Proceedings of the 2015 International Conference on Industrial Engineering and Operations Management
Dubai, United Arab Emirates (UAE), March 3 – 5, 2015

An integrated cognitive performance evaluation framework for urban search and rescue applications

Steven Jiang and Antonio Lee
North Carolina A&T State University
United States
xjiang@ncat.edu
xjiang.ncat@gmail.com

***Abstract*—A variety of techniques and methods are available to evaluate cognitive performance. However, traditional cognitive performance evaluation techniques incorporate only the conscious or systematic aspect, failing to take into consideration the subconscious or intuitive aspect. This leads to incomplete measures and produces ineffective designs. In order to fill the gaps in past research, this study developed a theoretical framework to facilitate the integration of situation awareness (SA) and intuitive pattern recognition (IPR) to enhance the cognitive performance representation in Urban Search and Rescue (USAR) applications. The purpose of this framework is to provide a common structure for the integration of SA and IPR in USAR domains. The integrated framework consists of a sequence of procedures that can be used as a blueprint in the identification of the USAR responder's total cognitive performance to both investigate and improve the system design.**

Keywords—cognitive performance; situation awareness; intuitive pattern recognition; urban search and rescue

I. INTRODUCTION

Urban Search and Rescue (USAR) consists of responders who work to stabilize damaged structures, locate and extricate victims, identify risks of additional collapses, and provide medical treatment to victims. USAR environments are highly complex, and can sometimes be too dangerous to deploy USAR responders to locate and assist victims due to structural hazards that have the potential for secondary collapses, hidden hazards such as the disbursement of toxic gases, and personal hazards such as getting lost inside a building or extreme exhaustion (Murphy et al., 2009). The utilization of rescue robots can avoid placing USAR responders in harm's way while still being able to analyze the situation and relay feedback to the USAR responder. Over time, continuous advancements in this technology have permitted the use of highly autonomous rescue robots shifting the responder's initial duties from a more physical presence to a more mentally based position. Therefore, it is important to address the effectiveness of the system that measures the responder's cognitive performance. Existing cognitive performance evaluation methods range from qualitative questionnaires and interviews to quantitative biomechanical measurement tools. However, these methods only incorporate the conscious or systematic aspect of performance (the situational awareness component), and fail to integrate the subconscious or intuitive aspect to account for the ideas and conceptualization of the total responder's decision-making experience (Klein, 2008). Situation awareness (SA) is a valuable and frequently used component when assessing cognitive performance in complex environments. However, assessing the situation awareness component only accommodates the conscious or systematic piece of the USAR responder's decision-making ability failing to recognize the subconscious component, which plays an important role in how they make decisions in complex environments such as USAR. Neglecting the intuitive aspect when assessing cognitive performance can lead to insufficient development of interface designs, which can have serious consequences. Therefore, research needs more effort devoted towards incorporating both conscious and subconscious aspects of cognitive performance in interface designs. This study proposes an integrated framework to evaluate the responder cognitive performance. In an attempt to understand relationships and their contribution to evaluating the effectiveness of the interface design, the framework provides a way to account for the responder's comprehensive decision-making performance. In order to study responder's cognitive performance within the domain of USAR, the study uses concepts from theoretical frameworks such as rapid prototyping technique, Accumulated Clues Task (ACT), and Quantitative Analysis of Situational Awareness (QUASA).

II. THE INTEGRATED FRAMEWORK

A framework that integrates situational awareness and intuitive pattern recognition (IPR) to enhance the cognitive performance representation in USAR was developed. The integrated framework consists of a sequence of procedures that can be used as a blueprint in the identification of the USAR responder's total cognitive performance to both investigate and improve the system design.

The integrated framework consists of six steps. (1) constructing a cognitive task analysis to understand the cognitive tasks in USAR domain, (2) identifying knowledge associated with a particular task and utilizing the developed SA and IPR design requirements to form SA and IPR goals and scenarios; (3) developing a SA and IPR design to execute an assessment for all cognitive components; (4) collecting cognitive performance data; (5) an approach to evaluate findings quantitatively; and 6) drawing conclusions.

