The working memory hypothesis of mental fatigue

Linda Jongman, Theo Meijman, and Ritske de Jong
Department of Experimental and Work Psychology
University of Groningen
Grote Kruisstraat 2/1, 9712 TS Groningen, The Netherlands.
+31 50 363 6289
linda@tcw3.ppsw.rug.nl

In this study, mental fatigue is defined as a subjective feeling of fatigue combined with a negative change in performance, due to time spent on cognitively demanding tasks.
These feelings of fatigue and changes in performance occur independently from the influences of time of day, learning, or investment of physical effort. The most important change in performance reported by many authors in relation to fatigue is the deterioration of the organization of behavior (e.g. Bartlett, 1943; 1953; Broadbent, 1979; Holding, 1983). Behavior seems to loose cohesion when people become mentally fatigued.

We explore the hypothesis that mental fatigue involves a decline in working memory functioning. More specificly, a reduction of working memory capacity. Working memory capacity is here taken in a broad sense, involving both maintenance and organization of information. The first aspect refers to how well a person can keep relevant information active during concurrent processing (see the activation-based approach as described by Just & Carpenter, 1992). The second aspect of working memory capacity refers to the ability to maintain an adequate and efficient organization of goals and goal structures.

Our working memory notion of fatigue is based on the source-activation concept of the ACT-R theory (Anderson & Lebiere, 1998). Lovett, Reder & Lebiere (1997) indicated that source activation is related to working memory capacity. They found that individual differences in performance on a working memory task could be nicely simulated by changes in ACT-R's source activation parameter (W). They also showed that this individual-bound estimation of W is relatively stable and correlates well with other working memory measures (Daily, Lovett & Reder, submitted). Accordingly, we assume that every individual has a baseline for W. And, in addition to this baseline, we hypothesize that W fluctuates according to changes in mental circumstances, like mental fatigue.

If our hypothesis about mental fatigue is right, and W does decrease when people become mentally fatigued, there will be a point in time when an individual's W is not sufficient anymore to do the task at hand. People will get problems in keeping relevant information active causing them to skip actions or perform incorrect actions. This corresponds closely to the deterioration of the organization of behavior as mentioned by many fatigue researchers. Because human beings are adaptive, we would expect them to adapt their behavior to the changed (mental) circumstances. Suppose there are two possible strategies for a certain task, an efficient strategy which is highly dependent on W (high-W), and a less efficient strategy that is less dependent on W (low-W). Usually, ACT-R would predict that people choose the most efficient strategy, in this case the high-W strategy. However, if during task performance W decreases due to fatigue, the high-W strategy will lead to many errors due to retrieval failures. ACT-R's parameters-learning mechanism would predict in that case that the expected gain of the high-W strategy decreases. At some point, the expected gain of the high-W strategy may drop below the expected gain of the low-W strategy, resulting in a switch in strategy. Therefore, we predict that in order to protect performance, people switch to a strategy that is less dependent on W and thus less dependent on working memory functioning.

To test this hypothesis, we made people perform a fault-diagnosis task in which they were taught two strategies: a hypothesis-and-test strategy (high-W) and a tracing-back strategy (low-W). Participants had to perform this task right before (PRE-test) and right after (POST-test) a fatiguing manipulation (details of the experiments are described in Jongman, Meijman & De Jong, submitted). On the PRE-test, as expected, participants mostly chose the high-W strategy. However, after the fatiguing manipulation, the use of this high-W strategy decreased significantly, as we predicted. This switch in strategy choice was not found for participants in the control condition, confirming the strategy switch was indeed related to fatigue.

In addition to the fault-diagnosis task, participants also had to perform another task, called the "coffee task" (details and results are described in Jongman & Taatgen, 1999). Performance on this coffee task can be distinguished into two levels. The first level is the actual carrying out of the task, which in this task consisted of performing mental calculations. In addition, participants could increase performance efficiency by monitoring regularities in the task, which can be considered a second performance level. Both aspects of the task were highly dependent on working memory functioning. The use of this second level of the task can be considered a high-W strategy. Consistent with the results of the fault-diagnosis task, participants made less use of information on this second level, when they became fatigued. Non-fatigued controls still used the information to the same degree.

