Action Errors, Error Management, and Learning in Organizations

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Abstract

Every organization is confronted with errors. Most errors are corrected easily, but some may lead to negative consequences. Organizations often focus on error prevention as a single strategy for dealing with errors. Our review suggests that error prevention needs to be supplemented by error management—an approach directed at effectively dealing with errors after they have occurred, with the goal of minimizing negative and maximizing positive error consequences (examples of the latter are learning and innovations). After defining errors and related concepts, we review research on error-related processes affected by error management (error detection, damage control). Empirical evidence on positive effects of error management in individuals and organizations is then discussed, along with emotional, motivational, cognitive, and behavioral pathways of these effects. Learning from errors is central, but like other positive consequences, learning occurs under certain circumstances—one being the development of a mind-set of acceptance of human error.

Contents

INTRODUCTION

It is a good time to examine the function of errors for learning and other organizational outcomes: The first book on the psychology of errors appeared in English 100 years ago (Freud 1914), and the topic has never before been reviewed in the *Annual Review of Psychology*. Our article shares with Freud's book the idea that errors are important to understand human psychology, although we do not concentrate on Freudian slips or linguistic errors but instead on action errors. In this article, we define action errors as unintended deviations from plans, goals, or adequate feedback processing, as well as incorrect actions resulting from lack of knowledge (Frese & Zapf 1994, Reason 1990, van Dyck et al. 2005, Zapf et al. 1992). In short, our thesis is that we can never completely eradicate action errors; therefore, a second line of defense is necessary. This defense is called error management—an active approach to errors that reduces negative error consequences and enhances positive effects, such as learning and innovation. Error management is made possible through quick detection and damage control. Before we explicate error management, we discuss the function of errors.

The Function and Consequences of Errors

Action errors are fundamental for human development and organizations. The development of individuals and the development of humankind are intimately related to trying to do something new, making errors, and then trying to improve. Any new action includes some fumbling at first and is therefore an error-prone approach (however, a pure trial-and-error approach is not useful, as discussed below). This error-prone approach also applies to the development of culture. Culture develops by consecutive dealings with past errors and mistakes that lead to new problems; invariably, mistaken solutions propel this development further (Festinger 1983). Because societies do not blindly reproduce past mistakes, development upward occurs.

Innovations are not possible without making errors because any innovation implies actions in a new and therefore unknown environment. Philosophers of science have described the process of scientific advancement as one of eliminating wrong approaches in the sense of falsificationism. Errors can reveal the boundary conditions of systems, including scientific systems of thought. Risky hypotheses are better for science than nonrisky ones. Freud used slips of the tongue as examples for the breakdown of the psychological systems of ego and superego, thus supporting psychoanalytic theory (Freud 1914). Similarly to human and technical systems, boundaries can be analyzed by (micro)errors, for example, danger zones of nuclear power plants (Hollnagel 2011, Rasmussen et al. 1987).

Errors are also the raw material for tragic events and catastrophes. Nearly 15 years ago, it was estimated that 98,000 deaths per year were caused by medical errors in US hospitals (Kohn et al. 2000). Although this high death rate has been challenged by others (McDonald et al. 2000), this extrapolated statistic woke up the medical industry. Reason (1990) described how errors contribute to accidents. Quality concerns are also related to errors, although less dramatically.

Action Errors, Inefficiencies, Violations, Judgment Errors, Failures, Risks, and Error Taxonomies

Action errors can be distinguished from inefficiency and from violations. Inefficient actions achieve their goals, albeit with detours. However, most of us have standards (goals) of efficiency, and thus detours are often conceptualized as errors. Violations are different from errors because they involve a conscious intention to break a rule or to be nonconforming to a standard; in contrast, errors are unintentional deviations from goals, rules, and standards (Frese & Zapf 1994, Hofmann & Frese 2011b, Reason et al. 1990).

The research described in this review needs to be differentiated from research on errors in judgment and decision making (cognitive biases and heuristics; Weber & Johnson 2009). Our article discusses goal-directed actions. Action errors, as we use them, imply the nonattainment of a goal and nonconformity to some plan, whereas judgment errors are usually ascertained in relation to logical and statistical norms of rationality—this conceptualization was criticized for being content blind (Mousavi & Gigerenzer 2011), that is, for not considering the context in which decision making takes place. For action errors and their consequences, the context matters (Goodman et al. 2011); therefore, error occurrences are often investigated in applied field studies rather than in highly controlled and possibly artificial experimental settings.

A literature on failure also exists. Failure refers to negative organizational outcomes—these are usually the result of but often also a combination of errors, violations, risks, and chance factors (Hofmann & Frese 2011b). Failures and errors need to be clearly differentiated because not every error leads to failure: Errors can be detected and corrected immediately, or they may occur in a safe environment and thus not lead to failure (which is a consequence of an error). Administering the wrong drug to a patient (the error) may or may not lead to adverse effects because the development of failure depends on the particular drug administered and the health condition of the patient as well as any other medication that might interact with the wrong drug (Homsma et al. 2009).

Finally, errors and risks need to be differentiated. Risks reside in the environment, whereas errors occur in the interaction of individuals with the environment (Rasmussen et al. 1987). If risks are calculated to be 50%, then failing to reach the goal is not an error. The feeling of "I should have known better" is constitutive for errors and would not appear in a 50% risk situation (Hofmann & Frese 2011b). However, miscalculation of a risk may constitute an error; miscalculations often occur when people underestimate the risks of violating a rule (e.g., driving faster than allowed) (Reason 1997).

Errors are multifaceted, and thus taxonomies of errors have been developed. Most error researchers differentiate at least mistakes (a wrong intention is formed) from slips or lapses (failure of execution) (Reason 1990). We do not have the space here to discuss taxonomies of errors (Hofmann & Frese 2011b) in more detail.

Individual and Organizational Errors

Up to this point, we have discussed errors from an individual perspective. An organizational perspective poses conceptual and empirical challenges. Organizational conditions influence individual and organizational errors (Goodman et al. 2011). Communication is an essential characteristic of teams and organizations—communication may be positive for error management, but it may also trigger team or organizational errors. Team errors are often related to communication failures and failures of updating and sharing of information (Bell & Kozlowski 2011). Sasou & Reason (1999) differentiated between individual and shared errors: An individual error implies that one person makes an error; in contrast, in a shared error two or more people jointly make an error. Listed below are examples of the ways in which teams and organizations can help or hinder error detection, error communication, or quick error correction (Sasou & Reason 1999).

1. Organizational rules or standards may determine which errors appear. For example, standards on the responsibility to provide or to actively get information have different consequences for attributing blame when an error occurs. Also, writing up rules in checklists may affect the type of errors made. When checklists are taken seriously, errors may occur in areas that are not regulated by checklists (Reason 1997); when checklists are not taken seriously, there may be more errors of omission.
2. Team members' help determines whether error cascades appear. Team members may detect or even correct errors, arresting the tendency of errors to escalate into more errors. For example, in crew resource training, aircraft crew members learn to detect errors, to communicate errors to the pilot, and to observe a protocol of error handling (Kanki et al. 2010). On the negative side, teams may increase errors because the presence of others may lead to social distractions and social loafing (Hollenbeck et al. 1995).
3. Teams or organizations do not always correct individual errors. Bell & Kozlowski (2011) provide the example in which the USS *Vincennes* mistakenly shot down an Iranian civilian plane in 1988. One radar console operator thought the airplane was a military fighter and mistakenly claimed that it was descending toward the ship. An individual error leading to negative effects depends on the degree of task interdependency; "...when there is a high level of work flow interdependence... accompanied by a shared understanding of the task and team responsibilities, team members will have greater opportunity to identify and correct individual errors before they have an impact on team performance" (Bell & Kozlowski 2011, p. 119).
4. Reason (1990) differentiated between active and latent errors. Latent errors reside in weakened organizational defenses and are related to managerial decisions, safety procedures, organizational structure, and cultural factors. The "damaging consequences [of latent errors] may lie dormant for a long time, only becoming evident when they combine with active failures and local triggering factors to breach the system's many defenses" (Reason 2005, p. 58). Examples are the Bhopal disaster (Reason 1990) and the death of mountaineers climbing Mount Everest (van Dyck 2009).

