Commentary on Cowan:
The magical number 4 in short-term memory: a reconsideration of mental storage capacity

Dispelling the magic: towards memory without capacity

Niels A. Taatgen
Department of Cognitive Science and Engineering, University of Groningen
Grote Kruisstraat 2/1
9712 TS Groningen
Netherlands
email: niels@tcw2.ppsw.rug.nl
homepage: http://tcw2.ppsw.rug.nl/~niels

Abstract:
The limited capacity for unrelated things is a fact that needs to be explained by a general theory of memory, rather than being used itself as a means of explaining data. Assuming a pure storage capacity is therefore not the proper stance for doing memory research. Instead a theory is needed that explains how capacity limitations arise from the interaction between the environment and the cognitive system. The ACT-R architecture, a theory without working memory but a long-term memory based on activation, may provide such a theory.

The goal of science has always been to show that things in the world that appear to be accidental can be explained by a set of systematic and fundamental principles. Miller's magical number seven and subsequent theories based on the idea are attempts to find such principles. Cowan tells us that the magical number is not seven, but actually four. Still the word "magical" lingers around this mysterious capacity. My proposal is not to attack the "seven" aspect of the principle, but rather the "magical" part of it, since we all know that magic doesn't really exists. Whereas in Miller's article short-term capacity was just an empirical fact, it has subsequently grown into a theory that states that people actually have a pure storage capacity. Let us elaborate on this idea. If we take capacity seriously, the number of items that can be stored by an individual has to be an integer. A capacity of 3.5 only makes sense as a group average, not as a property of an individual. An individual can either retain three items or four items, not three-and-a-half. An individual capacity of 3.5 only has any meaning if the individual can sometimes remember three items, and sometimes four items. But this is hard to reconcile with the idea of a fixed capacity. It becomes even harder to explain development. Even according to Cowan's own data, the capacity of adults is larger than the capacity of children. But how then does this capacity grow? Are there sudden increases in which the capacity is incremented by one?
The problem of the target article is that it already assumes there is a capacity limit, and that it can be studied separately from the rest of memory. If one wants to prove there is indeed a limit-capacity short-term store, the relation to long-term memory has to be taken into account. When something drops out of short-term memory, is it really gone? Sometimes the exact information is irretrievable, but the vast literature on implicit learning and priming suggests that everything that happens in short-term memory has some long-term impact. So what of the alternative account, that short-term memory is no separate entity, but just a part of long-term memory? This would be a much more parsimonious solution, provided it can explain the empirical facts of a limited short-term store.

I would like to argue that an explanation of short-term store based on properties of long-term memory is much more interesting than assuming a separate entity. Why is the capacity four, and not five? A theory that proposes a buffer of limited size does not provide any answers.Take for example the subitizing phenomenon, the fact that people seem to be able to recognize up to four dots in the visual field, but have count if there are more. One could postulate the theory that the visual system has an built-in capacity to recognize up to four things, and be done. Peterson and Simon (2000) offer an alternative account. According to their theory, the visual system can immediately recognize a set of dots, if it has seen these dots in the same array before often enough. The number of possible configurations of dots increases exponentially by the number of dots. Therefore the human visual system receives enough examples of four-dots configurations to recognize any of them instantly, but not of five or more. Except of course when a particular configuration occurs often enough: anyone can recognize the five-dot pattern on a die instantly. The advantage of the Peterson and Simon account is that they show how the seemingly magical number four can be explained by an interaction between environment and the cognitive system.

Short-term memory capacity is not something that can be used to explain the outcomes of experiments, but is rather something that needs to be explained itself. One possible explanation is the one offered by the ACT-R architecture (Anderson & Lebiere, 1998). ACT-R has a long-term declarative memory that also serves as working memory. To keep track of the current context, a single-item focus of attention is used. All items that have to be memorized are stored in declarative memory. Since declarative memory is activation-based, interference and decay can produce the same sort of effects usually assumed to be produced by limited short-term memory. These limitations are, however, context dependent: if there are associations between the items to be memorized or with other items in memory, it is easier to retrieve the information. Short-term memory without context is only important if one presumes its capacity is a fundamental property. Short-term memory within a context is much more useful. I have demonstrated (Taatgen, 1999a; 1999b) that individual differences on simple memory task might be used to explain individual differences in skill acquisition.

