



## Working memory capacity and reading skill moderate the effectiveness of strategy training in learning from hypertext<sup>☆</sup>

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### Abstract

Cognitive and metacognitive strategies are particularly important for learning with hypertext. The effectiveness of strategy training, however, depends on available working memory resources. Thus, especially learners high on working memory capacity can profit from strategy training, while learners low on working memory capacity might easily be overtaxed. In addition, efficient basic reading comprehension processes are important for strategy training to be successful: When both the newly acquired strategies and poorly routinized basic reading comprehension processes compete for working memory resources, navigation within the hypertext and learning might deteriorate rather than improve. In an experiment, 64 undergraduates learned with a comprehensive expository hypertext after receiving either a cognitive or a metacognitive or no strategy training. In line with the predictions, learners high on working memory capacity or reading skill could profit from learning strategy training in terms of learning outcomes and the quality of their navigational behavior. Learners low on working memory capacity or reading skill, in contrast, performed worse in both training conditions compared to the control condition. The improvement in learning outcomes for skilled learners as well as the impairment in learning outcomes for unskilled learners could be shown to be indirect effects mediated by the quality of navigational behavior.

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Hypertexts are non-linear computer-based texts that consist of individual pages connected via hyperlinks. Readers may navigate from one page to another by clicking on a hyperlink. Compared to learning with expository texts that follow a linear structure, learning from expository hypertext can be beneficial in complex learning tasks because hypertexts provide learners

with more degrees of freedom in accessing and organizing information according to their specific needs and interests. At the same time, the non-linearity of hypertexts poses higher demands on the self-regulatory skills of learners (e.g., Shapiro & Niederhauser, 2004). Learning strategies may be particularly important to take advantage of the hypertext's non-linearity (Azevedo, Guthrie, & Seibert, 2004). Accordingly, learning strategy training which is explicitly tailored to the specific characteristics of expository hypertexts promises to have large positive effects on the efficiency of the learning process and the quality of learning outcomes (Azevedo & Cromley, 2004). From an aptitude–treatment–interaction perspective, however, not all kinds of learners may be expected to benefit from this training to the same extent. In this article, we will argue that the availability of ample working memory resources is a crucial precondition for learning strategy training to be successful. This is because learning strategies are resource-demanding,

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especially when these strategies have been acquired only recently. As a consequence, learners with small working memory capacities or poorly routinized basic reading comprehension processes are easily overtaxed, which may even lead to deteriorated learning outcomes after training.

In the following sections, we will start with an account of strategic processing in hypertext use, following Weinstein and Mayer's (1986) classification of cognitive and metacognitive learning strategies. We will especially dwell on the role of working memory capacity for the efficient use of newly acquired strategies, and on the relationship of available working memory and reading skill. From these two lines of research, we will derive the prediction that individual differences in working memory capacity and reading skill moderate the efficient use of newly acquired strategic knowledge in a similar fashion: While learning strategy training may have positive effects on learning with hypertext in learners with a high working memory capacity or well-routinized basic reading comprehension processes, they may even be harmful in learners with a low working memory capacity or poorly routinized basic reading comprehension processes. We tested these predictions in a training experiment in which university students were given a training of cognitive or metacognitive learning strategies. In addition to assessing learning outcomes, we also monitored learners' navigational behavior while interacting with the hypertext. In this way, we were able to investigate whether the hypothesized effects of learning strategy training, working memory capacity and reading skill on learning outcomes are mediated by the quality of navigational behavior.

### 1. Strategic processing in learning with hypertext

Learning strategies are activities that learners may intentionally engage in to improve or regulate learning processes. Following the traditional conceptualization of metacognitive skills as second-order cognitive processes (Brown, Bransford, Ferrara, & Campione, 1983), we adopt the distinction between cognitive and metacognitive learning strategies that has been put forward by Weinstein and Mayer (1986) and others (e.g., Pintrich, Smith, Garcia, & McKeachie, 1993). We view this distinction as a useful heuristic. However, it is important to note that our argument is also consistent with frameworks of self-regulated learning that present a unitary perspective (for example, the information-processing model proposed by Winne, 2001).

*Cognitive strategies* are strategic information-processing activities. Two types of cognitive strategies that may be particularly relevant for learning with hypertext are organization and elaboration. Organization strategies are directed at grasping the semantic macrostructure, i.e. the topical and conceptual structure of learning materials (van Dijk & Kintsch, 1983). In learning with hypertext, organization strategies may support learners in actively constructing a macrostructural representation of the text contents despite the lack of a specific sequence in which topics and subtopics are introduced. In addition, organization strategies may help learners to understand how a given hypertext is structured in technical terms (e.g., its link

structure and the available navigational features). Elaboration strategies are directed at the construction of a situation model of the text content, i.e. a referential representation that integrates information from the text with prior knowledge (van Dijk & Kintsch, 1983). Elaboration strategies may be especially helpful in learning with hypertexts because they support learners to infer semantic and conceptual relationships between contents of different nodes in the hypertext. In contrast to linear expository texts that guide learners in the construction of a coherent situation model, hypertexts require a much greater deal of active elaboration.

*Metacognitive strategies* are second-level processes that control and regulate information-processing activities (e.g., cognitive learning strategies). Two types of metacognitive strategies which may be particularly relevant for learning with hypertext are planning and monitoring (e.g., McNamara & Shapiro, 2005). Learners use planning strategies to break down a general learning goal into more specific subgoals or to decide, for example, what they want to study, which kinds of learning materials they want to use, or when they want to study these materials. In contrast to typical linear expository texts, hypertexts leave it to the learner to select particular contents and to decide on the order in which these contents are processed. Therefore, the use of planning strategies may be regarded as essential for learning with hypertext. Monitoring strategies refer to activities such as observing one's own progress in learning, checking on whether the current learning activities still serve the actual learning goal, or detecting comprehension difficulties that make it necessary to consult other parts of the learning materials. Similar to planning, the non-linear structure and the greater degrees of freedom of expository hypertexts requires a great deal of monitoring activities on behalf of the learner.

In line with these considerations, a number of experimental and correlational studies have demonstrated that the use of cognitive and metacognitive strategies can indeed foster learning with hypertext (Azevedo & Cromley, 2004; Azevedo et al., 2004; Young, 1996). For example, Azevedo and Cromley (2004) conducted a training study on learning with hypermedia. In the course of the training, students were instructed to make use of self-regulated learning (SRL) strategies. The bundle of strategies that was taught to participants comprised of cognitive strategies (such as knowledge elaboration, prior knowledge activation or summarization) as well as metacognitive strategies (such as planning and monitoring). Students who had received the SRL training performed much better than untrained students, and think-aloud data indicated that they implemented SRL strategies in a better way than untrained participants.

Similar results were reported by Richter, Naumann, Brunner and Christmann (2005) who also found that cognitive learning strategies (assessed by think-aloud protocols) enhanced learning outcomes by improving learners' interaction with the hypertext, i.e. their navigational behavior. Generally, learners differ greatly in their selection of hypertext pages, the time they spent on these pages, and their navigational paths (e.g., Shapiro, 1998; Shapiro & Niederhauser, 2004). It is likely that some aspects of navigational behavior reflect the application of

learning strategies. For example, the ability to select and focus on pages with content that is relevant for the learning task (knowledge seeking, Lawless & Brown, 1997) might be based on organization, planning, and monitoring strategies. Among other aspects of navigational behavior such as the linearity and connectedness of learners' navigational paths, selecting and focusing on task-relevant pages is also a strong determinant of learning outcomes (Gräsel, Fischer, & Mandl, 2001; McEneaney, 2001; Naumann, Richter, Flender, Christmann, & Groeben, 2007; Niederhauser, Reynolds, Salmen, & Skomolski, 2000; Puntambekar & Stylianou, 2005; Richter, Naumann, & Noller, 2003). Against this background, it seems plausible to assume that the effects of learning strategies on learning outcomes are at least partly mediated by learners' navigational behavior.

## **2. Working memory capacity as a limiting factor of strategy use**

Despite the overall beneficial role of cognitive and metacognitive strategies in learning with hypertext, the use of these strategies is not always advantageous. When learning strategies have only recently been acquired, in particular, their use poses great demands on working memory capacity, which in turn may have deteriorating effects on learning (Sweller, van Marrienoer, & Paas, 1998; Winne, 2001). Theoretically, this proposition is backed by two quite general assumptions from cognitive psychology. First, cognitive models of skill acquisition assume that newly learned skills rely on declarative representations and serial cognitive processes that require a large amount of working memory capacity (e.g., Anderson, 1987). Only at a later point, when skills have been transformed into procedural knowledge and routinized by practice, working memory load is reduced. Second, working memory capacity is limited (e.g., Just & Carpenter, 1992). As a consequence, when resource demands of cognitive processes that are carried out at a given time point exceed the capacity limits, they interfere with each other and performance is impaired or slowed down. It seems reasonable to suppose that these two general principles also apply to cognitive and metacognitive learning strategies and their interactions with other cognitive processes. Accordingly, individual differences in working memory capacity can be expected to moderate the effectiveness of learning strategy training.

