Effectiveness of error management training

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Author note

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Abstract

In error management training, participants are explicitly encouraged to make errors and learn from them. Error management training has frequently been shown to lead to better performance than conventional trainings that adopt an error avoidant approach. The present study investigates self-regulatory processes mediating this effect. Fifty-five volunteer students learned a computer program under 1 of 3 conditions: error avoidant training, error management training, or error management training supplemented with a metacognitive module. As predicted, both forms of error management training lead to better transfer performance than error avoidant training (d=0.75). Mediation hypotheses were fully supported: Emotion control and metacognitive activity (from verbal protocols) mediated performance differences. These findings highlight the potential of promoting self-regulatory processing during training.

Self-Regulation in Error Management Training: Emotion Control and Metacognition as Mediators of Performance Effects

"Errors are great because you learn so much from them!" – Such a statement stressing the positive function of errors may sound quite ironic for many of us, given the rather negative view of errors generally held in society. Early in school we learn that errors are punished by poor grades, and workplace errors can have severe consequences for individuals and organizations, and may even lead to catastrophes such as the Chernobyl meltdown. From this point of view, there is nothing good about errors. From a psychological perspective, however, errors make it possible to learn (Fisher & Lipson, 1986). This is the perspective taken by proponents of error management training: Errors provide informative feedback and should, therefore, be explicitly incorporated into the training process (Heimbeck, Frese, Sonnentag, & Keith, 2003). Consequently, training participants are exposed to many errors during the training situation and are encouraged to use these errors as a learning device by means of positive error statements such as the one in the opening sentence.

Error management training studies have shown that error management training leads to better performance by participants than error avoidant training, which is designed to prevent participants from making errors, when learning new computer programs (Chillarege, Nordstrom, & Williams, 2003; Dormann & Frese, 1994; Frese, 1995; Frese et al., 1991; Heimbeck et al., 2003; Nordstrom, Wendland, & Williams, 1998). Others have added to these findings, for example, by applying error management training to driving simulation training (Ivancic & Hesketh, 2000), by comparing error management training with behavior modeling (Debowski, Wood, & Bandura, 2001; Wood, Kakebeeke, Debowski, & Frese, 2000), and by testing aptitude-treatment interactions of training condition and person characteristics (Gully, Payne, Koles, &

Whiteman, 2002; Heimbeck et al., 2003). Despite the growing body of research dealing with error management training, evidence illuminating the psychological mechanisms underlying its effectiveness remains scarce. Only a few studies explicitly looked at potentially mediating processes (Debowski et al., 2001; Wood et al., 2000), and none of these arrived at conclusive results. Our study aims to fill this gap by using both questionnaire and verbal protocol data to identify mediating processes in error management training.

The present study contributes to the existing research in the following ways: First, it replicates existing error management training studies. Second, the major focus of our study is on processes mediating the effects of error management training on task performance. More specifically, we argue that error management training – but not error avoidant training – stimulates self-regulation of emotions (i.e., emotion control) and self-regulation of cognitions (i.e., metacognition) during skill acquisition. We further propose that the quality of these self-regulatory processes determines later task performance. This argument is consistent with educational theory stressing the importance of metacognition in self-regulated learning (e.g., Schunk & Zimmerman, 1994) and with Kanfer and colleagues' resource allocation perspective in skill acquisition (e.g., Kanfer & Ackerman, 1989). Third, we present and test a new variant of error management training specifically designed to enhance metacognitive activity. To our knowledge, no study has explicitly tried to systematically change elements of error management training in order to improve its effectiveness. In the following, we will briefly describe the basic concepts underlying error management training. Then, we will discuss processes that potentially mediate the effectiveness of error management training.

The Concept of Error Management Training

The basic principle of error management training is that participants are given opportunities to make errors during training. Participants are provided with only minimal information (e.g., information about the functions of the computer program to be learned) and are then given the opportunity to individually explore the system. It can be generally stated that errors occur during goal oriented behaviour, that they imply that a goal has not been reached, and that they could have been potentially avoidable (Zapf, Brodbeck, Frese, Peters, & Prümper; 1992; Frese & Zapf, 1994; Reason, 1990). In error management training, for example, if the goal of a participant is to enlarge an object that is visible on the computer screen, and if he or she instead moves this object, this would be an error. Errors can, in principle, be distinguished from inefficient actions, because inefficient actions still lead to the goal. However, inefficient actions can be conceived as erroneous when it is assumed that most people hold a standard of efficiency. In error management training, inefficient actions can occur as well. For example, if the task was to insert three additional columns into an existing table, and if the participant first deleted the whole table and then inserted a new table with the desired number of columns, this would be inefficient and considered an error although the goal has been reached.

Error management training is similar to exploratory learning (Bruner, 1966) which emphasizes the importance of allowing the learner to actively explore ideas and to test them (e.g., Greif & Keller, 1990). There are two characteristics of error management training, however, that show its greater emphasis on making errors and using them as a learning device, compared with classical approaches to exploratory learning. First, in contrast to exploratory training, error management training tasks are quite difficult right from the start, thereby exposing participants to many error situations (Heimbeck et al., 2003; Hesketh & Ivancic, 2002). Since explicit training tasks are given, participants have clear external objectives during training, whereas pure discovery methods often lack this kind of structure (Mayer, 2004). The second characteristic of error management training is that participants are explicitly informed about the positive function of errors during training and are presented error management instructions to reduce potential frustration in the face of errors (Dormann & Frese, 1994; Frese, 1995). Error management instructions are brief statements such as "Errors are a natural part of the learning process!" or "The more errors you make, the more you learn!", designed to frame errors positively (Frese et al., 1991). Error avoidant training, on the other hand, mimics many conventional tutorials adopting a negative attitude toward errors: Step-by-step instructions are provided to prevent errors from occurring, and participants are not informed about the positive functions of errors (Frese, 1995).

In several training experiments, error management training that included error management instructions proved superior to error avoidant training across diverse participant samples (students as well as employees), training contents (e.g., computer training, driving simulator training) and training lengths (1-hour training to 3-day training sessions). These training experiments comprised one or more training phases and subsequent test phases which assessed performance in terms of number of correct task solutions (Chillarege et al., 2003; Debowski et al., 2001; Nordstrom et al., 1998; Wood et al., 2000), ratings of correctness, efficiency, and speed of solutions in difficult tasks (Dormann & Frese, 1994; Frese et al., 1991), or number of errors in transfer tasks (Ivancic & Hesketh, 2000). A recent study by Heimbeck et al. (2003) highlighted the crucial role of error management instructions in error management training: Error management training was superior not only to error avoidant training but also to pure exploratory training without error management instructions. Thus, according to this study, only the combination of providing participants (1) with ample opportunities to make errors, and (2) explicit encouragement to learn from their errors by means of error management instructions improved task performance.

Error management training is not expected to affect all types of learning outcomes at any time. First, error management training aims at improving performance *after* (as opposed to *during*) training. That is, most error management training studies differentiate one or more *training* phases from later *test* phases. During training, participants are encouraged to make errors. During the test phase, however, participants are aware that their performance is being assessed (e.g., Wood et al., 2000). This distinction is crucial, given that manipulations positively affecting training performance may negatively affect performance in the long run and vice versa (Goodman, 1998; Hesketh, 1997; Schmidt & Bjork, 1992). In other words, error management training aims to improve transfer performance, not training performance. In fact, training performance may be worse in error management training in terms of error rate, efficiency, or training time because participants are not directly guided to correct solutions; rather they experiment, explore, make errors, and sometimes arrive at wrong solutions.

Second, error management training should affect different types of transfer tasks differentially. Transfer implies that "knowledge, skills and attitudes" are "transferred from one task or job to another" (Hesketh, 1997, p. 318). Two types of transfer can be distinguished (Ivancic & Hesketh, 2000): (1) *Analogical transfer* refers to problem solutions that are familiar or analogous. (2) *Adaptive transfer* entails "using one's existing knowledge base to change a learned procedure, or to generate a solution to a completely new problem" (Ivancic & Hesketh, 2000, p. 1968). From a practical perspective, adaptive transfer is most relevant, because not all potential work-related problems and solutions can be taught during training (Hesketh, 1997;

Kozlowski et al., 2001). For example, not all functions of a new word processing program can be explained during a one-day training. Back on the job, however, training participants may encounter unexpected problems while working with the word processing program and, in contrast to the protected training situation, might not have any assistance at all. In this respect, error management training resembles the transfer situation more than error avoidant training – an issue that is captured in the principle of transfer appropriate processing which postulates that those processes required on transfer tasks should be practiced in training (Morris, Bransford, & Franks, 1977).