Figure 1 shows some results from an ACT-R model of short-term store that I have adapted from an earlier version (Taatgen, 1999a). The original model memorized a list of up to ten digits, and attempted to reproduce them. It neatly reproduced Miller's 7+/-2 effect. Since the original model was allowed to rehearse, I removed the rehearsal, and obtained the results in figure 1: the magical number four, but without any internal capacity limitations. The figure shows three curves, a simulated low, average and high capacity individual. The individual differences were produced by variation of an ACT-R parameter that controls the spread of activation (based on Lovett, Reder & Lebiere, 1997). The reason why the curve drops off so dramatically at around four items has nothing to do with the number four itself. It rather has do to with the fact that as the string of numbers grows, the effects of decay, interference and the increased probability of doing something wrong if more responses are required are multiplied, and cause performance to drop suddenly at this point.

References

Anderson, J.R. & Lebiere, C. (1998). The atomic components of thought. Mahwah, NJ: Erlbaum

Lovett, M. C., Reder, L. M., & Lebiere, C. (1997). Modeling individual differences in a digit working memory task. In Proceedings of 19th Conference of the Cognitive Science Society, (pp. 460-465). Mahwah, NJ: Erlbaum.

Peterson, S.A. & Simon, T.J. (2000). Computational evidence for the subitizing phenomenon as an emergent property of the human cognitive architecture. Cognition, 24(1), 93-122.

Taatgen, N.A. (1999a). Cognitief modelleren, een nieuwe kijk op individuele verschillen. Nederlands tijdschrift voor de psychologie, 54(4), 167-177.
Taatgen, N.A. (1999b). A model of learning task-specific knowledge for a new task. In Proceedings of the 21th annual meeting of the cognitive science society (pp. 730-735). Mahwah, NJ: Erlbaum.

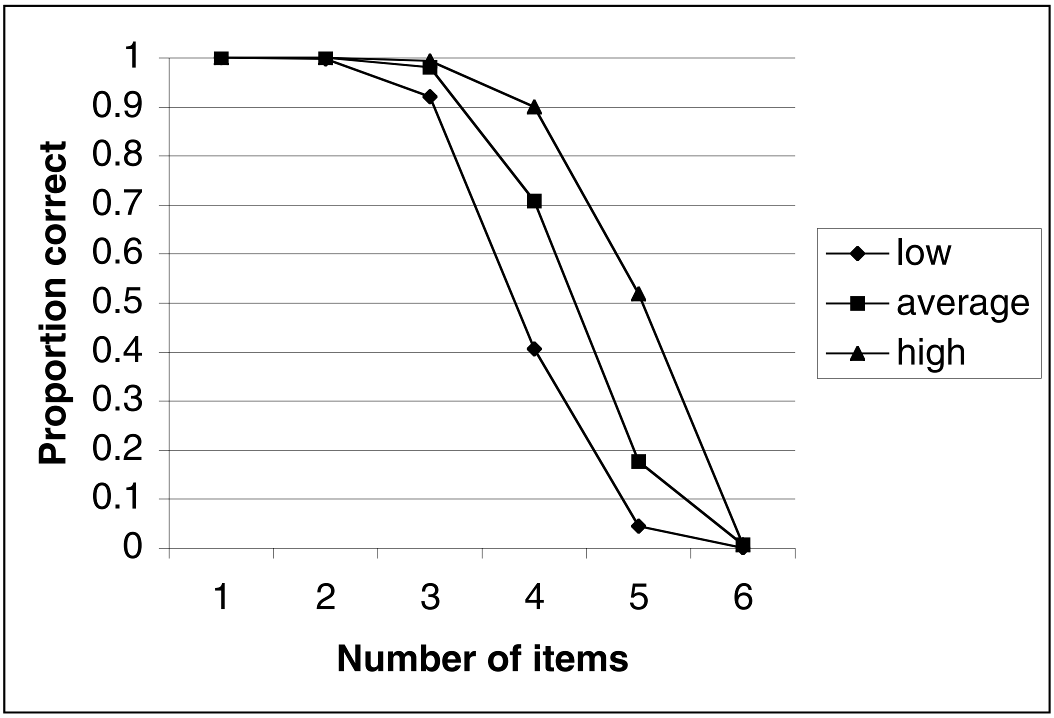

Figure 1