## **3. Working memory capacity and reading skill**

Reading itself is an activity that draws upon working memory to a considerable degree. Many of the component processes of reading comprehension, such as semantic and syntactic integration of words within sentences, establishing coherence relations between sentences, and establishing a coherent representation of comprehensive texts, demand working memory resources. In all of these processes, information from the text and information retrieved from long term memory must be temporarily kept in memory to be integrated with newly incoming information while further portions of the text are processed (e.g., Just & Carpenter, 1992). However, even adult

readers without specific reading difficulties (such as college students) differ widely in the degree to which basic reading comprehension processes are routinized (e.g., Perfetti, 1994). These individual differences in reading skill have direct consequences for the amount of cognitive resources available for other tasks. For this reason, not only working memory capacity itself but also reading skill may be assumed to be a moderator of the short-term effectiveness of learning strategy training. The better the routinization of basic reading comprehension processes, the more working memory resources are available to implement and practice newly acquired cognitive and metacognitive strategies in an appropriate manner. Accordingly, highly skilled readers, i.e. those with efficient basic reading comprehension processes, should profit most from a training of cognitive or metacognitive strategies in learning with hypertext. For readers with low levels of reading skill, in contrast, a training of these strategies might even have deteriorating effects on learning outcomes because their working memory capacity might easily be overtaxed. In this case, not only the implementation of the newly acquired strategies may suffer but also the reading comprehension processes themselves, leading to backfire effects of cognitive and metacognitive strategy training.

## **4. Rationale of the present experiment**

The purpose of the present experiment was threefold. The first goal was to directly test the assumption that individual differences in working memory capacity moderate the extent to which cognitive and metacognitive strategy training can be used effectively in the acquisition of declarative knowledge from hypertext. In particular, we expected a stronger (positive) relationship of working memory capacity and learning outcomes in learners who had received a strategy training compared to those who had not received such a training. Stated with regard to the moderating role of working memory capacity, we expected that a training of cognitive or metacognitive learning strategies would improve the learning outcomes of learners with a large working memory capacity because these learners should be able to spare working memory resources to implement and practice these strategies. For learners with a small working memory capacity, in contrast, we expected that the attempt to use recently acquired learning strategies would interfere with other types of comprehension processes, rendering the training ineffective or even harmful.

The second goal was to test the assumption of a similar moderating role of reading skill. We expected a stronger (positive) relationship of reading skill and learning outcomes in learners who had received a strategy training compared to those who had not received such a training. Stated differently, we expected that a strategy training would benefit the learning outcomes of skilled readers, i.e. those with highly routinized basic reading comprehension processes, because these readers should be able to allocate the amount of working memory resources needed for a successful implementation of the acquired strategies. For unskilled readers, in contrast, we expected the training to be ineffective or even deteriorate

learning outcomes, because large parts of these learners' working memory resources are needed to carry out basic reading comprehension processes. When newly acquired cognitive or metacognitive learning strategies pose additional demands on working memory, these strategies cannot be implemented and practiced in an appropriate way and may even interfere with reading comprehension, resulting in worsened learning outcomes. It is important to note that despite the fact that we predicted the same patterns of interaction effects for working memory capacity and reading skill, the predictions refer to different types of processes. Working memory capacity is an individual difference variable that poses general restrictions on cognitive resources. Deficient reading skill, in contrast, can restrict the availability of cognitive resources because cognitive resources are used up for basic reading comprehension processes.

We included two different types of strategy training, cognitive and metacognitive strategy training, to be able to investigate potential differences in the effects of these types of training on learning outcomes in an exploratory fashion. Most previous training studies have examined the effects of combined cognitive and metacognitive strategies in learning from linear text (e.g. McNamara, 2004; McNamara, Levinstein, & Boonthum, 2004) or learning from hypertext (e.g., Azevedo & Cromley, 2004). Theoretically, both training types can be assumed to be beneficial for learners high reading skill or working memory capacity. For this reason, we made no specific prediction of whether one or the other training would be more efficient.

The third goal was to investigate whether the quality of interacting with the expository hypertext, i.e. the navigational behavior of learners, would mediate the hypothesized interac-

tion effects of learning strategy training and working memory capacity or reading skill on learning outcomes. Theoretically, this goal is motivated by the general idea that learning strategies improve learning outcomes by making navigational behavior more effective (e.g., Richter et al., 2005). If working memory capacity and reading skill indeed moderate the effectiveness of learning strategy training, the same pattern of effects that was hypothesized for learning outcomes as a dependent variable may also be expected for the quality of the interaction with the hypertext. In other words, the navigational behavior of learners on a high level of working memory capacity or reading skill should be improved by a training of cognitive or metacognitive strategies whereas the navigational behavior of learners on a low level of working memory capacity or reading skill should be impaired by the same training. We included the frequency of visits to task-relevant pages as a measure of the quality of navigational behavior. This measure may be assumed to be indicative of the ability to select and focus on relevant contents (knowledge seeking, Lawless & Brown, 1997). As such, it is likely to be positively related to learning outcomes (e.g., Richter et al., 2003).

In combination, both hypotheses add up to the prediction of a mediating role of the quality of navigational behavior: The hypothesized interaction effect of learning strategy training and working memory capacity or reading skill on learning outcomes should be mediated by the quality of navigational behavior (moderated mediation, Preacher, Rucker, & Hayes, 2007; see Fig. 1). We tested these predictions in an experiment with learning materials and learning tasks that resembled everyday, self-regulated learning activities of the participants (psychology undergraduates) as closely as possible.

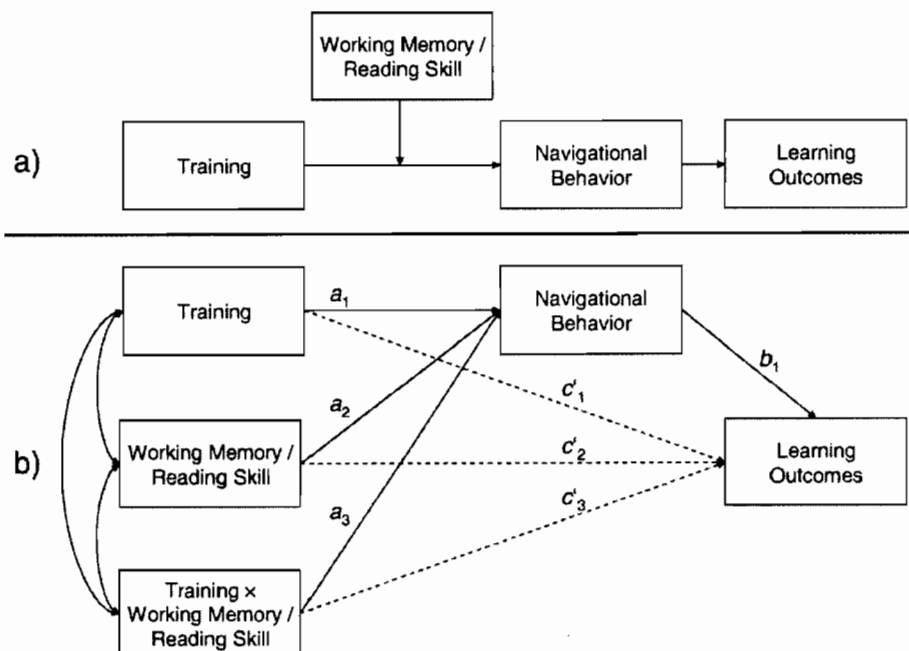


Fig. 1. Moderated mediation model (a) and corresponding path diagram (b). The effect of learning strategies on the quality of navigational behavior was assumed to be moderated by working memory capacity or reading skill, while the quality of navigational behavior was assumed to linearly predict learning outcomes. The dotted lines in (b) refer to direct effects, the solid lines to indirect effects that are mediated through the quality of navigational behavior.

## 5. Method

### 5.1. Participants

Sixty-four undergraduate psychology students (72% female, mean age 24.3 years,  $SD=4.5$ ) from the universities of Cologne and Heidelberg participated in the study. They were either paid €35.- (approx. \$40.-) or received credit for their participation. All of the participants had taken introductory psychology courses but none of them had taken courses in the psychology of perception or visual perception prior to the experiment.

### 5.2. Hypertext material

We used a comprehensive expository hypertext that provided declarative knowledge on the psychology of visual perception. The hypertext consisted of 230 nodes, divided into nine sections such as a general introduction to visual perception, the physiological basis of visual perception, perception of color, perception of space, or perception of movement. The hypertext's nodes were interconnected by a total of 540 cross-reference links that connected nodes within the same as well as in different sections. Each of the nine sections was directly accessible from the introductory page and through a small browser, which mimicked the introductory page and was shown at the bottom left of each page (see Fig. 2 for screen shots). Additional non-linear navigational aids were a backtrack function, a history list, a dynamic table of contents (lists of sub-sections opened up when participants clicked on chapter or section headers) and a browser called gallery, which displayed figures from each chapter of the hypertext. Clicking on these figures opened the respective chapter (e.g., clicking on a figure of the Mueller–Lyer illusion opened the chapter on the Mueller–Lyer illusion). In a survey among 20 hypertext experts, the hypertext was rated as highly prototypical and well usable (Flender & Christmann, 2000).