We expect error management training to be particularly effective in promoting adaptive transfer, because participants learn to deal with unexpected problems during training. For analogical transfer, the prediction is less clear. As outlined by Ivancic and Hesketh (2000), errors made during training may facilitate the retrieval of similar problems and their solutions, thereby promoting analogical transfer. On the other hand, error avoidant training might be as successful for analogical transfer as error management training: In order to solve analogical problems, participants of error avoidant training only need to apply the correct strategies they learned during training to the new (but analogous) problem. Therefore, we expect analogical transfer to be the same in both error management training and error avoidant training. This prediction is consistent with the results of prior error management training studies. For example, Heimbeck et al. (2003) predicted and found group differences only for difficult tasks but not for easy tasks (cf. Dormann & Frese, 1994; Frese, 1995). They argued that performance in easy tasks should not benefit from error management training, because easy tasks require only a low degree of skill and do not lead to many errors. In sum, we expect to replicate the group difference in adaptive transfer that has been found in earlier studies.

Hypothesis 1: Error management training leads to better adaptive transfer than error avoidant training.

Processes in Error Management Training

Several mechanisms for the effectiveness of error management training have been proposed in the literature, although only few studies have attempted to directly test these potential mechanisms. Two groups of mechanisms have been proposed: (1) Cognition-based approaches highlight the function of exploration and associated deeper level processing during training (Dormann & Frese, 1994; Heimbeck et al., 2003). Additionally, other authors suggest that metacognition is important (Ivancic & Hesketh, 2000). (2) Emotion/motivation-based approaches investigate the emotional or motivational processes potentially facilitating or debilitating learning during training, such as intrinsic motivation (Debowski et al., 2001; Wood et al., 2000) or frustration (Chillarege et al., 2003; Nordstom et al., 1998).

We do not reject the proposed mechanisms but suggest that these can be integrated in a self-regulatory perspective that acknowledges the significance of both cognitive and emotional processes in error management training. Self-regulation refers to processes "that enable an individual to guide his/her goal-directed activities over time", comprising "modulation of thought, affect, behavior, or attention" (Karoly, 1993, p. 25). In error management training, self-regulatory processes are particularly important due to the low degree of structure and the lack of external guidance (Schmidt & Ford, 2003). We argue that participants in error management training learn to use self-regulatory skills that prove valuable when confronted with new problems not practiced in training – problems that require adaptive transfer (Ivancic & Hesketh, 2000). In the following, we will refer to emotion control and metacognition as two self-regulatory skills mediating error management training effectiveness.

Emotion Control in Error Management Training

Emotion control is a skill involving "the use of self-regulatory processes to keep performance anxiety and other negative emotional reactions (e.g., worry) at bay during task engagement" (Kanfer, Ackerman, & Heggestad, 1996, p. 186). Emotion control is expected to and has been shown to be particularly important for learning in early phases of skill acquisition where errors and setbacks are most likely to occur. Failures in emotion control result in impaired learning and performance, because negative emotions divert attentional resources to the self and away from the task at hand (Kanfer & Ackerman, 1989; Kanfer et al., 1996; Kluger & DeNisi, 1996). Not all types of emotion control processes, however, can be expected to be equally beneficial. For example, mere suppression of negative emotions drains resources (Muraven & Baumeister, 2000) and can result in cognitive deficits, whereas reappraisal of the emotional event, modifying emotions before they unfold, does not (Richards & Gross, 2000). We propose that error management training helps participants to develop and practice beneficial skills of emotion control early on in training because error management instructions frame errors positively and thereby encourage participants to adopt a positive perspective on errors. In error avoidant training, however, participants are prevented from making errors, and this does not prepare them to handle their negative emotional reactions to errors. As a result, when they are confronted with new tasks in the test phase without guidance, they are more likely to encounter negative emotions debilitating their performance. In sum, we expect a mediation effect of emotion control.

Hypothesis 2: Emotion control mediates the effect of training conditions on adaptive transfer in that (a) error management training leads to higher emotion control than error avoidant training, and (b) emotion control positively affects adaptive transfer.

Metacognition in Error Management Training

Notwithstanding the critical role of emotional control processes during skill acquisition, cognitive control processes should also be considered because the mere absence of negative emotions does not quite ensure learning. Rather, the free attentional resources at one's disposal need to be devoted to task-related activities that maximize task learning (Kanfer & Ackerman, 1989). Following theorizing by Ivancic and Hesketh (2000; Hesketh & Ivancic, 2002), we propose that metacognition is powerful in promoting transfer and that error management training fosters metacognitive activity.

Metacognition implies that an individual exerts self-regulatory "control over his or her cognitions" (Ford, Smith, Weissbein, Gully, & Salas, 1998, p. 220), and involves skills of planning and monitoring as well as evaluation of one's progress during task completion (Brown, Bransford, Ferrara, & Campione, 1983; Schraw & Moshman, 1995). Metacognition has been shown to be related to academic achievement (e.g., Pintrich & De Groot, 1990; Schunk & Zimmermann, 1994) and to problem-solving performance (Berardi-Coletta, Buyer, Dominowski, & Rellinger, 1995; Davidson & Sternberg, 1998), and is assumed to be particularly useful in learning environments that provide little external structure or guidance (Schmidt & Ford, 2003). In error management training, metacognitive activities are encouraged because "errors prompt learners to stop and think about the causes of the error" (Ivancic & Hesketh, 2000, p. 1968). Participants then need to come up with solutions to the impasse, implement them, and monitor their effectiveness (Ivancic & Hesketh, 2000). These metacognitive activities can be conceived as higher-order strategies (Ford et al., 1998) that help participants to master new tasks on their own. Error avoidant training, however, does not necessarily offer the opportunity to engage in metacognitive activities because participants are provided with the correct task solutions and do not need to explore the system on their own. In sum, we expect a mediation effect of metacognitive activity.

Hypothesis 3: Metacognitive activity mediates the effect of training conditions on adaptive transfer in that (a) error management training leads to higher metacognitive activity during training than error avoidant-training, and (b) metacognitive activity positively affects adaptive transfer.

In addition, our study aimed to explore whether the effect of error management training could be improved by supplementing error management instructions with additional instructions specifically designed to enhance metacognitive activity. Although we assume that error management promotes both emotion control and metacognitive activity and that these two processes enhance performance, supplementary instructions could be even more powerful: If not all participants spontaneously engage in emotion control or metacognitive activity, additional instructions specifically designed to improve one of these processes may be more effective than error management instructions alone. For emotion control, we would not expect a strong effect of supplemental instructions aimed at improving emotion control because standard error management instructions already have a component of emotional relief (e.g., "There is always a way to get out of an error situation!"), and because prior studies suggest that error management training alone can have an effect on emotional outcomes (Frese et al., 1991; Nordstrom et al., 1998). Thus, an additional effect on the regulation of emotions may be less likely. For instructions specifically designed to enhance metacognitive activity, however, an additional effect seems more likely: When left without further guidance in error management training, some participants may rely on less effective strategies such as unsystematic trial-and-error (van der Linden, Sonnentag, Frese, & van Dyck, 2001). Similarly, Mayer (2004) argues that exploratory training methods can be improved by providing help in guiding participants' cognitive activity in productive directions (cf. Bell & Kozlowski, 2002). Consequently, additional instructions highlighting the benefits of and explaining how to make use of metacognitive activity may direct the participants' attention to more effective strategies and, therefore, be more successful than error management instructions alone. On the other hand, it may be argued that since error management training already is powerful in promoting metacognitive activity, there might not be any more room for an add-on effect of any supplementary instructions. Because of these conflicting expectations on the role of metacognitive instructions, we put forth an open research question:

> Does error management training supplemented by metacognitive instructions lead to better adaptive transfer than error management training alone?

Method

Participants

Participants were 55 volunteer university students with majoring in education (i.e., primary and secondary education). As an incentive, participants took part in a lottery that was conducted after completion of the study where they could win 1 of 3 monetary prizes (equivalent to about 50, 30, and 20 dollars). The sample was composed of 53 women (94%). Mean age was 23.1 years (*SD* = 5.2). Most participants reported having had work experience (86%), with 27% having worked regularly before they started attending the university and 70% working on regular basis while studying (*M* = 11.6 hours per week, *SD* = 9.2). Participants' experience with computers differed broadly, but none of them had ever worked with the specific software used in this study. This was a prerequisite for participation. Accordingly, when making the appointment for the training session and again directly before the training started, we asked participants whether they had used the program before. Participants were randomly assigned to training conditions.

Experimental Design and Procedure

Participants were trained to create overhead slides with a presentation program (PowerPoint 2000 for Windows) in 1 of 3 training conditions. Sessions were run individually for each participant and lasted two and a half hours (including a 10-minute break). Sessions comprised (1) an introductory phase (identical for all participants), (2) the actual training phase where the experimental manipulation took place, and (3) a test phase (identical for all participants).

