Effectiveness of Error Management Training: A Meta-Analysis

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Abstract

Error management training (EMT) is a training method that involves active exploration as well as explicit encouragement to make errors during training and to learn from them. Past evaluation studies, which compared skill-based training outcomes of EMT with those of proceduralized error-avoidant training or exploratory training without error encouragement, yielded considerable variation in effect sizes. The present meta-analysis compiles the results of the existing studies and seeks to explain this variation. Although the mean effect of EMT across all identified 24 studies ($N = 2183$) was positive and significant (Cohen's $d = 0.44$), there were several moderators. Moderator analyses showed effect sizes to be larger for posttraining transfer than for within-training performance (transfer performance: $d = 0.56$) and for performance tasks that were structurally distinct (adaptive transfer) rather than similar (analogical transfer) to training tasks (adaptive transfer: $d = 0.80$). In addition, both active exploration and error encouragement were identified as effective elements in EMT. Results suggest that EMT may be better suited than error-avoidant training methods to promote transfer to novel tasks.

Keywords: errors, training, training evaluation, adaptive transfer

Effectiveness of Error Management Training: A Meta-Analysis

Errors at work are a nuisance. Errors interrupt the work flow, error correction can be time-consuming and frustrating, and some workplace errors have severe consequences for individuals and organizations. It is therefore not surprising that people usually prefer to avoid errors in the first place. Consistent with this approach, many scholars in the area of learning and training take a negative view of errors. A famous example is Skinner (1953) who equated errors with punishment that can inhibit behavior but does not contribute to learning. Similarly, Bandura (1986) views errors as detrimental to learning and promotes a guided and error-free learning environment. In his classical monograph on social-cognitive theory, he states that "[w]ithout informative guidance, much of one's efforts would be expended on costly errors and needless toil." (p. 47). The present research deals with a training method that, in contrast to these approaches, takes an explicitly positive view of errors during training. This training method, which is called error management training (EMT), is based on the assumption that errors are a natural byproduct of active learning: As learners actively explore the environment, errors will inevitably occur. Furthermore, errors can have an informative function for the learner, as they pinpoint where knowledge and skills need further improvement (Ivancic & Hesketh, 1995/1996). Therefore, participants in EMT are explicitly encouraged to make errors during training and to learn from them.

Early studies applied EMT to teach software skills (Frese et al., 1991). To determine training effectiveness, skill-based training outcomes of EMT were compared with those of alternative training methods. Most of these alternative methods were proceduralized training methods which mimic conventional tutorials that adopt a negative attitude toward errors: Detailed step-by-step instructions on correct task solutions were provided in order to prevent participants from making errors. Other studies compared EMT with exploratory training methods that did not contain any more task information than the EMT condition but that lacked the explicit encouragement and positive framing of errors during practice or that even gave instructions to avoid errors. Early studies consistently reported EMT to be effective in terms of posttraining outcomes (i.e., scores on tests given to participants after training). For example, four studies (described in Frese, 1995) reported positive and large effect sizes (Cohen's d of about 1) in favor of EMT, indicating that participants of EMT on average outperformed those of the comparison training by one standard deviation. Later studies replicated this effect with slightly lower effect sizes (e.g., Nordstrom, Wendland, & Williams, 1998; Wood, Kakebeeke, Debowski, & Frese, 2000). Yet, still other studies found opposite results. For example, a study using an electronic search task found a proceduralized training group to perform better than the EMT group by three quarters of a standard deviation (η^2-value from ANCOVA = .13, which corresponds to about $d = -0.75$, Debowski, Wood, & Bandura, 2001). Similarly, in a study using a decision making task, a training group that received explicit instructions to avoid errors during training performed significantly better than an EMT group, with a medium effect size ($d = -0.50$, Gully, Payne, Koles, & Whiteman, 2002).

Why would studies that, at least at first glance, draw on the same theoretical background and use similar designs, come to such opposite results? Can systematic sources be identified that account for these differences and, if so, how are they related to prevalent issues in learning and training research? The present research seeks to answer these questions. We propose that EMT can lead to better training outcomes than exploratory or proceduralized training methods that do not utilize errors at all or that even emphasize error avoidance. Yet, depending on the particular features of how the training is conducted and evaluated, the effectiveness of EMT—as reflected in the direction and magnitude of the study's effect size—will vary. To this end, we apply meta-analytical techniques to existing studies that compare EMT with alternative training methods (i.e., purely exploratory or proceduralized training methods) and systematically search for moderators. In the following, we will first describe the theoretical background and typical study design of existing studies on EMT. Then, we will address some issues prevalent in the learning and training literature to develop hypotheses about factors that moderate the effectiveness of EMT.

Theory and Design of EMT

There are two characteristics of EMT that distinguish it from alternative training methods, such as proceduralized training and purely exploratory training. First, participants are given only minimal guidance and otherwise are encouraged to actively explore and experiment on their own. In addition, EMT creates a learning environment in which errors are likely to occur. For example, in software training, participants are given only some basic information on the structure and functions of the software. They are then asked to independently work on difficult training tasks without any additional information about how to solve the tasks—a procedure that almost inevitably leads to many errors. In respect to this minimal guidance, EMT is similar to exploratory training but it differs from proceduralized training methods that seek to minimize errors by providing detailed step-by-step instructions on correct task solutions. Second, EMT involves explicit encouragement of errors. Participants are given so-called error management instructions which are brief instructions that tell participants to expect errors while they work on the training tasks and that emphasize the positive informational feedback of errors for learning (Frese et al., 1991). The core idea of these instructions is then summarized in positive statement such as "The more errors you make, the more you learn!" or "You have made an error? Great! Because now you can learn something new!". During the training session, the trainer repeats these statements and reminds participants to reflect on errors whenever they happen, but does not provide any further assistance when an error occurs. This emphasis on and positive framing of errors during training is not present both in purely exploratory training and in proceduralized training methods which usually do not mention the issue of errors at all or even give instructions to avoid errors during training.