As mentioned before, we assume people differ in their baseline for W. We therefore expect people to differ in their susceptibility to fatigue as well. For extremely high-W individuals performance need not be affected at all, when they become fatigued, because they have some "spare" activation. However, for low-W individuals even a small decrease in W can decrease performance and thus result in a need to switch to a less W-dependent strategy. In our experiments (Jongman, Meijman & De Jong, submitted) we gained some evidence for this prediction. In the second experiment, participants also had to complete the Raven Progressive Matrices Test (Raven, 1962). Carpenter, Just and Shell (1990) suggested that the main factors determining performance on the Raven-test are working memory capacity and efficiency of goal management, which nicely captures our definition of working memory capacity and the notion of source activation. It seems therefore plausible to assume that people who perform well on the Raven-test also have a high W and vice versa. When the participants were split on the median according to their Raven-scores into a high-Raven and a low-Raven group, it appeared that it were only the fatigued low-Raven participants who switched to a less W-dependent strategy. For the non-fatigued controls, we did not find a difference between the high- and low-Raven group. These results are consistent with our working memory hypothesis of fatigue.

ACKNOWLEDGEMENTS

This research project is part of Netherlands Concerted Research Action "Fatigue at Work". The authors would like to thank Netherlands Organization for Scientific Research (NWO) for making this research possible.

REFERENCES

Anderson, J.R. & Lebière, C. (1998). *The atomic components of thought*. Hillsdale, NJ: Erlbaum.

Bartlett, F.R.S. (1943). Fatigue following highly skilled work. *Proceedings of the Royal Society, 131*, 247-257.

Bartlett, F.R.S. (1953). Psychological criteria of fatigue. In W.F. Floyd & A.T. Welford (eds.), *Symposium on fatigue.* London: H.K.Lewis.

Broadbent, D.E. (1979). Is a fatigue test possible now? The Society Lecture 1979. *Ergonomics, 12,* 1277-1290.

Carpenter, P.A., Just, M.A. & Shell, P. (1990). What one intelligence test measures: A theoretical account of the processing in the Raven Progressive Matrices Test. *Psychological review, 97,* 404-431.

Daily, L.Z. Lovett, M.C & Reder, L.M. (submitted). Modeling individual differences in working memory performance: A source activation account.

Holding, D.H. (1983). Fatigue. In G.R.J. Hockey (ed.) *Stress and fatigue in human performance*. New York: Wiley.

Jongman, L., Meijman, T. & De Jong, R. (submitted). Thinking or doing? Which strategy do people choose when they are mentally fatigued?

Jongman, L. & Taatgen, N. (1999). An ACT-R model of individual differences in changes in adaptivity due to mental fatigue. *Proceedings of the 21th Annual Conference of the Cognitive Science Society* . Hillsdale, NJ: Erlbaum.

Just, M.A. & Carpenter, P.A. (1992). A capacity theory of comprehension: individual differences in working memory. *Psychological review, 1*, 122-149.

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

Raven, J.C. (1962). *Advanced Progressive Matrices, Set II*. London: H.K. Lewis.

The working memory hypothesis of mental fatigue

Linda Jongman
Experimental and Work Psychology
University of Groningen, The Netherlands
e-mail: linda@tcw3.ppsw.rug.nl

Overview

- mental fatigue
- working memory capacity
- the hypothesis
- evidence gained so far
  - fault-diagnosis task
  - coffee task

Mental fatigue

- a subjective feeling of fatigue
- negative change in performance
- due to time spent in cognitively demanding tasks
- independently from time of day, learning or investment of physical effort

Processes possibly influenced by mental fatigue

Prefrontal functions
(West, 1996)