Introductory phase. In the beginning, all participants received a 2-page manual containing general information about the program. This manual briefly explained the menu and toolbars, how specific functions can be activated to create objects (e.g., a rectangle), and how existing objects can be modified (e.g., enlarging a rectangle). Also, participants were informed about the undo function of the program. All participants received the same manual so that task information was held constant across training conditions. Reading time was approximately five minutes. Participants were allowed to refer to their manuals during the entire training session (but not during the test phase).

After reading the manual and before the actual training started, participants first worked on a simple slide. In this way they could get accustomed to handling the mouse for creating objects and to thinking aloud while working ("warm-up" exercise for verbalization, Taylor & Dionne, 2000, p. 415). This introductory task included creating and modifying a circle, a rectangle, a text box, and an arrow while following written instructions. The experimenter demonstrated the first few steps. She read the written instructions out loud (e.g., "Click on the icon 'rectangle' in the drawing toolbar.") and then carried out the described actions while verbalizing them. Participants were asked to complete the task following the written instructions while thinking aloud (for instructions on thinking aloud, see below). No time limit was given for the introductory task. Mean time for task completion was 16.80 minutes (SD = 5.04) and did not differ between experimental groups, F (2,52) = 0.21, p = .81.

Training phase. After the introductory phase, the actual training began in which the training condition was experimentally manipulated. Participants were consecutively given copies of two slides printed on paper. The task was to reproduce these slides as closely as possible. The first slide required creating, moving, and modifying (e.g., coloring) diverse objects such as rectangles, triangles, textboxes, and stars. The second slide involved creating and modifying a table by simple formatting such as coloring cells and centering cell entries. To complete each slide, participants were given 15 minutes, resulting in a training time of 30 minutes. Those participants who finished the two slides before the training time was up received a third slide to work on during the remaining time. This third slide looked different than the former ones but required program functions similar to those already used. The number of participants who worked on the third slide did not differ between experimental groups, F (2,52) = 1.14, p = .33.

Participants completed the training tasks in 1 of 3 training conditions: error avoidant training, error management training, or error management training supplemented with a metacognitive module. In the *error avoidant training* (n = 18), participants received detailed written instructions (similar to those in the introductory practice phase) explaining task solution in a step-by-step manner. This training condition resembled commercially available software tutorials. Participants were asked to follow the instructions closely. They were told that these instructions would enable them to learn the most important program functions in the shortest time, and that by following the instructions participants would become familiar with the correct functions from the very beginning.

In the *error management training* condition (*n* = 17), participants were not provided with any information on task solution. They received instructions emphasizing the positive function of errors during training and were encouraged to make errors and learn from them. Additionally, the following error management instructions derived from earlier error management training studies were presented (cf. Heimbeck et al., 2003; Debowski et al., 2001; Dormann & Frese, 1994; Wood et al., 2000): "Errors are a natural part of the learning process!", "There is always a way to leave the error situation!", "Errors inform you about what you still can learn!", and "The more errors you make, the more you learn!". During training, the error management instructions were prominently displayed on a poster and verbally repeated by the experimenter.

Participants in the *error management training plus metacognition* (*n* = 20) condition initially received exactly the same treatment as participants in the error management training condition. That is, before they worked on the first training slide, they were not provided with any information about the task solution but were given instructions emphasizing the positive function of errors and error management instructions. When the participants worked on the second training slide, however, treatment differed in that participants received additional instructions designed to enhance metacognitive activity. These metacognitive instructions were derived from a study conducted by King (1991; cf. also McInerney, McInerney, & Marsh, 1997; Schmidt & Ford, 2003) in which pairs of children were trained in strategic questioning while solving problems. In King's study, the children were provided with an index card listing questions concerning metacognitive planning, monitoring, and evaluation (e.g., "Are we getting closer to our goal?", "What worked? What didn't work?"). In the present study, these questions were adopted and slightly modified. Participants were first given brief written instructions explaining the benefits of strategic questioning while working on the training tasks. They were then told to pose and answer these questions to themselves whenever appropriate while working on the task. For example, when they did not know what to do next, participants were told to analyze the problem and develop a strategy by asking and answering questions like "What is my problem? What am I trying to achieve?" or "What do I know about the program so far that can be useful now?". Finally, the list of questions to be posed was prominently displayed on a poster during training and verbally repeated by the experimenter. To make sure that participants followed instructions on strategic questioning during training, they were told that the questions they posed and answered would be tape-recorded and counted later on (which was actually the case, since the method of thinking aloud was used during training; see below).

Participants in all three groups were informed about the undo-function of the program and the delete key before the training started. This was done to keep knowledge about these error correction options constant. No further help was provided during training. Only in the few cases where participants could not continue with the task, did the experimenter intervene (e.g., one participant accidentally closed the working file; another participant accidentally "lost" a toolbar that was essential for task completion). The number of interventions by the experimenter did not differ between training conditions, $F\ (2,52) = 0.86$, $p = .43$.

During the entire training, the method of thinking aloud was used. Instructions for thinking aloud were carefully constructed following recommendations by Ericsson and Simon (1993). Instructions were: "While you are working on the slide, please verbalize all your thoughts. Just speak out whatever comes into your mind, no matter what it is.". When participants stopped verbalizing for more than 10 seconds, they were prompted to continue

("Please keep on talking."). Empirical evidence suggests that this type of verbalization instruction is least obtrusive to participants' cognitive processing (Ericsson & Simon, 1993; Taylor & Dionne, 2000). The number of prompts for continuing verbalization did not differ between training conditions, $F\ (2,52) = 1.97$, $p = .15$.

Test phase. Tasks and instructions in the test phase were identical for all participants. Participants were handed printed copies of three slides. As in the training phase, the task was to reproduce these slides as closely as possible. The test slides, however, were more difficult than the training slides (cf. Dormann & Frese, 1994; Heimbeck et al., 2003). The first test slide comprised bullet points with text items and a figure consisting of several framed and colored text boxes and arrows. The main task of the second test slide was to produce and to format a table. For the third slide, a vertical bar chart had to be created and edited with the diagram function of the program. Additionally, all three test phase slides involved picking a specific design template and predefined layouts of the program. Since pilot testing had indicated that these were extremely difficult tasks, all participants were informed about the menu options where they would find the required functions. Participants were given 12 minutes to complete each slide, resulting in an overall testing time of 36 minutes. Before testing started, participants were told that this was the test phase in which they were to demonstrate what they had learned during the training session (cf. Wood et al., 2000).

Measures

Performance. Performance ratings were conducted on the basis of the slides the participants had created during the training and the test phase. Each task was divided into meaningful observable subtasks. For example, the task to create a figure consisting of several textboxes and arrows was divided into seven subtasks: "at least one textbox present", "all textboxes present", "position of text within textbox correct", "at least one arrow present", "all arrows present", "format of arrows correct", and "relative positions of textboxes and arrows correct". The subtasks served as coding units and were rated as either correctly completed or not (dichotomous rating; cf. Heimbeck et al., 2003). A second rater coded a randomly chosen subset of training and test slides. The two raters were the first author and a graduate student who was trained to use the coding system. Both raters were blind to the experimental condition. For the training phase slides, Cohen's kappa was .87 (based on a subset of 270 coding units). To arrive at a measure for overall *training performance*, the number of completed subtasks was computed for each participant.

For the ratings of the test phase slides, Cohen's kappa was .89 (based on a subset of 768 coding units). We further divided the subtasks of the test phase into tasks of low and high distinctiveness from training slides. A subtask was rated as low in distinctiveness if it required mere repetitions of program functions used in training (e.g., creating a textbox, changing the color of a rectangle), or if a program function used in training had to be applied in a similar though not exactly identical manner as in training (e.g., inserting a 4 x 4 table when the training task was to insert a 3 x 3 table). A subtask was rated as high in distinctiveness if a completely new function had to be applied for task completion (e.g., complex formatting of a table, inserting and editing a diagram). Inter-rater agreement on this distinction of high-low distinctiveness for the 64 subtasks of the test slides was high (Cohen's kappa = .84). Cases where the ratings of both raters differed were resolved by discussion. Low-distinctiveness subtasks solved were summed to represent *analogical transfer*; high-distinctiveness subtasks solved were summed to represent *adaptive transfer* (cf. Ivancic & Hesketh, 2000). All analyses are based on these sum scores. As outlined in the introduction, we expected performance differences between experimental groups only for adaptive transfer but not for analogical transfer.

Verbal protocol data. Participants' thinking-aloud during training was transcribed verbatim and segmented with each phrase (either complete or incomplete) constituting a segment (cf. Sonnentag, 1998). Mere expressive utterances (e.g., "Hum", "Okay", "Yup") were coded as such and excluded from further analyses. Due to technical problems (microphone dysfunctions and broken videotapes), audio data of six participants was lost, resulting in a sample size of n = 49 for all analyses comprising verbal protocol data (error avoidant group: n = 14, error management training group: n = 16, error management training plus metacognition group: n = 19).