5. Both detection and error prevention are affected by sharing error knowledge in teams and organizations.

The Error Management Perspective

The error management perspective assumes that it is futile to attempt to prevent all errors from occurring. Most laypeople and scholars think that error prevention is the most important approach. This is understandable: Errors are nuisance factors that may lead to negative and even catastrophic consequences (Reason 1997); it just seems right to prevent them. In school and at work, people take errors as indicators of poor performance, negligence, and even lack of intelligence (Mangels et al. 2006). People intuitively understand that errors lead to blaming and generalizations to the whole person, in the sense of fundamental attribution errors and hindsight biases (Li et al. 2012, Roese & Vohs 2012) (although these errors may be differentially distributed across genders and cultures, some generality exists). "Losing face" and "face work" relate to being caught making an error (Goffman 1955). All of these factors produce a negative mind-set toward error making. People do not like to be seen making an error, and the best way out seems to be error prevention.

We argue that errors are ubiquitous. Errors cannot be completely prevented; the cognitive apparatus of humans is made for error-prone heuristic processing and not for potentially error-free algorithmic processing (Reason 1990). This is also one of the major reasons for bounded rationality (Simon 1990). Difficult tasks or stressors (such as time pressure) demand attention, and attention is a limited resource (Hockey & Earle 2006). Moreover, the mind wanders, and attention is not completely determined by the tasks at hand (Smallwood 2013). A cursory look at the number of errors reported shows that most people make approximately 2 to 4 errors per hour in every task they do. Although the type of task (routine versus complex) and experience make a difference, practically every person makes at least a few errors. For example, in computer work we observed approximately 4 errors per hour; experts make the same number of errors and in some cases even more errors than nonexperts (about 3.8 to 5.4 errors per hour), although their errors are of a different type (Pruemper et al. 1992). The number of errors goes up when new tasks are performed; for example, car enthusiasts driving a new car make about 10 per hour, and experienced individuals make about 6 errors when washing clothes with a new washing machine for 10 minutes (Pruemper et al. 1993).

People and organizations typically attempt to prevent errors from occurring in the first place (Zakay et al. 2004). Because it is impossible to reduce the number of errors to zero, an exclusive strategy of error prevention has its limits. As Reason (1997, p. 25) argues for aviation, "Human fallibility, like gravity, weather, and terrain, is just another foreseeable hazard in aviation." Therefore, Frese (1991) introduced the concept of error management as an add-on strategy to error prevention. **Figure 1** displays differences between error prevention and error management. Through design (of tools, systems, organizations) and through training (of individuals, groups/teams), prevention works by blocking erroneous actions (meaning goal-directed behaviors, but also communication acts). In contrast, the error management strategy starts *after* an error has occurred and attempts to block negative error consequences or to reduce their negative impact through design or training (Hofmann & Frese 2011b, van Dyck et al. 2005). Error handling is not the same as error management because error handling is a descriptive term, whereas error management is a prescriptive strategy of effectively dealing with errors (Frese 1991). Error management involves coping with errors to avoid negative error consequences, controlling damage quickly (including reducing the chances of error cascades), and reducing the occurrence of particular errors in the future (secondary error prevention) as well as optimizing the positive consequences of errors, such as long-term learning, performance, and innovations.

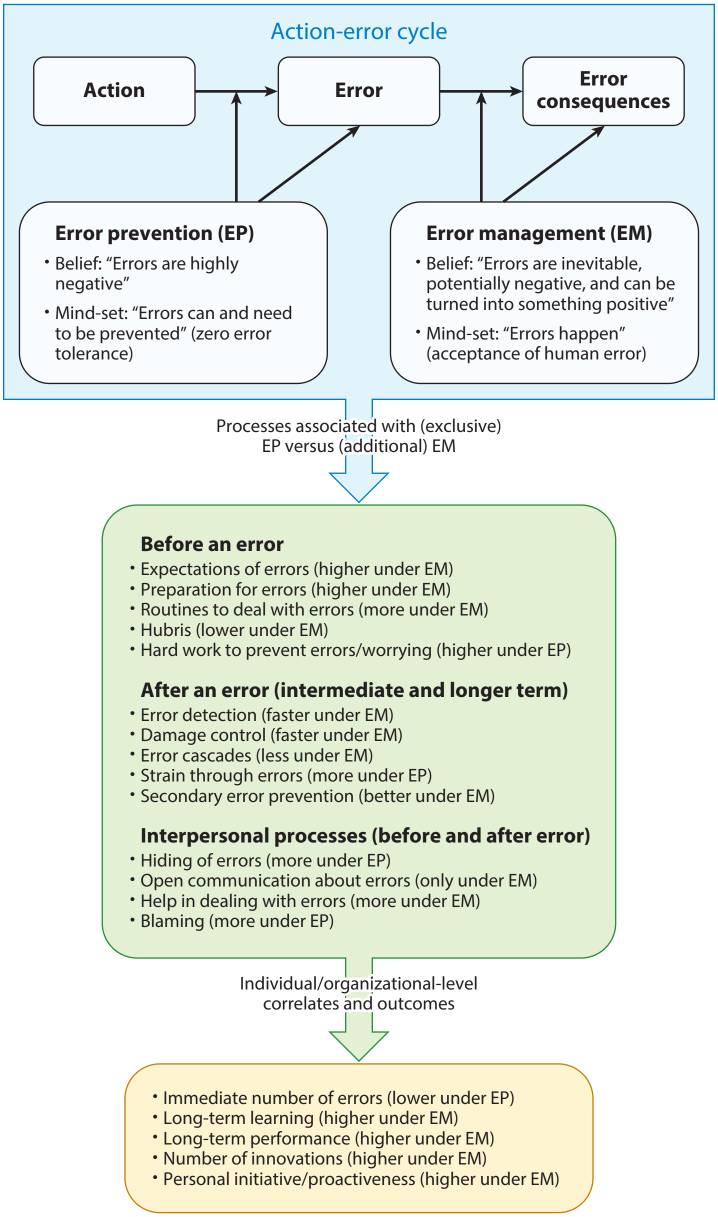

Figure 1

Error prevention, error management, and associated processes and outcomes.

Error management includes organizational defenses, for example, intervention by a second person (e.g., a copilot) or the use of training devices, such as a flight simulator, to expose trainees to typical errors and encourage them to find a way out (or error management training described later). The containment building around a nuclear reactor is an error management device because it confines radioactive gas. The best example of an error management system is the "undo" command on a computer. People do not even need to know what went wrong—once they suspect an error, activating undo helps them restore the status quo ante.

Organizations need to utilize error prevention as well as error management; however, they differ in their underlying belief about errors and the mind-set of acceptance or tolerance of errors (**Figure 1**). Differences in error-related processes affect individual and organizational outcomes. These processes can be categorized with regard to time frame (before versus after an error has occurred; cf. Goodman et al. 2011) and to whether interpersonal processes are involved (e.g., open communication about errors versus hiding of errors; cf. Rybowiak et al. 1999). For example, we propose that under an error management approach, errors will be expected and therefore detected and controlled faster than under an exclusive error prevention approach. Similarly, we assume that blaming for errors and hiding of errors will be more common under an error prevention approach because the occurrence of an error is perceived to be highly negative and threatening. These error-related processes are examined in the following sections.

PROCESSES OF ERROR MANAGEMENT

Error Detection

Error detection is the realization that an error has occurred without necessarily knowing the reasons for it. Error detection is the most important part of the error management process because without error detection, there cannot be any useful error management.