In addition to the experimental hypertext on visual perception, we used a hypertext on the psychology of old age in a baseline task. This hypertext was less comprehensive than the experimental hypertext (54 nodes), but the structure and navigational aids of both texts were identical. Psychology of old age was chosen as a topic for the baseline task because it has little overlap with the topic of the experimental hypertext but still falls into the area of psychology (our participants' major area of studies). All hypertexts had been written specifically for the research reported here.

### 5.3. Procedure and tasks

Experimental sessions were run in groups of up to five participants. The sessions started with a baseline essay writing task. Participants studied the baseline hypertext on the psychology of old age and were asked to write an essay on the question of whether there is a general decline of cognitive abilities in old age. They were assigned 15 min to study with the hypertext and 15 min to complete the essay. Subsequently, participants received a training in either cognitive learning

strategies ( $n=19$ ) or metacognitive learning strategies ( $n=23$ ) or they were assigned to a control group ( $n=22$ ), in which only general information on the potential advantages of learning with hypertext but no information on learning strategies was given. In both training conditions, participants were asked to study and subsequently use six different learning strategies. Participants in the cognitive training condition were trained in three organization strategies and three elaboration strategies. The organization strategies trained in this condition were familiarizing oneself with the text contents, identifying parts of the text being relevant for the learning task, and getting an overview of the structure of the hypertext and its navigational devices. The elaboration strategies trained in the cognitive training condition were realizing conceptual relationships between different pages of the hypertext, integrating prior knowledge and text contents, and forming expectations about the contents of upcoming pages of the hypertext. Participants in the metacognitive training condition were trained in three planning strategies and three monitoring strategies. The planning strategies trained in this condition were setting a learning goal and developing a navigational strategy, translating the general learning goal into more concrete subgoals, and revising learning goals and strategies during learning if necessary. The monitoring strategies trained in the metacognitive training condition were comprehension monitoring, monitoring the relevance of text contents for the actual learning goal, and monitoring depth of processing during learning.

All training materials were tailored to the use of these strategies in learning with hypertext. The planning strategies taught in the metacognitive training condition, for example, were related to the proper planning of hypertext navigation. Likewise, the organization strategies taught in the cognitive training condition were directed at grasping the structure of the hypertext and its navigational features. The experimental sessions comprised of a training and an assessment phase. The training combined elements of explicit instruction (Ross, 1988), behavior modeling training (Taylor, Russ, Darlene, & Chan, 2005), and self-guided practice (Donchin, 1989). Accordingly, the training consisted of an instruction phase and a practice phase.

### 5.4. Instruction phase

Participants were provided with handouts describing the respective strategies and how to appropriately use them, and asked to read these handouts carefully. In these handouts, each strategy was first presented shortly and then elaborated on approximately half a page with respect to how exactly it might be used. In the control condition, they received a handout on hypertext and its potential advantages for learning. Additionally, the experimenter gave a 30-minutes presentation on the strategies. The presentation included six 2-minute video clips in which a model demonstrated the use of each strategy by verbalizing the respective strategies during interacting with the hypertext on the psychology of old age that had been used in the baseline assessment task. In the control condition, the experimenter gave a presentation on hypertext and its potential



Fig. 2. Screen shots of the introductory page (a) and a typical content page (b) of the experimental hypertext.

advantages for learning. There were no video demonstrations in the control condition.

### 5.5. Practice phase

In the second part of the training, participants were asked to study with the hypertext in order to write an essay on a specific topic within the area of visual perception. Participants in the training condition were told that they should practice the application of the strategies that they had just learned while

interacting with the hypertext. To make the results less dependent on the distinctive features of one particular topic, we used a total of four essay writing tasks. The assignment of these tasks to practice vs. assessment phase as well as to the two training conditions and the control condition were counter-balanced across participants. All four tasks were comparable in difficulty and in the scope of the contents that had to be studied to accomplish the task. Most importantly, each task required that contents from two different sections of the hypertext had to be related to each other. Either one task referred to perceptual

constancy, perception of color, optical illusions, and perception of form. Each task comprised of two subtasks. The task referring to perceptual constancy, for example, was given with the following instructions:

- (a) Please describe what perceptual constancy is. Address constancy of form, and how it might be explained. Compare possible explanations to explanations for constancy of size.
- (b) Describe what constancy of size is and how it might be explained. Amongst other things, relate the explanations for constancy of size to the explanation for constancy of form.

Participants had 45 min to study with the hypertext and another 45 min to write the essay. They were allowed to take notes while studying with the hypertext. During writing, participants had no access to the hypertext but were allowed to use the notes they had taken. Participants wrote their essays on a computer using *Word for Windows*.

5.6. Assessment phase

After a 1-hour break, participants were assigned a second essay writing task on a different topic. Participants in the training conditions were asked to make use of the strategies they had been practicing. The procedure for the essay writing task in the assessment phase was the same as for the practice essay, with the only difference that participants now had 1 h to study for and 1 h to complete their essay.

5.7. Measured variables

5.7.1. Working memory capacity, reading abilities and prior knowledge

Two weeks before the experimental sessions, individual differences in working memory capacity, reading ability and

prior knowledge were assessed. Working memory capacity was measured through the reading span test (Daneman & Carpenter, 1980). The reading span was computed as the number of unrelated sentences for which both the sentences' last word and meaning can simultaneously be kept in memory and reproduced in the correct order. We used the German version of the test material provided by Hacker, Veres, and Wollenberger (1994). Reading skill was assessed with the subtest *Sentence Verification* of a German-speaking reading skills test called ELVES (*Assessment of the efficiency of component reading processes in adult readers according to the strategy model*, Richter & van Holt, 2005). This subtest captures the efficiency of sentence-level reading comprehension processes (word recognition, syntactic parsing, semantic integration). Fifteen statements are to be judged as "true" or "false" as fast as possible. Response speed and accuracy are combined into test scores by summing up the reciprocally transformed response times for all correct answers. As a consequence, test scores increase with correct and fast responses. The internal consistency of the scale was .87 (Cronbach's  $\alpha$ ) in the present sample. Working memory capacity and reading skill measured with ELVES had a correlation of .67 (Table 1), indicating that the two variables are related to each other but do not capture identical constructs. Prior knowledge was measured through 12 multiple choice items (one correct answer, three distractors) that referred to knowledge about basic concepts in the area of visual perception (e.g., "Fovea"). This scale had an internal consistency of .64 in the present sample. The mean item difficulty was .20, indicating an overall low prior knowledge in our participants (Table 1).

5.7.2. Baseline performance and learning outcomes

For the assessment of baseline performance and learning outcomes, participants' essays from the baseline task and the assessment phase were divided into idea units and the number of task-related idea that contained correct information was

Table 1  
Means, standard deviations and correlations for all variables

	Correlations		1	2	3	4	5	6	7
	M	SD							
<i>Predictor variables</i>									
1. Training vs. control <sup>a</sup>	-0.01	0.48							
2. Cognitive vs. metacognitive training <sup>b</sup>	0.03	0.47	.06						
3. Prior knowledge (0–12)	2.50	2.08	.08	.06					
4. Working memory capacity (1–6)	2.41	1.26	-.08	-.03	.13				
5. Reading skill	18.56	4.84	-.23	.26*	.22	.63***			
6. Baseline number of task-related idea units (log.)	3.15	0.32	-.21	-.15	.12	.36**	.22		
<i>Navigational behavior</i>									
7. Number of visits to task-related pages (log.) <sup>c</sup>	4.17	0.55	.01	-.01	.19	.17	.34**	.20	
<i>Learning outcome</i>									
8. Number of task-related idea units (log.)	3.67	0.34	-.15	.06	.18	.34**	.42***	.52***	.56***

Note. N=64.

\* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$  (two-tailed).

<sup>a</sup> Contrast-coded, training (n=42)=1/3, control (n=22)=-2/3.

<sup>b</sup> Contrast coded, cognitive training (n=19)=-1/2, metacognitive training (n=23)=1/2.

<sup>c</sup> N=63 due to missing log file data for one participant.

counted. The reliability of the segmentation into idea units was .94 (proportion of agreement). The intercoder-reliability for identifying correct task-related idea units was .68 (Cohen's  $\kappa$ ), a value that indicates good interrater agreement according to the recommendations by Landis and Koch (1977). Interrater agreement was estimated from an independent sample of three essays and three coders (two of the authors and a student research assistant, cf. Naumann et al., 2007). The coders were familiar with the content of the hypertext material and provided their judgments on the basis of a detailed list of task-relevant sections of the hypertext. Being based on frequencies, the number of task-related idea units for both the experimental session and the baseline were heavily skewed to the right. We applied a logarithmic transformation prior to all statistical analyses to normalize the distributions of these variables (Cohen, Cohen, West, & Aiken, 2003, ch. 6).