The second half of the training phase, in which participants created and formatted a table, was critical for the present research question. Only in this phase did all three training conditions differ (the first training phase was identical for the error management training and the error management training plus metacognition group). Also, the task in this phase was rather difficult and, therefore, required deliberate and conscious processing, which is a prerequisite for verbal protocols to "generate rich and valid data" (Taylor & Dionne, 2000, p. 415). We therefore based our analyses on the verbal data of the second training phase. Another potential threat to the validity of verbal protocol data are general verbalization tendencies of participants (as a person characteristic) influencing critical verbalizations. Thus, we counted the verbalizations of participants during the introductory phase in which no experimental manipulation had occurred. The general verbalization tendencies of participants (as indicated by number of phrases per minute) did not differ between the experimental groups, $F(2,43) = 0.20$, $p = .82$. Protocols of the critical training phase comprised an average number of 166.9 segments (SD = 57.3) and did not differ in length between experimental conditions, F (2,46) = 1.78, p = .18.

Each segment was classified into 1 of 2 major categories and into a more specific subcategory within the major category (cf. Berardi-Coletta et al., 1995; Sonnentag, 1998). The first major category, which was the focal category in our study, was metacognitive statements; statements reflecting metacognitive control of planning, monitoring and evaluation were categorized here. The second major category, which we called task-focused statements, subsumed statements that indicated task-orientation but lacked the cognitive control characteristic for metacognitive processing. Only very few segments did not fit into either category (M = 2.31, SD = 2.05) and were deleted from further analyses. The number of nonclassifiable segments did not differ between experimental conditions, F (2,46) = 0.40, p = .67. The two major categories of metacognitive versus task-focused statements map the distinction made by Berardi-Coletta et al. (1995) between processing level (i.e., metacognition) and problem level as two general levels of cognitive-attentional focus during problem solving. The most frequent subcategories of metacognitive statements and task-focused statements along with sample statements are listed in Table 1. The two most frequent categories in task-focused statements refer to mere descriptions by participants on what action step they were just performing (see Table 1, category 2a) or what action step they were about to perform (Table 1, category 2b). These categories may appear similar to the second metacognitive category listed, "Monitoring – observing changes" (Table 1, category 1b). The difference is that statements coded in the latter category reflected more detailed and attentive observations by participants that did not refer to the performed action itself (as in categories 2a and 2b, Table 1) but to the visible changes on the computer screen that were the *result* of an action performed.

The statements were classified by the first author and a graduate student who was trained to use the coding system. Cohen's kappa was .80 for the distinction between the two major categories (based on a subsample of 2,000 segments). Although inter-rater agreement remained acceptable on the level of subcategories (Cohen's kappa = .69), we based our main analyses on the broader level because our hypotheses did not refer to specific metacognitive subprocesses but to overall metacognitive activity of participants. If a statement was categorized as metacognitive and the same statement was then merely repeated by the participant, these repetitions were counted as such and excluded from further analyses. We then calculated the percentage of metacognitive statements relative to the number of all statements to represent *metacognitive activity* during training.

Emotion control. Emotion control during task engagement was assessed shortly after the test phase using a self-developed 8-item scale. Items were subject to a pilot test involving an independent sample ($N = 79$), while closely following definitions of the construct as outlined by Kanfer and colleagues (e.g., Kanfer & Ackerman, 1989; Kanfer et al., 1996). We used this self-developed scale in our study because existing measures of emotion control or related constructs did not seem to fit our purposes. Although Kanfer and colleagues have used a measure for emotion control in a study dealing with job search activities (Wanberg, Kanfer, & Rotundo, 1999), there are two reasons why their items did not seem suitable for our study. First, their items are mostly specific to their research question (e.g., "I get anxious even thinking about a job interview"). Second, their items appear to measure emotion control only indirectly by measuring negative emotions (i.e., anxiety in the sample item) as an indicator of *lack* of emotion control. The items we developed were designed to capture strategies for *regulation* of negative emotions that participants actively engage in, rather than negative emotions per se. In this respect, our scale resembled coping questionnaires (e.g., Carver, Scheier, & Weintraub, 1989; Folkman & Lazarus, 1985) or more recently published scales on emotion regulation at work in service employees (e.g., Grandey, Dickter, & Sin, 2004; Totterdell & Holman, 2003), where items directly refer to regulatory strategies one might use when experiencing a stressful encounter. However, in line with Kanfer's conceptualization of emotion control that our research was based on, our scale's emphasis was on controlling emotions and sustaining attention during completion of a specific task. We used a modified version of Wanberg et al.'s (1999) item instruction: Participants were asked to rate their reaction to problems they faced during task completion. All items began with the root "When difficulties arose" with various stems following including "I purposely continued to focus myself on the task" and "I calmly considered how I could continue the task". Items were answered on a 5-point Likert scale ranging from 0 (*does not apply*) to 4 (*applies*). Cronbach's alphas were .82 in the pilot sample and .80 in the present sample.

Error orientation. As a manipulation check, error orientation during task completion was assessed using two subscales of the Error Orientation Questionnaire (EOQ; Rybowiak, Garst, Frese, & Batinic, 1999). The original questionnaire is designed to measure "attitudes to and … coping with errors at work" (Rybowiak et al., 1999, p. 527) of individuals or groups. For the present study, we chose 2 of the 8 EOQ subscales covering important individual error orientations which we expected to be affected by error management instructions (EOQ subscale *error strain*) and by metacognitive instructions (EOQ subscale *learning from errors*). In order to fit the present research question, we slightly modified the instructions and items to capture error orientations during task completion (rather than general orientations at work). The subscale *error strain* consisted of five items involving negative emotional reactions to errors and being afraid of making errors (e.g., EOQ item "I feel embarrassed when I make an error" was changed to "I felt embarrassed when I made an error"). Cronbach's alpha was .81 for this scale. The subscale *learning from errors* comprised four items covering the extent to which people used errors to learn (e.g., EOQ item "Errors help me to improve my work" was changed to " Errors helped me to improve my work"). Cronbach's alpha was .82 for this scale.

Computer experience. Before the onset of the study, participants were asked how many years they had been using a computer and which computer applications they used (e.g., word processing programs, spreadsheet programs). We used *years of computer usage* and *number of applications* as two indicators of computer experience and included these variables as covariates in all analyses. There were no pre-experimental differences between training conditions in years of computer usage, $F\,(2,52) = 0.25$, $p = .78$, and in number of applications, $F\,(2,52) = 0.51$, $p = .67$.

All participants had worked with text processing programs before (such as Word for Windows). We asked participants which functions of text processing programs they employed, because the presentation program taught in this study shares many features with common text processing programs. For example, participants were asked whether they regularly formatted texts, used bullets, or created and formatted tables. We used the *number of functions* regularly employed by participants as a third indicator of computer experience and included this variable as another covariate in all analyses. There was a pre-experimental difference between training conditions in number of functions: Before the study began, participants of error avoidant training knew more computer functions relevant to the program taught, $F\,(1,52) = 4.61$, $p < .05$, $\eta^2 = .08$ (for the descriptive statistics, see Table 1).

Results

Intercorrelations of Study Variables

Descriptive statistics and intercorrelations of the study variables are displayed in Table 2. As expected, intercorrelations between computer experience and performance variables were in the middle range with all but one coefficient being significant. We included all three computer experience variables as statistical controls in all further analyses.

Manipulation Checks

To assure that participants had interpreted the error management instructions and the metacognitive instructions in the intended way, error orientation of participants during task completion were compared. We expected *error strain* to be lower in both error management training groups than in the error avoidant group because error management instructions frame errors positively, and errors should, therefore, be perceived as less threatening. Planned contrasts revealed that this was the case: Error strain was significantly higher in the error avoidant group compared to the error management training groups, F (1,49) = 5.81, $p < .05$, $\eta^2 = .11$, but did not differ between error management training groups, F (1,49) = 0.03, $p = .86$. We further expected *learning from errors* to be particularly high in the error management training plus metacognition condition because the metacognitive instruction given to this group stressed the usefulness of metacognitive planning, monitoring, and evaluation for learning over and above the rather general positive framing of errors in the error management instructions. Again, this was the case. Learning from errors was significantly higher in both error management training groups compared to the error avoidant group, F (1,49) = 8.11, $p < .01$, $\eta^2 = .14$, and a direct comparison of the two error management groups revealed that it was highest in the error management condition with the metacognitive instructions, F (1,49) = 4.17, $p < .05$, $\eta^2 = .08$.

Taken together, these results suggest that both the error management instructions and the metacognitive instructions worked in the intended way.

To assess whether participants in the error management training plus metacognition group followed instructions to pose and answer questions related to metacognitive planning, monitoring, and evaluation during training, we counted how often participants of all training groups posed questions similar to those listed in the metacognitive instructions (Cohen's kappa = .71 based on 2,000 segments). As expected, the number of questions was largest in the verbal protocols of the error management training plus metacognition condition, $F\ (1,43) = 23.30$, $p < .01$, $\eta^2 = .35$, indicating that participants had followed metacognitive instructions.

