Bethel, E.C., Borokhovski, E. (2010). Cognitive load theory and working memory training. The 2010 American Educational Research Association Annual Meeting, Denver, CO. 30 April - 4 May 2010.

# Cognitive Load Theory and Working Memory Training


## Abstract
Working memory is the cognitive mechanism for accessing and processing information from sensory input or recalled from long term memory. Working memory has a limited capacity. In this regard, the limits of working memory set the boundaries of learning potential. Instruction that makes efficient use of limited working memory will increase learning possibilities. Cognitive load theory and the cognitive theory of multimedia instruction prescribe evidence-based strategies to maximize learning through efficient use of working memory capacity. Recent research demonstrates that working memory capacity can be increased through training, and that these increases transfer to other cognitive constructs. The present study examines how these memory gains translate into gains in the three types of cognitive processing described by cognitive load theory.


## Introduction

Working memory is the brain's mechanism for accessing and processing information from sensory input or recalled from long term memory. Working memory has a limited capacity for information storage and processing. In this regard, the limits of working memory set the boundaries of learning potential. Instruction that makes efficient use of limited working memory will increase learning possibilities. Cognitive load theory and the cognitive theory of multimedia instruction prescribe evidence-based strategies to maximize learning through efficient use of working memory limits. Recent research demonstrates that working memory capacity can be increased through memory training, and that these increases can be transferred to other cognitive constructs. The present study examines how these memory gains translate into gains in the three types of cognitive processing described by cognitive load theory.

## Objectives or purposes

The objectives of the present proposed study are to determine: (i) whether working memory gains from dual *n*-back training translate into consequent reductions in cognitive load; (ii) the degree to which each of the three types of cognitive load is impacted by dual *n*-back training; and (iii) whether dual *n*-back working memory gains result in specific or general processing capacity gains. The research hypotheses for the study are:

Hypothesis 1: Participants with dual n-back training will experience lower overall cognitive load in learning tasks.

Hypothesis 2: Participants with dual n-back training will experience lower extraneous, intrinsic, and germane load in learning tasks.

Hypothesis 3: Participants with dual *n*-back training will experience increases in extraneous, intrinsic, and germane processing capacity.

## Theoretical framework

### Cognitive Load Theory and the Cognitive Theory of Multimedia Learning

Cognitive load theory (Kirschner, 2002; Sweller, 1994, 2005; Sweller, van Merriënboer, and Paas, 1998) and the cognitive theory of multimedia learning (Mayer, 2001, 2005a, 2008; Mayer & Moreno, 2003) have been successful in explaining ways in which instruction can promote or hinder learning. According to these theories, learning involves the construction and automation of schema for information processing. Instruction should be designed to maximize learning, and hence must encourage schema formation and automation. Because schema construction places a considerable demand on limited working memory resources, instructional activities that do not promote schema construction should be avoided.

## Cognitive Load

Cognitive load refers to the processing demands placed on working memory capacity during learning. Cognitive processing can be of three types:

- *intrinsic* – essential for understanding the learning content and the result of the complexity of the material and the prior knowledge and expertise of the learner;
- *extraneous* – the result of the inherent complexity of the learning environment but does not directly support learning;
- *germane* – promotes schema formation through the organization of learning content and the integration of that content with learner prior knowledge and experience (Mayer, 2008; DeLeeuw & Mayer, 2008).

Total cognitive load cannot exceed the limits of working memory capacity. Learning is promoted when instructional design minimizes extraneous load in order to free up resources for intrinsic and germane processing, each of which play an essential role in learning (Mayer, 2008). Cognitive load theory (CLT) and the cognitive theory of multimedia learning (CTML) are robust in that they are supported by reams of evidence, and successfully predict learning outcomes particularly for novice learners.