### 5.7.3. *Quality of navigational behavior*

While participants studied with the experimental hypertext, their navigational paths were recorded. As a measure of the quality of navigational behavior, we determined the pages of the hypertext that were particularly relevant for the respective essay. For the task referring to perceptual constancy, for example, all pages providing information on perceptual constancies (e.g., constancy of form, constancy of size, constancy of color) and pages providing explanations for perceptual constancies were classified as task-relevant pages. We then counted the visits to these pages using the software tool LOGPAT (Log File Pattern Analysis, Richter et al., 2003). The number of visits to task-relevant pages reflects the extent to which participants were able to find, select, and focus on the contents that were relevant for their learning task. Again, to account for the skewness of the raw frequencies, we applied a logarithmic transformation prior to all statistical analyses.

## 6. Results

Descriptive statistics and intercorrelations for all variables in the study are given in Table 1. Prior knowledge, working memory capacity, and baseline performance did not differ between the training groups and the control group or between training groups, indicating that the groups were equivalent with respect to these variables (Table 1, columns 3–4, lines 3, 4, 6). There was a slightly higher level of reading skill in the metacognitive compared to the cognitive training group. Importantly, however, reading skill did not differ between the training groups and the control group. An a-priori  $\alpha$ -level of 5% was set for all statistical tests. As measure of effect size, we report the decrement in the ratio of explained to total variance ( $\Delta R^2$ ).

For each working memory capacity and reading skill as a moderator, we tested for the hypothesized moderation and mediation effects separately in sequences of three steps. First, we probed whether learning outcomes were indeed dependent on training, working memory capacity or reading skill, and, most importantly, the hypothesized interaction between training and the respective individual difference variable (step one).

Subsequently we tested whether navigational behavior would be dependent on training and working memory capacity or reading skill in a manner comparable to the pattern for learning outcomes (step two). Provided that this turned out to be the case, it would make sense to conduct explicit tests of whether any effect of training on learning outcomes conditional on working memory capacity or reading skill would be mediated by navigational behavior (step three).

For the first two steps we conducted multiple regression analyses with interaction terms (moderated regression analyses, Aiken & West, 1991). In step one, learning outcome was regressed on training condition (training vs. no training and cognitive vs. metacognitive training), the baseline number of task-related idea units, prior knowledge, working memory capacity or reading skill and the interaction of training condition and working memory capacity or reading skill. All predictors were entered simultaneously into the regression model. The baseline number of idea units, prior knowledge, working memory capacity, and reading skill were entered as  $z$ -standardized variables. Training condition was entered as two contrast-coded dummy variables. The first contrast captured the difference between training conditions (either cognitive or metacognitive) and the control condition, with training conditions being coded as 1/3 and the control condition being coded as  $-2/3$ . The second contrast captured the difference between the two training conditions, with cognitive training being coded as  $-1/2$  and metacognitive training as  $1/2$ . In step two, we regressed the number of visits to task-related pages on the same set of predictors with the exception of the baseline number of idea units. In step three, we determined the strength of the hypothesized conditional indirect effects as products of the direct paths linking training to navigation and navigation to learning outcomes while working memory capacity or reading skill were held constant on distinct values.

We report the results in two sections. The first section describes the results for working memory capacity as moderator variable, the second section describes the results for reading skill as a moderator variable.

### 6.1. *Results for working memory capacity as a moderator variable*

#### 6.1.1. *Step 1: Predicting learning outcomes from working memory capacity and training*

6.1.1.1. *Effects of essay writing tasks.* There were no differences between essay writing tasks in the number of task-related idea units, and there were no interactions between essay writing tasks and any of the predictor variables (for all tests:  $F < 1$ ). Therefore, all analyses were collapsed across essay writing tasks.

6.1.1.2. *Tests of distributional assumptions.* Residuals of the regression model for the number of task-related idea units were distributed normally (K-S  $z$ -test with Lillefors-boundaries:  $z(64) = 0.07$ ,  $p > .20$ ) and displayed no heteroscedasticity when plotted against the predicted values.



6.1.1.3. *Parameter estimates and hypothesis tests.* The parameter estimates of the regression model with the number of task-related idea units as criterion variable and working memory capacity as potential moderator of training effects are summarized in Table 2 (left columns). There were no main effects for training, neither for the contrast between the training conditions and the control group, nor for the contrast between the cognitive and metacognitive training conditions. As predicted, however, there was a large positive effect for working memory capacity. The main effect of working memory capacity was qualified by a large interaction with training condition ( $F(2,56)=13.01, p<.001, \Delta R^2=.21$ ). This interaction effect was mainly due to the first interaction contrast, capturing the difference between the average regression slope in the training conditions as compared to the regression slope in the control condition (Fig. 3a).

To interpret the interaction, we conducted simple slopes analyses (according to Aiken & West, 1991, ch. 2). In line with the predictions, these analyses revealed medium to strong positive effects of working memory capacity within the cognitive training condition ( $B=0.30, SE_B=0.07, t(56)=4.17, p<.001$ , one-tailed,  $\Delta R^2=.14$ ) and the metacognitive training condition ( $B=0.23, SE_B=0.08, t(56)=3.00, p<.01$ , one-tailed,  $\Delta R^2=.07$ ). In the control condition, in contrast, working memory capacity had no effect ( $B=-0.06, SE_B=0.04, t(56)=-1.47, p>.05$ , one-tailed,  $\Delta R^2=.02$ ). Probing differences between conditions at a high level of working memory capacity (one standard deviation above the mean) showed, as predicted, an advantage of trained over untrained participants ( $B=0.28, SE_B=0.09, t(56)=3.04, p<.01$ , one-tailed,  $\Delta R^2=.08$ ), while the cognitive and the metacognitive training proved to be equally efficient ( $B=0.03, SE_B=0.13, t(56)=0.25, p>.05$ , two-tailed,  $\Delta R^2=.00$ ). At a low level of working memory capacity, in contrast, trained participants performed considerably worse than untrained participants ( $B=-0.37, SE_B=0.09, t(56)=-3.99, p<.001$ , one-tailed,  $\Delta R^2=.13$ ), again independently of

which training they had received ( $B=0.19, SE_B=0.13, t(56)=1.50, p>.05$ , two-tailed,  $\Delta R^2=.02$ ).

In sum, there were no average effects of the strategy training, but the predicted aptitude–treatment–interaction of training and working memory capacity was observed: There was a strong positive effect of working memory capacity on learning outcomes in the training conditions, whereas no such relationship existed in the control condition. The intersection points of the regression lines were located at average values of working memory capacity (Fig. 3a), which implies that while the training proved to be beneficial for participants high on working memory capacity, the performance of participants low on working memory capacity was impaired. Given that the effects of strategy training were moderated by working memory capacity, it seemed reasonable to test whether these effects would indeed be a result of improved or impaired navigation, as predicted by the model displayed in Fig. 1.

6.1.2. *Step 2: Predicting navigational behavior from working memory capacity and training*

6.1.2.1. *Effects of essay writing tasks.* There were no differences between essay writing tasks in the number of visits to task-related pages, and no interactions between essay writing tasks and any of the predictor variables (for all tests:  $F<1.44, p>.24, \Delta R^2\leq.01$ ). Accordingly, all analyses were collapsed across essay writing tasks.

6.1.2.2. *Tests of distributional assumptions.* Residuals were distributed normally (K–S z-test with Lillefors-boundaries:  $z(63)=0.07, p>.20$ ) and displayed no heteroscedasticity when plotted against the predicted values.

6.1.2.3. *Parameter estimates and hypothesis tests.* The parameter estimates for the regression model with visits to

Table 2

Summary of moderated regression analyses for the effects of cognitive and metacognitive training and working memory capacity on learning outcomes (number of task-related idea units) and navigational behavior (visits to task-related pages)

	Dependent variable							
	Number of task-related idea units (log.)				Visits to task-related pages (log.)			
	B	SE <sub>B</sub>	t(56)	ΔR <sup>2</sup>	B	SE <sub>B</sub>	t(56)	ΔR <sup>2</sup>
Intercept (B <sub>0</sub> )	3.69	0.03			4.19	0.06		
Prior knowledge <sup>a</sup>	0.02	0.03	0.53	.00	0.07	0.06	1.15	.02
Baseline number of idea units <sup>a</sup>	0.15	0.04	3.92***	.13	–	–	–	–
Working memory <sup>a</sup>	0.16	0.04	4.05***	.13	0.22	0.08	2.94**	.12
Training vs. no training <sup>b</sup>	–0.05	0.07	–0.72	.00	0.01	0.14	0.05	.00
Cognitive vs. metacognitive training <sup>c</sup>	0.11	0.08	1.45	.02	–0.01	0.16	–0.03	.00
(Training vs. no training) × working memory	0.32	0.06	5.04***	.21	0.48	0.13	3.62***	.18
(Cognitive vs. metacognitive training) × working memory	–0.08	0.10	–0.76	.01	0.13	0.21	0.60	.00
Model fit	R <sup>2</sup> =0.54				R <sup>2</sup> =0.24			
Omnibus test	F(7,56)=9.44, p<.001				F(6,56)=2.98, p<.05			

Note. Working memory: Working memory capacity (reading span).