We also used the verbal protocol data to further illuminate whether participants in error management training had in fact made more errors during training than participants in error avoidant training who received detailed instructions on the task solution (note that despite these instructions participants in this condition could still make errors; e.g, because they did not read the instructions correctly). Although not an exact count, the category "Negative evaluation without explanation" can serve as an indicator of errors in training, because statements subsumed under this category imply that participants' preceding action did not lead to the desired outcome (category 2c in Table 1). As expected, the statements in this category were much more frequent in the error management training groups ($M = 20.91$, $SD = 9.23$) compared to the error avoidant group ($M = 8.79$, $SD = 4.68$), $F\ (1,43) = 15.68$, $p < .01$, $\eta^2 = .27$.

Finally, to get a better picture of what exactly happened in the training conditions, we inspected the frequency of task-focused statements in the training groups. In the error avoidant training group, about one third of the statements comprised reading or repeating the written instructions on task solution (category 2e in Table 1; $M = 31.31$, $SD = 11.71$; numbers refer to percentage relative to all statements). Participants in this condition also frequently described what they were currently doing (category 2a; *M* = 19.37, *SD* = 6.65) or what they were about to do (category 2b; *M* = 11.56, *SD* = 5.39). In error management training, too, participants frequently described the present step (category 2a; *M* = 24.92, *SD* = 10.30) or the next step (category 2b; *M* = 20.79, *SD* = 5.46), but the third most frequent category was the error category (category 2c; *M* = 12.36, *SD* = 4.48). Taken together, these analyses suggest that the experimental manipulation was successful: Participants in error avoidant training worked along the lines of the written instructions during training, and participants in error management training frequently made errors while working on their own.

Main Effects of Training Condition on Transfer Performance

Hypothesis 1 predicted adaptive transfer performance to be superior in both error management trainings than in error avoidant training. In an open research question, we further explored whether participants in the error management training plus metacognition condition (i.e., with additional metacognitive instructions) would perform better than those in classical error management training without additional metacognitive instructions. For performance in analogical transfer, we did not expect any differences between training groups. We first tested this with a repeated measures ANCOVA with training structure as the between-factor, transfer type (i.e., analogical and adaptive transfer) as the within-factor, and with computer experience variables as covariates. As expected, a significant interaction between training condition and transfer type emerged, F (2,49) = 4.20, $p < .05$, $\eta^2 = .15$. In line with predictions, analogical transfer did not differ between groups, F (2,49) = 0.39, $p = .68$, but adaptive transfer did, F (2,49) = 4.34, $p < .05$, $\eta^2 = .15$.

We found clear support for Hypothesis 1 (Table 3): Adaptive transfer was superior in error management training conditions compared to error avoidant training with a medium to large effect size of $\eta^2 = .12$ (note that the correlation reported in Table 2 between the variable contrasting error avoidant training with error management trainings is not significant whereas the ANCOVA contrast from Table 3 is because the correlation does not take the control variable computer experience into account). The difference between the two error management training conditions (open research question) was not significant ($p = .26$).

Emotion Control and Metacognitive Activity as Mediators of Adaptive Transfer Performance

In Hypotheses 2 and 3 we predicted that emotion control and metacognitive activity during training mediate the effect of training condition on adaptive transfer performance. We first tested these hypotheses separately and then simultaneously for emotion control and metacognitive activity using the procedure recommended by James and Brett (1984). According to this procedure, variable *b* mediates the effect of variable *a* on variable *c* if the following conditions are met: (1) *a* has an effect on *b*, (2) *b* has an effect on *c*, and (3) the effect of *a* on *c* disappears when *b* is held constant. The first and second conditions were met: Table 2 reveals that the training condition (i.e., contrast variable 1) was significantly related to both mediators, and that both mediators were significantly related to adaptive transfer performance. The third condition was tested in hierarchical regression analyses in which training condition was entered as a predictor after controlling for mediating variables. Results are displayed in Table 4. When entered after emotion control or metacognitive activity in separate analyses, the effect of training condition vanished (after emotion control: $\beta = .17$, n.s., after metacognitive activity: $\beta = .01$, n.s.). Further, when entered after both mediators emotion control and metacognitive activity, the effect of training condition disappeared ($\beta = -.08$, n.s.), and the effects of both mediators remained significant ($\beta = .24$ for emotion control, $\beta = .27$ for metacognitive activity, both *p*s $< .05$). Thus, Hypotheses 2 and 3 were supported: Emotion control and metacognitive activity fully and independently mediated the effect of training condition on performance.

To supplement the ordinary least squares regression analyses, structural equation modeling (SEM) was conducted using the maximum likelihood (ML) procedure in LISREL (Linear Structural Relationships; Jöreskog & Sörbom, 1996). These analyses were conducted because SEM offers the advantages (1) that parameters can be estimated simultaneously, (2) that an overall model fit can easily be obtained, and (3) that additional paths can be introduced into the model and tested for statistical significance. Although LISREL and similar approaches are commonly used as large sample size procedures, recent evidence suggests that SEM-ML can also yield appropriate estimates in mediation models with small samples (Hoyle & Kenny, 1999). In our models, to keep the subject-to-parameter ratio at an acceptable level and to keep the model simple, we did not include the control variables as exogenous variables but used residuals instead. That is, we regressed the four study variables (predictor training condition, the mediators emotion control and metacognitive activity, and criterion adaptive transfer) on the computer experience variables, and used the covariance matrix of the residual variables as input for the LISREL analyses. The model had an excellent fit, χ^2 ($df = 2$) = 1.09, $p = .58$, RMSEA = .00, AGFI = .94, NFI = .98, CFI = 1.00. Standardized parameter estimates of the model are depicted in Figure 1. All hypothesized paths were significant. We further tested the indirect effects of training condition on adaptive transfer for significance using Sobel's first-order solution for standard errors of indirect effects (MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). Both the paths, via emotion control ($t = 2.99$, $p < .05$) and via metacognitive activity ($t = 5.21$, $p < .01$), were significant.

In a second LISREL model we introduced an additional direct effect of training condition on adaptive transfer (additional to the paths depicted in Figure 1). This path was estimated to be zero (-.09 in standardized solution, $t = -0.57$). Also, the model fit did not improve, $\Delta\chi^2$ (df=1) = 0.34, $p > .75$. Thus, replicating results of the regression analyses (cf. Table 4), the effect of training condition on adaptive transfer was fully und independently explained by the mediators emotion control and metacognitive activity in LISREL analyses.

We further explored the relationship between emotion control and metacognition with LISREL. As can be seen in Table 2, the manifest zero-order correlation between these two variables was significant ($r = .38$, $p < .01$). In a third LISREL model we introduced a correlation between emotion control and metacognitive activity (in addition to the paths depicted in Figure 1). In this model, the correlation was estimated to be zero (.09 in standardized solution, $t = 0.86$), and model fit did not improve, $\Delta\chi^2$ (df=1) = 0.76, $p > .50$. Thus, the training condition served as an explanatory variable in the mediation model: Emotion control and metacognitive activity covaried only to the extent to which both processes were evoked by the training condition.

Discussion

The main goal of our study was to identify processes mediating error management training effectiveness. In line with resource allocation theories assuming a limited amount of attentional resources (e.g., Kanfer & Ackerman, 1989; Kluger & DeNisi, 1996), we argued that error management training helps to exert self-regulative control that in turn leads to better learning and performance. More specifically, we proposed that error management training enhances both emotional self-regulation (i.e., emotion control) and cognitive self-regulation (i.e., metacognitive activity). A second goal of our study was to explore whether there is still room for an add-on effect of additional metacognitive instructions over and above the effect of classical error management training without such instructions.

Our study replicated the main effect on performance that has frequently been found in error management training studies (e.g., Chillarege et al., 2003; Dormann & Frese, 1994; Frese et al., 1991; Heimbeck et al., 2003; Nordstrom et al., 1998; Wood et al., 2000): Error management training participants outperformed those in error avoidant training on an adaptive transfer test. This effect was appreciable (effect size equivalent to a Cohen's *d* of 0.75), given that the error avoidant group was not a nontraining control group. A direct comparison of the two error management training conditions (i.e., error management training vs. error management training supplemented by metacognitive instructions) did not reveal any performance difference. It is possible that the metacognitive instructions were too weak in this study because participants were to engage in metacognitive activities individually whereas other studies had participants work in dyads (King, 1991) or in cooperative groups (McInerney et al., 1997). In a recent study by Schmidt and Ford (2003), the effect of a metacognitive intervention for individual learners depended on their dispositional goal orientation. Also, given that metacognitive activities require effortful and time-consuming processing, the practice phase in the present study might have been too short for the benefits of metacognitive activities to fully develop. Future research should investigate whether metacognitive instructions can improve error management training under conditions involving longer time periods or multiple sessions.

