# Cognitive Resilience: Reflection-In-Action and On-Action

Jonathan Back, Dominic Furniss, Ann Blandford

University College London Interaction Centre, United Kingdom
{j.back, d.furniss, a.blandford}@ucl.ac.uk

**Abstract.** Identifying cognitive strategies that people use to support resilient performance has rarely been the focus of experimental work. Our experiments have found that the pervasiveness of failures during human computer interaction can be recognized by individuals, but underlying cognitive and attentional causes cannot. Understanding how individuals recover from failure and adapt to new environmental demands can be studied in the laboratory, however, this requires a paradigmatic shift away from developing traditional 'single cause' explanations. Previous research has strongly suggested that individuals are reliant on 'bottom-up' cues from the environment when planning future actions. By systematically manipulating factors that influence an individual's awareness of environmental cues, work reported in this paper has revealed some novel insights. Resilient individuals are able to spontaneously generate new strategies in-action that support response to regular disturbances. Furthermore when provided with a 'window of opportunity' to reflect-on-action, individuals can rehearse future actions so that the influence of any residual strain (or load) can be mitigated against (feedforward strategy). Further work on understanding strategies adopted by resilient individuals may facilitate the development of systems that explicitly support cognitive resilience.

## 1 INTRODUCTION

Cognitive psychologists have found that 'human error' can be provoked within a laboratory environment and that the development of causal accounts enables the frequency of certain types of errors to be predicted (e.g., Byrne and Bovair, 1997; Gray, 2000). Demonstrating that 'human error' is not the product of some stochastic process has led to a better understanding of human cognition but has had little impact on research and practice in safety, risk analysis, and accident analysis. Laboratory studies have focused on errors that occur during practiced routine performance, where a participant performs an incorrect sequence of actions. Outside the laboratory, identifying incorrect action sequences is not possible since the context in which those sequences took place cannot be easily understood. Dekker (2005) suggested that error classification disembodies data: it removes the context that helped to produce the behavior in its particular manifestation. "*Without context, there is no way to re-establish local rationality. And without local rationality, there is no way to understand human error*" (Dekker, 2005, p 60). We argue that 'cognitive resilience' is an intrinsic component of local rationality. Identifying cognitive strategies that people use to support resilient performance might help to account for behavior. Individuals are resilient if they are able to recognize, adapt to and absorb variants, changes, disturbances, disruptions, and surprises (Woods & Hollnagel, 2006). This paper will discuss the extent to which cognitive strategies that support resilience are identifiable in the laboratory.

One of the first attempts to demonstrate the non-stochastic nature of errors was suggested by Rasmussen and Jensen (1974). The idea that errors can be categorized as being skill-based, rule-based, or knowledge-based allows errors to be attributed to different cognitive factors. However, whether an error is classified as skill-based, rule-based, or knowledge-based may depend more on the level of analysis than on its ontogeny (Hollnagel, Mancini, & Woods, 1988). For example Gray (2000) argued that the same behavior, e.g. "taking the wrong route during rush hour", can result from lack of knowledge (not knowing about a faster route) or misapplication of a rule (knowing that one route is the fastest during rush hour and the other is fastest on the off hours but applying the 'off hours' rule in the rush hour). In addition, this behavior could be caused by a slip (taking the more familiar route when the intention was to take the less familiar but faster one) or be intentionally wrong (too much traffic to get into the correct lane).

The focus of laboratory work on human error has been to develop 'single cause' accounts of slip errors. Slip errors can occur systematically even when individuals have the required 'expert' procedural knowledge to perform a task correctly. For example, Byrne and Bovair (1997) showed that post-completion error (a type of slip) is sensitive to working memory demands. If the environment imposes high working memory demands then this type of error is more likely. Therefore, an individual who has an increased capacity to process information is less likely to make a slip error. This type of finding is of interest to cognitive scientists but is of little use to researchers and practitioners in safety, risk analysis, and accident analysis. An understanding of human performance is only useful when the context (local rationality) that helped to produce the behavior is understood. Elucidating this context may be possible if cognitive strategies that people use to support resilient performance can be identified.

This paper reports on a series of experiments that aimed to reveal some of the strategies that individuals use during human computer interaction. These strategies help individuals to detect, recover from and mitigate against failure. Previous research has strongly suggested that users are reliant on 'bottom-up' cues from the environment when planning future actions (Payne, 1991). It is hypothesized that the development of cognitive strategies is dependent on an individual's awareness of environmental cues. By systematically manipulating factors that influence an individual's awareness of cues, different strategies that support resilient performance may emerge.