Four processes of detection have been differentiated (Zapf et al. 1994): Direct error hypothesis is the immediate knowledge of a specific error, error suspicion implies that something seems to be unexpected but it is unclear whether anything, or what, is wrong, standard check indicates that one does some security check, and affirmative evaluation means that something is evaluated as correct.

Error detection depends strongly on the complexity of the task. Error detection in complex tasks is lower than in simple tasks (Zapf et al. 1994): Errors were detected at very high rates in simple typewriting even when the experienced typist was blindfolded (Rabbitt 1978). In contrast, only about half of the errors and threats were detected by aircraft crews completing complex tasks in their normal work within a dynamic environment (Thomas 2004).

Detection during action is different from detection as a result of an action cycle (Frese & Zapf 1994, Zapf et al. 1994). Error detection during action is often triggered by a feeling that something may have gone wrong and a subsequent error search. People need to compare their behavior with a goal—thus detection here is the result of internal goal comparisons. The second major category of error detection is detection via external forces, with two important subcategories. The first subcategory of external goal comparison implies that an external party (e.g., computer system, colleagues, supervisors) provides error feedback to the person who made the error. Three preconditions need to be fulfilled for effective external goal comparison. (*a*) The feedback has to be clear; ambiguities in the feedback make it less likely that an error will be accepted. (*b*) The other party has to have valid knowledge of the goals of the actor. (*c*) The third condition is access, which means that the "other" must be able and motivated to observe and monitor the actor. These prerequisites of external goal comparison have also been summarized as "situational awareness" or "sensitivity" (Weick et al. 1999, p. 96 ff.). Sometimes this situational awareness is not important, as in the example of evident error (here the "other" has good reasons to assume knowledge of the goals of the actor, e.g., correct spelling; Zapf et al. 1994). The second subcategory of external goal comparison, limiting function, implies that actors can simply not continue with their plan when they face a plan barrier (for example, when people try to open their car and notice that they forgot their key); here, error detection is assured because one cannot persist in one's actions.

Error detection contains a number of complexities. First, the ease of detection depends on the specific class of errors, with wrong movements being easy to detect (e.g., typewriting errors); in contrast, errors that involve wrong judgments and wrong plans are much more difficult to detect (Zapf et al. 1994). Second, without feedback people cannot detect errors. Proprioceptive feedback (during action) is only useful for highly trained actions; most people also need feedback as a result of an action cycle. Complex jobs, delay in feedback (as in delayed market results), and ambiguous feedback all lead to difficulties in error detection (Hofmann & Frese 2011b). Moreover, ambiguity of the feedback may increase the tendency of people to rely more on confirming feedback and to discount errors (Reason 1990). Dynamic systems (in which facets interact to produce changes in the environment, e.g., in a simulation of a firm or a nuclear power plant in which the cooling system malfunctions) add complexity to error detection—a reason why Dörner (1996) is so skeptical about the ability of people to detect errors in dynamic systems. People tend to think linearly and have difficulties in predicting exponential curves of effects; they are even less able to deal with contingent effects (Dörner 1996).

The timing of error detection is crucial. The longer it takes to detect an error, the more negative the error consequences tend to be (Reason 1990). The sooner people start to suspect an error, the higher are their chances to detect it (Allwood 1984). Experienced workers can, to a limited extent, anticipate errors they are about to make. Older research on manual typewriters showed that the muscular pressure was lower when keys were pushed down erroneously than when they were correct (Rabbitt 1978). An early warning sign of errors may also be the so-called negative potential (error negativity) that is followed by positive deflection; these warning signs show up in event-related brain potentials in electroencephalogram research and may be indicators of early error detection (Falkenstein et al. 2000). Error negativity may eventually be used to help reduce negative error consequences.

Up to this point, we have discussed individuals detecting errors. Team- or organizational-level efforts may make error detection easier in some ways but harder in others. Error detection is easier if several people are able to observe and monitor each other for potential errors (Bell & Kozlowski 2011). One prerequisite, however, is that team or organizational members need to anticipate potential errors—which requires a sort of "preoccupation with failures" (Weick et al. 1999). Another prerequisite is open communication about errors within these teams. Research suggests that covering up errors—rather than reporting and openly discussing them—is relatively frequent in organizations: If individuals feel they may be faced with negative consequences when admitting an error (e.g., job loss, harm to personal reputation, embarrassment), they may not be motivated to report the error but rather to hide it from other organizational members. When members feel safe, errors can instigate fruitful discussions and collaborative problem-solving activities (Edmondson & Lei 2014).

Other responses are defensiveness, denial, and blaming others instead of taking responsibility for errors (van Dyck et al. 2005). If errors are experienced as a threat to one's self and one's position in the organization, blaming others may be used as a strategy to deflect attention from oneself. Blaming likely leads to negative effects in organizations; however, the role of error blaming is not entirely negative. For example, Tjosvold et al. (2004) found a small but statistically significant positive effect of blaming on learning. It is possible that different types of blaming exist; some types are more constructive and related to analyzing errors thoroughly, whereas others are unproductive and related to hiding errors (X.Y. Gao, S.H. Sun, M. Frese, C. Childs & S. Ang, unpublished manuscript; Madsen & Desai 2010).

People are also reluctant to report errors in a strong hierarchy (Shimizu & Hitt 2011). One of the reasons for a series of accidents that beset the South Korean airlines in the 1970s (Milanovich et al. 1998) was that all pilots came from the military, which has a strong hierarchical orientation. Error management interventions in the airline industry reduced the strong hierarchical relationship between the captain and the co-captain (Kanki et al. 2010) and trained them into reporting errors and accepting these reports in spite of the hierarchical distance; although there are still some inconsistencies of the findings, the overall picture of error management training in the cockpit is promising (Salas et al. 2006, 2010).

Thus, people need to be at ease to report errors, but their perspectives also need to be different enough to detect errors. If all people see the same situation in a similar way as wrong or right, chances to detect errors are lower. If people are too different, it may be difficult to persuade others where the error lies (Dahlin et al. 2005). Depending upon the culture, error expectation may be lower or higher; unanticipated events are more difficult to perceive (Hofmann & Frese 2011b). Also, since there is some division of labor between individuals or between teams or even different organizations in complex systems, there needs to be clear understanding of what happens at the interfaces between them. An example for this is the NASA mission that went awry (the Mars Climate Orbiter) because one company had used metric data in its calculations while another company had used English units. Both companies did things right, but the interface was not communicated well enough, which led to underestimates of the effects of the thrusters (Bell & Kozlowski 2011).

Avoiding or Reducing Negative Error Consequences: Damage Control

Damage control aims to reduce the negative error consequences. Timing is crucial here: Accident research works from the assumption that there is a short time window between errors and negative consequences (e.g., milliseconds); in contrast, strategy research assumes long time windows (e.g., months or even years). A short time frame often provides the advantage of immediate feedback, but the disadvantage is that error handling strategies have to be started and executed within a few (milli-)seconds. A long time frame often means that feedback is inadequate to provide warning signals; however, the longer time frame also allows the active development of early warning signals. It is even possible to run experiments or simulations of potential error situations to make intelligent errors quickly (Sitkin 1992).

Reducing the chances of error cascades. Error cascades imply a crescendo of errors on top of each other—one error leading to the next (Goodman et al. 2011). An intervention to control error damage may lead to unknown situations that in turn lead to new errors. Reason (1997) describes the Chernobyl disaster consisting of six mistaken interventions of this kind. So why do people make more errors after they just made an error before? One major reason is that errors lead to cognitive overload. Whenever an error appears, the person then has to deal with two tasks—first, the content task at hand and second, dealing with the error (damage control). Thus, the error produces dual tasks. People doing several tasks at the same time tend to make more errors than if they can concentrate on one task (Oberauer & Kliegl 2006).