The most intriguing finding of this study is the strong support for our mediation hypotheses: Group differences between error avoidant training and error management training in adaptive transfer performance were fully and independently explained by emotion control and metacognitive activity during training. Supplemental analyses with LISREL further revealed that the empirical zero-order correlation between the two mediators was fully accounted for by training condition in the mediation model. In other words, error management training induced both emotion control and metacognitive activity during training, and these processes enhanced performance in tasks that required finding new solutions. From a self-regulatory perspective, emotional self-regulation (emotion control) and cognitive self-regulation (metacognition) were equally important for adaptive transfer to occur.

Our results concerning emotion control are consistent with theory and research by Kanfer and colleagues (Kanfer & Ackerman, 1989; Kanfer et al., 1996). They argued that emotion control is a skill useful in early phases of skill acquisition because it helps to direct attention away from the self and to the problem at hand in the face of errors and setbacks. From this point of view, error management training may be regarded as a form of emotion control training because participants are confronted with errors early on in training and learn to exert emotion control in order to deal with them. Similarly, within the framework of transactional stress theory (Lazarus & Folkman, 1984), error management training may be thought of as a form of cognitive reappraisal training, because error management instructions reframe errors positively. As a consequence, participants in error management training can conceive errors as less threatening but rather as positive and useful events, which in turn reduces the experience of negative emotions in the face of errors.

Our results concerning metacognitive activity conform to educational theory and research highlighting the benefits of metacognition during learning (e.g., Schunk & Zimmermann, 1994; cf. also Schmidt & Ford, 2003), and with theorizing by Ivancic and Hesketh (2000; Hesketh & Ivancic, 2002). Ivancic and Hesketh (2000) delineated that error management training instigates metacognitive planning, monitoring, and evaluation because errors encourage a systematic analysis of the error's cause as well as an implementation and testing of potential solutions. Error avoidant training that prevents participants from making errors, in contrast, does not provide the opportunity to practice emotion control and metacognition because participants simply follow correct instructions and do not need to work out solutions on their own. This line of argument is also consistent with cognitive theories of action regulation. For example, action theory (Frese & Zapf, 1994; Hacker, 1998) posits that errors disrupt premature automatization of actions because they make learners rethink their strategy. Similarly, control theory (e.g., Lord & Levy, 1994) proposes that discrepancies between standards and feedback (i.e., errors) initiate an increased allocation of attention to the task and that learning occurs when these discrepancies are resolved.

Strengths and Limitations

Although our data shows emotion control to be an effective mediator of adaptive transfer performance, one may doubt whether our measure of emotion control was unbiased because participants filled out the emotion control items soon after they had completed the performance test. More precisely, our results might be distorted due to what is known as self-handicapping in test anxiety research (e.g., Laux & Glanzmann, 1987): Poor performing participants might have indicated their emotion control to be low simply because they were aware of their poor performance. This is an issue that applies not only to the present or other error management training studies using questionnaire data to measure processes (e.g., Debowski et al., 2001; Wood et al., 2000), but to nearly all studies where participants were asked for self-ratings of psychological variables after performance assessment. Although we are confident that not all interindividual variance in emotion control was solely due to participants' self-serving bias, this alternative explanation cannot be ruled out based on the self-ratings we collected after the test phase. A better strategy would be to collect emotion control data during the training session or right before the performance phase or alternatively, to use a method other than self-reports that is less subject to self-serving bias.

Our measurement of metacognitive activity is unaffected by participants' potential self-serving bias. First, we derived this measure not from participants' self-ratings but from verbal protocol ratings that were blind to experimental condition and performance scores. Second, for both methodological and conceptual reasons, we were careful to make a time-lagged prediction: We predicted *later* adaptive transfer performance from the metacognitve activity measure that had been assessed *earlier* in training. From a methodological perspective, this time lag has the advantage that mediator and outcome variable are less likely to be confounded. From a conceptual perspective, we were interested in processes not just concurrent with but predictive for adaptive transfer performance.

Although we feel that our approach to use verbal protocol data for process analyses was successful, one may raise objections concerning the validity of thinking aloud protocols in general. There has been an intensive debate as to whether thinking aloud protocols reflect cognitive processes of participants or whether the processes are critically altered (e.g., Schooler, Ohlsson, & Brooks, 1993). For two reasons we are confident that the conclusions we drew in our study from verbal protocol analysis are valid. First, we carefully followed recommendations to avoid obtrusive instructions for thinking aloud (Ericsson & Simon, 1993; Taylor & Dionne, 2000). Second, our results concerning the superiority of error management training compared to error avoidant training replicated results of other studies with similar effect sizes (Chillarege et al., 2003; Dormann & Frese, 1994; Heimbeck et al., 2003; Frese et al., 1991; Ivancic & Hesketh, 2000; Nordstrom et al., 1998; Wood et al., 2000). If our verbal protocol data were invalid, this would imply that our study produced the *same effects* as other studies, but that these effects were due to *different processes* – an assumption that is of low plausibility.

An obvious drawback to our study is the composition and small size of our sample. It should be noted, however, that other error management training studies (e.g., Debowski et al., 2001; Wood et al. 2000) as well as other studies using verbal protocol analysis (e.g., Ball, Langholtz, Auble, & Sopchak, 1998) have relied on small and sometimes even smaller samples. More importantly, we found group differences in performance as well as process variables *despite* the relatively low statistical power due to the small sample – a finding that corresponds to the considerable effect sizes for these differences (Cohen, 1994; Kramer & Rosenthal, 1999; Sonnentag, 1998). Also, as mentioned above, the superiority of error management training compared to error avoidant training has been found in other studies using larger samples. For reasons of research economy, the use of thinking aloud analysis restricted our sample to a limited number of volunteer students (despite the rather small number of participants, about 18,000 coding units were available from the verbal protocols).

Implications for Future Research

The present study focused on processes in training and did not look at individual differences potentially affecting performance. Some studies, however, suggest that participants may differentially benefit from error management training or error avoidant training depending on person characteristics such as cognitive ability, openness to experience, or goal orientation (Gully et al. 2002; Heimbeck et al., 2003). Future studies should look at differential processes induced by such interactions of training condition and person characteristics. Furthermore, given the strong predictive power of emotion control and metacognitive activity, it would be interesting to identify person characteristics that promote exertion of emotion control and metacognitive activity during training. For example, participants high in learning goal orientation may be more likely to engage in effortful metacognitive activity during training. Likewise, avoidance goal orientation, directed at the avoidance of potential failure in the task and of negative judgment by others, may be negatively related to emotion control in the face of setbacks during training. Apart from the influence of goal orientations as stable person characteristics, goal orientations as temporal states may be affected by error management training as well. Error management instructions, emphasizing the positive role of errors during learning may encourage a learning or mastery orientation. In fact, there are studies that, among other instructions, use positive error statements similar to error management instructions when manipulating learning goal orientation (e.g., Kozlowski et al., 2001).

Starting from the notion that errors instigate metacognitive activity, our study demonstrated the power of *overall* metacognitive activity in error management training. A more microanalytical approach that examines actions and cognitions following errors could further illuminate the processes of how errors instigate metacognitive activity. For example, do errors trigger metacognitive activity immediately? Or does it take several errors to finally engage in effortful metacognitive activity? Another possibility is that there is no simple one-to-one relation between errors and metacognitive activity but that the low level of structure and the frequent errors in error management training together induce a general metacognitive processing mode during training. Future research could use methods such as behavior observation or analyses of concurrent video and verbal protocol data to gain insight into the dynamics of errors and metacognitive activity in error management training.

Such a microanalytical approach could also provide an insight to component processes of metacognitive activity (i.e., planning, monitoring, or evaluation) that are specifically important for the effects of error management training. In post-hoc exploratory analyses, we identified three of the metacognitive subcategories (cf. Table 1) as significant individual predictors of adaptive transfer (partial correlations controlling for computer experience variables > .37, all *p*s < .05). These subcategories were "Planning – generation of hypotheses" (category 1a in Table 1), "Monitoring – observing changes" (category 1b), and "Evaluation – explicit explanation" (category 1d). Although the results of these exploratory analyses should be interpreted with caution, they might provide some initial directions for future research dealing with metacognitive subprocesses.