## Measuring Cognitive Load

One of the persistent challenges of cognitive load research is one of measurement (Schnotz & Kürschner, 2007; DeLeeuw & Mayer, 2008; Brünken et al., 2003; Paas, Van Merriënboer, & Adam, 1994). Researchers commonly use one of three types of measures: dual-task reaction-time measures (Brünken et al., 2003; Brünken et al., 2002; Sweller, 1998; Chandler & Sweller, 1996), perceived effort ratings (Paas et al., 2003; Paas & Van Merriënboer, 1994; Paas, Van Merriënboer, & Adam, 1994), and perceived difficulty ratings (Ayres, 2006; Kalyuga et al., 1999; Mayer & Chandler, 2001). Each of these has been shown to be sensitive to adjustments in the design of instruction and hence useful for evaluating the impact of instruction on cognitive load.

Building on the findings of earlier studies, DeLeeuw and Mayer (2008) test each of the measures to determine first whether their findings would in fact support a tri-modal theory of cognitive load, and second, which measure was sensitive to which type of cognitive load. In that study, participants studied an instructional unit designed to tax the three modes of cognitive processing. Cognitive load was measured using each of the conventional measures (dual-task response times, effort ratings, and difficulty ratings). The results confirmed the tri-modal model of cognitive load and that the different measures were in fact sensitive to different modes of cognitive load: timed dual-task measures – extraneous load, effort ratings – intrinsic load, and difficulty ratings – germane load.

## Working Memory Training

Both CLT and CTML are based on the common understanding that working memory capacity is limited and fixed, so instructional efforts must focus on making the best use of limited working memory resources. Recent studies (for example, Jaeggi et al., 2008; Dahlin et al. 2008; Lee et al. 2007) have demonstrated that through specialized training, working memory capacity can be increased. These are not the first studies to demonstrate working memory improvements. In the past, however, improvements have been limited to memory tasks equivalent or similar to the training itself (Healy et al., 2006; Ericsson & Delaney, 1998). Cognitive training effects have failed to transfer to other learning-related constructs. In at least one of the recent studies, however, increases in working memory have been shown to transfer to tasks not similar to the training, including those reflecting learning-related constructs such as fluid intelligence (Jaeggi et al., 2008). In this study, participants who received computer-based training on dual *n*-back tasks demonstrated working memory and fluid intelligence increases related to the amount of training they received.

For CLT and CTML, learning capacity is directly linked to working memory capacity. This link is supported by neuroscience and cognitive science research linking working memory to intelligence constructs (for example, Bühner et al., 2008; Colom et al., 2008; Oberauer et al., 2008; Schweizer & Moosbrugger, 2004). Increases in working memory capacity should translate into increases in learning capacity, as learners should be able to manage greater cognitive load during learning tasks. In dual *n*-back training, participants increase their ability to recall information presented in dual modes – training for extraneous capacity. Gains in intrinsic capacity can also be inferred as intrinsic capacity is essentially a storage issue – the number of inter-related concepts can be activated in working memory at once (Sweller, 1994). If gains can be transferred to dissimilar working memory tasks as demonstrated in Jaeggi et al. (2008), germane load should also be reduced.

Dual *n*-back training should result in gains in intrinsic, extraneous *and* germane processing capacity.

## Methodology, data sources, and materials

Participants for the study are graduate and undergraduate students. The study employs a two-group pretest-posttest design with random assignment.

Both groups are given a content pretest to determine domain knowledge and experience. Both groups complete an e-learning module on the physics of tuning a Junkanoo drum making use of animations, diagrams, text, and narration. Cognitive load measures are those used in DeLeeuw and Mayer (2008). Extraneous load is measured using dual task response time. At four points in the module, extraneous load is increased by presenting a narrated diagram with redundant on-screen text. Redundancy can lead to extraneous load because learners are forced to reconcile the two verbal components (DeLeeuw and Mayer, 2008). Participants are asked to complete a secondary task – response times will be higher when extraneous load is high. Participants are asked to press the space bar as soon as they notice gradual changes in background color. Higher response times indicate greater cognitive load.