Potentially, there is even a third task, namely dealing with one's emotions; these emotions are part of an "internal dialogue" that arises due to error. Clinical psychologists talked about negative effects of perfectionism leading to beliefs that an error constitutes a catastrophe (Ellis & Ellis 2014). If errors are perceived to be catastrophes, then there is a high need to deal with one's internal dialogue, which is primarily negative and can overshadow a rational approach to the error (Ellis & Ellis 2014). This tendency is more pronounced if individuals or collectives have developed a highly negative mind-set toward errors. Error cascades may follow due to the triple tasks—the work task, damage control, and dealing with one's own internal dialogue. Thus, reducing error strain through developing a more positive mind-set towards error individually or through organizational culture may help to control error cascades.

Systems damage control. Systems can make it easy to control damage. Computer programs have been developed for this purpose (e.g., the undo command). Windows on the interface of a computer allow the users to shuttle between different tasks and know how far they have advanced on each of them; system error messages suggest lessons from an error. In addition, going back to a known point provides damage control.

The time period to react to an error can be affected by system characteristics. The more dynamic a system, the greater the chance that errors can have catastrophic effects (Dörner 1996). One can design systems that increase the time period between an error and its consequences; computer systems often do precisely that (e.g., potential ship destinations and routes may be calculated on the computer and may help in a captain's real-world decision making).

Organizations' and teams' damage control. Latent errors appear in organizations, and the longer they are in the organizations, the more likely it is that they will interact with local triggers to produce negative events (Reason 1997). When errors are not communicated quickly, organization executives are likely to make wrong decisions, and the defense systems of an organization are put under strain (Weick et al. 1999).

Crew resource training has shown that even in high-velocity systems, such as airplanes, there is often enough time to correct an error when communication between the pilot, copilot, and crew is enhanced, when communication routines are developed, and when the copilot actively monitors and warns of errors and problem situations (Kanki et al. 2010). Moreover, rapid error management strategies can be taught, making communication and error responses rapid and routinized; simulator trainings for aircraft, air traffic control, surgery, and nuclear power plants help with such damage control. The four-eyes principle in the banking industry (consulting one more person on all important banking decisions) is another example of using the time between the error and its negative error consequences in well-functioning teams (this example also illustrates that such a system can break down if all actors are under pressure to produce high returns without regard to quality of the actions).

Damage control within the social realm: re-establishing trust and gaining forgiveness. In the social realm, any error (and violation) affects the social relationships or the social fabric of a team/organization. How does denial of error or an apology help here? Although we cannot do justice to the full literature in this area, we briefly touch upon some social psychology research examining trust repair and rendering forgiveness. Apparently, it is more useful to repair trust by apologizing for making an error, and it is more effective to deny if one has committed a violation [strangely, Kim et al. (2004) use the term "trust violation" throughout, but one experimental condition describes an error and the other one a violation]. A similar effect has been shown in an online auction system (Utz et al. 2009), providing external validity and generalizability for the experiment by Kim et al. (2004).

Error management can often only reduce negative consequences rather than eliminate them. Again, speed is important here. A business example of such a quick response is the advertising campaign of Mercedes-Benz after a so-called elk test showed that a new car model toppled over when the driver simulated the sudden move necessary to avoid colliding with an elk. Very shortly after this was reported, Mercedes-Benz advertised their error and described how they would deal with it technically and in terms of a recall (Toepfer 2014). This example shows that admitting an error is one part of the error management process to regain public trust. Similarly, admitting a mistake and developing an action plan leads to higher stock prices than does not admitting the mistake (Lee et al. 2004).

Forgiveness for an error is higher than for a violation (Fehr et al. 2010). Intentional deviations (violations) are not forgiven but rather lead to blaming (Fehr et al. 2010). In addition, when the harm is more severe, there tends to be less forgiveness (Fehr et al. 2010). We think it is important to integrate the literature on the process of forgiveness and regaining trust in research on errors and violations (X.Y. Gao, S.H. Sun, M. Frese, C. Childs & S. Ang, unpublished manuscript).

POSITIVE OUTCOMES OF ERROR MANAGEMENT

As outlined above, error management aims at reducing or eliminating negative error consequences and at increasing positive consequences, such as long-term learning, performance, and innovation; the latter are the topics of this section.

Learning from Errors

In the following, we present theoretical arguments and empirical findings of the literature on how error management benefits learning. We group these propositions on the basis of their focus on processes of psychological functioning, namely, emotional, motivational, and cognitive/attentional processes. We also discuss the issue of learning from errors with minor versus major negative consequences.

Traditional learning theory's "law of effect" assumes that positive reinforcement as well as punishment (the latter includes errors) instigates learning. One implication is that trial and error leads to learning. However, the error part of trail and error does not necessarily lead to learning. Often, there is no learning from doing something wrong because the number of other wrong actions is nearly infinite. Thus, trial and error does not lead to the knowledge of which actions are effective in this situation. Moreover, punishment (which includes errors) can lead to immobilization (Skinner 1953).

A thinking-aloud study looked into this issue in more detail (van der Linden et al. 2001). Learning from errors depended on the response to the errors. A pure trial-and-error approach of blindly trying things out showed no positive relationships with learning and performance; both rigid/repetitive exploration and excessive information search even proved to be negatively related to performance. The only approach that produced positive effects involved reflexive and systematic thinking and experimentation. Thus, only a considered and hypothesis-driven approach to errors (metacognition) helps with learning from errors. This small study may have profound consequences: On the one hand, there is no learning with trial and error after an error [which proves Skinner's (1953) critique of punishment right], but on the other hand, it is possible to learn from errors and punishment under certain conditions (proving wrong Skinner and the neobehaviorists as well as some humanistic psychologists who worry about the frustrations of errors).

Learning from errors can take different forms of knowledge: Errors lead to knowledge about the errors just made; this may help to avoid those errors in the future (error management as secondary error prevention). Another form of learning is the result of experimentation—in this case, errors lead to exploring the system and, thereby, to a better understanding of the system. A third form of learning includes the development of a mind-set of how to deal with errors. A fourth form reduces one's negative emotions that normally appear as a result of errors. All four forms of error learning likely happen. However, we tend to think that error management suggests a more general mind-set approach rather than just learning how to avoid specific errors in the future.

One stream of research deals with error management training, which is an active learning approach that emphasizes experimentation and exploration by participants rather than a tight structure and the guidance of participants. Participants work on difficult tasks and inevitably make many errors. They are encouraged to solve the problems and to handle errors themselves. Error management training was often applied in developing computer skills. An early application taught word processing; participants were asked to solve difficult tasks, and they received a list of commands without further guidance (back then computer programs were complicated, and people had no preknowledge). To reduce potential frustration of participants, Frese et al. (1991) and further studies provided error management instructions (also called heuristics); these were statements emphasizing the positive function of errors during training (e.g., "Errors are a natural part of learning," "I have made an error, great!"). The authors found that participants in the error management training outperformed those in the so-called error avoidant training—in the latter, participants received extensive guidance by written instruction on solving the same complex tasks. Several studies compared the effectiveness of error management training with error avoidant training. A meta-analysis of 24 experimental studies (Keith & Frese 2008) found error management training to increase performance on complex transfer tasks (these tasks were different from those used in training). The average effect size associated with complex transfer tasks in the meta-analysis was large (Cohen's d of 0.80; Keith & Frese 2008). Tasks similar to training tasks showed a smaller effect size favoring error management training (Cohen's $d = 0.20$; Keith & Frese 2008). More recent studies yielded similar effect sizes (Carter & Beier 2010, Cullen et al. 2013, Loh et al. 2013). Thus, empirical research suggests that encouraging exploration and errors during training benefits learning more than providing detailed guidance and error avoidance, particularly if the goal is to transfer the training content to difficult tasks.

