brain stem system that is regulated by neurotransmitters. The second level of consciousness is called 'awareness driven by the awareness system at bottom' and closely related with the attentionalsystem. Perception of environments and attentional motor control for performing goal-directed behavior are led by awareness. Finally, the third level of consciousness is called 'recursive-consciousness' and goes with those cognitive processes like thinking which requires recursive function of information processing. This high-level recursive consciousness includes a top-down executive control that is responsible for, e.g., social interactions with others. When consciousness layers are compared with working memory, awareness working memory corresponds to the awareness consciousness, and high-level working memory corresponds to the recursive consciousness with executive function. High-level working memory has an executive function that effectively controls attention and monitors one's own performance so as to achieve task goals effectively. High-level working memory shifts the focus of attention and self-monitors in order to improve performance in tasks that require higher cognitive brain function. Cooperative activation of different brain areas is important for effective working memory performance and active consciousness.

Exercises

1. What are differences between working memory and short term memory (STM)?
2. How working memory capacity is measured by the reading span test (RST)?
3. What regions of the brain compose the neural bases of working memory?
4. What kind of executive function corresponds to the highest level of active consciousness?

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