- Inhibition of interfering stimuli
- Inhibition of prepotent responses
- WM processes which enable retrieval of information
- WM processes concerning preparation of responses

Working memory capacity

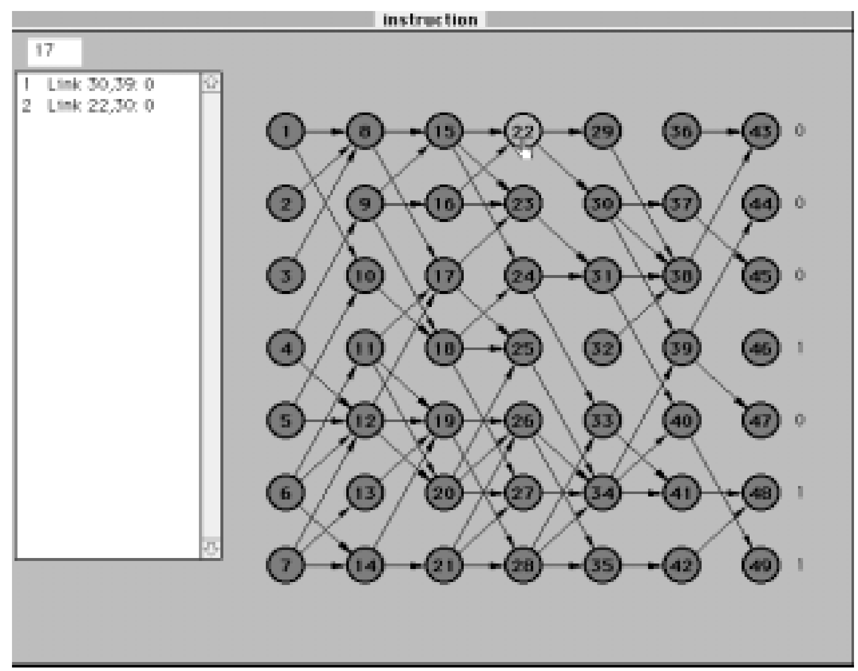
(in ACT-R "source activation")

2 aspects

- keeping relevant information active
- efficiency of organization of goals and goal structures

Source activation (W)

- Influences the signal/ noise ratio
- Enables retrieval of relevant information
- It is shown that W can be related to (individual differences in) WM capacity (Lovett, Reder & Lebiere, 1997)



Hypothesis

mental fatigue involves a reduction in working memory capacity ("W")

– strategy choice: fatigued participants will choose strategies that are less dependent on working memory capacity

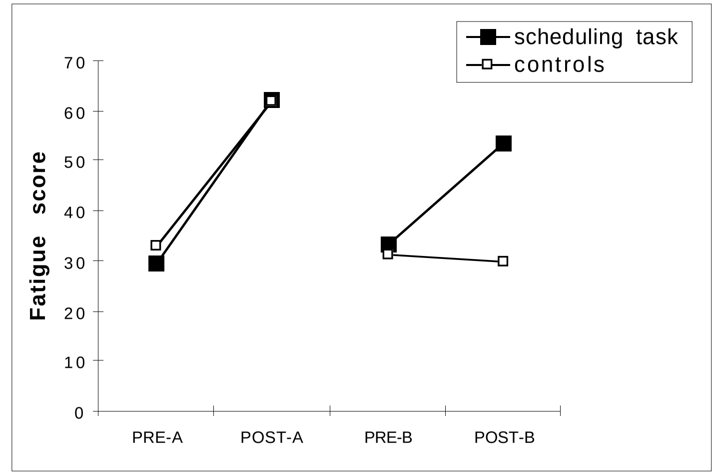
(Expected gain of W-dependent strategy is lowered; conflict resolution favors alternative strategy)

– individual differences: participants will not be equally susceptible to mental fatigue

