Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 84 (2014) 55 – 61

Procedia Engineering

www.elsevier.com/locate/procedia

"2014ISSST", 2014 International Symposium on Safety Science and Technology

Cues and cue-based processing: implications for system safety

Mark WIGGINS, Thomas LOVEDAY, Lucy LYONS*

Centre for Elite Performance, Expertise, and Training
Macquarie University, North Ryde, New South Wales, Australia, 2120

Abstract

In process control systems such as electricity power control, the success of a response to a change in the system state is largely dependent upon the capacity of operations controllers to identify, diagnose, and respond to the change. However, despite the importance of these skills in ensuring system safety and integrity, little or no information is acquired pertaining to the skills of operators and how these might impact the system more broadly. Using a cue-based theoretical framework, the present study examined the extent to which an assessment of different aspects of cue utilization could differentiate operator performance in four electrical transmission organizations. Using four tasks that comprise the assessment tool EXPERTise, the performance of 112 electrical controllers was examined, and the results revealed patterns of performance that could provide indicators for intervention. By using a comparative approach to cue utilization, it obviates the need for absolute judgments. Instead, it not only provides an assessment of the relative cue utilization within the organization, but performance on each of the four tasks provides a clear direction for managers in developing interventions that will ensure the safety and integrity of the system in the future.

Peer-review under responsibility of scientific committee of Beijing Institute of Technology

Keywords: System Safety, Cues, Cue Utilization, Expertise

1. Introduction

Contemporary industries are becoming increasingly dependent upon the efficient and accurate operation of complex systems. Whether it is aviation, rail, or shipping, the co-dependencies are such that a relatively minor failure in one part of the system can subsequently trigger much more serious failures. Often, the initial triggers are

* Corresponding author. Tel.: +61 29850 9705; fax: +61 2 9850 8066.
E-mail address: mark.wiggins@mq.edu.au

Peer-review under responsibility of scientific committee of Beijing Institute of Technology
doi:10.1016/j.proeng.2014.10.409

very difficult to detect and, as Reason [1] notes, they remain latent until a particular combination of events occurs that will cause their activation.

In many cases, latent conditions relate to aspects of human performance, including a lack of training, experience, rest, and supervision [2]. For many years and in many instances, the impact of these conditions might be mitigated by other factors, referred to as defences [3]. These might include standard operating procedures, the availability of other crew or, in some of the more advanced systems, computer-based decision support. The fact that the impact of latent conditions is managed reflects positively on the safety management system, since the overall integrity of the system is safeguarded at multiple levels. However, the fact that these conditions remain resident within the system means that they must be detected and interventions developed at the appropriate level within the system.

The introduction of guards, procedures, and technical support to control the impact of latent conditions on system performance is akin to taking a cough suppressant for influenza. While it will manage at least one of the symptoms, it does not necessarily impact the virus itself. What is necessary, in this case, is an intervention at the cellular level to ensure that the influenza virus is either killed or expelled. In removing the virus, we remove the coughing symptoms, which in turn, allows the patient to resume normal activities.

In the context of system safety, responding to issues at the 'cellular' level equates to responding to those fundamental performance-shaping factors that can, in time, impact the safety and integrity of a system [4]. The difficulty lies in identifying these factors within the complexities of a system. Moreover, there are a number of performance-shaping factors, such fatigue and stress that are highly dynamic and variable, and may differ from shift to shift [5]. Nevertheless, those performance-shaping factors that are more stable as constructs and could be assessed on a regular basis, thereby ensuring that elevated risks to the system are appropriately identified for remediation.

2. Situation assessment and cues

In most complex systems, operators are now required to use technological support to manage various processes. Referred to as process control, it reflects a cyclical strategy whereby indicators of the system state are monitored on a regular basis for anomalies that will require an intervention [6]. The use of interfaces, therefore, 'distances' the operator from the system and, in some cases, operators can be many hundreds of kilometres from the systems they are operating (e.g. Unmanned Aerial Vehicles, Driverless Trains). This distance from the operational environment requires that the operators interpret the system state based on a set of artificial indicators, each of which embodies cues.

Cues represent feature-event or feature-object associations in memory, and their use is intended to reduce the demands on cognitive load, thereby enabling resources to be employed for other functions [7]. The use of cues tends to be associated with greater levels of performance in the operational environment [8]. This improvement in performance draws from operators' capacity to quickly and efficiently, identify and diagnose changes to the system. In identifying, at an early stage of the process that a change has occurred, together with the nature of those changes, operators can anticipate the interventions required and respond both accurately and rapidly, thereby safeguarding the overall performance of the system.

