Research Focus

Exceptional memorizers: made, not born

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In a recent study, Maguire and colleagues failed to find systematic differences in brain anatomy between world-class memory performers and matched control subjects. The world-class performers exhibited distinctive patterns of brain activation during memorization, but these patterns were directly attributable to the experts' unique encoding strategies and acquired memory skills. Discussed here are the implications for broad attainability of highly skilled memory performance in professional and everyday activities.

Expert performance in areas such as medical diagnosis, music, chess and sport has been shown to require extensive knowledge and cognitive mechanisms acquired through extended practice [1–3]. This research cannot, however, directly address whether one must be born with superior memory, to attain exceptional levels of performance. In a recent study, Maguire, Valentine, Wilding and Kapur used brain-imaging techniques to compare the brain anatomy and the patterns of brain activation of a group of world-class memory performers with that of a matched control group [4].

When individuals are able to recall large amounts of information seemingly effortlessly [5,6], most people will infer that they must have a naturally superior memory that is qualitatively different from ordinary adults'. When researchers studied these extraordinary individuals, however, their memory was truly exceptional only for materials that seem meaningless to most adults, such as lists of digits, unrelated words, and chess positions [7]. Furthermore, memory performance for those types of meaningless materials can be dramatically improved by mnemonic training.

Chase and I [8,9] demonstrated that regular college students can attain world-class memory performance after extensive practice and proposed skilled-memory theory as an account for how ordinary people can acquire exceptional memory (see Box 1). In a recent comprehensive review of exceptional memory performance, Wilding and Valentine [10] concluded that the skilled-memory theory did indeed account for truly exceptional memory performance involving specific types of materials, such as digits. But they also proposed evidence for the existence of naturally superior memory, where some people's memory for specific materials was never truly exceptional but consistently well above average for several different materials tested. Most important, these subjects reported that they did not use mnemonic encoding strategies.

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Imaging the brains of world-class memory performers

The current study by Maguire *et al.* provides the first examination of the brain anatomy and patterns of brain activation in ten of the world's foremost memory performers [4]. Most of the participants had placed at the highest levels in the World Memory Championships, where the winners attain the best overall performance in many types of memory tests with different stimulus materials. Maguire *et al.* also recruited ten control subjects whose spatial ability and intelligence matched those of the memory experts.

When the structural MRI images for the brains of memory experts and control subjects were compared, Maguire *et al.* could not find any systematic anatomical differences. Although it is impossible to prove the absence of systematic differences in the experts' brains, it is unlikely that future studies would be able to recruit enough world-class memory performers to provide tests with much greater statistical power.

This study also recorded the brain activity (fMRI) of both groups of participants while they were engaged in memorizing three types of selected stimuli illustrated in Fig. 1, namely three-digit numbers, faces, and snow crystals. Following the study phase, all participants were given recognition tests for the three types of stimuli. Consistent with earlier research [10], experts showed a large advantage over controls for memory of digits, but no reliable difference for snow crystals. The memory performers' advantage for faces was reliable and intermediate in magnitude. After completing the recognition test, the participants gave detailed descriptions of their encoding strategies during the memorization. All of the memory performers reported using previously acquired techniques for generating associations, such as mnemonics, to

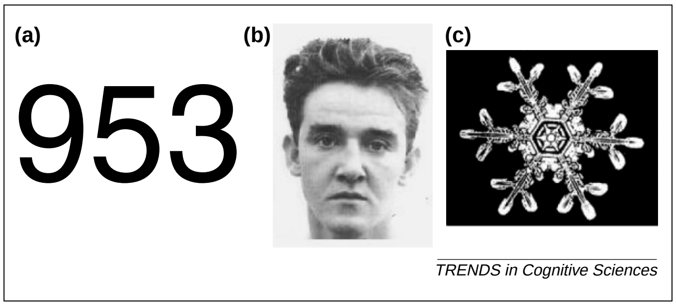

Fig. 1. Examples of the three types of stimuli used by Maguire *et al.* [4]. (a) Three-digit numbers. (b) Black-and-white photographs of faces. (c) Snowflakes (Reproduced from Ref. [25] with permission of Dover Publications Inc.). (Whole figure reproduced with permission from Ref. [4]. Copyright 2003 Nature Publishing Group.)

Box 1. Acquiring exceptional memory by mnemonic associations and extended practice

Short-term training can improve memory performance, but most improvements are modest and specific to the type of material practiced [7]. When practice was extended to several hundred hours, college students keep gradually increasing their memory for digits to an exceptional level [8,14] – surpassing the memory performance of all exceptional individuals previously studied [5,6]. The trained students displayed three types of changes characteristic of skilled memory [8,9].

First, the students didn't just rehearse the presented digits. They broke up the list into groups consisting of three digits. For each group they deliberately generated meaningful associations to pre-existing knowledge to attain storage in long-term memory (LTM). For example, some students were experienced runners and encoded 359 as '3 minutes 59 seconds for running a mile'. Other mnemonic methods for memorizing digits require first learning a memorable word for each two-digit combination [15,16]. For example, if 59 is '*lip*' and 47 is '*rock*', then 5947 can be remembered by an interactive image of '*lips* kissing a *rock*'.

Second, when the students started to store several digit groups in LTM, they initially had problems retrieving them in the correct order. They developed retrieval structures: each group could be associated with a unique set of retrieval cues during encoding and the same cues are activated to retrieve the group at recall. The familiar mnemonic 'method of loci' [15,17] illustrates this principle. Participants form interactive images between the items to be picked up at the market, such as catsup and locations in their house, like 'catsup sprayed in the kitchen sink'. At the time of recall the participants can then activate the locations to serve as a unique retrieval cue to retrieve each item.