The theoretical foundation of EMT is action theory which describes action-oriented mental models as the basis of work-related actions (Frese & Zapf, 1994; Hacker, 1998). For example, an individual's action-oriented mental model of a photocopy machine may entail various aspects of how the machine works (e.g., how the original copy is 'read' in, how the copy paper 'travels' within the machine), enabling the individual to effectively operate the machine as well as to react to potential problems (e.g., to place the original copy in the right space, to fix up a paper jam if it occurs). The more adequate a mental model is, the more successful will the actions be, and adequate mental models are best acquired by actively dealing with the subject matter (e.g., by actually operating the photocopy machine rather than reading its manual). In this context, errors serve an important feedback function because they indicate where one's mental model is not adequately developed and thereby encourage its correction (Frese, 1995).

The view of errors as feedback is consistent with other theories that stress the importance of feedback for learning (Kluger & DeNisi, 1996; Latham & Locke, 1991) but it goes beyond regarding errors as negative feedback that indicates non-achievement of a particular goal. Rather, learners are encouraged to use errors as a basis to think ahead and to try out something new. This focus on informative aspects of errors is a distinctive feature of the error management approach (Frese, 1995; Ivancic & Hesketh, 1995/1996). The emphasis on active exploration as the primary method of learning is consistent with other active learning approaches (Bruner, 1966; Hesketh & Ivancic, 2002; Greif & Keller, 1990) but it is in contrast to approaches that stress guidance and correct behaviors during practice. In social-cognitive theory, for example, which is the theoretical basis of behavior modeling training, active exploration and errors are viewed as needless and time-consuming. According to Bandura (1986), learners should be "spared the costs and pain of faulty effort" (p. 47) and instead receive guidance that leads to flawless behavior. Feedback should focus on positive aspects of the learner's behavior and should be given in the form of positive social reinforcement, that is, praise for correct execution of tasks (Taylor, Russ-

Eft, & Chan, 2005).

Prior Research on EMT and Aims of the Present Study

To evaluate the effectiveness of EMT, most studies used a design which compared EMT with an alternative training method, such as proceduralized or purely exploratory training, in terms of skill-based learning criteria (Kirkpatrick, 1987; Kraiger, Ford, & Salas, 1993), for example, number of tasks solved successfully (Chillarege et al., 2003; Heimbeck et al., 2001; Nordstrom et al., 1998; Wood et al., 2000), 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). The majority of studies, particularly the earlier ones, were conducted in the area of software skills (Frese, 1995); other studies investigated decision-making tasks (e.g., Gully et al., 2002) or used EMT in driving training (Ivancic & Hesketh, 2000). The major aim of the earlier studies was to assess the overall effectiveness of EMT compared with proceduralized error-avoidant training methods. More recent studies focused on interactions of person characteristics and training method (e.g., Heimbeck et al., 2003; Gully et al., 2001) or on emotional or cognitive processes that potentially explain the effectiveness of EMT (e.g., Chillarege et al., 2003; Nordstrom et al., 1998; Wood et al., 2000). In a recent study, Keith and Frese (2005) found empirical support for the notion that EMT increases participants' tendency to use two self-regulatory skills: Participants learn to exert emotion control aimed at reducing negative emotional reactions to errors and setbacks (Kanfer, Ackerman, & Heggestad, 1996) and they engage in metacognitive activities involving planning, monitoring, and evaluation of one's progress during task completion and revision of strategies (Brown, Bransford, Ferrara, & Campione, 1983). Such metacognitive activities are instigated because "errors prompt learners to stop and think about the causes of the error" (Ivancic & Hesketh, 2000, p. 1968) and to experiment with different solutions.

Given the existing empirical evidence and the theoretical propositions describing how making errors can potentially be fruitful for learning and performance, EMT may be expected to be generally effective compared with alternative training methods that do not encourage errors during training. As already pointed out, however, considerable variation exists among effect sizes from studies that evaluate the effectiveness of EMT. The major aim of the present research is to identify variables that account for this variation—variables which, technically speaking, moderate the effectiveness of EMT. In the following, we derive several moderator hypotheses based on prevalent issues in the learning and training literature that we suggest to be particularly relevant for EMT (Figure 1).

Within-Training Performance Versus Posttraining Transfer Performance

In classical comparative training studies, two (or more) groups of participants practice the same tasks under different training conditions (e.g., different instructions, different frequencies of feedback; Hesketh, 1997). Training effectiveness is then ascertained based on participants' performance on a separate task that is given to them after the actual training and which is the same across groups. In other words, the independent variable is manipulated in the training phase in which the skills are acquired; the dependent variable is collected in a posttraining transfer phase in which the learned skills are applied to separate tasks. This conceptual and operational distinction is essential to make sure that potential performance differences between groups do not vanish once the particular manipulation is removed but that they can really be attributed to relatively permanent changes which "qualify for the label *learning effects*" (Schmidt & Bjork, 1992, p. 208). A second reason why this distinction is important, is the phenomenon that manipulations which appear to boost immediate performance during training may be relatively useless for posttraining transfer performance and vice versa. A prominent example is the study by Shea and Morgan (1979) in which participants learned three movement tasks either in a blocked-practice or in a randomized order. During training, the blocked-practice group performed better than the random-order group. On a posttraining transfer task, however, the pattern was reversed and participants who had learned under the random-order condition outperformed those of the blocked-practice condition, particularly if the transfer task was given in random order.

