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Data Entry Error In Mobile Keyboard Device Usage Subject To Cognitive, Environmental, And Communication Workload Stressors Present In Fully Activated Emergency Operations Centers

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DATA ENTRY ERROR IN MOBILE KEYBOARD DEVICE USAGE SUBJECT TO COGNITIVE, ENVIRONMENTAL, AND COMMUNICATION WORKLOAD STRESSORS PRESENT IN FULLY ACTIVATED EMERGENCY OPERATIONS CENTERS

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ABSTRACT

The diversity and dynamic nature of disaster management environments necessitate the use of convenient, yet reliable, tools for technology. While there have been many improvements in mitigating the effects of disasters, it is clearly evident by recent events, such as Hurricane Katrina that issues related to emergency response and management require considerable research and improvement to effectively respond to these situations.

One of the links in a disaster management chain is the Emergency Operations Center (EOC). The EOC is a physical command center responsible for the overall strategic control of the disaster response and functions as an information and communication hub. The effectiveness and accuracy of the disaster response greatly depends on the quality and timeliness of inter-personnel communication within an EOC. The advent of handheld mobile communication devices have introduced new avenues of communication that been widely adopted by disaster management officials. The portability afforded by these devices allows users to exchange, manage and access vital information during critical situations. While their use and importance is gaining momentum, little is still known about the ergonomic and human reliability implications of human-handheld interaction, particularly in an Emergency Operations Center setting.

The purpose of this effort is to establish basic human error probabilities (bHEP's) for handheld QWERTY data entry and to study the effects of various performance shaping factors, specifically, environmental conditions, communication load, and cognitive load. The factors selected are designed to simulate the conditions prevalent in an Emergency Operations Center. The objectives are accomplished through a three-factor between-subjects randomized full factorial experiment in which a bHEP value of 0.0296 is found. It is also determined that a combination of cognitive loading and environmental conditions has a statistically significant detrimental impact on the HEP.

for my parents
they are the foundation on which I stand

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CHAPTER ONE: INTRODUCTION

Background

Throughout history, humankind has suffered nature's fury. Earthquakes, hurricanes, and tornados are a sampling of the armaments in nature's arsenal. These disastrous events lead to a myriad of problems, including property destruction, ecological ruin and, most importantly, human casualties. However, humanity has come to realize that the real disaster lies not with in the occurrence of the natural event itself, but in their failure to effectively respond to nature's onslaught; that the effects of natural events can be mitigated through research, planning, and technology.

In developing management strategies for these natural events, one of the chief difficulties faced is effective communication and coordination between the responding agencies and government officials. In an effort to alleviate this difficulty, the U.S. Federal Government developed the National Incident Management System (NIMS) in 2004. NIMS structures and defines the overall operating characteristics of an emergency response. The system is modular, scalable, and provides a common framework under which persons and organizations, both local and distant, can communicate effectively. A primary NIMS operating characteristic is that local multiagency coordination systems are in charge of the strategic command and control of an incident. These coordination systems are known as Emergency Operations Centers (EOCs).

EOCs, by their very definition, are data and communication intensive organizations. Since individuals involved in EOC operations are not at the incident site, their decisions are primarily based on the data and communications they receive from external sources. And as such, these decisions are crucially affected by the incoming data quality and delivery rate. Technology is critical in improving the delivery rate and amount of data that is exchanged between an EOC and external parties. One such technological device is the Research in Motion (RIM) Blackberry Smartphone, which offers EOC personnel several advantages, such as: (RIM 2009)

- *Multi-tasking:* Text messages can be composed while the individual is engaged secondary or tertiary tasks, such as in a verbal conversation.
- *Non-intrusive:* Verbal communications require greater amounts of attention than text messages do. Text messages can be read or composed in parts without interrupting other individuals.
- *Inter-operability:* Blackberry text messages are platform independent. They can be sent to any e-mail capable computer or handheld device regardless of manufacturer or operating system.
- *Record/Data Logging:* Information is stored on the device and in some cases on a server as well. Data can be hence be referred to later as needed.
- *Portability:* A major advantage handheld devices offer over notebook/laptop computers. They can be easily stored in a pocket or hand-carry without requiring much space or adding weight.