A. *Cognitive Task Analysis*

A cognitive task analysis (CTA) is often one of the strategies used to describe the knowledge required for cognitive performance (Van Merrienboer, et al., 2002). CTA uses a variety of interview and observation strategies to capture accurate and complete descriptions of cognitive processes and decisions. The purpose of a cognitive task analysis is to define the decision requirements systematically and psychological processes used by expert individuals (i.e., performers) in accomplishing results (Hoffman et al., 1998).

The initial step includes developing a general understanding of the USAR domain in which the cognitive task analysis will be conducted, and developing a sense of vocabulary associated with the USAR domain. Next, two or more USAR Subject Matter Experts (SMEs) should be recruited as they display in-depth knowledge of the domain requirements in USAR environments. To be considered as reliable candidates, SMEs should have recent experience in both teaching and performing cognitive skills in USAR situations. After recruiting SMEs, information associated with USAR related tasks should be identified and structured. A series of potential sub-steps are suggested, which include: Documented literature review and analysis; Observation; Structured and/or Unstructured interviews; and Concurrent verbal protocol analysis.

B. *SA and IPR Requirements*

A set of questions are designed to elicit descriptions of specific types of USAR domain knowledge, skill, and appropriate examples. A series of twenty requirements are developed to guide the design of the statements used to measure SA and IPR related goals. The design requirements are separated into four categories consisting of general information, goals, cues, and system design. These categories address the requirement needs specific to SA, IPR, and both. If the potential goals demonstrated by an USAR event do not comply with general information guidelines, remove or alter those USAR events to fit the guidelines. These guidelines highlight areas such as the type of information the statements should provide and the format in which the goal should comply. In the event these guidelines are unmet, eliminate or alter the potential goal to fit the criteria.

The guidelines illustrated in Table 1 address the constraints of the requirements in regards to the type of cue information provided in association with the goals of the USAR events and demonstrate that the cues provided must satisfy limitations such as addressing the USAR theme at all times and the ability to be easily identified in the USAR event. Violations of any of the guidelines should result in eliminating or altering the associated goals to fit the criteria. The guidelines address the constraints of the requirements with regard to design guidelines for cues and the system in the USAR domain. This component illustrates the manner in which the SA and IPR design should present the information. If the goals of the USAR event do not align with how the system presents the information, eliminate or alter the goals to fit the criteria.

From these guidelines USAR events should be developed that comply with the requirements for situation awareness goals, and intuitive pattern recognition goals; associated cues should be determined; and goals should be aligned with consistent system design set up.

TABLE I. SUMMARY OF DESIGN GUIDELINES FOR CUES AND THE SYSTEM IN USAR DOMAIN

		SA	IPR	Both
SA and IPR Cue	Cues presented should support USAR theme at any point			✓
	Cues presented should be easy to identify in the USAR environment			✓
	Cues should be provided in a logical and consistent order according to USAR protocol		✓	
SA and IPR System	Dynamic representation of the entire USAR landscape should be displayed		✓	
	Use automation for assistance in carrying out consistent actions rather than higher level cognitive tasks			✓
	Physical tasks for the USAR responder should be minimized			✓