Intrinsic load is measured using mental effort ratings. At four points in the module, the instruction uses unusually complex sentences. Sentence complexity requires learners to hold several concepts in mind in order to understand the main point (DeLeeuw and Mayer, 2008). At each point, participants are asked to rate their mental effort on a nine-point scale from 1 (very low) to 9 (very high).

Germane load is measured using difficulty ratings. At the end of the lesson, participants are asked to rate the lesson on a nine-point difficulty scale from 1 (extremely easy) to 9 (extremely difficult). Additionally, participants complete a posttest of content learning.

Prior to the lesson, the treatment group completes 14 sessions of dual *n*-back training (see Fig. 1).

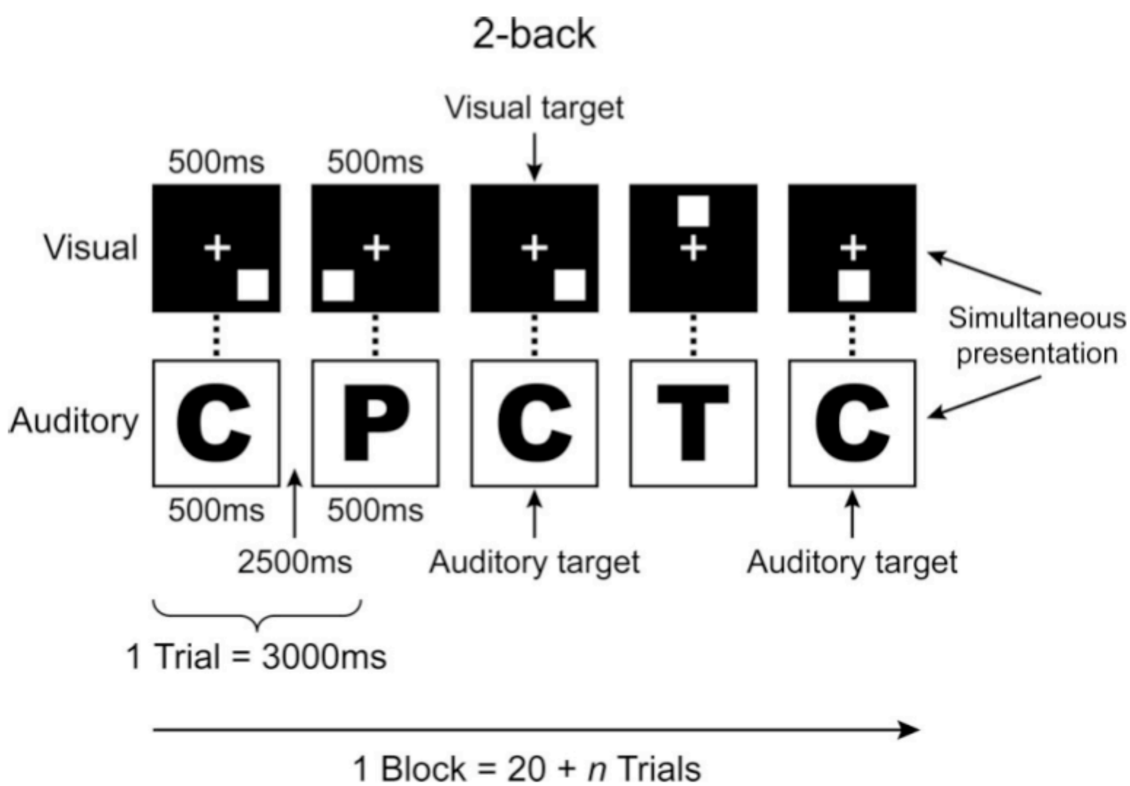


**Fig. 1.** The *n*-back training task shown for *n* = 2 back. Participants are given an auditory and visual stimulus simultaneously every 3 sec. Participants must record whether either of the stimuli repeat the stimulus *n*-spaces back (in this case 2-back). For each training session participants complete 20 blocks in approximately 25 min. (originally printed in Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences*, 105(19), 6829 © *PNAS*, 2008).