Related to this issue, future research could use an error taxonomy to identify what types of errors lead to learning because not all errors can be expected to be equally useful and informative or to automatically lead to metacognitive activity and subsequent enhanced performance. Within an action theory framework, an error taxonomy differentiates errors as to the level of action regulation involved in the error (Zapf et al., 1992; see also Rasmussen, 1982, who distinguishes between knowledge-based, rule-based, and skill-based regulation). The levels of regulation run from conscious regulation to automatic regulation. For example, Zapf et al. (1992) validated a taxonomy that distinguished errors in computer work. First, on the intellectual level, complex problem analyses are regulated which may lead to errors (e.g., planning errors occur when the user selects the wrong course of action for a task). Second, on the level of flexible action patterns, actions are regulated by schemata (e.g., habit errors occur when a well-known action is performed in the wrong situation). Third, on the sensorimotor level, stereotyped and automatic movements are organized (e.g., typing errors or wrong movements of the computer mouse occur here). We would expect, for example, that most learning in error management training occurs from errors on higher levels of regulation rather than from sensorimotor errors such as typos that can be detected and corrected immediately. Future research could use this taxonomy and identify types of errors that lead to learning, both in the present and in other kinds of tasks.

Another related issue deals with the question of how overall errors and errors of different types relate to adaptive transfer. The concept of error management training suggests that the number of errors should positively relate to subsequent transfer performance. Empirically, however, we would not expect a positive but rather a negative relationship because most errors are a result of lack of knowledge which is usually associated with poor performance. Another possibility is a nonlinear relationship of errors and performance that corresponds to the concept of an optimum number of errors for transfer to occur. Ivancic and Hesketh (2000) found a negative relationship between errors in training and performance on a transfer task. At the same time, however, participants tended not to repeat the same errors they made during training. These results possibly indicate that errors and subsequent transfer performance may be negatively related *between* persons but may be unrelated or even positively related *within* persons. Future research could address these questions using a design that involves multiple tasks and trials.

The present study, like other studies dealing with error management training, compared error management training to error avoidant training, the latter hindered participants from making errors by means of step-by-step instructions. Another, probably better known, training approach is behavior modeling which is based on Bandura's (1986) social cognitive theory. Within Bandura's framework, building self-efficacy by mastery experiences is crucial for learning and performance. A training program using behavior modeling usually involves a live or videotaped model demonstrating the correct strategies for task solution followed by the trainees' imitation of the model's behavior in practice (e.g., Gist, Schwoerer, & Rosen). Thus, behavior modeling is more structured than error management training. In complex tasks with ambiguous feedback and in tasks that require one single best strategy for task solution, behavior modeling probably results in better performance than error management training (Debowski et al., 2001). These two training techniques, however, do not necessarily have to be conceived of as mutually exclusive alternatives. Also, just like behavior modeling, error management aims at building self-efficacy. More specifically, error management is directed at building self-efficacy in the face of problems and errors that occur when working on new tasks. Future research could look at self-efficacy expectations as outcomes of error management training.

Another interesting issue for future research could be to examine the exact relation of emotion control and metacognitive activity. In our study, emotion control and metacognitive activity were conceptualized and shown to be independent mediators of performance effects. The interrelation between the two variables disappeared when training condition was taken into account. In other words, error management training enhanced both emotional and cognitive self-regulation which in turn led to improved performance. This result raises the question of how both processes are intertwined. For example, does metacognitive activity positively affect emotion control because participants engaged in metacognitive activity "forget" to get angry about an error? Or does emotion control serve as a prerequisite for metacognitive activity, because only if participants' negative emotions are controlled, can metacognitive activity be initiated? Theoretically, these kinds of questions go beyond the academic convention to describe emotional and cognitive processes as distinct phenomena using different theoretical models. We believe that the self-regulation perspective adopted in this paper provides a framework for integrating emotions and cognitions into a common model.

Implications for Theory and Practice

Our study corroborates the notion that emotional and cognitive self-regulation mediates effectiveness of error management training. This finding has important implications for both theory and practice. From a theoretical perspective, training research has always been interested in not only the question *if* training works but also *why* it works (e.g., Goldstein & Ford, 2002). Only very few error management training studies have up to now looked explicitly at the processes underlying error management training effectiveness, and none of these have provided conclusive results (Debowski et al., 2002; Wood et al., 2000). Our study contributes to a better theoretical understanding of why error management training leads to better performance than error avoidant training.

From a practical perspective, identifying effective mediators in training is particularly important because this information is useful for modifying error management training or for adapting its principles to another area. Our results suggest that error management training is effective, because it provides the opportunity to practice the metacognitive activities of planning, monitoring, and evaluation – skills that prove useful when it comes to tasks that require a new solution. Practitioners may consider explicitly integrating modules of error management training into the training process by giving participants the opportunity to make errors by working on difficult training tasks on their own and at the same time encouraging them to use their errors as a learning device.

Most importantly, our research highlights the critical role of the kind of information-processing participants engage in during training (cf. Hesketh & Ivancic, 2002). Stated differently, in our study the crucial question for adaptive transfer was not *what* material was learned during the training session (the material was identical in all training conditions) but rather *how* it was learned. When planning a training intervention, practitioners may focus their attention not only on the training material to be covered but also on the kind of information processing that is most promising for transfer to occur.

We are confident that the principles of error management training can be incorporated into areas other than computer training, although research concerning other areas is rare (Gully et al. 2002; Ivancic & Hesketh, 2000). We suggest that error management training is useful whenever the material to be learned cannot be covered completely during the training session and, consequently, for situations where participants need to 'learn to learn' when confronted with new tasks. This is related to the principle of transfer appropriate processing which postulates that those processes required on transfer tasks should be practiced during training (Morris et al., 1977). The present transfer task required discovery type activities involving learning from errors because solutions to problems distinct from those worked on during the training session had to be found. Consequently, error management training, which required the same type of activities during training, resulted in superior performance relative to error avoidant training that taught the correct solutions during training. In trainings covering a relatively small amount of material that is highly structured, however, it is probably more economical to teach the correct strategies directly because exploring and learning from errors may be too time-consuming. Related to this issue, in tasks that require one single best strategy for task solution, behavior modeling probably results in better performance than error management training (Debowski et al., 2001). It should be kept in mind that although error management training may be successful in promoting transfer performance, training performance itself may not be better or may even be worse than in error avoidant training. Not only will participants in error management training make more errors during training – after all, they are told to do so – it will also take them longer to solve the tasks on their own or, if time is limited, they will solve fewer tasks during the same training period than their counterparts in error avoidant training.

Also, when tasks are very complex, error management training should be combined with elements of guided training (Bell & Kozlowski, 2002) because due to the low level of structure and guidance in error management training, participants may run the risk of developing incorrect concepts of the training content (Frese, 1995; Mayer, 2004). For example, a guided approach comprising assistance and external feedback by the trainer could be used to develop basic competencies that subsequent error management training could build on (Debowski et al., 2001). Finally, high fidelity task feedback is probably a prerequisite for error management training because errors can serve as informative feedback only in systems that allow self-regulated error detection and correction. Many of the studies that successfully applied error management training have used computer tasks that usually provide clear task feedback. For example, if a participant takes action to insert a table into a document, he or she will immediately see whether the action leads to the desired goal or not. Other tasks that lack the kind of clarity of task-inherent feedback may not be well suited for error management training. In a social skills training, for example, error management training may not be helpful if a participant is not able to interpret others' reactions to his or her actions or speech correctly, so that augmented feedback by a trainer or by fellow participants may be required. On the other hand, once basic interpretation skills are developed, error management training may be effective in promoting transfer because in real-life interactions augmented feedback is not provided. It is our hope that this work encourages researchers and practitioners to take up error management training principles and apply them to other areas of skill acquisition.

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Table 1

Two Major Categories and Most Frequent Subcategories in Verbal Protocol Analysis

(1) Metacognitive statements
a. Planning – generation of hypotheses (e.g., "It must be possible to select these cells separately.", "If I mark the whole thing right here, I should be able to do the frame.")
b. Monitoring – observing changes (e.g., "Now I have these dotted lines again.", "And if I pull the mouse across them, these turn blue.")
c. Evaluation – derivation of general rules (e.g., "I first have to click on this thing here, then I get these dots and I can move it.", "I cannot do this until I have inserted the line.")
d. Evaluation – explicit explanation (e.g., "That's because I have clicked on this pen here.", "No, because I have to activate it first.")
(2) Task-focused statements
a. Description of present step (e.g., "I click on textbox.", "Now I pull this.", "And I center this one, too.")
b. Description of next step (e.g., "Now I will enter the text.", "Now I will center it again.", "I will make this more evenly spread.")
c. Negative evaluation without explanation (e.g., "No, that's wrong.", "No, I don't like that.", "I didn't want that.")
d. Spelling out while typing (text or numbers to be entered into the table)
e. Reading out or repeating instructions (error avoidant group only)