The speed of encoding and retrieval processes is increased with extended practice, which allows trained subjects to store rapidly long lists of items of a certain type of material in LTM for subsequent recall [8,9].

Large groups of adults have since been taught mnemonic methods. After extended practice with mnemonic techniques they dramatically improved their memory performance [18–20].

make the presented information more memorable. All but one of the memory performers reported using 'the method of loci' (see Box 1). In sharp contrast, none of the control group reported using any of the standard mnemonic techniques.

These qualitative differences in reported encoding processes allowed the investigators to explain the patterns of observed differences in brain activity between the two groups. Consistent with their reports of imagery and use of 'the method of loci,' the memory experts had higher activity in those brain areas that have been linked to spatial memory and navigation. These differences in activation were observable even when the experts encoded snowflakes - a type of material where the experts didn't show any superiority of memory over the control group. For the material with the largest difference in memory performance (digits), the experts reported distinctive mnemonic associations to images of people, animals, and objects (Box 1), whereas none of the subjects in the control group did so. Consistent with these reports, the expert group showed an increased brain activity in the brain regions involved in learning associations.

In summary, the observed differences in memory between the world-class memory performers and the control participants do not support the existence of naturally superior memory, and are consistent with the experts' skilled application of special encoding strategies. World-class memory performance requires extended practice; all of the experts in this study had extensive previous practice with these encoding strategies for an average of ten years [4]. Even so, mnemonic strategies do not lead to superior memory for all types of information and did not enhance their memory for snowflakes.

Implications of mnemonic training for superior memory in everyday activities

Mnemonic methods are effective in generating associations between otherwise 'meaningless' or unrelated information, such as dates and names. Mnemonic strategies are unlikely to benefit memory in skilled everyday activities, however, where memory encoding must be task specific and appropriate for the relevant tasks [11]. During skilled everyday activity information needs to be encoded to allow direct access to domain-specific knowledge necessary to complete the task. For example, encoding numbers as running times (see Box 1) will not be suitable in a task where two numbers are being multiplied and direct access to multiplication facts is required.

Box 2. Superior memory in everyday activities: the role of domain-specific skills and knowledge

When people read interesting books, their memory for relevant information is typically very good without any additional efforts to memorize. They don't need to generate mnemonic associations (see Box 1) because the important information is spontaneously meaningful to them. In skilled activities, people spontaneously encode information using their relevant knowledge within the domain. For example, people who have acquired skill in mental multiplication often know the mathematical structure of each number between 000 and 999. They demonstrate superior memory for digits that is not explicitly trained or based on arbitrary mnemonics, but reflects memory skills that mental calculators develop to be able to multiply large numbers 'in their heads'. In a theoretical extension of 'skilled memory theory' [8] Kintsch and I [11,21] proposed that people could develop domain-specific encoding methods to expand their effective working memory by relying on storage in LTWM (long-term working memory) in domains of expertise as well as skilled everyday activities such as text comprehension.

Experts acquire LTWM during many years of deliberate practice to support the working memory demand of representative task activities [11,21]. The same acquired LTWM mechanisms can explain why experts' memory is sometimes exceptional. For example, chess masters can recall briefly presented positions from chess games consisting of over twenty chess pieces using their LTWM. But, when the same chess pieces are randomly rearranged on the chessboard, chess masters' recall is roughly comparable to that of novices [22,23].

Skilled everyday activities, such as text comprehension, impose large demands on working memory. During text comprehension readers rely on their extensive knowledge to encode the information in LTWM. Consequently, individual differences in how much knowledge people have about the specific topic of a text is one of the most important predictors of an their comprehension and memory of that text [11,24].

Superior memory in everyday activities reflects memory skills and knowledge acquired over an extended time to attain proficient performance in those activities.

In a theoretical extension of 'skilled memory theory,' Kintsch and I [11] proposed that one can enhance memory in specific everyday activities, such as text comprehension, as well as in domains of expertise (see Box 2). We described how people can acquire skills to encode information in LTM rapidly and in such a manner that it can later be readily accessed, thus expanding their task-specific working memory (long-term working memory, LTWM).

Recent brain-imaging studies show that subjects exhibiting exceptional performance activate brain regions different from those activated by control subjects [12,13]. Most important, the differential brain activation is consistent with cognitive processes predicted by LTWM accounts. For example, exceptional mental calculators rely on storage in LTM [12] and expert mental abacus calculators encode numbers in a manner qualitatively different from controls [13].

In conclusion, the recent evidence from imaging brain activity during exceptional performance [4,12,13] provides very strong support for the acquired nature of exceptional memory. It shows that the experts' reported encoding methods differ qualitatively from those of the controls and that the differential pattern of activation of brain regions during memorization can be explained by these strategy differences. This research provides compelling evidence that ordinary people can dramatically improve their memory performance with appropriate strategies and practice. But, knowing that improvement of performance is possible is different from understanding the specific processes of physiological adaptation of the brain and detailed modification of skills that occurs during extended skill acquisition. It is now time to apply cognitive and brain-imaging methods to study the process of skill acquisition, and to explain why only some people persist with training and eventually reach exceptional levels of performance.

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Six-year-olds' contradictory judgments about knowledge and beliefs

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By around the age of 4 years, children acknowledge that people can have false beliefs about the world. Six-year-olds are still inclined, however, to confuse their own knowledge with that of more ignorant others. In a recent paper, Hulme, Mitchell and Wood offer a novel explanation for six-year-olds' tendency to make such errors when asked to choose a picture to put in a story character's thought bubble.

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