\*p<.05, \*\*p<.01, \*\*\*p<.001 (one-tailed).

<sup>a</sup> z-Standardized.

<sup>b</sup> Contrast-coded: training conditions = 1/3, control condition = –2/3.

<sup>c</sup> Contrast-coded: cognitive training = –0.5, metacognitive training = 0.5.

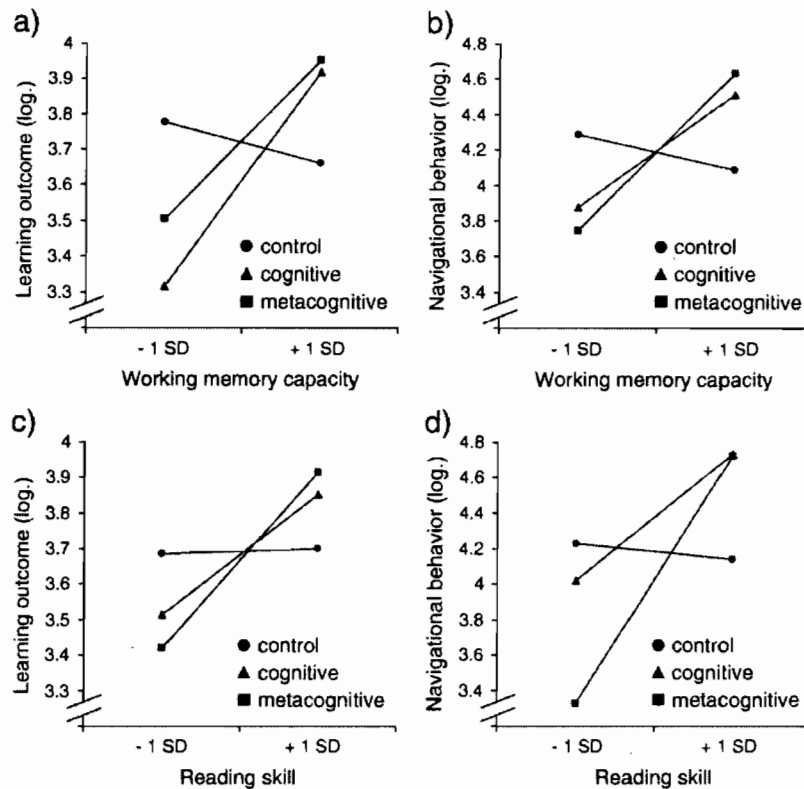


Fig. 3. Effects of training and working memory capacity (a) on learning outcomes (number of task-related idea units in the participants' essays), and (b) on the quality of navigational behavior (number of visits to task-related pages). Effects of training and reading skill (c) on learning outcomes (number of task-related idea units in the participants' essays), and (d) on the quality of navigational behavior (number of visits to task-related pages).

task-related pages as the criterion variable and working memory capacity as potential moderator are provided in Table 2 (right columns). There were no main effects for training, neither for the contrast between the training conditions and the control group nor for the contrast between the cognitive and the metacognitive training conditions. Working memory capacity, in contrast, had a large positive effect, that was again qualified by a large interaction effect with training condition ( $F(2,56) = 6.79, p < .01, \Delta R^2 = .18$ ). As in the previous analysis, the interaction was due to the interaction contrast comparing the average regression slope in the trained groups to the slope in the control group whereas there was no difference between the regression slopes in the two training conditions (Fig. 3b).

To interpret the interaction, we computed simple slopes. In line with the predictions, these analyses revealed a medium-sized positive effect of working memory capacity in the cognitive training condition ( $B = 0.32, SE_B = 0.15, t(56) = 2.12, p < .05$ , one-tailed,  $\Delta R^2 = .06$ ) and a large effect in the metacognitive training condition ( $B = 0.45, SE_B = 0.15, t(56) = 3.04, p < .01$ , one-tailed,  $\Delta R^2 = .13$ ). In the control condition, working memory capacity had no effect ( $B = -0.10, SE_B = 0.08, t(56) = -1.21, p > .05$ , one-tailed,  $\Delta R^2 = .02$ ). Probing differences between conditions at a high level of working memory capacity (one standard deviation above the mean) revealed a medium-sized advantage of trained over untrained participants ( $B = 0.49, SE_B = 0.19, t(56) = 2.58, p < .01$ , one-tailed,  $\Delta R^2 = .09$ ), while the cognitive and the metacognitive training

proved to be equally efficient ( $B = 0.12, SE_B = 0.27, t(56) = 0.45, p > .05$ , two-tailed,  $\Delta R^2 = .00$ ). At a low level of working memory capacity (one standard deviation below the mean), in contrast, trained participants had fewer visits to task-related pages than untrained participants ( $B = -0.47, SE_B = 0.19, t(56) = -2.51, p < .01$ , one-tailed,  $\Delta R^2 = .09$ ) but again, there was no difference between the cognitive and the metacognitive training conditions ( $B = -0.13, SE_B = 0.26, t(56) = -0.51, p > .05$ , two-tailed,  $\Delta R^2 = .00$ ).

Overall, the results for navigational behavior as a dependent variable closely resembled the results for learning outcome as a dependent variable. Participants high on working memory capacity could benefit from the cognitive and metacognitive strategy training, while participants low on working memory capacity performed worse after receiving one of these types of training. In the light of these results, it is plausible to assume that the interaction effects of training and working memory capacity on learning outcome were mediated through navigational behavior. Some evidence for this assumption was provided by the fact that the direct effects of working memory capacity and its interaction with training condition on learning outcomes were considerably weakened by including navigational behavior as a predictor (Fig. 4a), indicating a partial mediation of these effects through navigational behavior. In addition, we directly estimated and tested the mediating role of navigational behavior in step three.

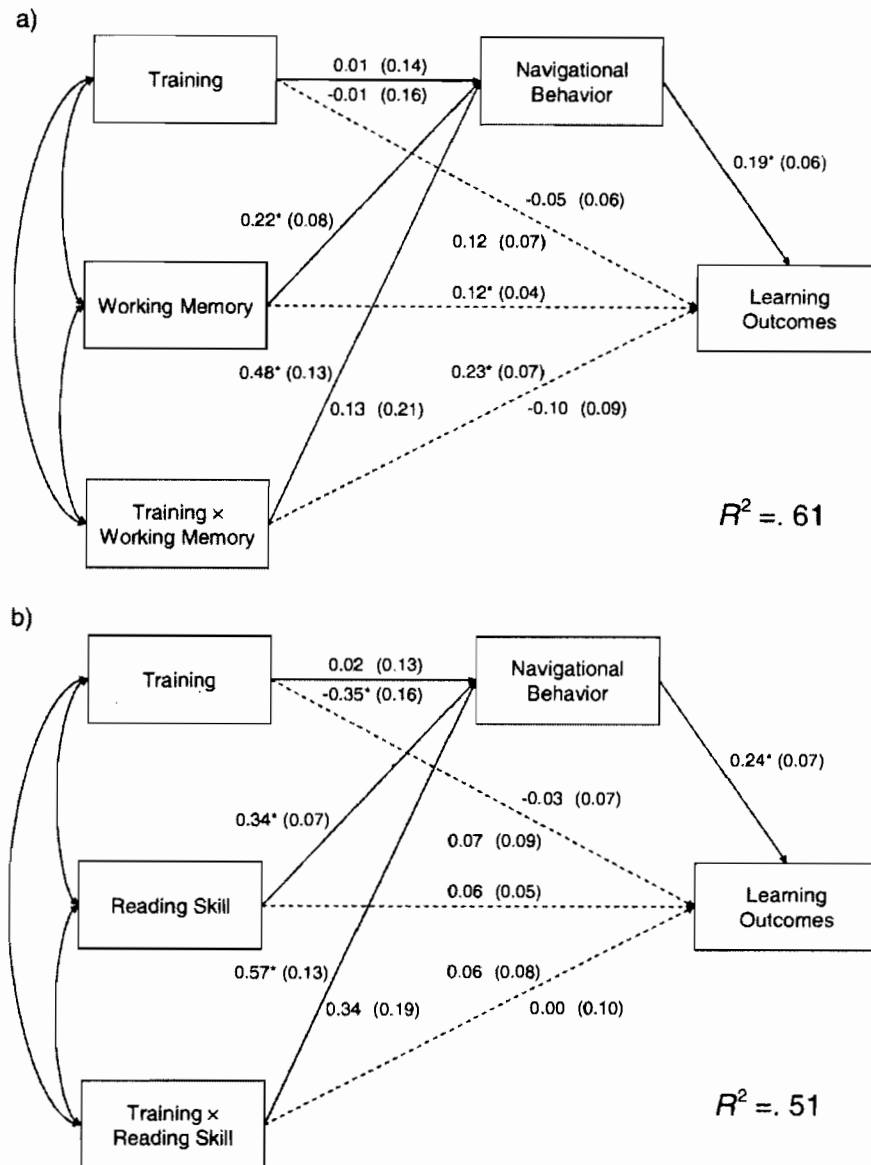


Fig. 4. Estimates of the regression weights in the moderated mediation model with (a) working memory capacity as moderator and (b) reading skill as moderator (unstandardized regression weights and standard errors). For the paths representing the main effect of training and the interaction of training with working memory capacity or reading skill, the coefficient printed above the path reflects the effect of the contrast variable comparing both training conditions to the control condition (or the corresponding interaction contrast), and the coefficient printed below the path reflects the effect of the contrast variable comparing cognitive and metacognitive training (or the corresponding interaction contrast). Coefficients marked with an asterisk turned out to be significant ( $p < .05$ ). Dotted lines refer to direct effects, solid lines to indirect effects.