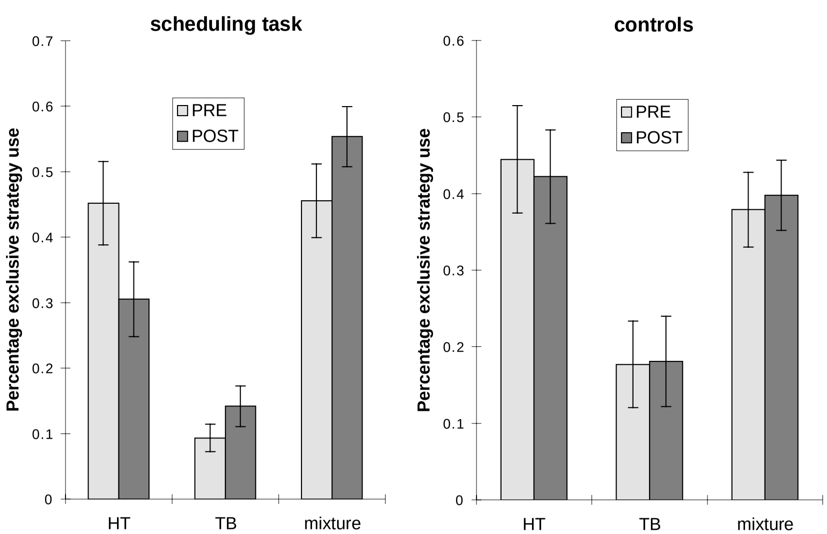
Experimental design

Day A	Day B
	coffee task (PRE)
training day	fault-diagnosis task (PRE)
(training of the tasks used on day B)	mentally loading task (2 hours)
	fault-diagnosis task (POST)
	coffee task (POST)