## 2 SELF-REPORTING AND RECOGNIZING FAILURES

Errors are one measure of the quality of human performance. For example, Miller (1956) identified an important property of working memory by discovering that individuals make errors when recalling more than 7 (+/-2) elements of information. However, the everyday concept of error presupposes a goal. This can make the classification of errors difficult if an individual is interacting in an exploratory way to satisfy a learning goal, especially when a user is adopting a trial-and-error approach. A better understanding of error is only possible if a way of differentiating between errors and exploratory interactions (where errors or sub-optimal moves can be an expected or even a desired outcome) is possible. However, humans are not always able to describe their goals or able to recognize the extent to which a goal has been addressed. In an attempt to investigate this issue, a problem solving game was designed that allowed participants to verbally self-report erroneous and exploratory interactions (*see* Back, Blandford, & Curzon, 2007a). Twenty participants were encouraged to develop their own distinctions between what should be considered erroneous or exploratory. The game specified a series of locations (rooms) and placed objects within rooms or within the player's inventory (possessions). Objects such as a locked door were not designed as permanent obstacles, but merely as problems to be tackled. Solving problems frequently involved finding objects and then using them in the appropriate way. One aim was to discover whether self-reports provide useful information about the strategies individuals use to mitigate against error. Two types of report were possible: 1) An 'Elective Report' made at any time during interaction; 2) A 'Debrief Report' which required a participant to review a trace of their own behavior immediately after a task was completed.

When comparing the elective reports with the debrief reports no significant differences were associated with the frequency of erroneous reports. However, exploratory interactions were significantly more frequently reported using the elective self-report mechanism. Woods, Johannesen, Cook, and Sarter (1994) argued that self-reports can be biased by hindsight which prevents them from being a useful tool for understanding interaction. Our analyses showed that the elective mechanism was able to elicit a significantly wider range of exploratory move types than the debrief mechanism. This supports the notion that outcome knowledge (knowing how things turned out) biases self-reporting processes, especially when reporting exploratory moves. A qualitative analysis revealed that exploratory self-reports provided useful information about problem solving strategies that participants were trying out. Crucially, many exploratory reports (65%) outlined strategies that participants used to avoid making persistent errors.

During interaction, the pervasiveness of errors was recognizable but underlying cognitive and attentional causes were not. Only 20% of elective error reports associated were reasoned accounts of error. During debrief reporting, participants were more able to provide a reasoned accounts (72% of these reports were reasoned). Based on these findings we argue that the error recognition process is dependent on cognitive context and the availability of environmental cues. Reasoning about errors during interaction is harder than when performing a debrief report because different environmental cues are 'salient'. During the debriefing session participants were required to debug their task performance. Critically, participants were not reminded of task objectives. Therefore, the only way of detecting erroneous moves was to recall intentions based on the availability of environmental cues. When performing a debrief report immediately after interaction, participants were able to reconstruct intentions and were actively looking for environmental cues that could be used to execute those intentions.

In summary, an opportunity to reflect-on-action is essential for an individual to reason about why failures occurred, enabling future strategies to be formulated. However, an understanding of the exploratory strategies that individuals actually use can only be elicited during interaction (reflection-in-action).

## 3 REFLECTION-IN-ACTION AND ON-ACTION

Schön (1987) describes two types of reflection: reflection-in-action and reflection-on-action. The former takes place as events unfold, where the participant will perceive the situation as new but implicitly compare it to prior experience, situate possibilities for new actions and carry out experiments to decide a course of action. The latter happens further away from the event temporally, where the participant will formalize the situation and actions so they can evaluate and think about the situation. For example, a footballer will be reflecting-in-action during the game by responding to opportunities presented to him by his team mates and the opposition; during the half time break the team‘s coach will facilitate reflection-on-action by describing what was good, what could be improved, and how to change their tactics.

The Repetitions-Distinctions-Descriptions (RDD) Model (Nathanael & Marmas, 2006) provides a graphical illustration of how reflection-in-action is distinguished from reflection-on-action. Figure 1 shows an abstracted version of the RDD model presented by Nathanael and Marmas (2006, p. 233). Here repetitions account for the normal routine actions of individuals, where these are abnormal or there is opportunity to try something different then a ‘distinction’ in the normal routine can be made and the participant reflects-in-action (RIA) to alter their practice, this altered practice can then be absorbed in normal routine if appropriate. Reflection-on-action (ROA) occurs in detached moments where participants may formalise new understandings of their situation for action i.e. the situation is not only distinguished but described and reflected upon away from the event.