From a practical perspective, these results (and similar results found in domains other than simple movements; cf. Schmidt & Bjork, 1992) imply that conclusions about training effectiveness can be misleading if they are based on skill-based measures that are assessed within the training phase and that training designs should generally include an additional posttraining transfer phase for evaluation. Conceptually, the results imply that introducing difficulties during training may enhance transfer, at least if these difficulties elicit psychological processes that are also useful during transfer (Hesketh, 1997; Salas & Cannon-Bowers, 2001). EMT, which gives ample opportunities to make errors during training, is an example for such a training method: It introduces difficulties during training that can be beneficial for transfer because the processes elicited during training, such as emotion control and metacognition, promote learning (Ivancic & Hesketh, 1995/1996; Keith & Frese, 2005). Accordingly, compared with training methods that do not encourage errors during training, immediate performance within the training phase may not differ or even be depressed in EMT, as participants make errors, explore, and sometimes arrive at suboptimal solutions. Positive effects of EMT can be expected for performance in a posttraining transfer phase in which participants are aware that their performance is being evaluated and that errors are no longer encouraged (cf. Wood et al., 2000).

Hypothesis 1: EMT leads to better posttraining transfer performance but not to better within-training performance than proceduralized or exploratory training methods that do not encourage errors during training.

In operational terms, Hypothesis 1 implies that the type of evaluation outcome moderates the effectiveness of EMT compared with alternative training methods; studies using posttraining transfer performance as criterion will yield larger effect sizes than studies using within-training performance; only for the former studies, the mean effect size will be significant (cp. Figure 1).

Analogical versus Adaptive Transfer Tasks

The previous section dealt with the issue of posttraining transfer performance (as opposed to within-training performance) in general. Yet, it can be useful to distinguish between different types of transfer when evaluating training effectiveness. One such distinction, which is based on the similarity of training and transfer tasks, is between analogical and adaptive transfer (Ivancic & Hesketh, 2000; cf. Barnett & Ceci, 2002, for a similar distinction between near and far transfer). Transfer implies that knowledge and skills are "transferred from one task or job to another" (Hesketh, 1997, p. 318). *Analogical* transfer refers to situations where problem solutions of the transfer tasks are familiar or analogous to those of the training tasks. *Adaptive* transfer comprises "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). Adaptive transfer implies that rote application of a procedure learned in training is not sufficient but that the problem at hand is structurally different from those encountered during training and requires the learner to modify the learned procedures (Ivancic & Hesketh, 1995/1996).

The goal of a particular training program can be to promote analogical transfer, for example, when a limited and clear-cut behavioral repertoire is to be performed on the job that can, in principle, be taught within the allotted training time. In cases in which not all potential work-related problems and their solutions can be taught, however, the training goal may be to promote adaptive transfer, that is, to enable participants to develop new solutions to structurally novel problems by using and adapting the skills they acquired during training. Training researchers have suggested that explicitly allowing and encouraging errors to occur during training, as is done in EMT, may be one means to promote adaptive transfer (e.g., Ivancic & Hesketh, 1995/1996; Smith, Ford, & Kozlowski, 1997). When confronted with errors during training, participants may engage in mindful processing (Salomon & Perkins, 1989), such as metacognition (Keith & Frese, 2005), and thereby gain knowledge and acquire skills that are particularly useful to solve structurally distinct adaptive transfer tasks (Ivancic & Hesketh, 2000). EMT may promote analogical transfer as well, because errors during training instigate attention which, in turn, facilitates later retrieval of similar problems and their solutions (Ivancic & Hesketh, 1995/1996, 2000). Yet, to promote analogical transfer, other training methods that emphasize errorfree learning and correct procedures for a particular task may be equally effective as they teach directly the required procedures which are then merely applied to the similar transfer task. As a consequence, the advantage of EMT in comparison with such training methods can be expected to be smaller for analogical than for adaptive transfer tasks.

> *Hypothesis 2*: The effectiveness of EMT in comparison with proceduralized or exploratory training methods that do not encourage errors during training will be more pronounced for adaptive than for analogical transfer tasks.

In operational terms, Hypothesis 2 implies that the type of transfer tasks used in studies moderates the effectiveness of EMT compared with alternative training methods; studies using adaptive transfer tasks will yield larger effect sizes than studies using analogical transfer tasks while for both groups of studies, the mean effect size will be significant (cp. Figure 1).

Task-Generated Feedback

As outlined above, action theory views errors during training as valuable pieces of information because they serve as feedback for one's actions and can point out what aspects of one's knowledge need further correction and refinement (Frese & Zapf, 1994). In general, feedback permits an individual to judge the extent to which he or she has achieved the goal or standard (Carver & Scheier, 1998; Frese & Zapf, 1994; Hacker, 1998; Ilgen, Fisher, & Taylor, 1979; Latham & Locke, 1991; Sonnentag, 1998). Errors are one form of negative feedback that indicates a deviation between the goal or standard and the current state (Frese & Zapf, 1994). In addition to the judgment about the current state, errors and feedback can be used retrospectively to evaluate the effectiveness of one's previous strategies (Neubert, 1998) and, based on this evaluation, to adjust one's strategies accordingly. For this positive function of errors to take effect, however, it is a precondition that errors can be detected at all. Given that EMT provides only little external guidance—participants work independently during training and without constant monitoring by a trainer who informs about the correctness of their actions—, this implies that the task itself needs to provide clearly interpretable and informative feedback for EMT to be effective (e.g., noticeable visual changes on the display that appear in response to the user's actions are one type of informative feedback). Stated differently, on tasks that only provide feedback that cannot be readily interpreted, EMT may be less suitable compared with alternative training methods that give external informative guidance (Debowski et al., 2001).

Hypothesis 3: The effectiveness of EMT in comparison with proceduralized or exploratory training methods that do not encourage errors during training is limited to tasks that provide clear feedback.

In operational terms, Hypothesis 3 implies that clarity of the task-generated feedback moderates the effectiveness of EMT compared with alternative training methods; studies using clear-feedback tasks will yield larger effect sizes than studies using tasks with unclear feedback and only for studies using clear-feedback tasks, the mean effect size will be significant (cp. Figure 1).