Table 2

Means, Standard Deviations, and Intercorrelations of the Study Variables

	Variable	1	2	3	4	5	6	7	8	9	10	11	12
	Training conditions[a]												
1.	Contrast 1	--											
2.	Contrast 2	.05	--										
	Computer experience												
3.	Years of computer usage	.08	-.05	--									
4.	Number of applications	-.16	-.02	.27*	--								
5.	Number of functions	-.28*	.11	.34*	.44**	--							
	Performance variables												
6.	Training performance	-.15	-.15	.30*	.25	.38**	--						
7.	Analogical transfer	.00	-.01	.42**	.41**	.46**	.70**	--					
8.	Adaptive transfer	.18	.15	.49**	.41**	.49**	.63**	.77**	--				
	Mediators												
9.	Emotion control	.42**	.15	.07	-.25	-.02	.12	.20	.30*	(.80)			
10.	Metacognitive activity	.63**	.31*	.14	-.16	-.13	-.04	.10	.32*	.38**	--		
	Manipulation checks												
11.	Error strain	-.31*	-.02	-.15	.17	-.08	-.13	-.24	-.24	-.68**	-.18	(.81)	
12.	Learning from errors	.34*	.30*	.07	-.07	.12	-.07	.09	.19	.48**	.44**	-.28*	(.82)
	Descriptive Statistics												
	Total												
	M	0.35	0.05	5.10	1.95	4.36	25.95	24.73	10.87	2.97	4.88	0.85	2.60
	SD	0.95	0.83	3.02	1.22	2.03	9.00	4.89	5.35	0.61	3.52	0.72	0.70
	Error avoidant group												
	M	-2.00	0.00	4.75	2.22	5.17	27.89	24.72	9.50	2.60	1.40	1.17	2.26
	Sd	0.00	0.00	2.59	1.22	1.89	7.84	5.11	4.59	0.66	1.81	0.75	0.68
	Error management group												

M	1.00	-1.00	5.49	1.82	3.65	26.65	24.82	10.53	3.04	5.01	0.69	2.50
Sd	0.00	0.00	3.19	1.63	1.87	10.31	5.15	6.07	0.59	1.74	0.69	0.71
Plus metacognition group												
M	1.00	1.00	5.07	1.80	4.25	23.60	24.65	12.40	3.24	7.35	0.69	2.99
Sd	0.00	0.00	3.35	0.77	2.12	8.71	4.70	5.20	0.41	3.49	0.65	0.52

Note. $N = 55$ (error avoidant group: $n = 18$, error management training group: $n = 17$, error management training plus metacognition group: $n = 20$). For all analyses involving metacognitive activity: $n = 49$. Alpha coefficients are shown in parentheses on the diagonal when applicable. Plus metacognition group = Error management training plus metacognition group.

[a] Contrast 1 compares error avoidant training with both error management training groups (error avoidant training = -2, both error management training groups = +1), Contrast 2 compares error management training groups (error avoidant training = 0, error management training = -1, error management training plus metacognition = +1).

* $p < .05$, two-tailed. ** $p < .01$, two-tailed.

Table 3

Effects of Training Condition on Adaptive Transfer (ANCOVA Contrasts Controlling for Computer Experience)

		Effect size	
	F (*df*)	η^2	Cohen's *d*
Error avoidant vs. error management training groups (group 1 vs. groups 2+3)	6.75* (1,49)	.12	0.75
Error management training vs. error management training plus metacognition (group 2 vs. group 3)	1.28 (1,49)	--	--

Note. $N = 55$. For this analysis, the appropriate effect size estimate is η^2 representing the explained variance. For ease of interpretability, Cohen's *d* was additionally calculated based on residuals after controlling for computer experience.

* $p < .05$, two-tailed.

Table 4

Emotion Control and Metacognitive Activity as Mediators of Training Effects on Adaptive Transfer

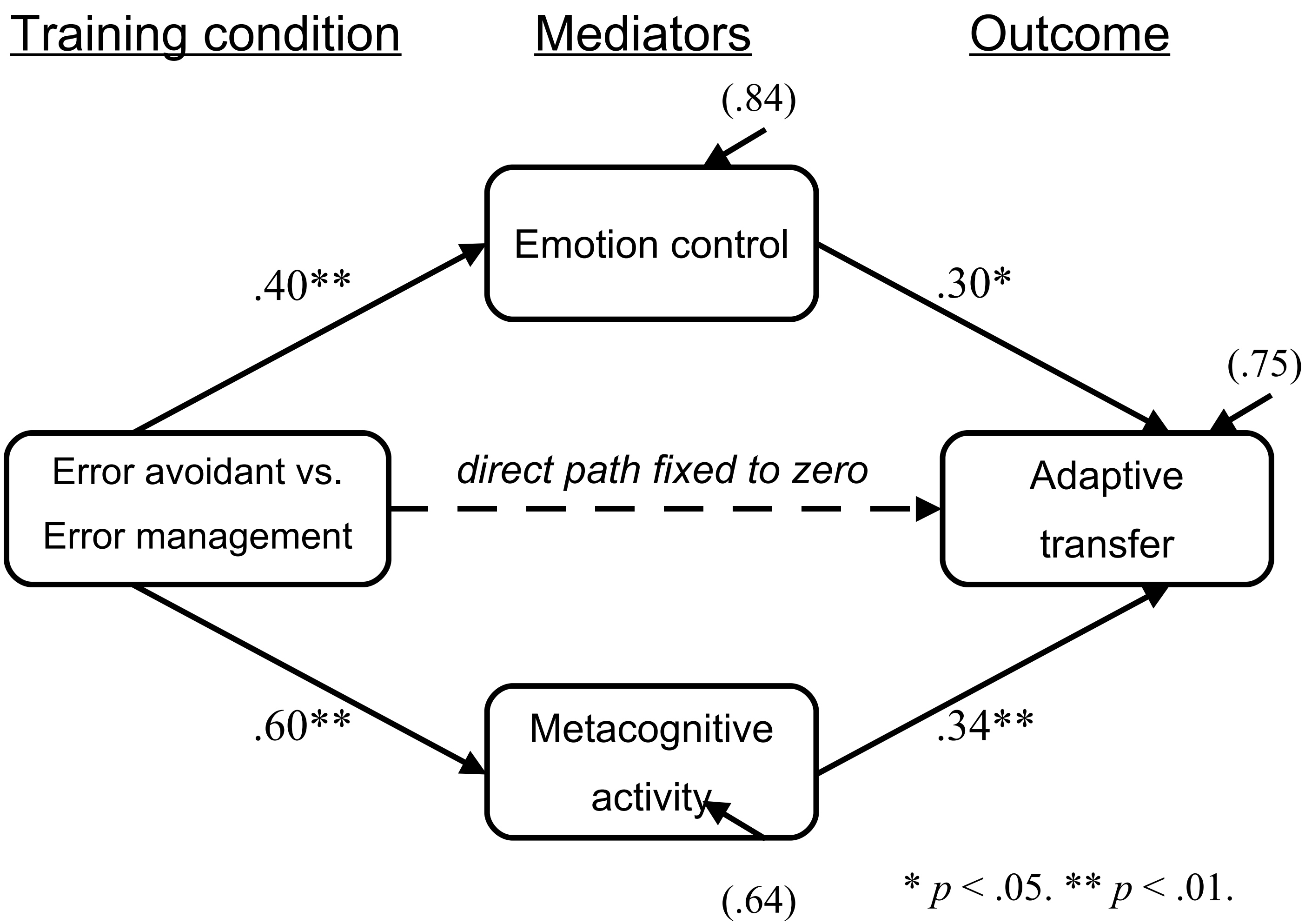
Predictor /step	*B*	*SE B*	β	R^2	ΔR^2
Direct Effect of Training Condition					
1. Computer experience variables (controls)				.38**	
Years of computer usage	0.60	0.21	.34**		
Number of applications	0.85	0.54	.19		
Number of functions	0.76	0.33	.29*		
2. Training condition				.46**	.08**
Error avoidant vs. Error management	1.69	0.62	.30**		
Mediation by Emotion Control					
2. Mediator				.51**	.12**
Emotion control	3.20	0.91	.37**		
3. Training condition					
Error avoidant vs. Error management	0.98	0.65	.17	.53**	.02
Mediation by Metacognitive Activity					
2. Mediator				.53**	.11**
Metacognitive activity	0.54	0.17	.35**		
3. Training condition					
Error avoidant vs. Error management	0.03	0.86	.01	.53**	.00
Mediation by both Emotion Control and Metacognitive Activity					
2. Mediators				.57**	.16**
Emotion control	2.16	1.01	.24*		
Metacognitive activity	0.42	0.17	.27*		
3. Training condition				.58**	.00
Error avoidant vs. Error management	-0.46	0.85	-.08		

Note. $N = 55$. For all analyses involving metacognitive activity: $n = 49$.

* $p < .05$, two-tailed. ** $p < .01$, two-tailed.

Figure Caption

Figure 1. Emotion control and metacognitive activity mediating effects of training condition on adaptive transfer (standardized parameter estimates from LISREL analysis).


Training condition
Mediators
Outcome
(.84)
Emotion control
.40**
.30*
(.75)
Error avoidant vs.
Error management
direct path fixed to zero
Adaptive
transfer
.60**
.34**
Metacognitive
activity
(.64)
* p < .05. ** p < .01.