subjective measurement of fatigue



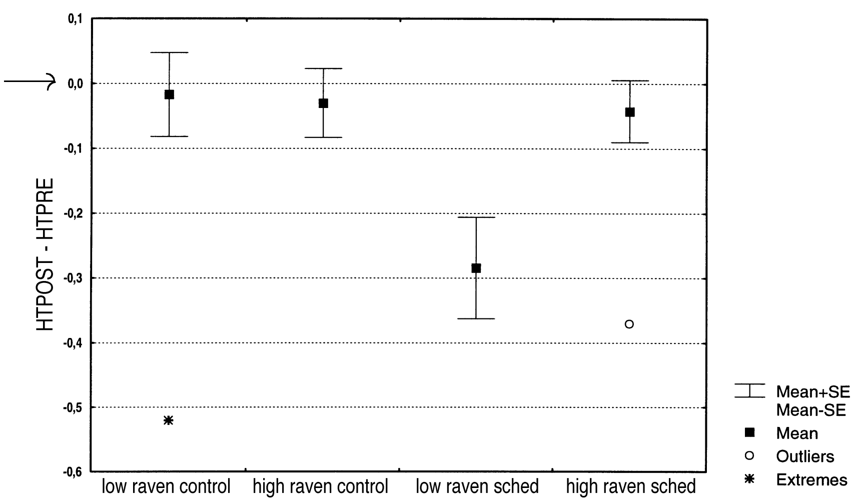
Strategy choice

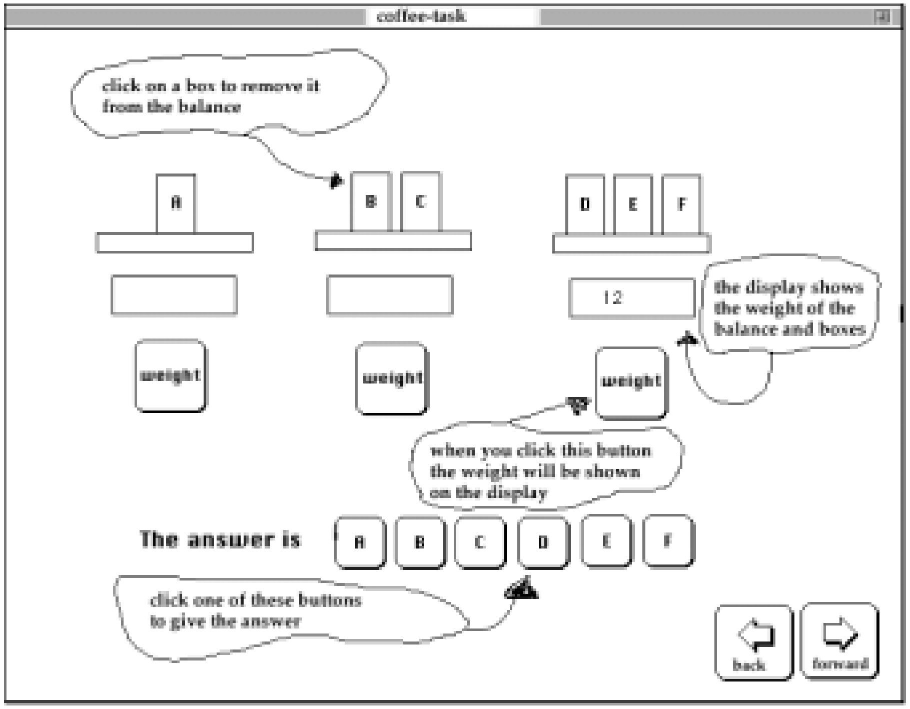


Individual differences

(low-Raven versus high-Raven)

dif = 0





Adaptivity measure

Performance can be optimized by choosing the optimal balance (the balance with the highest probability per packet) to start with.

If a participant always chooses the optimal balance to start with, the probability distribution will remain close to the neutral distribution (resp. 17, 33 and 50%).

Adaptivity measure

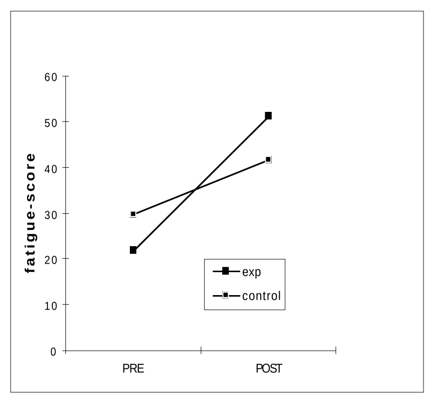
$$\text{Deviation}_i(j) = 50 - P_3 \quad (1)$$

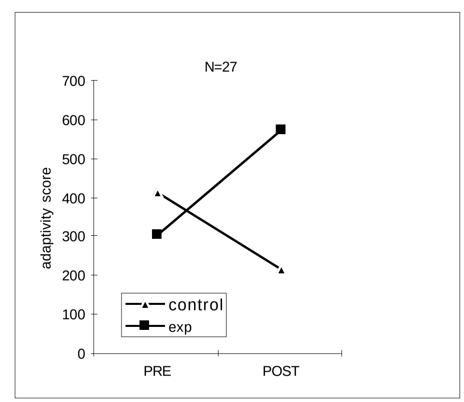
P_3 is probability (as percentage) that goal-packet is on the balance containing 3 packets

$$\text{Adaptivity}(i) = \text{sum}_j [D_i(j)^2] / n \quad (2)$$

Results coffee task

correlation change in fatigue, change in adaptivity $r = .50$ $p < .01$





2 Strategies

- Choose the same balance as on previous trial (P)
- Choose balance that contained goal-packet on previous trial (A)

category	correlations	
	PRE adaptivity	POST adaptivity
PA	-.53**	-.72***
PnA	.90***	.86***
nPA	-.67***	-.61***
nPnA	-.42*	-.44*

* p<.05, ** p<.01, *** p<.001

- Only the high-fatigue group shows a decrease in responses in the nPA-category ($p < .025$)

Conclusions

Consistent with WM-hypothesis of fatigue:

- People do indeed switch to a less working memory dependent strategy when they become fatigued
- There is an indication that high-W individuals are less susceptible to fatigue