Effective Elements of EMT: Active Exploration and Error Management Instructions

There are two elements in EMT that distinguish it from alternative training methods: the element of active exploration (i.e., participants receive only little external guidance and explore the tasks independently) and the element of error encouragement (i.e., participants receive error management instructions that frame errors positively and encourage errors during training). As stated above, error management theory assumes both elements to be effective in EMT: Active exploration is important because adequate mental models are best acquired by direct action. A positive view of errors, as is conveyed in error management instructions, is essential for learning to occur, because "developing an error tolerant attitude … maximize[s] the informational value of errors " (Ivancic & Hesketh, 1995/1996, p. 115). If errors are not tolerated but viewed negatively, participants will likely be frustrated from errors and refrain from further exploration, with the result of fewer learning opportunities (cf. van Dyck, Frese, Baer, & Sonnentag, 2005).

Recent studies have—and justifiably so—criticized that studies comparing EMT with proceduralized error-avoidant training, which does not include exploration nor encouragement of errors and, thereby, differs in both elements from EMT, confound these two elements. As a result, observed differences in training outcomes cannot be unequivocally attributed to either one element (e.g., Bell & Kozlowski, 2007; Gully et al., 2002). There are, however, a few attempts in the literature on EMT to dissociate the two elements by varying them both. For example, Heimbeck et al. (2003) found EMT (i.e., active exploration with error management instructions) to lead to better training outcomes not only than proceduralized training (i.e., no exploration, no error management instructions) but also than purely exploratory training (i.e., active exploration only, no error management instructions). In addition, there are some EMT studies that do not vary the exploration element but only the element of error encouragement (i.e., error management instructions vs. no such instructions). If we assume both elements of EMT, active exploration and error encouragement, to be additively effective elements, the following meta-analytical pattern should emerge: Both the comparison of EMT with proceduralized and the comparison with exploratory training should yield significant differences. Moreover, the comparison with proceduralized training should yield larger differences than the comparison with exploratory training (because the combination of two elements, exploration and error encouragement, should yield larger differences than only one element of exploration).

Hypothesis 4: Both active exploration and error management instructions are effective elements in EMT.

In operational terms, Hypothesis 4 implies that the type of comparison training method moderates the effectiveness of EMT; studies comparing EMT with proceduralized error-avoidant training will yield larger effect sizes than studies comparing EMT with exploratory training (cp. Figure 1). At the same time, the comparison of EMT with exploratory training will still yield significant mean effect sizes.

Method

Pool of Primary Studies

To identify empirical studies that investigated the effectiveness of EMT, an electronic search was conducted in relevant databases (PsychInfo, SSCI, and the German database Psyndex), supplemented by manual searches of conference programs, of reference lists of identified studies, and by contacting authors of published papers and other researchers in the field (the initial search was conducted in spring 2004; the data base search was updated in fall 2006). In line with the theory of EMT outlined above, training methods were considered to represent EMT if they met the following two criteria: First, the training involved active exploration in that participants were not guided to correct task solutions but worked independently to find solutions on their own. Second, making errors during training was explicitly encouraged by providing participants with error management instructions that stressed the positive function of errors for learning. The search yielded 24 studies (overall $N = 2183$) that met these criteria. Three additional studies were identified that explicitly referred to the theory of EMT but that did not operationalize EMT according to the aforementioned criteria (for example, participants did not actively explore and make errors themselves but were presented with potential errors selected by the researchers or participants did not receive error management instructions; Ivancic & Hesketh, 2000; Joung et al., 2006; Lorenzet et al., 2005). In order to retain a study pool that is sufficiently homogenous with regard to the training method examined, these three studies were not included in the present meta-analysis (cf. Oswald & McCloy, 2003).

All 24 studies evaluated training effectiveness by comparing EMT with an alternative training (i.e., we did not identify any studies using a no-training control group as comparison). Thus, all effect sizes compiled in the present meta-analysis refer to *relative* effectiveness (i.e., compared with an alternative training) rather than to *absolute* effectiveness of EMT (i.e., compared with no training at all). Of the 24 studies, 11 were unpublished (e.g., master's theses/dissertations, technical reports, or manuscripts in preparation). All studies but one were experimental laboratory studies with participants or small groups of participants randomly assigned to training conditions. The majority of the trainings taught a new software (k = 18) or electronic search of databases (k = 3). The remaining three trainings used a computerized decision making task. Participant samples of six studies consisted of employees recruited in the community; the remaining studies used samples of university students. In two studies, participant dyads (rather than individuals) worked together and were the unit of analysis.

If studies compared one or more EMT conditions with more than one other training condition, we calculated the mean effect size for use in further analyses. Similarly, if studies assessed multiple training outcomes, we included the mean effect size. If the multiple outcomes assessed were not similar but referred to tasks of different levels of difficulty, we only included the most difficult task because this is the most relevant variable from a theoretical point of view. Using only one effect size per study is recommended in order to avoid statistical dependencies (Hedges & Olkin, 1985; Hunter & Schmidt, 1990; Lipsey & Wilson, 2001; Rosenthal, 1991). Brief descriptions of the 24 studies as well as their effect sizes are listed in Table 1.

Coding of Study Characteristics and Interrater Agreement

Corresponding to our research hypotheses, we coded four study characteristics as potential moderators. All but one of the 24 studies were coded independently by a second rater.

Interrater agreement (Cohen's kappa) was good to excellent according to Fleiss (1981), with coefficients ranging from .65 (for clarity of task feedback) to 1 (for type of comparison training; .83for type of evaluation outcome; .91for type of transfer tasks). Cases in which initial codings of the two raters differed were resolved by discussion.