C. *USAR Design Development*

Computer-based simulated scenarios are constructed that emulate the behavior of the prototype system and environment allowing the assessment of cognitive processes performed by the USAR responder. There are a variety of simulation tools available that have the potential to meet the capabilities required for the USAR scenario recreation. However, because research in the USAR field has experienced the most vigorous development in recent years within the robotics community, many of the USAR tasks focus on robotic behaviors and the development of robotics simulation software to represent USAR scenarios (Kitano et al., 1999). Examples of possible robotic simulation software identified as appropriate but not limited to representing USAR scenarios include: MissionLab, Microsoft Robotics Developer Studio (MRDS), Unified System for Automation and Robot Simulation (USARSim), and Webots. One of the most effective and user-friendly robotic simulation software is Microsoft Robotics Developer Studio (MRDS). MRDS is a window-based environment used for robot control and simulation (Johns and Taylor, 2009). It is an integrated programming environment making it possible to debug robotics applications without having to make any assumptions about the underlying hardware (Johns and Taylor, 2009). The robotic simulation software should provide a development platform that supports the creation of USAR scenarios. Distinctive simulated components should be developed to assist in the assessment of USAR responder's cognitive performance with regard to situation awareness, intuitive pattern recognition. In the end, it is important that the simulation provide the ability to create the appropriate components in a format consistent with the requirements.

D. *SA and IPR Requirements*

Using this framework, objective measures of SA and IPR are developed to investigate total cognitive performance for the USAR scenarios. Cognitive workload also is measured as a comparison analysis between cognitive effort and cognitive performance. Therefore, to collect data from the functional interface design(s) and validate the USAR environments described in the previous sections, a number of computer based probes and computerized post-task participant questionnaire are developed.

Using the simulation software, computer based probe designs for the USAR are constructed to collect the cognitive performance of the responder in regards to SA and IPR. The computer-based probes provide the ability to display the query information in regards to SA statements and IPR statements, collected in Section 2.2. Then, the probes are programmed to be answered at discrete decision points throughout the simulated scenarios. The answered SA component yields output in the form of the responder's situational understanding based on the percentage of correct situations identified. In addition, the IPR component yields output in the form of the responder's intuitive response displayed by the percentage of correct situational responses recognized.

In addition to using simulation software, a computerized post task questionnaire (for the USAR domain) is constructed to collect cognitive workload data from the responders. The computerized post task questionnaire provides the ability to display USAR related statements that measure cognitive workload usually across six dimensions, namely, effort, mental demand, performance, frustration, and physical demand. These items then are rated on a 0-100 percent scale. Where a rating of 0 means the USAR responder was not working hard to understand and react to that situation, and 100 means the USAR responder was working extremely hard to understand and react to that situation.

In addition to collecting SA and IPR scores, it is vital to define an appropriate representation of the impact of each component on the responder's cognitive performance at a sufficient level to allow realistic cognitive performance values to be estimated. Since there is limited research that supports an established quantitative breakdown between situation awareness and intuitive pattern recognition in USAR domains, an alternative approach was developed. For this framework, in order to provide an accurate percentage breakdown, active USAR SMEs are recruited to document their perceived percentage of impact between situational awareness and intuitive pattern recognition in USAR environments. A highly suggested approach in collecting this information is the use structured and/or unstructured interviews as this allows the ability for direct questions about the USAR domain. Then, an averaged percentage is applied to each component to model USAR SA percentage of impact breakdown and IPR percentage of impact breakdown.

E. Performance Data Evaluation

In order to assess the responder's cognitive performance and cognitive workload, the measurements must be quantified to verify different measurement levels. Since the collected measures should convey the key pieces of information specific to the situational awareness percentage scores, intuitive pattern recognition percentage scores, cognitive workload percentage scores, and impact percentage of SA and IPR components, a quantitative approach is needed to integrate and evaluate the total cognitive performance and cognitive workload.

Given that the cognitive tasks within the integrated framework represent percentages of correctly identified situations for situation awareness performance and percentages of correctly recognized responses for intuitive pattern recognition performance, model formulation can be described in terms of the system's ability to match the responder's total cognitive performance. The total cognitive performance of the USAR responders can be described as the summation of the responder's situation awareness (*SAR*) plus the responder's intuitive pattern recognition (*IPRR*). The responder situation awareness (*SAR*) performance is measured by the summation of the cognitive impact percentage breakdown multiplied by the percentage of correctly identified situations. Whereas, the responder intuitive pattern (*IPRR*) recognition performance is measured by the summation of the cognitive impact percentage breakdown multiplied by the percentage of correctly recognized responses. The results from both calculations should then be added together to generate the total cognitive performance of the USAR responder.