At a theoretical level, cues form a fundamental component of recognition-driven models of decision-making [9]. These are models that purport to describe the behavior of experts, and the role of the cue, in this case, is to enable an assessment of the situation, sufficient to trigger an appropriate representation in memory. It is these mental representations or mental models that provide the framework for subsequent interventions. Therefore, it is important in a time-constrained, potentially high-consequence situation, that cues that are identified and interpreted by operators, trigger rapidly, the appropriate mental representation in memory

Where operators possess either a limited repertoire of cues in memory, or are incapable to associating particular cues with mental representations, there is an inherent risk that an operator will either fail to recognize and respond to a change in the system state or will only do so once the system has progressed to a state from which it is unrecoverable. As a consequence, the cue-based representations that are held in operators' memories need to be accurate and reliable. More importantly from the perspective of system safety, a method is necessary to establish levels of cue-based processing within both individuals and amongst a broader cohort, particularly where a system is dependent upon accurate diagnosis and/or where there are changes to the technologies employed to exercise control over the system.

2.1. Assessing cue-based processing

The fundamental difficulty associated with assessments of cue-based processing is the problem of individual experience. Since cues are acquired through experience, and operators differ in both the quality and the quantity of their experiences, it is particularly difficult to form a judgment as to whether or not a particular feature-event/object relationship in the form of a cue is accurate. Assessments of expert performance clearly demonstrate that experts adopt quite different strategies to recognize and respond to a problem, with relatively equivalent outcomes in accuracy and response time [10]. This idiosyncrasy in the repertoire of cues in memory is a product of individual differences in the capability and the opportunity to acquire cues. Some operators will undergo highly structured training under an effective instructor that enables cue-based associations to be acquired systematically. For other operators, the experiences in the formation of expertise might have been more ad-hoc, leading to differences in both the rate and the types of cues acquired.

Irrespective of the specific cues that are resident in memory, the fact that operators possess cues in memory, together with a relatively greater level of performance, suggests that they have acquired a level of experience sufficient for the formulation of cues. Cues can only be acquired once a signature feature is extracted from the environment, is associated with a specific event or object, and is then retained in memory [11]. Inevitably, this process requires repeated trials or the accumulation of experience. Through either trial and error or a more directed process of instruction, operators will acquire and then refine the original associations so that they become ever more accurate and efficient [12].

Given that skill acquisition, especially at higher levels of performance, relies on increasing levels of efficiency and accuracy in the utilization of cues, it might surmised that an assessment tool that tests the efficiency and the accuracy of cue utilization would reflect different levels of skill acquisition. If, in the context of high technology environments, the tool assessed cue utilization in the context of specific interfaces, a domain-specific process of assessment could be developed that would provide information pertaining to the levels of skill acquisition amongst a particular cohort and, therefore, highlight any apparent risks to the integrity of the system. Using standard psychometric techniques, a benchmarked dataset could be developed across a particular industry that would assist in assessments of training initiatives, system integrity, new technologies, and new employees.

2.2. EXPERTise and cue utilization

The Expert Intensive Skills Evaluation (EXPERTise) is a situation judgment test that is designed to assess cue utilization across a range of domains, but particularly those that involve the use of interfaces [13]. It is designed around four psychological tests, each of which has been validated separately as a differentiator of expert and non-expert practitioners. The Feature Identification test establishes the capacity of the operator to identify signature features quickly and accurately from an array. The Paired Association test involves the presentation of a series of features and events/or objects where the operator is asked to consider the relatedness of the terms. The Feature Discrimination task seeks operators' responses to a domain-related problem and then their subsequent assessment of the importance of a list of key features in their response to the problem. Finally, the Transition Task involves operators seeking information pertaining to an ambiguous, domain-related problem, and the formulation of a response. In combination, performance on the four tasks has been shown to differentiate higher and lower levels of performance in power transmission control [14], software engineering [15], medicine [16], and aviation [11].

EXPERTise has afforded researchers the capacity to acquire data across different organizations within a domain, and thereby draw comparisons as a prelude to the development of a benchmark dataset. The aim of this study was to acquire comparative cue utilization datasets in the context of power transmission control, from which broader conclusions could be drawn about the differences between organizations and the subsequent implications for system safety.

3. Methodology

3.1. Participants

The participants in this study comprised 112 operators from within power transmissioncontrol. The organisations from which the participants were drawn were located in Australia and New Zealand and consisted of operations and 330KV and 135KV levels. While they used different interfaces to exercise control over the system, all of the operators were familiar with Supervisory Control and Data Acquisition control interfaces.