The dichotomous variable *type of evaluation outcome* was designed to describe whether the study design included a separate posttraining transfer phase for performance evaluation in which participants were aware that their performance was being evaluated (*posttraining transfer performance*) or whether no such separate phase existed. For example, if the performance score in one of several training trials (during which, in the case of EMT, errors were still encouraged) served as criterion performance in the study, this was coded as *within-training performance*. The dichotomous variable *type of transfer task* was designed to capture whether the criterion tasks were structurally similar to the tasks that participants had worked on during training (*analogical transfer*), or whether the tasks required the development of new solutions (*adaptive transfer*; Ivancic & Hesketh, 2000). The critical dimension was task distinctiveness rather than task difficulty (Frese & Zapf, 1994; Keith & Frese, 2005). For example, if participants were tested on the same tasks as in training but under greater time pressure, these tasks may be more difficult but not structurally distinct, indicating analogical transfer. The dichotomous variable *clarity of task feedback* was designed to describe the feedback provided by the task. It was coded based on the information provided in the method sections and, if available, appendices of the studies, such as general task descriptions (including screenshots) and descriptions of system responses to users' actions. If the feedback enabled participants to track the consequences of their actions and to detect errors, this was coded as *clear task feedback*. For example, if a user inserts a table in a document and the software responds by visually displaying the table in the document, this is interpretable feedback. If there was ambiguous or no feedback or if further information (e.g., background knowledge) was required to understand whether an action was correct or not, this was coded as *unclear task feedback*. For example, some statistics programs (as used in the study by Dormann & Frese, 1994) generate rather complex and comprehensive outputs that may not be readily interpretable for novice users. As another example, electronic data bases provide ambiguous feedback in the sense that although the system would display several records in response to the search statements, it may be difficult for the searcher to judge the relevance of these records and, in turn, the appropriateness of one's search strategy (Debowski et al., 2001). The categorical variable *comparison condition* described the training method that EMT was compared with in a given study. None of the comparison conditions involved explicit error encouragement (consequently, this training characteristic was not coded), but they differed in the amount of guidance. A comparison condition was coded as *proceduralized* if participants received step-by-step instructions or close personal guidance to correct task solutions during practice. A comparison condition was coded as *exploratory* if participants practiced the training tasks without guidance, irrespective of how much guiding information they received otherwise. For example, if participants first received some information on the task but then practiced the training tasks independently, this was coded as exploratory. Some studies used more than one comparison condition out of which some were proceduralized and others were exploratory. To account for these studies, we coded them as *both*.

Data Analytic Strategies

Meta-analytic techniques as described by Hedges and Olkin (1985) were used. Mean effect sizes were calculated using the small-sample correction formulas for unbiased effect sizes (Hedges, 1981). Moderating effects of single dichotomous variables were tested with the procedure analogue to ANOVA by Hedges (1982). All analyses were based on random or mixed effects models which take both subject-level and study-level sampling error into account. The ANOVA analog partitions the overall variance into a portion that is explained by the independent variable (i.e., the moderator variable) and an unexplained residual portion. These two portions are represented in a Q statistic (i.e., $Q_{between}$ and Q_{within}). The Q-test is analogous to the F-test in ANOVA or regression analysis and can be interpreted accordingly. Thus, a significant $Q_{between}$ statistic indicates that the moderator variable significantly explains variability of effect sizes (Lipsey & Wilson, 2001).

Results

The overall mean effect size across all studies included in the meta-analysis was significant (Table 2), suggesting that overall, EMT leads to better training outcomes compared with training methods that do not encourage error during training. The test of homogeneity was not significant, indicating that, from a purely statistical perspective, effect size variability was not any greater than would be expected from sampling error. Yet, the homogeneity test suffers from low power for detecting true variance across studies and can often lead to the false conclusion that no moderators exist, particularly when primary studies are relatively few and based on small samples. Therefore, we still tested our a priori theoretical moderator hypotheses (this procedure is in line with recommendations in the literature; e.g., Lipsey & Wilson, 2001; Oswald & McCloy, 2003; Rosenthal & DiMatteo, 2001; Schmidt & Hunter, 2002).

Hypothesis 1 predicted EMT to lead to better posttraining transfer but not to better within-training performance than proceduralized or exploratory training methods that do not encourage errors during training. This hypothesis was supported as evaluation phase significantly affected the magnitude of the effect sizes ($p < .01$; cf. Table 2). Studies using a training phase for evaluation yielded a non-significant mean effect size ($p = .45$). Studies using a posttraining transfer phase for evaluation yielded a significant medium mean effect size ($d = 0.56$, $p < .01$). Hypothesis 2 predicted the effectiveness of EMT to be larger for adaptive than for analogical transfer performance. This hypothesis was supported as type of transfer task significantly affected the magnitude of the effect sizes ($p < .01$; cf. Table 2). Studies using an analogical transfer task as criterion yielded small but significant mean effect size ($d = 0.20$, $p < .05$) and studies using an adaptive transfer task as criterion yielded a significant and large mean effect size ($d = 0.80$, $p < .01$). Hypothesis 3 predicted the effectiveness of EMT to be limited to tasks with clear feedback. This hypothesis received only limited support: The effect of clarity of feedback on the magnitude of the effect sizes did not reach significance at the 5% level ($p = .08$; cf. Table 2). The statistics in subsamples, however, indicated that only studies using tasks with clear feedback yielded a significant positive effect ($d = 0.56$, $p < .01$), whereas studies using tasks with unclear feedback yielded a non-significant mean effect size ($p = .28$). Hypothesis 4 predicted both active exploration and error encouragement to be effective elements of EMT. This hypothesis was supported. First, the comparison condition significantly affected the magnitude of the effect sizes ($p < .05$, cf. Table 2). Studies comparing EMT with proceduralized training, which involves no exploration and no error encouragement, yielded higher effect sizes than studies comparing EMT with exploratory training, which involved exploration but no error encouragement. Second, at the same time, the comparison of EMT with exploratory training yielded a small but significant mean effect size ($d = 0.19$, $p < .05$).