The cognitive workload component should be documented as the amount of mental effort required from each USAR participant performing each task. The cognitive workload component is recognized as a post-test performed directly following each task. This method yields output in the form of the percentage of mental workload for each task. In order to obtain percentage scores for these dimensions, a scale of twenty bipolar ratings were developed, a score from 0% - 100% is assigned to each point on the scale to the nearest 5%, and each dimension is assigned an individual scale. Next, in an effort to prioritize and assign weights based on the significance of the dimension, a paired comparison between the dimensions was performed. Finally, a global workload score was developed across all dimensions. Hence, these dimensions provide insight on the mental workload experienced when performing these complex tasks.

F. Drawing Conclusions

Having the cognitive components accounted for and integrated in the framework provides the ability to assess the USAR participant's total cognitive performance accurately. Throughout the human factors community, a significant amount of research correlates cognitive improvement with positive cognitive performance. Research also supports the idea that there is an inverse relationship between cognitive performance and the amount of cognitive workload required when performing complex tasks. For example, as cognitive performance increases the cognitive workload would decrease or vice versa (Parkes, 1995). Therefore, the variation between the two components (total cognitive performance and cognitive workload) should be used to determine the cognitive performance of the USAR responder in relation to the amount of mental effort required by the responder when performing cognitive tasks. In ensuring satisfactory results, a comparison of the USAR participants' cognitive performance should be investigated with a focus on the state of the responder's cognitive performance and cognitive workload.

III. Conclusion

When disaster strikes, USAR responder's decision making process plays a significant role in this highly complex, and often very dangerous environment. A variety of techniques and methods are available to evaluate the responder's cognitive performance. However, traditional cognitive performance evaluation techniques fail to take into consideration the subconscious or intuitive aspect and can lead to incomplete measures and produce ineffective designs which can have serious consequence for USAR missions. This study developed a theoretical framework to facilitate the integration of situational awareness (SA) and intuitive pattern recognition (IPR) to enhance the cognitive performance representation in USAR applications. The purpose of this framework is to provide a common structure for the integration of SA and IPR in USAR domains that take into consideration both conscious and subconscious aspects of cognitive performance. The integrated framework consists of a sequence of procedures that can be used as a blueprint in the identification of the USAR responder's total cognitive performance to both investigate and improve the system design.

Acknowledgment

This research is partially funded by NSF Engineering Research Center of Compact Efficient Fluid Power.

References

[1] Murphy R, Kravitz, J et al. (2009). Mobile robots in mine rescue and recovery. Robotics & Automation Magazine, IEEE 16(2): 91-103.

[2] Klein, G (2008). Naturalistic Decision Making. Human Factors, 50(3), 456-460. doi: 10.1518/001872008X288385.

[3] Van Merriënboer, JJG, Clark, RE et al. (2002). Blueprints for complex learning: The 4C/ID-model. Educational Technology Research and Development 50(2): 39-61.

[4] Hoffman, RR, Crandall, B et al. (1998). Use of the critical decision method to elicit expert knowledge: A case study in the methodology of cognitive task analysis. Human Factors: The Journal of the Human Factors and Ergonomics Society 40(2): 254-276.

[5] Kitano, H, Tadokoro, S, Noda, I, Matsubara, H, Takahsahi, T, Shinjou, A, and Shimada, S (1999). Robo cup rescue: Search and rescue in large-scale disasters as a domain for autonomous agents research. In IEEE: International Conference on Systems, Man, and Cybernetics, IEEE Press (Vol.6, pp.739-743). Tokyo, Japan.

[6] Johns, K, and Taylor T (2009). Professional Microsoft robotics developer studio, Wrox.

[7] Parkes, KR (1995). "The effects of objective workload on cognitive performance in a field setting: A two-period cross-over trial." Applied Cognitive Psychology 9(7): S153-S171.