Overall, participants had accumulated a mean 11.77 years of experience (SD = 12.25) in electrical network control, and were aged between 21 and 61 years of age. The vast majority were males (93.7%) while 79% indicated that they work directly in electric transmission control.

3.2. Materials

The materials comprised the electrical power control version of EXPERTise, which was available to complete on-line. For the Feature Identification Task, participants were shown an open circuit breaker on a SCADA interface for 1.5 seconds, and were asked to identify, from a selection of four options, the transmission line on which the fault had occurred. Twoversions of the Paired Association Task were included, the first of which displayed two, domain-related terms sequentially, and participants were asked to rate their relatedness on a seven-point Likert Scale. In the second version of the Paired Association Task, the terms were presented simultaneously and participants again, rated their relatedness on a seven-point Likert scale.

For the Feature Discrimination Task, participants were provide with a scenario in which multiple transmission lines had tripped, and they were asked to indicate their first response under the circumstances. Thereafter, they were asked to rated, on a seven-point Likert scale, the importance of the various features in their assessment of the scenario. Finally, in the Transition Task, participants were advised of a report of a potential security breach and were asked to acquire additional information from a menu list of information.

The construct validity of the outcomes of EXPERTise has been established previously in power transmission control, aviation, pediatrics, and software engineering. The test-restest reliability of the outcomes of EXPERTise has been assessed in the context of power transmission control [17].

3.3. Procedure

Participants were recruited through their respective organisations, and EXPERTise was completed on-line. The program took approximately 40 minutes to complete. Participants received no remuneration for their participation in the task, although, for most of the participants, the program was completed during work hours.

4. Results

Following data cleaning and checks for normality, the data were subjected to a one-way Multivariate Analysis of Variance, incorporating the organization as the independent variable, and the different components of cue utilization as the dependent variables. Using the Wilk's criterion, a statistically significant multivariate main effect was evident for organization,$F(15,265) = 4.33$, $p < .001$. Subsequent, univariate tests indicated that the organisations differed significantly on all five variables (see Table 1)

To examine further, the nature of the relationships between the organizations, a series of analyses was undertaken to establish the pattern of the relationships between the different organizations. The results displayed in Fig. 1 indicate reveal a complex pattern of performance, In the Feature Identification Task (a), Organization D outperforms the remain organizations, with Organization C displaying the lowest level of accuracy. For the Paired Associations Tasks (b & c), the pattern of performance is relatively consistent across the two versions, with higher levels of variance generally associated with a more nuanced repertoire of feature-event associations in memory. The results indicate that Organizations A and B are operating at relatively higher levels of performance, while Organization D is operating at a relatively lower level of performance.

Table 1. Summary of the univariate outcomes across organizations

Variable	*F (df)*	*p*	*η2*
Feature Identification Accuracy	2.86 (3, 100)	0.04	0.08
Paired Association (1) Variance	4.14 (3,100)	0.01	0.11
Paired Association (2) Variance	7.19 (3, 100)	0.00	0.18
Feature Discrimination Variance	3.65 (3, 100)	0.15	0.99
Transition Task Ratio	5.33 (3,100)	0.00	0.14

Like the Paired Association Task, performance on Feature Discrimination Task (d) is based on assessments of the variance of responses. In this case, the results reveal relatively higher levels of performance associated with Organization A and lower levels of performance associated with Organization D. Finally, assessment in the Transition Task is based on the ratio of information screens accessed in the sequence in which they were presented to participants, against the total frequency of pairs of information screens available to be accessed. Lower ratios are normally associated with higher levels of cue-based performance during problem-solving. The results revealed relatively greater performance for Organizations A and D.

5. Discussion

The aim of this study was to examine whether assessments of the different aspects of cue utilization would differentiate organizations in the context of power control, and whether this information would prove useful as an indicator of potential latent conditions that could impact system safety. Greater levels of cue utilization have been associated with higher levels of performance across a range of contexts, including medicine and power system control. EXPERTiseis a Situation Judgment Test that is designed to provide a comprehensive assessment of the utilization of cues. It comprises a number of tasks, each of which is based on the application of cues in response to domain-relevant stimuli.

The results of a comparative analysis of organizations across Australia and New Zealand revealed statistically significant differences in performance both comprehensively, and across the different tasks that comprise EXPERTise. The pattern suggested that, in some organizations (e.g. Organization D), performance was relatively greater in recognizing signature features, as evident in performance on the Feature Identification and Transition tasks. However, the same organizations performed at a relatively lower level in the capacity to discriminate between feature-event associations, as evident in performance on the Paired Association and Feature Discrimination tasks. In combination, the results suggest that while operators in these organizations may recognize relatively rapidly, a change in the system state, they may not necessarily possess the nuanced associations the might be indicative of a sophisticated mental model to respond effectively to the range of failures that may occur.