Discussion

Summary of Results and Implications for Theory and Practice

The present meta-analysis compiled results from 24 studies that investigated the effectiveness of EMT. These studies compared training outcomes of EMT with those of proceduralized or exploratory training methods that did not involve explicit encouragement of errors (i.e., relative effectiveness of EMT). The average effect across all studies was positive (Cohen's $d = 0.44$), indicating that EMT leads to, on average, better training outcomes than these alternative training methods. This result demonstrates that deliberately incorporating errors into training can be an effective means to promote learning and it is in contrast to many traditional training approaches that exclusively focus on correct behaviors and deny any positive functions of errors during training (e.g., Bandura, 1986; Skinner, 1953).

This meta-analysis further identified several moderator variables that affected the magnitude of the effect size. First, EMT appeared to be effective only when posttraining performance but not when within-training performance is considered. This result is in line with training theory and research emphasizing the distinction between within-training and posttraining transfer performance (Goodman & Wood, 2004; Hesketh, 1997; Schmidt & Bjork, 1992). From a practical perspective, this result implies that trainers should not focus on optimizing within-training performance, which may be slowed down in EMT as participants make errors, but to keep in mind that a training method can be effective despite apparently impaired initial performance, as may be the case with EMT. Also, this result underscores empirically the call for evaluating training effectiveness, be it of EMT or any other training method, on the basis of posttraining outcome measures rather than performance during training itself (Hesketh, 1997; Schmidt & Bjork, 1992). Second, the present results showed EMT to be particularly effective when adaptive transfer rather than analogical transfer is involved. Thus, using EMT to deliver training seems most useful when the major training goal is to transfer learned skills to novel problems that require the development of new solutions (i.e. adaptive transfer), for example, in situations in which the skills required on the job are too diverse to be covered completely during the allotted training time. When the training goal is to learn and apply just one particular procedure, however, other training methods that involve direct instruction of this procedure may also be effective while being less time-consuming and less effortful than EMT (cf. Ivancic & Hesketh, 1995/1996). Third, the present meta-analysis found significant mean effect sizes not only in studies comparing EMT with proceduralized error-avoidant training (without active exploration and without error management instructions that encourage errors) but also in studies comparing EMT with exploratory training (with active exploration but without error management instructions). This finding can be interpreted to the effect that both elements of EMT, namely active exploration and explicit encouragement of errors, are effective in EMT and that any exploratory practice should be supplemented with error management instructions, given that these simple and easy-to-administer instructions can produce significant incremental effects. To further examine the feasibility of this interpretation, it would be desirable to conduct more studies that include both proceduralized and purely exploratory training in one experimental design. Finally, for one moderator, clarity of task-generated feedback, results were mixed and it can not be concluded that EMT was only effective when task-generated feedback is clear. This result may be due to the general usefulness of feedback for learning and performance: Although clarity of feedback may be important for EMT to be effective, it may be just as important for the other training methods that served as comparison training conditions for EMT. In addition, the relatively low interrater reliability for the feedback variable (Cohen's kappa = .65) may have contributed to the non-conclusive findings regarding this moderator.

Strengths, Limitations, and Directions for Future Research

This research compiled all currently available studies that evaluated the effectiveness of EMT, defined as active exploratory training with explicit instructions encouraging errors during training. Overall, the meta-analytical results suggest EMT to be an effective training method compared with training methods that do not encourage errors during training, such as purely exploratory and proceduralized training. In addition, this research illuminates the conditions under which EMT seems most promising and, by the same token, it helps to resolve conflicting findings in the literature: EMT is most likely to be effective for adaptive transfer tasks that require the application of learned skills to a structurally new problem and, conversely, it is likely to fare worse than other training methods if within-training performance rather than posttraining transfer is considered for evaluation.

Some cautionary remarks need to be made concerning the generalizability of the present results beyond the 24 primary studies included in this meta-analysis. Almost all (21 out of 24) studies used EMT to teach software skills (the remaining 3 studies used decision-making tasks delivered on the computer). Clearly, more research is needed to test to what extent the present results generalize to other technical skills (i.e., operating machines other than the computer) as well as to completely different types of skills (e.g., social skills, managerial skills). A recent study by Joung et al. (2006) provides an example of how the theoretical ideas underlying EMT can be applied in a non-computer setting. Joung et al. describe a variant of EMT in which participants do not explore and make errors themselves but in which researchers or trainers select other people's—actual or potential—errors which are to be presented to and discussed with participants (i.e., vicarious EMT; due to this different operationalization of EMT, this study was not included in the present meta-analysis). Joung et al. applied this vicarious variant of EMT in a training for firefighters who were presented with firefighting scenarios in training (i.e., firefighting stories based on real incidents). One group of trainees received scenarios that contained errors made by the incident controller (e.g., underestimation of resource requirements), whereas a second training group received scenarios without errors (i.e., success stories). When presented with new scenarios, participants of the first training group outperformed the second group in terms of problems identified in the firefighting practices. If future research could further substantiate that this kind of vicarious EMT can be similarly effective as the active form of EMT investigated in the present meta-analysis, this would open interesting opportunities for the practice of training. Vicarious EMT could be employed to incorporate errors in training whenever active exploration is not a viable option, for example, because of lack of adequate equipment (e.g., simulators) or, as may be the case with firefighting training, if the prospect of making errors oneself is too threatening and stressful for participants.

None of the currently available studies on EMT has actually measured on-the-job performance as a result of training but employed posttraining performance tasks to evaluate training effectiveness—a research gap that certainly should be filled. For two reasons, however, it could be speculated that EMT benefits on-the-job performance. First, errors not only occur during training but on the job as well, a situation in which there is usually no trainer available to assist with error-handling. EMT may be well suited to prepare for this situation, because participants learn to deal with errors independently from the very beginning (Frese, 1995; Ivancic & Hesketh, 1995/1996). Second, the present results show EMT to be particularly effective in promoting adaptive transfer, that is, performance on tasks that are structurally distinct from training tasks and that require the modification of a learned procedure. Both theoretical considerations (e.g., Hesketh, 1997) and empirical evidence (Keith & Frese, 2005) suggest that this is because participants learn to apply metacognitive skills in EMT which, in turn, prove useful when confronted with novel tasks not practiced during training. We suppose that these metacognitive skills, which enable participants to select and adjust their strategies according to the task at hand, serve as generalizable skills that are beneficial for on-the-job performance (cf. Ford et al., 1998; Smith et al., 1997).