A second stream of research deals with the notion of error management culture of teams and organizations. Errors occur and are important in any organizations (Reason 1990). Therefore, organizations implicitly or explicitly adopt shared practices and procedures on dealing with errors—the error management culture (or climate) (Keith & Frese 2011, van Dyck et al. 2005). Psychological safety—often measured as climate in groups—is similar to error management culture (although it is distinct psychometrically) and has been found to relate to learning and positive organizational outcomes (Baer & Frese 2003, Edmondson & Lei 2014). Psychological safety describes "individuals' perceptions related to the degree of interpersonal threat in their work environment" and involves "beliefs about how others will respond when one puts oneself on the line, such as by taking a risk, asking a question, seeking feedback, reporting a mistake, or proposing a new idea" (Nembhard & Edmondson 2012, p. 491). Psychological safety and error management culture are similar in their emphasis on organizational members' responses to errors as an important predictor of learning (operationally, one measure of Edmondson's seven-item measure of psychological safety explicitly refers to mistakes). Treatment of errors in organizations is, however, only one aspect of psychological safety, whereas it is the focus of the construct of error management culture. Also, error management culture is more action-oriented, as it comprises shared practices of dealing with errors. Psychological safety, in contrast, focuses more on "the emotional-motivational basis for interaction" within teams (Nembhard & Edmondson 2012, p. 496). In other words, psychological safety focuses more on what individuals in a team experience emotionally, whereas error management culture also entails how individuals and teams act upon errors.

An error management culture consists of common norms and practices—errors are accepted as inevitable, are used to learn, reactions to them are quick, and people communicate freely about their own and others' errors. Operationally, the commonly used measure of error management culture was derived from a measure that covers cognitive, affective, and behavioral aspects of orientations toward as well as responses to errors (the Error Orientation Questionnaire; Rybowiak et al. 1999, van Dyck et al. 2005). There are a number of positive consequences of error management culture in the areas of emotional reactions to errors, of innovations, and of performance (Keith & Frese 2011). In studies with auditors (accountants), a positive error management culture has also been shown to relate to feeling more responsible for errors (one's own and clients' errors; Gronewold & Donle 2011) and to more reporting of some types of errors (Gold et al. 2014), which are both prerequisites to learning from error. In the following sections we describe how error management leads to learning from errors.

Emotional processes associated with learning from errors. Errors are negative events and can evoke negative reactions such as anxiety and anger as well as shame and guilt (Carmeli & Gittell 2009, Zhao 2011). Some of these negative emotions may lead to reduced affective commitment to the organization (Shepherd et al. 2011). From a self-regulatory perspective, coping with one's negative emotions is a resource-demanding activity that draws away attention from the tasks at hand (cf. error cascades). If people are preoccupied with their negative emotions, necessary actions to correct the error and to contain negative error consequences may be delayed, with potentially harmful effects because the error consequences have more time to develop. Similarly, if a team devotes time to dealing with negative emotions or with finding someone to blame, necessary actions to contain the error consequences or to learn from it may be neglected (van Dyck et al. 2005). Thus, controlling negative emotions after an error is important. Therefore, error management training explicitly instructed participants to reduce negative emotions, switching from a (self-)blaming mind-set to a learning-oriented mind-set. Indeed, emotion control, which involves keeping negative emotions at bay during task completions, mediated the effectiveness of error management training on performance (Bell & Kozlowski 2008, Keith & Frese 2005). These findings indicate that the positive framing of errors in error management instructions (e.g., "Errors are a natural part of the learning process") may help learners to accept errors, which in turn helps to control negative emotions in response to errors and to stay focused on the task (Heimbeck et al. 2003).

Emotional processes associated with making errors not only affect individual work but also play a role in interpersonal processes in teams and larger units of organizations. Making and admitting errors are actions that are potentially associated with high costs for individuals because organizations' tangible and nontangible incentives (e.g., salaries, promotions, status, reputation, challenging project assignments) are often awarded for seemingly flawless performance (Zhao & Olivera 2006). Admitting an error may evoke fears of losing face and of being excluded from organizational benefits; on the other hand, talking about one's errors can lead to learning, both for individuals and for teams (Rybowiak et al. 1999). Similarly, people are more willing to voice a concern over an error in the team if they do not fear negative consequences for their voicing (Nembhard & Edmondson 2012). For these reasons, organizations should foster an environment and mind-sets of accepting human errors and support learning from errors (van Dyck et al. 2005).

Motivational processes associated with learning from errors. Errors can be motivating and demotivating; errors are demotivating when they are frustrating and disruptive. Strain may appear because time needs to be devoted to the correction of errors (Hofmann & Frese 2011b). When errors are framed as indicators of failure and lack of competence, they set off "negative self-evaluative reaction cycles" of self-doubt and dissatisfaction (Wood et al. 2000, p. 267). In contrast, a mind-set of acceptance of errors may even help to increase motivation. Personal mastery and task interest may be strengthened and benefit learning (Bell & Kozlowski 2008). Errors tend to interrupt actions, and an interrupted task tends to motivate the completion of this task (Ovsiankina 1928). Thus, errors may signal that something needs to be done; in the long run, errors help to motivate changing work procedures. Indeed, given the general tendency of humans to persist and to resist change, errors (e.g., failure of a project) may be a major motivator for change (Homsma et al. 2009, Shepherd et al. 2011).

Errors are by-products of motivated action. When people have control over their actions in the sense of autonomy at work, they develop a stronger sense of responsibility and higher intrinsic motivation (Oldham & Hackman 2010). Higher degrees of autonomy at work may not just enhance intrinsic motivation but may also lead to more errors (because there is no set way to do things). Intrinsic motivation has been suggested to be a mediating mechanism in error management training, although the results were not conclusive in that intrinsic motivation has been found to predict training outcomes in some studies (Bell & Kozlowski 2008) but not in others (Debowski et al. 2001, Wood et al. 2000).

A mind-set of acceptance of human error may instigate a learning goal orientation, which in turn may benefit learning (Bell & Kozlowski 2008, Heimbeck et al. 2003). Learning goals involve the development of competence and mastery in an achievement situation, whereas both performance-prove goals (gaining favorable judgments of competence) and performance-avoid goals (avoiding negative competence judgments by others) tend to avoid errors (Mangels et al. 2006). A learning goal orientation is positively associated with performance, a performance-avoid goal orientation is negatively associated, and a performance-prove goal orientation is unrelated to performance (Payne et al. 2007).

Goal orientations have been proposed to derive from different views of ability (Mangels et al. 2006). The view of ability as a fixed entity implies that ability is not changeable; thus, errors are symptoms of lack of ability. In contrast, a learning goal orientation includes views of malleable ability; that is, ability can be improved as a result of error feedback (Mangels et al. 2006). The error management approach should relate to a learning goal orientation with its malleable-ability view, whereas the performance-avoid goal orientation with its fixed-entity view should relate to error prevention (van Dyck et al. 2010). When errors are accepted and viewed as a natural part of human action and learning, errors are more likely to be seen as helpful for learning and development (Heimbeck et al. 2003). A training experiment found error management instructions to increase state-learning goal orientation among trainees low on trait-learning goal orientation (Bell & Kozlowski 2008). Another study assessing trait goal orientations and attitudes toward errors (error mastery and error aversion) during an error-prone task found relationships between learning goal orientation and error mastery and between performance-avoid goal orientation and error aversion (van Dyck et al. 2010).

Goal orientations as interindividual-difference or trait variables may moderate the extent to which people learn from errors. For example, Heimbeck et al. (2003) predicted and found support for an interaction of participants' trait goal orientations in the error-avoidant training condition. Other interindividual-difference variables studied in the context of error management training include cognitive ability, Big Five personality traits, and motivation as utility expectation (Carter & Beier 2010, Keith et al. 2010, Loh et al. 2013).