By contrast, those organizations that performed at a relatively higher level in discriminating between feature-event associations but were less effective in identifying key features (e.g. Organization C) suggests that operators within these organizations may possess a more nuanced repertoire of feature-event associations in memory, but are relatively less effective in detecting and responding to changes in the system state.

It is important to note in analyses of this type, that performance is not absolute and is merely relative to other organizations. There may be many reasons why operators within organizations differ in their performance, including the availability of well-developed systems of alarms and decision-support tools. Over time, exposure to these tools may diminish the requirement for operators to detect and diagnose changes in the system state, thereby impacting their cue-based performance. The data presented are simply designed as a benchmark to identify potential latent conditions within an organization. Through the acquisition of these data over time, it will become possible to assess the impact of interventions, thereby enabling assessments of the risks to system safety and integrity.

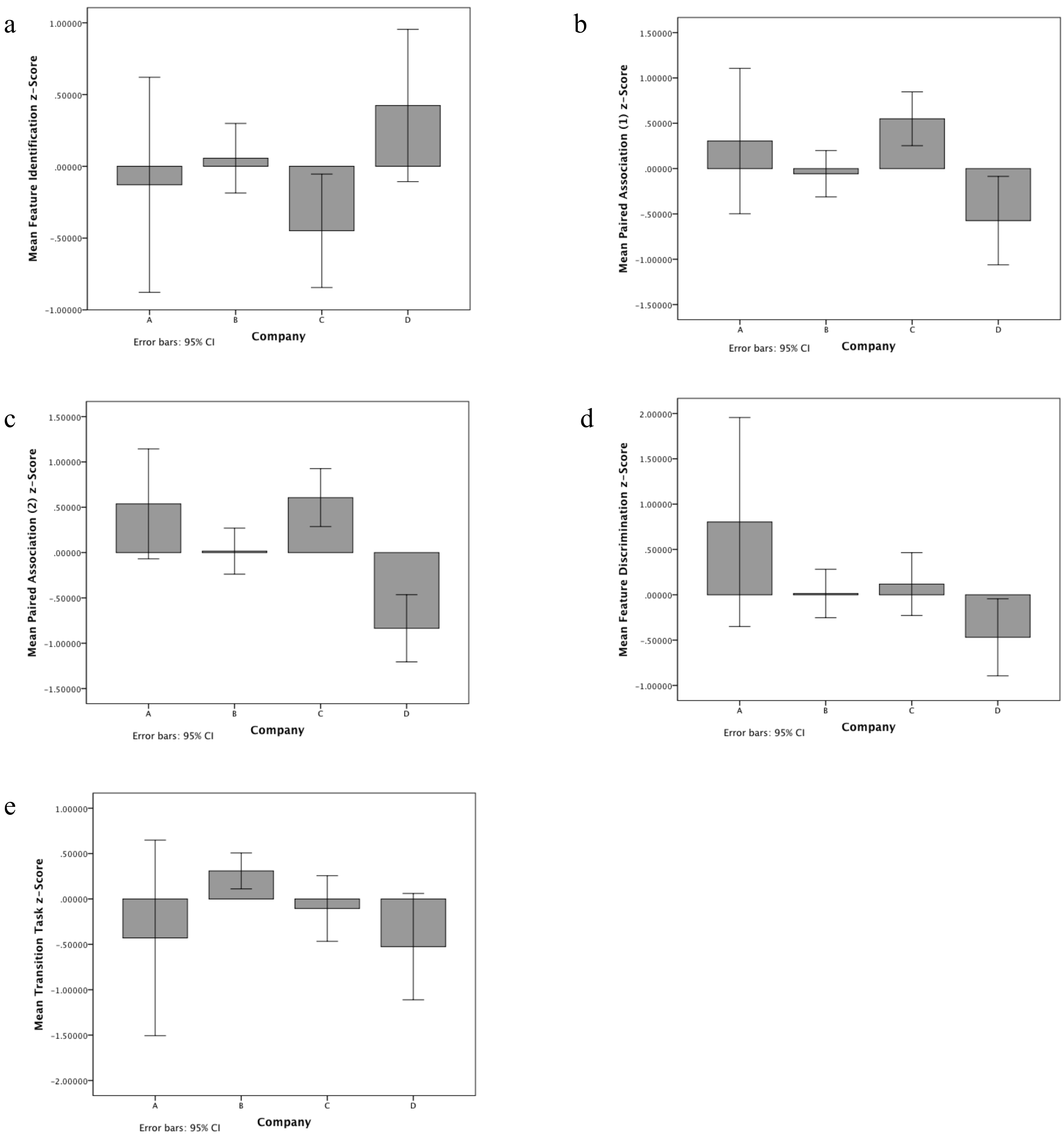

Fig. 1. (a) z-Scores for the Feature Identification Task, distributed across organizations; (b) z-Scores for the Paired Association Task (1), distributed across organizations; (c) z-Scores for the Paired Association task (2), distributed across organizations; (d) z-Scores for the Feature Discrimination Task, distributed across organizations; (e) z-Scores for the Transition Task, distributed across organizations

Although these data have been acquired in the context of power system control, there is little doubt, that the same approach could be applied across any advanced technology environment where operators interact with the system through interfaces. It will also be possible to establish the impact of changes to a system, at least at the level of human performance. Since human performance is often a significant source of system failure, it will provide a basis to identify, remediate, and then assess the impact on any changes that are made to the operation of a system.

Acknowledgements

Funding for this research was provided by the Australian Research Council under the Linkage Projects Program (LP130100023)

References

[1] J. Reason, Managing the risks of organisational accidents, Aldershot, UK,Ashgate, 1997.
[2] D.K. Busse, D.J. Wright, Classification and analysis of incidents in complex medical environments, Top. Hlth. Inf. Man. 20 (2000) 1-11.