Working memory gains are evaluated using the WAIS III letter-number sequencing battery subscale (Kaufman & Lichtenberger, 2005) administered pre and post training. The dual *n*- back training is believed to be beneficial, so the control group completes 14 sessions of dual *n*-back of compensatory training after the experiment.

## Discussion

In this proposed study, it is anticipated that participants completing dual *n*-back training will demonstrate working memory gains comparable to those reported in Jaeggi et al. (2008). Moreover, these gains are expected to manifest themselves in increased extraneous and intrinsic processing capacity, in other lower words dual-task response times and lower effort ratings. Finally, if these gains transfer to non-similar working memory tasks, as reported by Jaeggi et al (2008), participants should increase germane capacity which in turn should transfer to lower overall difficulty ratings.

## Scholarly significance and educational Importance

The Jaeggi et al. (2008) study is groundbreaking because it is the first study to show conclusively that fluid intelligence can be significantly and meaningfully increased (Sternberg, 2008). The present study attempts to replicate and build on those findings by investigating how the dual *n*-back training gains impact both storage and processing functions working memory; how the training gains impact the three types of cognitive load, and what are the consequent implications for instructional design. Further this study will confirm or otherwise whether storage and processing functions of working memory draw on the same limited resources, and whether capacity can be loaned from one function to the other.

## Limitations

While it is expected that 14 sessions of dual *n*-back training is sufficient to see significant and meaningful improvements in sensitive measures of working memory capacity and fluid intelligence (Jaeggi et al. 2008), it is unknown whether self-report measures used to measure intrinsic and germane cognitive load are sufficiently sensitive. Longer training periods and larger samples would improve the accuracy of the experiment. Additionally, as noted by DeLeeuw and Mayer (2008) the measures of cognitive load are cumbersome and may affect the learning situation.

Both the Jaeggi et al. (2008) study and the present study use samples of university students. Learning activities are the occupation of students, perhaps making them unusually receptive to this type of training. Certainly, they would be better prepared and able to commit time to this type of cognitive training. Similar studies need to be conducted with participants from more diverse backgrounds.

## Conclusion

Cognitive load theory and the cognitive theory of multimedia learning propose a model of cognitive architecture that explains the mechanisms through which working memory contributes to learning. The instructional principles that follow from this model have been shown to promote learning especially for domain novices. New research suggests ways that working memory capacity can be increased, thereby increasing learning capacity. This study attempts to refine how working memory training translates into increases in cognitive processing capacities as proposed by CLT and CTML.

## References:

Ayres, P. (2006). Using subjective measures to detect variations of intrinsic cognitive load within problems. Learning and Instruction, 16(5), 389–400.

Brunken, R., Plass, J. L., & Leutner, D. (2003). Direct measurement of cognitive load in multimedia learning. Educational Psychologist, 38(1), 53–61.

Brünken, R., Steinbacher, S., Schnotz, W., Plass, J., & Leutner, D. (2002). Assessment of cognitive load in multimedia learning using dual-task methodology. Experimental Psychology, 49, 109 –119.

Bühner, M., Kröner, S., & Ziegler, M. (2008). Working memory, visual–spatial-intelligence and their relationship to problem-solving. Intelligence, 36(6), 672–680.

Chandler, P., & Sweller, J. (1996). Cognitive load while learning to use a computer program. Applied Cognitive Psychology, 10, 151–170.

Colom, R., Abad, F. J., Quiroga, M. Á., Shih, P. C., & Flores-Mendoza, C. (2008). Working memory and intelligence are highly related constructs, but why? Intelligence, 36(6), 584–606.