Cognitive/attentional processes and behavioral activities associated with learning from errors. The act of learning itself is a cognitive process. Therefore, we need to examine the cognitive and attentional processes resulting from errors or from a mind-set of error acceptance. Errors disrupt the flow of action. They are negative surprises (Cannon & Edmondson 2005) that attract more attention than nonerrors (Wills et al. 2007). This attention is then devoted to understanding the sources of errors and to finding solutions (Ivancic & Hesketh 2000, Keith & Frese 2005). Errors may help improve the mental model of the work task (cf. Frese & Zapf 1994) because they pinpoint incorrect assumptions and signal the need to correct erroneous assumptions.

Error-related events are associated with richer mental models than are successful events (Ellis & Davidi 2005). Errors also disrupt automatic processing and enforce a switch to conscious and more effortful deeper-level processing (Keith 2011), which in turn facilitates learning (Ivancic & Hesketh 2000). In the context of error management training, metacognition functions as a mediator of training effectiveness (Bell & Kozlowski 2008, Keith & Frese 2005). Metacognition involves activities of planning, monitoring, evaluation, and revision of task strategies while working on a task (Keith & Frese 2005). Errors may instigate such processes because "errors prompt learners to stop and think about the causes of the error" (Ivancic & Hesketh 2000, p. 1968). Learners then have to come up with potential solutions to the problem, implement them, and monitor their effectiveness. Such problem-solving activities may lead to new solutions and improved procedures—provided that errors are not viewed as threats but as important learning information. Also, errors need to be detected, and therefore feedback is central (Keith & Frese 2008).

A frequent misconception of error management is that it is really a (secondary) error prevention device. We tend to think that the general mind-set change to acceptance of and learning from errors as a result of error management is particularly important. Heimbeck et al. (2003) and Bell & Kozlowski (2008) compared conditions of error learning with and without error management instructions and showed that error management instructions are crucial for the performance improvements of learning from errors. The error management instructions may be one of the reasons for the better performance of error management training in contrast to exploratory training (Keith & Frese 2008). Because the error management instructions are general and change the mind-set to using errors for learning, these results speak for a general mind-set approach and against the idea that the major pathway to high performance in error management training is through secondary error prevention.

In teams and organizations, such mind-sets may be facilitated by shared practices. Collective problem-solving activities and mindful processing (which is equivalent to metacognition) occur (Weick et al. 1999). Similarly, open communication about errors is a prerequisite to organizational learning from errors (as was discussed in the section on error detection). Collective learning constructs are acknowledged as important predictors of favorable organizational outcomes (Argote & Miron-Spektor 2011). However, organizational learning is still a somewhat fuzzy concept. Individual learning is inferred from relatively permanent changes in knowledge, skills, or attitudes that result from practice or experience (Kraiger 2002). Such changes in knowledge and skills of teams have rarely been assessed directly (Kozlowski & Ilgen 2006) but are usually inferred from changes in organizational performance (Madsen & Desai 2010). It is beyond the scope of this review to provide a thorough discussion of the phenomena of learning in larger units.

Learning from errors with minor versus major negative consequences. Research indicates that learning from error occurs; however, we know little about error characteristics and learning. One error characteristic that has received some attention in the literature is the issue of error consequences. In general, people can learn more from negative outcomes that may result from an error than from successes (positive outcomes). Incorrect responses (i.e., errors) affect memory and attention more than correct responses (Joung et al. 2006). A study with firefighters (Joung et al. 2006) indicates that it is better to learn from stories describing errors than from those describing successes. Sitkin (1992) suggests that failures may be more valuable for learning than are successes because there are liabilities of success: Successes and strategic persistence stimulated by successes may promote stability and short-term performance (Madsen & Desai 2010). In the long run, however, success may promote complacency, risk aversion, and decreased attention. Failures, in contrast, may instigate increased attention and experimentation, willingness to take risks, and, in turn, increased innovation and adaptability to changing circumstances.

One position held in the literature is that the more severe the error consequences, the more people will be motivated to learn from their errors (Homsma et al. 2009, Madsen & Desai 2010, Zakay et al. 2004). Errors with strong negative consequences attract attention and indicate unequivocally that something needs to done; this then leads to learning because people reflect on and discuss their errors, changing routines and understanding. Successful actions or errors with small negative consequences do not indicate a necessity for change. Therefore, errors with small consequences or those that can be corrected immediately are more easily overlooked or ignored.

In contrast to this position, Sitkin (1992) proposed that small failures are better motivators than are large failures. The natural reaction to errors is to feel threatened, and people may become more defensive and denying (Hajcak & Foti 2008) the higher the severity of negative consequences. Therefore, errors with mild to moderate consequences—visible enough to attract attention but mild enough not to evoke defensiveness and denial—may increase learning from error. In line with this reasoning, Sitkin (1992) suggested what he calls a strategy of small losses or intelligent failure, that is, failures in organizations that are of modest magnitude and that permit effective learning for the organization.

We agree with Sitkin's position, but we also need to caution that the natural tendency is to neglect low-consequence errors in comparison to high-consequence errors. This is vividly illustrated by Madsen & Desai (2010), who describe two incidents in the launch of two NASA space shuttles. In both cases (*Atlantis* in 2002 and *Columbia* in 2003), insulation foam from the left bipod ramp broke off during the launch and caused damage to the space shuttle. The damages differed, however, in the extent of negative consequences. In the case of *Atlantis*, the damage did not interfere with the mission, and the mission was ultimately considered a success. However, in the case of *Columbia*, the damage caused by the lost foam led to a breakdown of the thermal protection system and to disintegration of the shuttle during its reentry into the earth's atmosphere—all seven crew members lost their lives (Madsen & Desai 2010). Both missions were followed by NASA investigations, but the one after the tragic *Columbia* accident was by far more intensive. In both cases, the circumstances leading to the loss of foam were similar, yet the consequences differed dramatically, and the organization put much more effort in investigating the accident with severe negative consequences.

Other available evidence also supports the notion of a "negative outcome bias" (Zakay et al. 2004, p. 151)—more attention is paid to and more learning is instigated by events with more negative outcomes. For example, in a study in the chemical process industry, Homsma et al. (2009) found severity of error consequences to predict learning behaviors six weeks later. Zakay et al. (2004) experimentally varied severity of error consequences in a scenario experiment and found large effects in willingness to learn from error. Finally, Madsen & Desai (2010) analyzed learning from success versus from failure using long-term performance data from the orbital launch industry, concluding that organizations learn more from prior failures than successes; the authors state that their findings contradict the small-losses hypothesis, and they conclude that learning is related to the severity of error consequences.

The available findings notwithstanding, it should be noted that problems are associated with studying error learning in organizations. In particular, several characteristics of errors may be confounded. For example, severity of error consequences may be confounded with types of errors (lower-level versus higher-level errors in various error taxonomies), and the finding that people learn more from errors with more severe consequences may be actually due to these errors being more complex, higher-level errors (Zapf et al. 1992). Also, the finding that there may be a greater willingness to learn from errors with major consequences does not necessarily imply that learning from errors with minor consequences is not possible. Indeed, research on so-called after-event or after-action reviews (i.e., a systematic procedure of team reflection and discussion after completion of, for example, a mission or a project) indicates that learning is possible both from successes and from failures (Ellis et al. 2014). It is conceivable that it is not the severity of error consequences per se that instigates learning but instead that more severe error consequences merely facilitate the motivation to instigate learning behaviors and that interventions may be designed that instigate learning behaviors, such as systematic reflection (Ellis et al. 2014), irrespective of the outcome of an action.