- *Multi-function:* Blackberry handheld devices offer a wide variety of other functions such as cellular telephony, GPS, planner, contact manager, document storage, etc.
- *Specialized Applications:* While not currently widespread in the disaster management community, task-specific applications can be developed for Blackberry handheld devices that aid or replace traditional methods such as paper-based forms. These applications can be designed to interface directly with data servers.

Problem Statement and Significance

Although effective disaster management is a critical process, little research effort has been devoted to the study or identification of errors that occur in the EOC data and communication exchange process (McCauley-Bell, Durrani et al. 2008). This is a significant absence, given (1) the degree to which humans are relied upon in disaster management. There are also increasing trends in both the number of disasters reported annually and in the impacts of these disasters. As shown in Figure 1, there is almost an exponential growth in the number of reported disasters during the last century. Similarly, as shown in Figure 2 and Figure 3, the effect of these disasters, in terms of number of people affected and monetary loss, has also increased dramatically.

While several current human error evaluation methods exist, they are largely theoretical-causal or accident investigation models that have their origins in the study of domain-specific process control systems. For example, one recent domain-specific classification system, the Human Factors Analysis and Classification System (HFACS), an accident investigation model proposed by Shappell and Wiegman (2000), targets the aviation industry. However, emergency management presents a set of unique work conditions. Process control domains focus on standard procedures and physical operations, whereas the emergency management domain focuses on communication and information exchange.

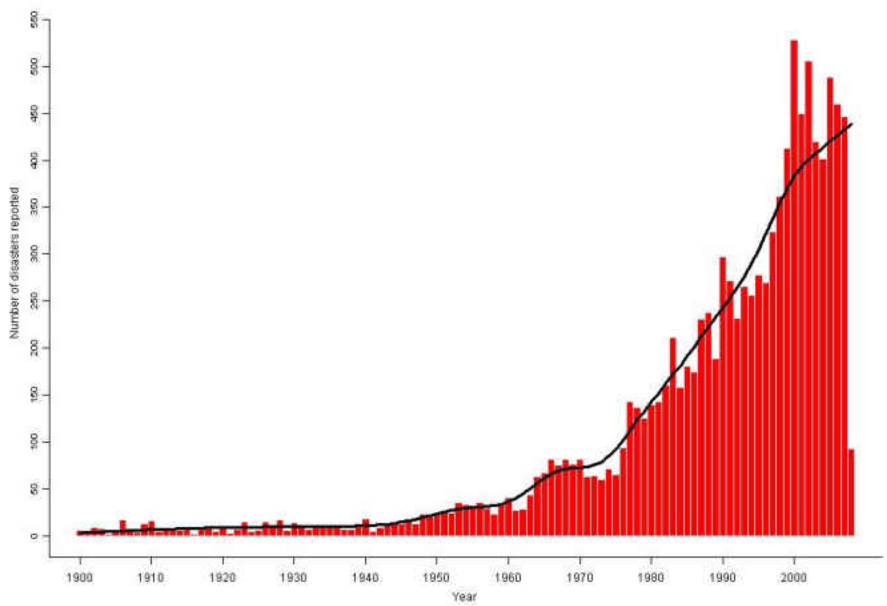


Figure 1: Natural Disasters Reported 1900-June 2008 (EM-DAT 2008).