6.1.3. Step 3: Probing indirect effects of training conditional on working memory

First, we tested whether the positive effect of the number of visits to task-related pages on the number of task-related idea units that participants produced in the essay writing task was constant across the training conditions and the control condition, which was the case ( $F(2,55)=0.16, p > .05, \Delta R^2 = .00$ ). To test for indirect conditional effects of training on learning outcomes, we relied on procedures suggested by Preacher et al. (2007). In terms of the notation used in the path diagram in Fig. 1, the indirect effect of training on learning outcomes through navigational behavior at a given value  $x$  of

working memory capacity can be expressed as  $b_1(a_1 + a_3[x])$ . Since the distribution of product terms is only asymptotically normal (e.g., McKinnon, Lockwood, & Williams, 2004; Shrout & Bolger, 2002), it is advisable to compute their standard errors through a bootstrapping procedure rather than to rely on distributional assumptions that can be met only in large samples. In small samples with a relatively limited power, such direct tests of indirect effects as products of direct paths are also better suited to address mediation hypotheses than a stepwise regression procedure (McKinnon, Lockwood, Hoffman, West, & Sheets, 2002). To date, moderated mediation models and bootstrap techniques for estimating the standard

errors in these models are elaborated only for models with one predictor variable. For this reason, we estimated two separate models for the indirect effects of the cognitive and metacognitive training conditions. We estimated conditional indirect effects of the training conditions by using an SPSS macro provided by Preacher and Hayes (2005). We computed estimates for the indirect effect of training through navigational behavior on learning outcomes for  $z$ -standardized working memory capacity for increments of 0.25 between  $-2$  and  $2$  (two standard deviations above and below the mean). For each of these models, 5000 bootstrap samples were used, and a percentile-based 95% confidence interval for the effect was estimated. The null hypothesis that no indirect training effect is present was rejected if zero was not included in the confidence interval.

At above-average levels of working memory capacity, cognitive training had a positive indirect effect on the number of task-related idea units, and this effect became stronger with increasing working memory capacity. Positive indirect effects of cognitive training were significant for participants with a working memory capacity of 0.75 standard deviations above the mean (estimate: 0.06;  $CI_{95\%}$ : >0.00 to 0.21) and higher. Likewise, positive indirect effects of metacognitive training were significant for participants with a working memory capacity of 0.75 standard deviations above the mean or higher (estimate: 0.09;  $CI_{95\%}$ : 0.01 to 0.21). For participants with a working memory capacity of two standard deviations above the mean, the indirect effect of cognitive training was estimated as 0.15 ( $CI_{95\%}$ : 0.02 to 0.42), and the indirect effect of metacognitive training was estimated as 0.23 ( $CI_{95\%}$ : 0.07 to 0.54).

Negative indirect effects of cognitive training were significant for participants with a working memory capacity of one standard deviation below the mean (estimate:  $-0.06$ ;  $CI_{95\%}$ :  $-0.20$  to  $-0.01$ ) or lower. Negative indirect effects of metacognitive training were significant for participants with a working memory capacity of 1.5 standard deviations below the mean (estimate:  $-0.15$ ;  $CI_{95\%}$ :  $-0.43$  to  $-0.01$ ) or lower. For participants with a working memory capacity of two standard deviations below the mean, the indirect effect of cognitive training was estimated as  $-0.13$  ( $CI_{95\%}$ :  $-0.39$  to  $-0.04$ ), and the indirect effect of metacognitive training was estimated as  $-0.21$  ( $CI_{95\%}$ :  $-0.56$  to  $-0.02$ ).

Thus, as expected, the pattern found for indirect effects of training on learning performance closely resembled the patterns found in the regression models for both learning outcomes and navigational behavior: While positive effects of training were present for participants with an above-average working memory capacity, these effects diminished with decreasing working memory capacity and even turned into a significant impairment of learning performance when working memory capacity was about one standard deviation below average.

## 6.2. Results for reading skill as a moderator variable

In order to test the hypotheses concerning interactions of training condition and reading skill, we employed the same

coding schemes and computational procedures as in the analyses for working memory capacity.

### 6.2.1. Step 1: Predicting learning outcomes from reading skill and training

6.2.1.1. *Effects of essay writing tasks.* There were no differences between essay writing tasks in the number of task-related idea units, and no interactions between the essay writing tasks and any of the predictor variables (for all tests:  $F < 1.32$ ,  $p > .27$ ,  $\Delta R^2 \leq .01$ ). Therefore, all analyses were collapsed across essay writing tasks.

6.2.1.2. *Tests of distributional assumptions.* Residuals of the regression model for the number of task-related idea units were distributed normally (K-S  $z$ -test with Lilliefors-boundaries:  $z(64) = 0.07$ ,  $p > .20$ ) and displayed no heteroscedasticity when plotted against the predicted values.

6.2.1.3. *Parameter estimates and hypothesis tests.* The parameter estimates for the regression model with number of task-related idea units as criterion variable and reading skill as a potential moderator of training effects are provided in Table 3 (left columns). There was no main effect for the contrast between the training conditions and the control group, and no main effect for the contrast between the cognitive and the metacognitive training conditions. As expected, however, there was a large positive main effect for reading skill, which was further qualified by a medium-sized interaction between training and reading skill ( $F(2,56) = 3.62$ ,  $p < .05$ ,  $\Delta R^2 = .07$ ). This interaction was due to the first interaction contrast, capturing the difference between the average slope of the regression lines in the training conditions as compared to the control condition. In contrast, there was no difference between the regression slopes for the cognitive and metacognitive training conditions (Fig. 3c).

To interpret the interaction, we conducted simple slopes analyses. In line with the predictions, these analyses revealed medium-sized effects of reading skill both in the cognitive training condition ( $B = 0.16$ ,  $SE_B = 0.07$ ,  $t(56) = 2.45$ ,  $p < .01$ , one-tailed,  $\Delta R^2 = .06$ ) and the metacognitive training condition ( $B = 0.24$ ,  $SE_B = 0.08$ ,  $t(56) = 2.97$ ,  $p < .01$ , one-tailed,  $\Delta R^2 = .09$ ), whereas there was no effect in the control condition ( $B = 0.01$ ,  $SE_B = 0.05$ ,  $t(56) = 0.13$ ,  $p > .05$ , one-tailed,  $\Delta R^2 = .00$ ). Probing differences between trained and untrained participants at a high level of reading skill (one standard deviation above the mean) revealed an advantage of trained participants over their untrained counterparts as predicted (associated with a small effect size,  $B = 0.18$ ,  $SE_B = 0.10$ ,  $t(56) = 1.75$ ,  $p < .05$ , one-tailed,  $\Delta R^2 = .03$ ). The cognitive and the metacognitive training proved to be equally efficient for participants at a high level of reading skill ( $B = 0.06$ ,  $SE_B = 0.15$ ,  $t(56) = 0.44$ ,  $p > .05$ , two-tailed,  $\Delta R^2 = .00$ ). At a low level of reading skill (one standard deviation below the mean), in contrast, trained participants did not only not profit from the strategy training, but performed worse than their untrained counterparts ( $B = -0.21$ ,  $SE_B = 0.11$ ,  $t(56) = -1.95$ ,  $p < .05$ , one-

Table 3

Summary of moderated regression analyses for the effects of cognitive and metacognitive training and reading skill on learning outcomes (number of task-related idea units) and navigational behavior (visits to task-related pages)