Another potential limitation of the present meta-analysis is the relatively small number of studies currently available in the area of EMT training, at least compared with meta-analyses that have a broader research focus (e.g., the IQ/performance relationship) or that deal with training methods which are older and more established than EMT (e.g., behavior modeling training). The problem with smaller study pools is that they are generally associated with lower statistical power. It should be noted, however, that we found several significant moderator effects *despite* this low power—a result that underscores the relevance of the identified moderators for the effectiveness of EMT. In addition, although the number of available studies as well as the type of outcome measures used in the primary studies may be criticized, the design of the included studies contribute to a strength of the present meta-analysis: All (but one) studies used a controlled experimental design with randomized assignment to training conditions, rendering causal inferences justified, namely, that differences in training outcomes between EMT and alternative training methods are in fact due to the training method employed (and not the result of pretraining differences or some other uncontrolled third variable).

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Table 1

Brief Descriptions and Statistics of Included Studies

Study	Training content	Alternative training condition(s)[a]	*d* (*SE*)
Bell & Kozlowski (2007)[b]	PC-based decision making simulation	- proceduralized training with error encouragement or avoidance instructions (4) - exploratory training with error avoidance instructions (2)	0.33 (0.12)
Chillarege et al. (2003)[b]	Software: Word processor	- proceduralized training with error avoidance instructions (1)	1.35 (0.27)
Debowski et al. (2001)	Electronic database search	- proceduralized (guided) training without error-related instructions, immediate error correction by trainer (1)	-0.73 (0.30)
Dormann & Frese (1994)	Software: Statistical package	- proceduralized training without error-related instructions, immediate error correction by trainer (1)	1.08 (0.39)
Frese et al. (1991)	Software: Word processor	- proceduralized training without error-related instructions, immediate error-correction by trainer (1)	0.99 (0.45)
Granados (2000)	Software: Presentation	- exploratory training without error-related instructions (1)	0.30 (0.32)
Greif & Janikowski (1987)	Software: Word processor	- proceduralized training/tutorial (1)	1.16 (0.62)
Gully et al. (2002)	PC-based decision making simulation	- exploratory training with error avoidance instructions (1) - exploratory training without error-related instructions (1)	-0.44 (0.16)
Heimbeck et al. (2003)	Software:	- proceduralized training with error avoidance instructions, immediate	0.72 (0.23)

	Spreadsheet	error correction by trainer (1)	
		- exploratory training without error-related instructions (1)	
Heinbokel (1990)	Software: Word processor	- proceduralized training without error-related instructions (1)	1.06 (0.53)
Irmer et al. (1991)	Software: Word processor	- proceduralized training without error-related instructions (standard training of software training school), immediate error correction by trainer (1)	0.95 (0.34)
Ivancic (1997), Study 1[b]	Software: E-mail	- proceduralized training with error encouragement or error avoidance instructions (4)	0.22 (0.37)
		- exploratory training with error avoidance instructions (2)	
Ivancic (1997), Study 3[b]	Software: E-mail	- exploratory training without error-related instructions (2)	-0.24 (0.30)
Keith & Frese (2005)	Software: Presentation	- proceduralized training without error-related instructions (1)	0.74 (0.30)
Keith & Mueller (2004)	Software: Presentation	- proceduralized training with or without error encouragement instructions (2)	0.21 (0.22)
		- exploratory training without error-related instructions (1)	
Lazar & Norcio (2003)[b]	Software: Web browser	- proceduralized (traditional) training with error encouragement or avoidance instructions (4)	0.09 (0.14)
		- exploratory training with error avoidance instructions (2)	
Nordstrom et al. (1998)[b]	Software: Word processor	- proceduralized training with error avoidance instructions (1)	0.53 (0.21)

Stiso & Payne (2007)[b]	PC-based decision making simulation	- exploratory training without error-related instructions (1)	0.11 (0.14)
Thiemann (1990)	Software: Word processor	- proceduralized training without error-related instructions, immediate error correction by trainer (1)	1.44 (0.62)
Van Dyck (2007a)	Software: Statistical package	- exploratory training with error avoidance instructions (1) - exploratory training without error-related instructions (1)	0.00 (0.36)
Van Dyck (2007b), Study 1[b]	Programming language	- exploratory training with error avoidance instructions (2) - exploratory training without error-related instructions (1)	0.77 (0.32)
Van Dyck (2007b), Study 2[b]	Programming language	- exploratory training with error avoidance instructions (2)	0.76 (0.23)
Wood et al. (2000)	Electronic database search	- exploratory training without error-related instructions (1)	0.69 (0.35)
Yorke (2006)	Software: Spreadsheet	- proceduralized training with error avoidance instructions, immediate error correction by trainer (1)	0.50 (0.14)

Note. Reported are Cohen's *d* effect sizes with small-sample correction for unbiased effect sizes (Hedges, 1981). The values may therefore differ slightly from those reported in the original studies. Positive effect sizes denote performance differences in favor of the error management training condition(s).

[a] Proceduralized training: Participants followed detailed step-by-step instructions; Exploratory training: Participants received basic task information and worked independently, without detailed step-by-step instructions. Number of training conditions in brackets.

[b] Study design included additional manipulation(s) that were ineffective, irrelevant for present research questions, or both, and that were disregarded in the present meta-analysis and therefore not described in this table (e.g., different task orders, additional manipulations unrelated to errors).