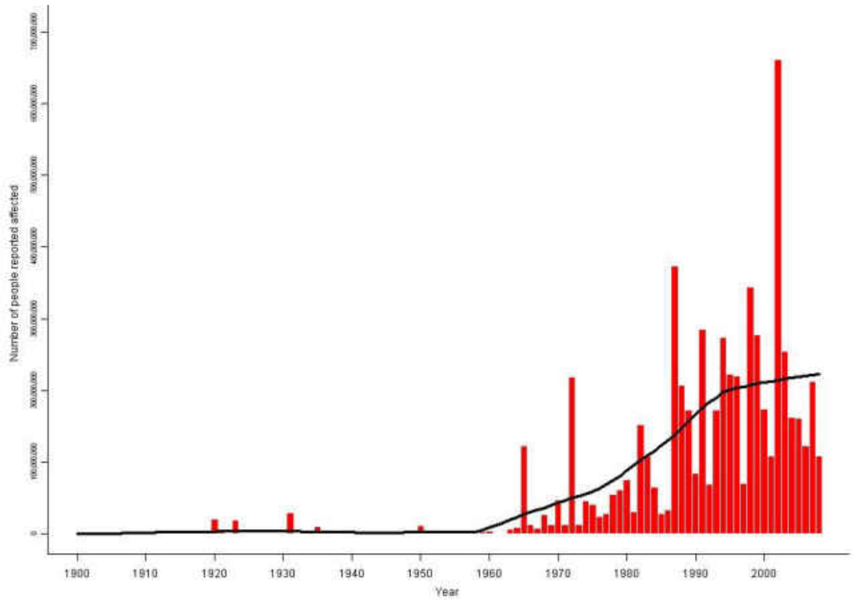


Figure 2: Number of People Reported Affected by Natural Disasters 1900-June 2008 (EM-DAT 2008).

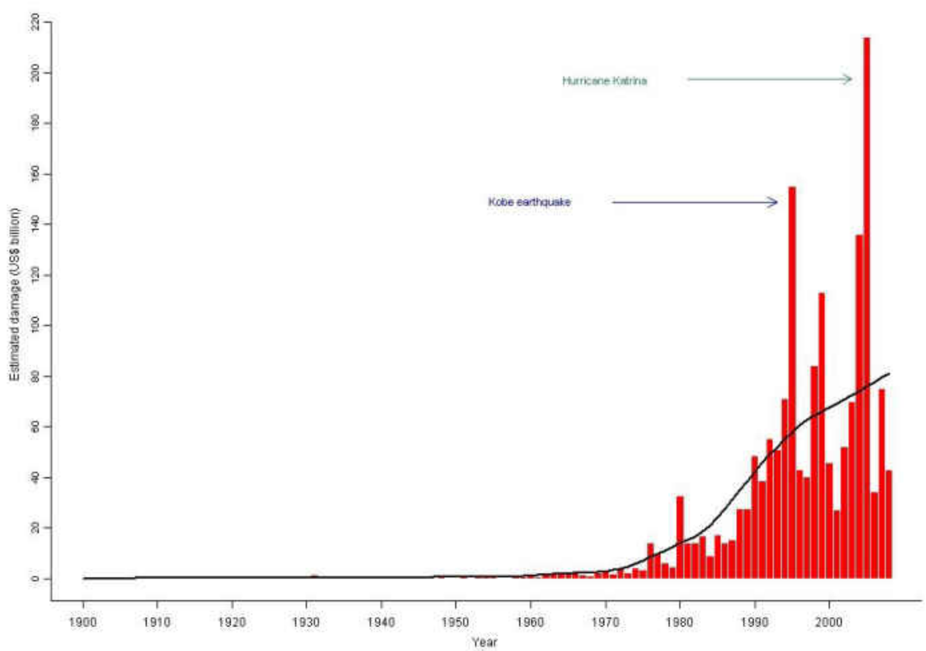


Figure 3: Estimated Damage Caused by Reported Natural Disasters 1900-June 2008 (EM-DAT 2008).

Due to these differences in focus, the need arises to develop an independent framework, one based on factors that affect communication, to assess opportunities for human error in an EOC. To achieve this, an initial effort on part of this research is the development of a framework for EOC human error research in EOC communication exchange processes. This framework and associated work is presented as Chapter 3 of this dissertation.

Similarly, there is a lack of published research in handheld data entry error. The popularity of handheld devices, particularly the Blackberry, is not limited to EOC personnel. There are approximately 21 million Blackberry users in the United States. Blackberry handheld devices account for 41% of the total number of smartphones sold, as seen in Figure 4 (RIM 2008). However, as shown in the Chapter 2, existing human error taxonomies and human reliability models have not accounted for the growth and popularity of handheld messaging devices.