	Dependent variable							
	Number of task-related idea units (log.)				Visits to task-related pages (log.)			
	<i>B</i>	<i>SE<sub>B</sub></i>	<i>t</i> (56)	$\Delta R^2$	<i>B</i>	<i>SE<sub>B</sub></i>	<i>t</i> (56)	$\Delta R^2$
Intercept ( <i>B</i> <sub>0</sub> )	3.68	0.04			4.20	0.06		
Prior knowledge <sup>a</sup>	0.01	0.04	0.13	.00	0.02	0.06	0.30	.00
Baseline number of idea units <sup>a</sup>	0.17	0.04	4.21***	.18	–	–	–	–
Reading skill <sup>a</sup>	0.14	0.04	3.40***	.12	0.34	0.07	4.68***	.25
Training vs. no training <sup>b</sup>	–0.02	0.08	–0.23	.00	0.02	0.13	0.13	.00
Cognitive vs. metacognitive training <sup>c</sup>	–0.02	0.09	–0.16	.00	–0.35	0.16	–2.20*	.06
(Training vs. no training) × reading skill	0.20	0.07	2.66**	.07	0.57	0.13	4.31***	.21
Cognitive vs. metacognitive training) × reading skill	0.07	0.10	0.76	.01	0.34	0.19	1.81	.04
Model fit	$R^2=0.45$				$R^2=0.37$			
Omnibus test	$F(7,56)=6.43, p<0.001$				$F(6,56)=5.44, p<0.001$			

Note. Reading skill: Test score in the ELVES subtest sentence verification (Richter & van Holt, 2005)

\* $p<.05$ , \*\* $p<.01$ , \*\*\* $p<.001$  (one-tailed).

<sup>a</sup> z-Standardized.

<sup>b</sup> Contrast-coded: training conditions=1/3, control condition=–2/3.

<sup>c</sup> Contrast-coded: cognitive training=–0.5, metacognitive training=0.5.

tailed,  $\Delta R^2=.04$ ), again independently from which training they had received ( $B=-0.09$ ,  $SE_B=0.13$ ,  $t(56)=-0.72$ ,  $p>.05$ , two-tailed,  $\Delta R^2=.01$ ).

In sum, the data pattern for reading skill and training predicting learning outcomes very closely resembled the pattern that had been found for working memory capacity. In particular, there were no training effects in average but a strong aptitude–treatment–interaction. Skilled readers could benefit from the cognitive and the metacognitive strategy training, while the learning outcomes of unskilled readers suffered from participating in the training (Fig. 3c).

### 6.2.2. Step 2: Predicting navigational behavior from reading skill and training

6.2.2.1. *Effects of essay writing tasks.* There were no differences between essay writing tasks in the number of visits to task-related pages, and no interactions between the essay writing tasks and any of the predictor variables (for all tests:  $F<1.11$ ,  $p>.35$ ,  $\Delta R^2=.00$ ). Therefore, all analyses were collapsed across essay writing tasks.

6.2.2.2. *Tests of distributional assumptions.* Residuals of the regression model for the number of task-related idea units were distributed normally (K–S z-test with Lillefors-boundaries:  $z(63)=0.08$ ,  $p>.20$ ) and displayed no heteroscedasticity when plotted against the predicted values.

6.2.2.3. *Parameter estimates and hypothesis tests.* The parameter estimates for the regression model with number of visits to task-related pages as criterion variable and reading skill as a potential moderator are summarized in Table 3 (right columns). As in all previous analyses, there was no difference between the average performance in the training conditions as compared to the control group. However, there was a significant difference between the training conditions, indicating slightly

more visits to task-related pages in the cognitive than in the metacognitive training condition. Reading skill had a strong positive main effect. Again, the main effect of reading skill was qualified further by a large interaction between reading skill and training condition ( $F(2,56)=9.75$ ,  $p<.001$ ,  $\Delta R^2=.22$ ). This interaction was due to the interaction contrast that represented the difference between the average slope in the training conditions and the control condition. The difference between the slopes in the two training conditions was not significant in a two-tailed test (Fig. 3d).

To interpret the interaction, we computed simple slopes for all experimental groups separately. Reading skill had no effect in the control condition ( $B=-0.04$ ,  $SE_B=0.09$ ,  $t(56)=-0.48$ ,  $p>.05$ , one-tailed,  $\Delta R^2=.00$ ), but as expected, there was a large positive effect of reading skill in the cognitive training condition ( $B=0.36$ ,  $SE_B=0.12$ ,  $t(56)=3.07$ ,  $p<.001$ , one-tailed,  $\Delta R^2=.11$ ) as well as in the metacognitive training condition ( $B=0.70$ ,  $SE_B=0.15$ ,  $t(56)=4.55$ ,  $p<.001$ , one-tailed,  $\Delta R^2=.23$ ). Probing differences between trained and untrained participants at a high level of reading skill (one standard deviation above the mean) revealed that as predicted, trained participants had considerably more visits to task-related pages than untrained participants ( $B=0.59$ ,  $SE_B=0.18$ ,  $t(56)=3.31$ ,  $p<.001$ , one-tailed,  $\Delta R^2=.12$ ). There was no difference between the cognitive and metacognitive training conditions for participants at a high level of reading skill ( $B=-0.01$ ,  $SE_B=0.26$ ,  $t(56)=-0.04$ ,  $p>.05$ , one-tailed,  $\Delta R^2=.00$ ). At a low level of reading skill (one standard deviation below the mean), in contrast, trained participants had significantly fewer visits to task-related pages than untrained participants ( $B=-0.55$ ,  $SE_B=0.19$ ,  $t(56)=-2.85$ ,  $p<.01$ , one-tailed,  $\Delta R^2=.09$ ). Additionally, participants in the metacognitive training condition had fewer visits to task-related pages than participants in the cognitive training condition ( $B=-0.69$ ,  $SE_B=0.24$ ,  $t(56)=-2.90$ ,  $p<.01$ , two-tailed,  $\Delta R^2=.09$ ).

In sum, the data for navigational behavior largely replicated the data for learning outcomes. While skilled readers could benefit from the cognitive and the metacognitive strategy training in terms of their navigational behavior, the navigational behavior of poor readers suffered from both types of training. The only difference between the training conditions was that the slope of reading skill was somewhat steeper in the metacognitive training condition compared to the cognitive training condition and intersected later with the regression line in the control condition. As a consequence, participants in the cognitive training conditions at low and average levels of reading skill had a slight advantage over their counterparts in the metacognitive training condition (Fig. 3d). Apart from that, given the overall strongly parallel results for navigational behavior and learning outcomes and the strong positive effect of navigational behavior on learning outcomes (Table 1), the results obtained in step one and step two suggest that the interaction effects of training and reading skill on learning outcome were mediated through navigational behavior. Evidence for this assumption was provided by the fact that the direct effects of reading skill and its interaction with training condition on learning outcomes disappeared after navigational behavior was included as a predictor in the model (Fig. 4b), indicating a full mediation of these effects through navigational behavior. In step three, we estimated and tested the mediating role of navigational behavior directly.

### 6.2.3. Step 3: Probing indirect effects of training conditional on reading skill

We employed the same procedure for testing moderated mediation effects that was outlined in step three for the analyses with working memory capacity as a moderator. These analyses revealed positive indirect effects of training on learning outcomes through the quality of navigational behavior for participants with above-average levels of reading skill that increased with reading skill. In contrast, negative indirect effects were found for participants with below-average levels of reading skill, and the magnitude of these effects increased with decreasing reading skill.

There were significant positive indirect training effects of cognitive training for participants with reading skill values of 0.25 standard deviations above the mean (estimate: 0.08;  $CI_{95\%}$ : 0.01 to 0.22) or higher. Positive indirect training effects for metacognitive training were significant for participants with reading skill values of 0.75 standard deviations above the mean (estimate: 0.11;  $CI_{95\%}$ : 0.02 to 0.24) or higher. For participants with reading skill values of two standard deviations above the mean, the indirect effect of cognitive training was estimated as 0.27 ( $CI_{95\%}$ : 0.07 to 0.56), and the indirect effect of metacognitive training was estimated as 0.35 ( $CI_{95\%}$ : 0.09 to 0.65).

Negative indirect effects of cognitive training were significant for participants with reading skill values of  $-1.5$  (estimate:  $-0.10$ ;  $CI_{95\%}$ :  $-0.28$  to  $-0.01$ ) or lower. Negative effects of metacognitive training were significant for participants with reading skill values of  $-0.75$  (estimate:  $-0.17$ ;  $CI_{95\%}$ :  $-0.39$  to  $-0.02$ ) or lower. For participants with reading

skill values of two standard deviations below the mean, the indirect effect of cognitive training was estimated as  $-0.16$  ( $CI_{95\%}$ :  $-0.41$  to  $-0.04$ ), and the indirect effect of metacognitive training was estimated as  $-0.40$  ( $CI_{95\%}$ :  $-0.86$  to  $-0.11$ ).

