Evidence from experimental studies

There is lots of support the the working memory model from experimental studies.

One such finding is the word length effect. **Baddeley et al (1975)** visually presented participants lists of words to recall. The lists contained either short, one-syllable words (e.g. sum, hate), or longer multisyllable words (e.g. association, opportunity). Although the lists contained the same number of words, the PPs consistently recalled more of the short than the long words. This shows that the phonological loop has a time-limited capacity - it can hold about as much speech as a person can say in 2-3 seconds.

Support for the working memory model also comes from dual task studies, in which participants carry out tasks separately and then simultaneously, to see in their performance deteriorates. According to working memory theory, it should be possible for people to perform two tasks simultaneously provided they use different components of WM.

Robbins et al (1996) gave chess players some problems to solve. The problems required the PPs to select the best move for a chess game in play. Chess is a game that requires both spatial processing and problem solving. They asked the PPs to do different things whilst they were solving the problems, and recorded how good their solutions were.

Concurrent task	*Quality of solutions to chess problems*
Tapping on the table.	No effect.
Thinking up random numbers and saying them aloud (a cognitively demanding task).	Got worse.
Pressing keys on a keypad to create a circular pattern (a spatial task)	Got worse.
Repeating the word ‘see-saw’ to themselves (a phonological task).	No effect.

The ‘tapping’ and the ‘see-saw’ tasks did not affect performance of the chess task because they use different WM components. However, the ‘random numbers’ task competed for the central executive and the ‘keypad’ task competed for the VSS, resulting in poorer performance.

Evidence from studies of the brain

Case studies of brain damaged patients may provide some support for th WM model. **Shallice and Warrington (1974)** studied KF, a man whose brain had been injured in a motorcycle accident. KF's LTM functioned normally, but his STM was severely impaired. Instead of around 7 items, KF was only able to recall 1 or 2 items from a list. Further investigation showed that KF forgot letters and digits much faster when he received them auditorily than visually. It was also found that KF had a normal STM span for meaningful sounds (e.g. a doorbell, a telephone ringing, a cart mewing) even though his STM span for words, letters and digits was very limited. The uneven pattern of deficits suggests that KF had more than one STM store, which is consistent with the WM model.

Another source of support for the working memory model comes from brain imaging studies. If the CE, the VSS and the PL are separate information processes, it seems likely that each would correspond to a different set of brain structures. It might therefore be possible to use brain imaging (e.g. PET or fMRI) to show that brain activity changes when different WM components are used.

Ma et al (2002) scanned participants' brains with fMRI while they did a letter recognition task involving rehearsal and a symbol recognition task where rehearsal was not possible. They found that the verbal task was associated with increased activity in the inferior frontal cortex, the inferior parietal cortex and the temporal gyrus. The visual task did not activate these areas. The visual task was accompanied by increased activity in the visual cortex and the superior parietal cortex. The different activation patterns in the different tasks are consistent with the idea that WM consists of separate components.

Applications of working memory theory

It is a strength of any theory when it helps us to understand things in new ways and offers new solutions to problems.

One way that WM theory has benefitted us is in the classroom. There are some children who make slow progress at school even though they do not have any identifiable developmental disorder. Such children may have difficulty following complex instructions and completing tasks. As they get older they may have delays with reading and maths, and their educational attainment is limited. In the past, we might have written these children off as slow, inattentive or lazy. However, we can now understand these children's problems as being due to working memory deficits which make it difficult for them to store sequences of instructions or actions. This has made it easier to design tests to identify children with WM problems early on and support them in ways that help them make better progress.

Similarly, WM theory has been applied to understanding the problem of dyslexia, which makes it difficult for some people to learn to read. Previously, dyslexia was poorly understood but things are much better since researchers realised it could be explained as a difficulty in converting visual information to auditory information in working memory. This has led to much better support for people with dyslexia and related problems.

WM theory has also been applied in engineering. Many accidents occur because of human error, because people were doing things that overloaded their working memory. Designers of tools and control systems have used WM theory to design tasks and controls that are less likely to overload WM or lead to errors. This could involve making sure that no single WM component has to do too much, reducing the amount of switching between different tasks the human operator must do, or ensuring that really important information (e.g. alarm signals) is presented in ways that cannot be ignored or overlooked.

Problems with working memory theory

One problem with WM theory is that the most important part of the theory is the one we know least about: the central executive. The trouble is, whilst it is relatively easy to design experimental tasks that use the VSS and not the PL or vice versa, it is difficult to design tasks that *only* use the CE and not the other two components. Therefore, it is difficult to do studies that show that the CE is a separate component from the other two. Some researchers have suggested that there is no need for the CE in the theory, and that WM is better understood as two independent systems, one visual and one auditory/verbal.

Baddeley (2000) suggested that the original WM model (Baddeley & Hitch, 1974) was incomplete because it did not explain how WM connects with LTM, nor how people are able to combine verbal and visual information in ways that allows them to make sense of stories and social situations. He later added a new component called the 'episodic buffer' that serves these functions.

A further problem with the working memory model is that it does not explain how emotional and motivational factors influence how working memory is used. For example, Damasio (1994) identifies brain injury patients whose working memory is apparently intact but still cannot function normally. Some are 'cognitively inert', that is, they are capable of using their working memory but for some reason do not. Others can perform normally on tests of working memory but are incapable of making sensible life choices in real situations. Without consideration of motivation and emotion, WM theory is incomplete (Baddeley, 2010).