Table 2

Overall Meta-Analytical Effect of Error Management Training, Moderator Effects, and Statistics in Subsamples

	Moderator analyses (ANOVA analog)		Statistics in subsamples							
								90%-CI		Homogeneity
	$Q_{between}$ (*df*)	Q_{within} (*df*)	*k*	*N*	*d*	*SE*	*z*	left	right	*Q* (*df*)
Overall effect			24	2183	0.44	0.10	4.36**	0.27	0.61	26.46 (23)
Type of Evaluation	10.61** (1)	23.99 (22)								
Outcome										
Within-Training performance			4	505	-0.15	0.20	-0.76	-0.47	0.17	1.39 (3)
Posttraining Transfer performance			20	1678	0.56	0.10	5.79**	0.40	0.73	22.60 (19)
Type of transfer	10.40** (1)	22.38 (22)								
Analogical transfer			13	1647	0.20	0.11	1.79*	0.02	0.39	18.31 (12)
Adaptive transfer			11	536	0.80	0.15	5.46**	0.56	1.05	4.07 (10)
Clarity of task feedback	2.92^{+} (1)	23.64 (22)								
Low clarity			7	1005	0.19	0.18	1.07	-0.10	0.49	7.15 (6)
High clarity			17	1178	0.56	0.13	4.60**	0.36	0.76	16.48 (16)
Comparison condition[a]	4.28* (1)	17.14 (17)								
Proceduralized training (no exploration, no error encouragement)			16	1257	0.58	0.11	5.03**	0.39	0.77	18.79 (15)

Exploratory training (exploration without error encouragement)	13	1158	0.19	0.11	1.69*	0.01	0.37	11.59 (12)

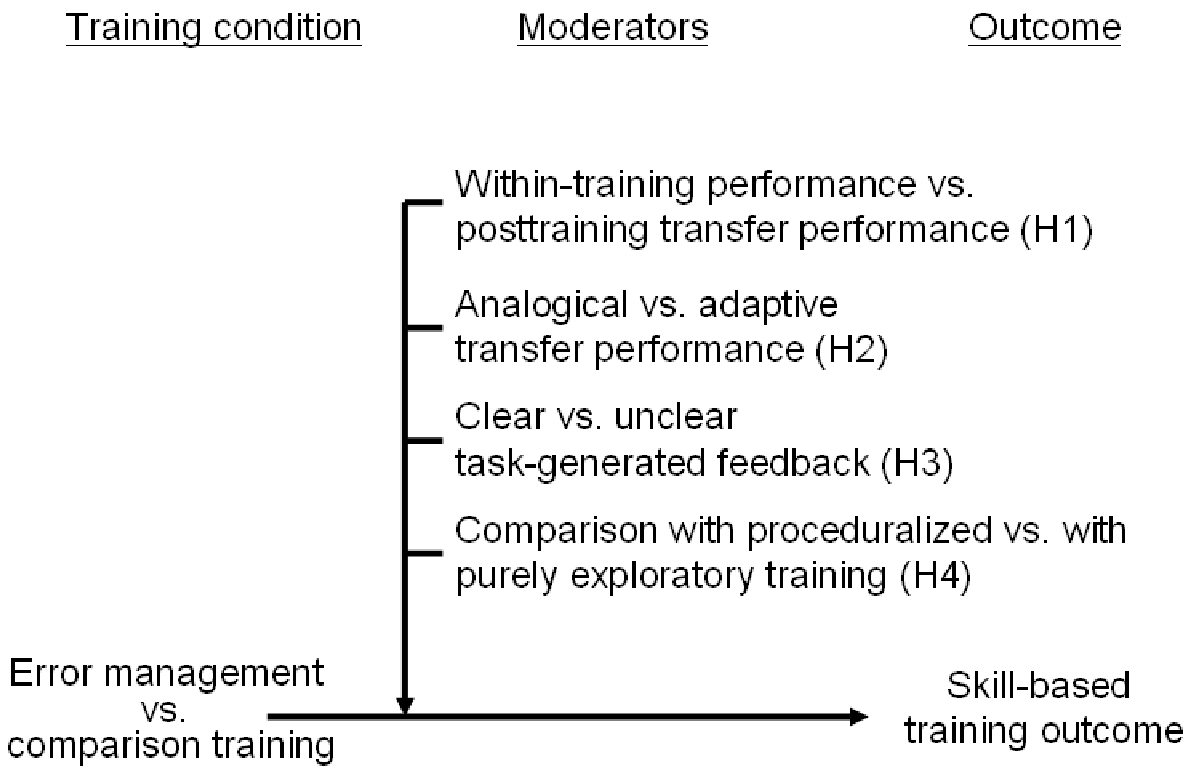
Note. Cohen's *d* effect sizes. CI = Confidence interval. One-tailed *z*-tests for directional hypotheses.

[a] To avoid statistical dependencies, the overall effect of comparison condition was tested with a dummy variable representing whether the comparison condition(s) were proceduralized training methods ($k = 11$) or exploratory training methods ($k = 8$). To calculate statistics in subgroups, two effect sizes from the studies that included both comparison conditions ($k = 5$) were drawn and added to the other studies using proceduralized or exploratory training methods for comparison, respectively. The total number of studies therefore does not add up to 24, and the total number of participants does not add up to 2183 (as five studies are represented twice).

$^{+}$ $p < .10$. * $p < .05$. ** $p < .01$.

Figure Caption

Figure 1. Meta-analytical hypotheses about factors moderating the effectiveness of error management training.


Training condition
Moderators
Outcome
Within-training performance vs.
posttraining transfer performance (H1)
Analogical vs. adaptive
transfer performance (H2)
Clear vs. unclear
task-generated feedback (H3)
Comparison with proceduralized vs. with
purely exploratory training (H4)
Error management
vs.
comparison training
Skill-based
training outcome