Error Management and Performance

Error management training leads to learning and improved performance. Theoretically, this effect should also appear in everyday work. For example, expecting to competently deal with errors (error competence) and being able to learn from errors (learning from error) (Rybowiak et al. 1999) should help individuals to manage unexpected events, to learn from errors on a long-term basis, and to show more personal initiative and proactive behavior. Being fearful of errors, in contrast, will reduce an active orientation at work. Empirically, error orientations indicative of error management have displayed relationships with a number of performance constructs, such as personal initiative (Putz et al. 2012, Rybowiak et al. 1999); predicting changes in personal initiative over time (Fay & Frese 2001); qualification, generalized self-efficacy, and long-term planning (Rybowiak et al. 1999); and the knowledge of tax accountants measured with an objective knowledge test after one year (Scheel & Hausmann 2013).

Situations of high uncertainty, such as unemployment or starting a new business (entrepreneurship), are probably particularly suitable for error learning because uncertain situations provoke errors. Indeed, training unemployed job seekers to learn from errors (called learning from failure in this study) was indirectly related to reemployment via its effect on the intention to seek a new job (Noordzij et al. 2013). Newly started businesses were more successful when their owners showed a high degree of action orientation after failure (Kazén et al. 2008) and when they were higher on learning from errors and error competence (Keith & Frese 2011).

In addition to these relationships with individual-level outcomes, team outcomes have been investigated in a number of studies. In the nursing sector, error management (alone or along with safety climate) predicted safety-related outcomes (e.g., levels of injuries, medication errors, nurses' back injuries; Chang & Mark 2011, Hofmann & Mark 2006) and also displayed some interactions with work-related variables. For example, working hard and engagement contributed to better-quality performance when safety climate and learning from errors was high (Mark et al. 2007).

Results on the company level also show relationships with important organizational outcomes. An error management culture has been found to benefit such outcomes as firm profitability (van Dyck et al. 2005) and safety performance (Fruhen & Keith 2014, Hofmann & Mark 2006). Organizations with a high error management culture actively deal with errors by fostering explicit communication about errors, coordinated error handling, quick error detection, and damage control. Cultures low in error management, in contrast, tend not to explicitly deal with the issue of errors but rather implicitly emphasize punishment and blaming for an error (van Dyck et al. 2005). Error management culture was shown to be positively related to firm performance in two studies in Germany (a longitudinal study on return on assets) and in the Netherlands (firm survivability) (van Dyck et al. 2005). Van Dyck et al. (2005) suggested error management culture to reduce negative error consequences; increase learning and innovativeness; lead to exploration, experimentation, and initiative; and reduce quality concerns. Some of these issues also came up in a qualitative study that compared companies high in error management with those low in error management (van Dyck et al. 2005). Another study related learning from errors to customer service. Team error learning modeled after Rybowiak et al. (1999) was related to supervisor ratings of customer service—unfortunately, as in many team studies, the number of teams in the study was small, reducing the power to find clear effects (Putz et al. 2012). Another study developed the concept of supply chain disruptions along the lines of error management items and examined companies' use of bridging (e.g., more intensive contacts with partners) versus buffering (e.g., searching for alternative suppliers) strategies (Bode et al. 2011).

Error Management and Innovations

Inventors (e.g., Thomas Edison is credited with the statement, "I have not failed. I've just found 10,000 ways that won't work") and descriptions of R&D (research and development) projects show that errors are associated with the development of innovative products, processes, or services (Economist 1999). Discoveries often enter new terrains of knowledge and, therefore, errors are important for scientific discovery (Klahr & Simon 1999); a surprise result may be the starting point for new discoveries (e.g., an observed object behaves differently from how it is expected to behave, such as the bacteria in Fleming's petri dish that led to the discovery of penicillin).

Error management and innovations are related for the following reasons. First, innovation processes are inherently contradictory and chaotic, and therefore innovative processes are inherently error prone (Bledow et al. 2009). A dominant theory on creativity and innovation argues that getting creative ideas happens serendipitously (Simonton 2003), and serendipity makes errors during the innovation process highly likely.

Second, since there is no prior knowledge of what constitutes useful innovations, experimentation is necessary; unfortunately, many experiments do not work out. Introducing new ideas into the market makes sense only after one has done intelligent experimentation. Thus, necessary mistakes should be made quickly and under safe circumstances (Sitkin 1992).

Third, errors themselves lead to exploration. As discussed above, errors make people become aware of their actions and their environment. This may lead to exploration and can, therefore, lead to new areas of inquiry and innovations (Bledow et al. 2009). Detection of the function of Viagra or penicillin appeared at first to be due to action errors. Obviously, only the prepared mind is able to develop an innovation from an accidental detection of a surprising phenomenon.

Fourth, any new idea, innovative product or service, or new theory implies that one enters new and unchartered territory—thus, there is less knowledge or fewer routines in this area and therefore more errors. In the entrepreneurship area, new business owners often have to explore new areas, and therefore they have to improvise (Baker & Nelson 2005). Errors are the results of these approaches.

Fifth, some creativity techniques are precursors of error management. They reinforce the idea that errors and creativity are related (Robledo et al. 2012). Brainstorming (whether done in groups or alone) assumes that there is one phase in which one should voice whatever comes to mind—even if it is wrong. Only in the second phase of evaluation should people test the efficacy and usefulness of ideas; thus, creativity techniques implicitly differentiate between errors and error consequences, allowing and enabling errors as important for creativity.

Finally, error management culture relates to performance via ambidexterity (N. Rosenbusch, K. Rosing, R. Bledow & M. Frese, manuscript submitted); ambidexterity implies that one is experimenting with new products and at the same time refining existing products/services (Bledow et al. 2009). Failures also instigate new ideas and increase the strength to follow through on these new ideas (Deichman & van den Ende 2013).

ERROR MANAGEMENT AND OTHER CONCEPTS

Error (Management), Violation (Management), and Safety Climate

As discussed, errors and violations are both deviations from goals, plans, and standards; however, violations are intended, whereas errors are not. Relationships between errors and violations occur because violations can take people outside boundaries of safety and into unforgiving environments; such environments tax the knowledge and skills and lead to errors (Lawton 1998). Violations and errors may interact in producing catastrophes, as happened in Chernobyl (Reason 1990). People violating rules may not quite understand the function of these rules and unintentionally underestimate the risks of violations (Lawton 1998).

Why would people break rules? In general, violations occur in organizations when low-priority goals are sacrificed in favor of high-priority goals (i.e., goal conflicts; for example, when workers have to observe safety and profitability standards simultaneously and when nurses have to respond quickly to emergencies and observe hygiene rules simultaneously). Time pressure and restrictions of behavior due to rules are also reasons to violate rules (Lawton 1998). In addition, organizations tend to increase the number of rules across their life span (often as a reaction to errors on some prior occasions). As Lawton (1998, p. 94) so eloquently explains, "It is important to remember that violations occur because rules exist." And, "Organizations like rules" (Reason et al. 1998, p. 289). Having a large number of rules often makes it impractical to follow all rules, so people have to ignore rules to get their work done (Lawton 1998). As organizations become overregulated, violation management becomes one viable option to respond to violations (in addition to violation prevention). We define violation management analogously to error management: Violation management starts after a violation has occurred. Violation management implies avoiding negative consequences altogether or reducing their negative impact.

The idea that violations lead to learning is supported by the results of a sophisticated meta-analysis on safety climate (Beus et al. 2010). It showed that the effects of injury on organizational safety climate (Rho $= -.29$) were as high as the negative effects of organizational safety on injury (Rho $= -.24$) (there was no significant difference between these two effects; Beus et al. 2010, p. 719). Thus, people recalibrated their ideas about the organizational safety climate because of injuries, and at the same time safety climate led to a reduction of injuries.