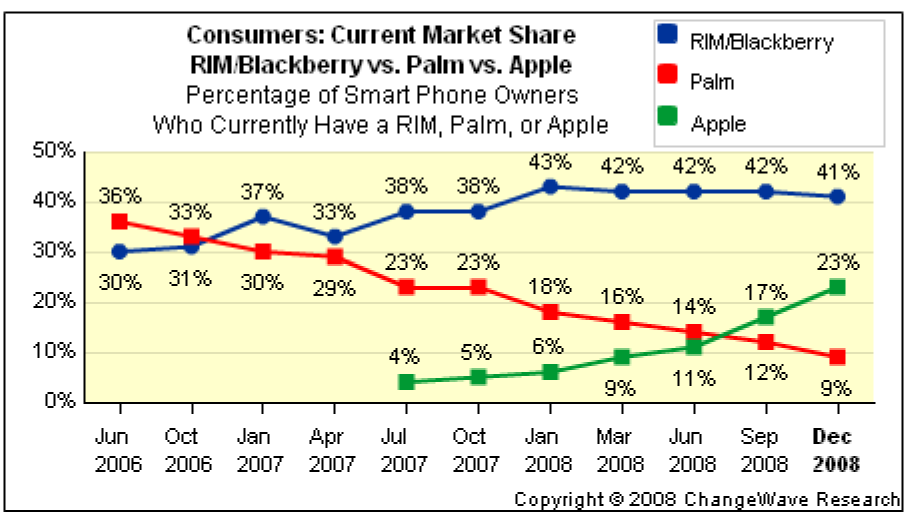


Figure 4: Smartphone Market Shares (Woods and Carton 2009).

Equally, and perhaps more important is that due to the lack of human error research in EOCs, the impact of certain EOC conditions on Blackberry data entry error rates is unknown. During an emergency situation, in which the EOC is in full activation, there is an increased presence of physical, cognitive and emotional stressors (Tufekci and Wallace 1998). From the analysis discussed in Chapter 3, it is found that employees within an EOC are exposed to high levels of heat, noise, communication workload and cognitive workload. This raises several questions, such as: "Do these factors affect the number of data entry errors that occur in an EOC at full activation?" "If they do, then how?" "Which factors or combinations of factors are significant?" Answering these questions will allow the identification and remediation of factors present in EOC operations that induce human error not only in Blackberry data entry tasks, but possibly in all general EOC operations.

Research Gaps and Objectives

From the preceding discussion and the literature review presented in Chapter 2, the following research gaps are identified:

1. The need to identify a research framework for EOCs. This includes identifying the processes and systems with human involvement.

2. Determining if performance shaping factors present in an EOC have a significant impact of human error.

3. Development of an EOC-specific human reliability assessment (HRA) model or modification of an existing model to quantify the risk of human error

4. Implementation techniques to increase human reliability based on the HRA model outcome.

5. Do interactions between performance shaping factors or error causing conditions have a significant effect on human error?

6. Determining if data entry errors occur when using a handheld device and if they can be measured and quantified as a basic human error probability (bHEP) value.

7. Can this bHEP value be influenced by external performance shaping factors present in an EOC?

Research Hypothesis

These research gaps provide many opportunities for research and investigation. However, for this effort, Research Gaps 2, 5, 6 and 7 will be addressed. The hypothesis is that:

> *Human errors occur in handheld device data entry and can be negatively influenced by EOC levels of noise, heat, communication workload and cognitive workload.*

Research Objectives

To address the hypothesis, the research will achieve the following objectives:

1. Define an accurate basic human error probability (bHEP) value of handheld device data entry. This will address Research Gap 6 directly.
2. Determine if certain EOC conditions, namely high heat and noise, high cognitive loading and high communication multi-tasking have a statistically significant effect on Blackberry handheld data entry bHEP. This objective will address Research Gaps 2, 5, and 7.