Dahlin, E., Nyberg, L., Bäckman, L., & Neely, A. S. (2008). Plasticity of executive functioning in young and older adults: Immediate training gains, transfer, and long-term maintenance. Psychology and Aging, 23(4), 720–730.

DeLeeuw, K. E., & Mayer, R. E. (2008). A Comparison of Three Measures of Cognitive Load: Evidence for Separable Measures of Intrinsic, Extraneous, and Germane Load. Journal of Educational Psychology, 100(1), 223–234.

Ericsson AK, Delaney PF (1998) Working memory and expert performance. In Logie R., Gilhooly K. J. eds. (1998). Working Memory and Thinking. Hillsdale, NJ: Erlbaum. 93–114.

Healy, A. F., Wohldmann, E. L., Sutton, E. M., & Bourne Jr, L. E. (2006). Specificity effects in training and transfer of speeded responses. Journal of experimental psychology. Learning, memory, and cognition, 32(3), 534.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. Proceedings of the National Academy of Sciences, 105(19), 6829.

Kalyuga, S., Chandler, P., & Sweller, J. (1999). Managing split-attention and redundancy in multimedia learning. Applied Cognitive Psychology, 13, 351–371.

Kaufman, A. S., & Lichtenberger, E. O. (2005). Assessing adolescent and adult intelligence. Hoboken, NJ: John Wiley & Sons, Inc.

Kirschner, P. A. (2002). Cognitive load theory: implications of cognitive load theory on the design of learning. Learning and Instruction, 12(1), 1-10.

Lee, Y., Lu, M., & Ko, H. (2007). Effects of skill training on working memory capacity. Learning and Instruction, 17(3), 336–344.

Mayer, R. E. (2001). Multimedia learning. New York: Cambridge University Press.

Mayer, R. E. (2005). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), Cambridge handbook of multimedia learning (pp. 31– 48). New York: Cambridge University Press.

Mayer, R. E. (2008). Applying the science of learning: Evidence-based principles for the design of multimedia instruction. American Psychologist, 63(8), 760-769.

Mayer, R. E., & Chandler, P. (2001). When learning is just a click away: Does simple user interaction foster deeper understanding of multimedia messages? Journal of Educational Psychology, 93, 390 –397.

Mayer, R. E., & Moreno, R. (2003). Nine Ways to Reduce Cognitive Load in Multimedia Learning. Educational Psychologist, 38(1), 43-52.

Oberauer, K., Süβ,H. M., Wilhelm, O., & Wittmann, W. W. (2008). Which working memory functions predict intelligence? Intelligence, 36(6), 641–652.

Paas, F., & van Merriënboer, J. J. (1994). Instructional control of cognitive load in the training of complex cognitive tasks. Educational Psychology Review, 6, 51–71.

Paas, F., van Merriënboer, J. J., & Adam, J. J. (1994). Measurement of cognitive load in instructional research. Perceptual & Motor Skills, 79, 419 – 430.

Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. M. (2003). Cognitive Load Measurement as a Means to Advance Cognitive Load Theory. Educational Psychologist, 38(1), 63-71.

Schnotz, W., & Kürschner, C. (2007). A reconsideration of cognitive load theory. Educational Psychology Review, 19(4), 469–508.

Schweizer, K., & Moosbrugger, H. (2004). Attention and working memory as predictors of intelligence. Intelligence, 32(4), 329–347.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. Learning and Instruction, 4(4), 295-312.

Sweller, J. (2005). Implications of cognitive load theory for multimedia learning. In R. E. Mayer (Ed.), Cambridge handbook of multimedia learning (pp. 19 –30). New York: Cambridge University Press.

Sweller, J., Van Merriënboer, J., & Paas, F. (1998). Cognitive Architecture and Instructional Design. Educational Psychology Review, 10(3), 251-296.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. Cognitive Science, 12, 257–285.

Sternberg, R. J. (2008). Increasing fluid intelligence is possible after all. Proceedings of the National Academy of Sciences, 105(19), 6791.