A large part of safety research, including organizational safety climate, has concentrated on violations of rules, and often the implicit or explicit goal was to prevent violations from occurring. From a practical perspective, the concentration on violations makes sense because violations are more easily prevented; they are organizationally caused and driven by conscious intentions that are changeable (in contrast to errors, which are understood not to be completely preventable because of their serendipitous nature). Sample items of safety climate are, "Supervisor frequently checks to see if we are all obeying the safety rules" and "Supervisor refuses to ignore safety rules when work falls behind schedule" (Zohar 2000). Empirically, safety climate is related to unsafe behaviors, adverse events, and accidents (negative relationships) (Nahrgang et al. 2011), and as displayed by Beus et al. (2010), the effects go in both directions. Communication is central to both error management and safety climate (Hofmann & Stetzer 1998).

Much of safety climate research relates to prevention rather than to management of violations. There are two exceptions: One study differentiated violation management (called managerial safety practices) from how well people were informed (safety procedures), safety information flow, and cynical attitudes toward rules for safety (called priority of safety) (Katz-Navon et al. 2005). All four factors were relevant for nurse teams, although some more complex relationships appeared (Katz-Navon et al. 2005).

The second study drove the differentiation of (*a*) errors and violations and (*b*) prevention and management to its logical conclusion. Nurse teams answered surveys on four different team climates: error prevention, error management, violation prevention, and violation management (respondents received clear definitions of each climate); path analytic results demonstrated that all four factors predicted changes in medical incident reports (X.Y. Gao, S.H. Sun, M. Frese, C. Childs & S. Ang, unpublished manuscript).

High-Reliability Organization and Error Management

Communalities and differences exist between error management theory and high-reliability approach. High-reliability organizations are defined by five strategies for dealing with hazards (Weick et al. 1999): preoccupation with failure (worry about negative consequences and suspiciousness), reluctance to simplify interpretations (skepticism toward easy explanations and complexity by divergent approaches), sensitivity to operations (broad operational awareness), commitment to resilience (improvisation and bouncing back from errors), and underspecification of structures (fluid decision making and flexibility). Weick et al. (1999) suggested that these five factors lead to mindfulness, which in turn enhances the capability to discover and manage unexpected events. A measure of these five aspects of the high-reliability organization is related to medication errors and patient falls (Vogus & Sutcliffe 2007b), and it interacts with trust in leadership in reducing medication errors (Vogus & Sutcliffe 2007a).

Similarities of error management theory (**Figure 1**) and the high-reliability approach are that people expect errors to happen (preoccupation with failure in high reliability), errors are random (reluctance to simplify interpretations), and quick error detection (sensitivity to operations). Error management theory also agrees that it is necessary to motivate and develop skills, routines, and communication processes to deal with errors (commitment to resilience) and that there is never just one answer to the error problem because one cannot predict particular errors (underspecification of structures). Moreover, research on error management training has shown that metacognizing is one important process by which error management leads to higher performance (Bell & Kozlowski 2008, Keith & Frese 2005), which is similar to Weick's concept of mindfulness and sense making.

There are also differences between these two approaches. First, error management theory differentiates between violations and errors because of their different processes (X.Y. Gao, S.H. Sun, M. Frese, C. Childs & S. Ang, unpublished manuscript). We are aware that it is often difficult for laypeople (and even safety professionals) to differentiate between errors and violations (Hofmann & Mark 2006, Reason 1997), but because both the prevention and the management of violations and errors are different practically and theoretically, it is useful to keep them distinct. Error management theory also differentiates between prevention and management, in contrast to the high-reliability approach, which includes items on both in the same measure, the "Safety Organizing Scale" (Vogus & Sutcliffe 2007b). From an organizational point of view, it makes a substantial difference whether organizations approach the issues of errors and violations primarily through prevention or also through management (van Dyck et al. 2005). Another difference is that error management theory accepts that errors and violations may have positive consequences.

With regard to pathways, error management theory suggests several (i.e., emotional, motivational, cognitive, and behavioral) and has empirically shown emotion control and metacognition to be effective. Surprisingly, we have not been able to find quantitative or experimental studies examining the pathway via mindfulness within the high-reliability approach; thus, the results of Keith & Frese (2005) may be the only test of the importance of mindfulness. Finally, the empirical work tends to be more quantitative and process oriented within the error management approach. The high-reliability approach is based on case studies (cf. Weick et al. 1999) and is, therefore, more contextual. We think that both methods are important, and we applaud the development of case studies within error management theory (van Dyck 2009) and quantitative studies in high reliability theory (Vogus & Sutcliff 2007a,b).

Several recent attempts have been made to integrate the high-reliability concept and error management theory, an endeavor we think is overdue, given the overlap of recommendations and approaches (Goodman et al. 2011, Ramanujam & Goodman 2011), but that beckons more scientific work.

SUMMARY POINTS

1. The error management perspective assumes that we can never completely eradicate action errors; therefore, a second line of defense is necessary. This defense is called error management—an active approach to errors that reduces negative consequences and enhances positive effects, such as learning and innovation.
2. Error management training proved to lead to better learning than not being allowed to make errors (Frese et al. 1991). One crucial aspect for this effect is exploration during training (as opposed to clear instructions on how to do things); the second is provision of error management instructions (as opposed to not changing the mind-set toward errors) (summarized and meta-analyzed by Keith & Frese 2008).
3. Error management instructions are brief instructions encouraging making errors during training and emphasizing their potential positive consequences. The main idea of these instructions is often displayed during training as short sentences such as, "I have made an error, great! Now I can learn something new!" (e.g., Heimbeck et al. 2003).
4. Frese (1991) provides the following concept of error management: "Error management does not mean to avoid the error per se but attempts to avoid the negative error consequences altogether to reduce the amount of the negative error effects" (p. 778). Hofmann & Frese (2011b, p. 33) further elaborated on the concept: "[E]rror management is designed to (a) control the potential damage of errors, (b) reduce the potential of error cascades, and (c) facilitate secondary error prevention" (i.e., prevention of similar errors in the future). In addition, error management helps to increase positive error consequences, such as learning and innovation.
5. Crew resource training in the airline industry was first described in 1993 and was later called error management training (Kanki et al. 2010) (summarized by Salas et al. 2006).
6. The concept of safety climate was introduced by Zohar (1980) and most recently has been related to error management culture (X.Y. Gao, S.H. Sun, M. Frese, C. Childs & S. Ang, unpublished manuscript).
7. Violations are different from errors because they involve a conscious intention to break a rule or to be nonconforming to a standard; in contrast, errors are unintentional deviations from goals, rules, and standards (Hofmann & Frese 2011b).
8. Classic error taxonomies were developed by Rasmussen et al. (1987) and Zapf et al. (1992).

FUTURE ISSUES

1. Personality and errors may interact.
2. Several theories are conceptually related to error management theory, but their relations have not yet been explored in detail. These theories include regulatory focus (Higgins 2012), learning goals (Mangels et al. 2006), need for cognition (Palmer & Feldman 2005), and coping (Folkman & Moskowitz 2004).
3. Error prevention, error management, and potentially violation prevention and violation management should be examined within the same studies to explicate their interrelationships and their differential effects (X.Y. Gao, S.H. Sun, M. Frese, C. Childs & S. Ang, unpublished manuscript).
4. Do differences exist in the etiology of errors with strong negative consequences (e.g., errors leading to abrupt ends of stellar careers, such as entrepreneurial careers) and everyday errors? How can employees and organizations be motivated to reflect on and to learn even from errors with mild consequences?
5. Establishing boundary conditions of error management theory, for example, risk compensation, may lead to risky behavior after people have learned error management (Wilde 1988). Under which conditions (if at all) can trial and errors lead to positive consequences (Keith & Frese 2008, van der Linden et al. 2001)?
6. Mediators of the relationships between error management and innovation need to be established. What are the relationships (if any) between learning organization and error management culture?
7. Is there a difference between unproductive blaming that is detrimental to error management and productive blaming in the sense of thorough and accurate analysis of error causes?
8. Do different errors (error taxonomy) lead to different ways of learning?

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