## 7. Discussion

The goals of the present study were to investigate whether reading skill and working memory capacity moderate the effects of strategy training for learning with hypertext, and whether the quality of navigational behavior mediates these effects. The same patterns of results was expected for working memory capacity and reading skill as a moderator variable. As expected, the learning outcomes of participants with a large working memory capacity were improved by both a cognitive and a metacognitive strategy training whereas the learning outcomes of participants with a small working memory capacity were deteriorated by both types of training. The same pattern of results was found for reading skill as moderator. These effects were mediated by the quality of navigational behavior: Both working memory capacity and reading skill also moderated the effects of strategy training on the quality of navigational behavior, which in turn had a strong positive effect on learning outcomes. Depending on the individual level of working memory capacity and reading skill, strategy training had differential indirect effects through the quality of navigational behavior. For learners high on working memory capacity or reading skill, these indirect effects were positive, whereas for learners low on working memory or reading skill, these indirect effects were negative. Overall, the results were highly similar for cognitive and metacognitive strategy training.

These patterns of effects are consistent with an interpretation in terms of cognitive resources. When learning strategies have been acquired only recently, the degree of routinization is low. As a consequence, the implementation of these strategies makes large demands on working memory capacity. Consequently, only learners high on working memory capacity can implement and use the strategies successfully. Basic reading comprehension processes, which are always involved in learning with hypertext, require working memory capacity as well but the working memory load imposed by these processes varies greatly with reading skill. Learners whose basic reading comprehension processes are well-routinized can allocate more cognitive resources to implementing the newly learned processes than learners whose basic reading comprehension processes are poorly routinized. Skilled readers are able to maintain their normal reading and, at the same time, make use of cognitive and metacognitive strategies to improve their navigation and learning outcomes. In the case of less-skilled readers, in contrast, reading and strategy use interfere. As a result, the quality of navigational behavior and learning outcomes decline.

Theoretically, these results contribute to the research on cognitive and metacognitive strategies in learning from hypertext because they suggest a general and simple explanation as to why strategy training and other measures designed to foster strategic processing sometimes succeed and sometimes

fail. Prompting the use of cognitive or metacognitive strategies by means of explicit training (e.g. Bannert, 2003), inducing appropriate goal-orientations (Vollmeyer & Burns, 2002; Zumbach & Reimann, 2002), or providing graphical overviews (Hofmann & van Oostendorp, 1999; Müller-Kalthoff & Möller, 2003) does not regularly lead to better learning outcomes. Rather, the bottom line of the research on this topic seems to be that less skilled students tend to be overtaxed by resource-demanding instructions. Müller-Kalthoff and Möller (2003), for example, reported that the effectiveness of a structural overview that was supposed to prompt learning strategies such as planning and organization, depended on students' prior knowledge and computer-related self-concept. Only when both prior knowledge and self-concept were high, access to the structural overview increased learning performance (for similar results on situation model construction, see Hofmann & van Oostendorp, 1999). Beishuizen, Stoutjesdijk, and van Putten (1994, Exp. 1) found no beneficial effects of explicit metacognitive support when participants possessed no prior domain knowledge (for analogous conclusions, see the studies summarized by Simons & De Jong, 1992). In the light of the research reported here, it seems not farfetched to assume that the common finding that especially skilled learners profit from methods that foster the use of cognitive and metacognitive strategies may be explained at least in parts by individual differences in the available amount of working memory. It is quite likely that the highly skilled learners in these studies were able to spend larger amounts of working memory capacity for the use of learning strategies than their less skilled counterparts. This, in turn, might have contributed to the greater effectiveness of methods promoting the use of cognitive and metacognitive strategies in those learners.

Last but not least, the theoretical framework developed here to explain differential effects of strategy training is general in the sense that it is consistent with research that goes well beyond the area of learning with hypertext. Kanfer and Ackerman (1989, Exp. 1), for example, showed that in complex tasks, a high degree of metacognitive activity can backfire if the skills needed to accomplish the task are not sufficiently routinized. Under these circumstances, large parts of the available working memory capacity must be allocated to the processes required by the task, and additional metacognitive processing will interfere rather than being helpful. Similarly, the use of metacognitive strategies in classroom learning situations is helpful only to the degree to which working memory capacity does not have to be almost completely spent on task-relevant processes (Cooper & Sweller, 1987; Winne, 2001).

Due to the fact that the research reported in this article is partly correlational, it also suffers from certain limitations. One limitation is that motivational differences between high- and low-ability participants might have contributed to the present effects. Future research on this topic should address the question of whether and to what extent high- and low-ability participants also differ in their motivation to implement newly acquired strategies. A second limitation is that we cannot rule out the possibility that those learners who were high on

working memory capacity and reading skill already had acquired a greater repertoire of cognitive and metacognitive learning strategies prior to the experiment. If this were the case, individual differences in the availability of learning strategies and not individual differences in the availability of working memory capacity might explain our results. However, data from two previous studies in which we measured the actual or habitual use of learning strategies make this interpretation seem unlikely. In one study (Naumann et al., 2007), the habitual use of cognitive and metacognitive learning strategies was assessed through the German version of the Motivated Strategies for Learning Questionnaire (Pintrich et al., 1993; Wild & Schiefel, 1994), and it was unrelated to the reading skill measure that was also used in the present study (cognitive strategies:  $r(45)=0.19$ ; metacognitive strategies:  $r(45)=0.04$ ,  $p>.20$ ). In another study (Richter et al., 2005), the actual strategy use was assessed through think-aloud protocols. Again, we found the use of learning strategies to be unrelated to reading skill (cognitive strategies:  $r(30)=0.10$ ; metacognitive strategies:  $r(30)=-0.02$ ;  $p>.20$ ). Still, replications of the present study are needed in which the availability of cognitive and metacognitive learning strategies is assessed prior to the training of learning strategies.

In spite of this limitation, the present results allow some tentative recommendations as to how to tailor learning strategy training in learning with hypertext to the needs of learners low on working memory capacity or reading skill. Although the present study included a practice phase that learners could use to routinize the newly acquired strategies, this practice phase was apparently too short for learners with low working memory capacity or inefficient basic reading comprehension processes. Quite generally, the present results suggest to provide less-skilled learners with ample time to practice the implementation of learning strategies and to transform them into procedural knowledge (Anderson, 1987; Woltz, 1988). A more specific possibility to reduce memory working load would be to apply a stepwise procedure, similar to the first-part-then-whole-approach in multimedia learning. In this approach, rather than confronting learners with all information at once and then having them study different parts, discrete parts of information are presented first, a sequence that has proven to be superior to the first-whole-then-parts sequence (Mayer & Chandler, 2001). Accordingly, especially less-skilled learners might be better off with a training approach that involves the teaching of simple strategies one-by-one and having learners practice the application of these strategies before they are confronted with a learning task that requires them to use a whole bundle of strategies at the same time. In this way, working memory load might be reduced to a degree that even for less-skilled readers or learners low on working memory capacity, learning strategy training would have positive rather than negative effects. For skilled readers or learners high on working memory capacity, in contrast, a more complex training that combines cognitive and metacognitive strategies might be even better. Further research would be desirable that directly addresses the utility of these approaches for learners on different skill levels.

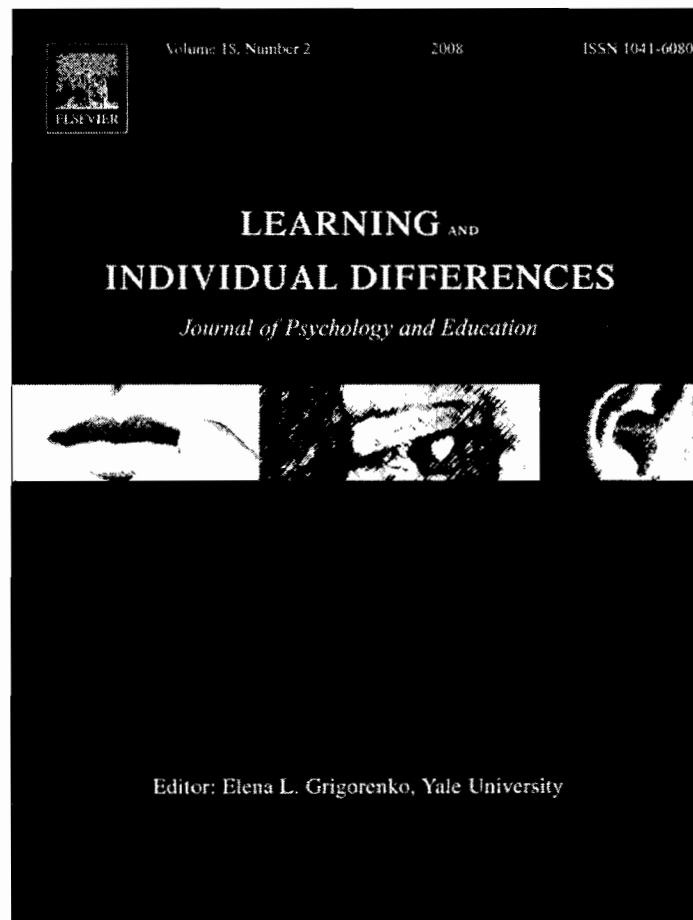
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