[3] P.D. Hollywell, Incorporating human development failures in risk assessments to improve estimates of actual risk, Saf. Sci. 22 (1996) 177-194.
[4] L.j. Bellmay, T.A.W. Geyer, J. Wilinson, Development of a functional model which integrates human factors, safety management systems, and wider organisational issues, Saf. Sci. 46 (2008) 461-492.
[5] D. O'Hare, Cognitive functions and performance shaping factors in aviation accidents and incidents,Int. J. Aviat. Psy. 16 (2006) 145-156,
[6] S.H. Han, H. Tang, D-G Im, Designing a human-computer interface for a process control room: A case study of a steel manufacturing company, Int. J. Ind. Erg.37 (2007) 383-393.
[7] M.W. Wiggins, The role of cue utilisation and adaptive interface design in the management of skilled performance in operations controlTheor.Iss. Erg. Sci. (2012) 1-10
[8] B. Morrison, M.W. Wiggins, N. Bond, M. Tyler, Measuring Cue Strength as a Means of Identifying an Inventory of Expert Offender Profiling Cues, J. Cog. Eng. Dec. Mak.7 (2013) 211-226.
[9] G. Klein, Naturalistic decision making, Hum. Fac. 50 (2008) 456-460.
[10] C. Speier, The influence of information presentation formats on complex task decision-making performance,Int. J. Hum.-Comp. Stud. 64 (2006) 1115-1131.
[11] M.W. Wiggins, D.Azar, J. Hawken, T. Loveday, D. Newman, Cue-utilisation typologies and pilots' pre-flight and in-flight weather decision-making, Saf. Sci. 65 (2014) 118-124.
[12] M.W. Wiggins, S.Brouwers, J. Davies, T. Loveday, Trait-based cue Utilization and initial skill acquisition: implications for models of the progression to expertise, Cognition, 5 (2014) 541.
[13] M.W. Wiggins, J. Harris, T. Loveday, D. O'Hare. EXPERTise. Multimedia Software, Macquarie University, Sydney, 2010.
[14] T. Loveday, M.W. Wiggins, J. Harris, N. Smith, D. O'Hare, An Objective Approach to Identifying Diagnostic Expertise Amongst Power System Controllers. Hum. Fact.55 (2013) 90-107.
[15] T. Loveday, M.W. Wiggins, Cue utilization and broad indicators of workplace expertise. J. Cog. Eng. Dec. Mak.8 (2104) 98-113.
[16] T. Loveday, M.W. Wiggins, B.J. Searle, M.Festa, D. Schell, The capability of static and dynamic features to distinguish competent from genuinely expert practitioners in pediatric diagnosis, Hum. Fact. 55 (2013) 125-137.
[17] T. Loveday, M. Wiggins, M. Festa, D. Schell, D.Twigg, Pattern Recognition as an Indicator of Diagnostic Expertise, in: P. Latorre Carmona, J. S. Sanchez & A. L. N. Fred (Eds.), Pattern recognition - Applications and methods,Springer, Berlin, 2013 pp. 1-11.