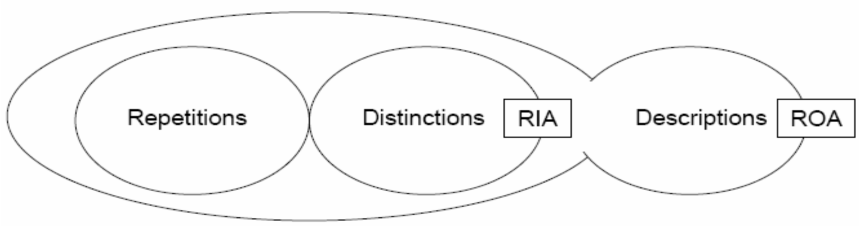


**Fig. 1.** The Repetitions, Distinction and Descriptions (RDD) Model adapted from Nathanael and Marmas (2006, p. 233). RIA = Reflection-in-action; ROA = Reflection-on-action

## 4 STRATEGIES FOR REFLECTING-IN-ACTION AND ON-ACTION

By systematically manipulating factors that influence an individual’s awareness of environmental cues, some novel insights into the nature of cognitive strategies people use to support resilient performance can be revealed. A simulation of a ‘Fire Engine Dispatch Center’ was developed. Two experiments using 24 participants each were run (see Back, Blandford, & Curzon, 2007b). Experiment 1 investigated the frequency of two classes of slip error under different cognitive and perceptual load scenarios. Experiment 2 investigated if a ‘window of opportunity’, used to rehearse procedural steps, reduced error rates. Results from both of these experiments demonstrate that individuals can develop cognitive strategies to maintain resilient performance when reflecting in-action and on-action. Two systematic error manifestations are briefly outlined below.

*Mode Error* - A visual display that informed participants of GPS signal status was provided. Participants were required to attend to this signal so that they could determine what type of route information had to be sent to a particular fire engine. Analysis revealed that if participants placed the mouse cursor close to the signal status display, they were significantly less likely to forget to attend to the display before selecting an appropriate route construction method. Avoiding this type of error can be considered a cognitive skill since it involves spontaneous personalized cue creation by reflecting-in action.
*Initialization Error* - When commencing a new trial an individual had to decide which call to prioritise before clicking on the 'Start next call' button. Forgetting to perform this call prioritisation procedure resulted in an initialization error. In Experiment 2 participants were given 4 seconds to reflect on requirements before commencing a trial: Within-subjects Conditions - A) call prioritisation always visible; B) call prioritisation not visible during reflection time. In Condition A participants were significantly better able to avoid initialization errors. Condition A allowed participants to reflect-on-action.

## 5 CONCLUSIONS

Rehearsal (reflecting-on-action) and personalized cue creation (reflecting-in-action) are examples of cognitive strategies that people can use to support resilient behavior. When a 'window of opportunity' for reflection exists then any residual strain (or load) can be mitigated against (feedforward strategy). Resilient individuals are able to spontaneously generate new strategies in-action that support response to regular disturbances (e.g., learning to use the mouse cursor as an environmental cue). Understanding how individuals recover from failure and adapt to new environmental demands can be studied in the laboratory, however, this requires a paradigmatic shift away from developing traditional ‘single cause’ explanations. An understanding of human performance is only useful when the context that helped to produce the behavior is understood.

## REFERENCES


Back, J., Blandford, A. & Curzon, P. (2007a). Recognising erroneous and exploratory interactions. To appear in *Proceedings of INTERACT 2007*.

Back, J., Blandford, A. & Curzon, P. (2007b). Slip errors and cue salience. To appear in *Proceedings of ECCE2007*.

Byrne, M. & Bovair, S. (1997). A working memory model of a common procedural error. *Cognitive Science, 21* (1), 31-69.

Dekker, S. (2005). *Ten questions about human error: a new view of human factors and system safety*. Lawrence Erlbaum Associates.

Gray, W. D. (2000) The nature and processing of errors in interactive behavior. *Cognitive Science, 24* (2), 205-248.

Hollnagel, E., Mancini, G. & Woods, D. (1988). *Cognitive engineering in complex dynamic worlds*. Academic Press.

Nathanael, D. & Marmas, N. (2006). The interplay between work practices and prescription: a key issue for organisational resilience. In E. Hollnagel & E. Rigaud (Eds.) *Proceedings of the Second Resilience Engineering Symposium* (pp. 229-237), 8-11 November 2006, Juan-Les-Pins, France.

Miller, G. (1956). Human memory and the storage of information. *Transactions on Info Theory, IT-2* (3), 128-137.

Payne, S. J. (1991). Display-based action at the user interface. *International Journal of Man-Machine Studies, 35*, 275-289.

Rasmussen, J., Jensen, A. (1974). Mental procedures in real-life tasks. *Ergonomics, 17*, 293-307.

Schön, D. (1987). *Educating the reflective practitioner*. San Francisco: Jossey-Bass.

Woods, D. D., Johannesen, L. J., Cook, R. I. & Sarter, N. B. (1994). *Behind human error: Cognitive systems, computers, complexity and hindsight*. CSERIAC, 94-01.

Woods, D. D. & Hollnagel, E. (2006). Prologue. In: Hollnagel, E., Woods, D. D. & Leveson, N. *Resilience engineering: Concepts and precepts* (pp. 1-7). Aldershot, UK: Ashgate.