In order to evaluate the research hypothesis, Research Gap 1 (identifying a research framework for EOCs) is addressed on a preliminary basis in order to further understand the performance shaping factors that are present within an EOC. This preliminary analysis is presented in Chapter 3. Chapter 4 explains the methodology and experimentation conducted to address the two research objectives. The results of the experimentation are presented and discussed in Chapter 5. Finally, Chapter 6 provides a set of final conclusions and a discussion on future work.

CHAPTER TWO: LITERATURE REVIEW

The objective of this chapter is to summarize the existing research and knowledge in the fields of human error, human reliability assessment, disaster management and handheld data entry. Key terms, definitions and terminology are defined and explained. Additionally, specific research and techniques are presented that explain the current state of the field.

Human Error

While there are many definitions of human error, the following definition by Hagen and Mays (1981) seems to be the most comprehensive. They state that human error can be defined as "…a failure on the part of the human to perform a prescribed act (or the performance of a prohibited act) within specified limits of accuracy, sequence, or time" (Hagen and Mays 1981). Hence, it is an out-of-tolerance action/inaction or deviation from the expected norm. It is important to note that the tolerances or limits of acceptable performance are system specific.

Research into human error dates back to early 1947 (Rankin, Hibit et al. 2000). Several taxonomies of human error have been developed since that time. However, even though extensive research has been conducted, the development of a comprehensive human error model remains an open issue (Shappell and Wiegmann 2000). One of the reasons behind this is the lack of an accurately reliable human error database (Kirwan 1997) (Kim 2001).

Kim and Jung (2003) and Kim and Bishu (2006) provide an exhaustive review of current full set HRA taxonomies, in which human error taxonomies are classified classify according to the following schema: phenomenological, cognitive mechanisms, and external environments. Phenomenological taxonomies define human errors in terms of incorrect "human outputs" (Swain 1967). Human errors are classified as either errors of commission or errors of omission. Errors of omission are defined as slips or lapses in performing a task, while errors of commission are defined as erroneous action taken while executing a task.

Taxonomies based on cognitive mechanisms can be considered a deeper level of classification based on the internal cognitive process of error. This includes such processes as: diagnosis, decision-making, hypothesis formation, activation, and choice of tactics. External environment taxonomies classify human errors in terms of the probable external causes of the error rather than the effect of the error. Gertman and Blackman (1984) classify errors in this schema to relate to external indicators such as glare, noise, telephone calls, social pressure, stress, bad equipment design, availability of information, use of controls, and illumination.

Reason's Generic Error Modeling System

No discussion about human error would be complete without an in depth look at Reason's Generic Error Modeling System (GEMS) (Reason 1990). The GEMS structure is derived from Rasmussen's skill-rule-knowledge framework of human performance. (Rasmussen 1986). Behavior at the Skill-Based (SB) Level represents "sensorimotor" actions; automated or highly integrated patterns of performance governed by "patterns of preprogrammed instructions". Behavior at this level can be thought of primarily as a way of dealing with routine activities in familiar situations. SB errors are normally attributed to deviations of force, space or time coordination. Rule-Based (RB) and Knowledge-Based (KB) levels are considered after the individual has become conscious of a specific problem. RB behavior involves the use of stored rules to govern human action. These are normally of the type: "if (state) then (diagnosis/action)". Errors at the RB level are due to the application of the incorrect rule or incorrect recall of the rules and/or subsequent procedures.

KB behavior entails unfamiliar or unique situations that must be dealt with in real time using conscious analytical processes and stored knowledge. Errors at this level are due to limited human cognitive resources and/or incomplete or incorrect knowledge. These three levels of performance correspond to the level of familiarity with the environment or task, with SB being the most familiar and KB being the most unfamiliar.

From Rasmussen's Skill-Rule-Knowledge classification of human performance, Reason defines three basic error types:

- Skill-based slips (and lapses)
- Rule-based mistakes
- Knowledge-based mistakes

Slips and lapses are defined as execution errors or memory failures. Mistakes are defined those actions that may run correctly according to a set plan of action, but the devised plan of action is incorrect. Skill based slips can be considers analogous to the errors of omission and commission as defined by (Swain and Guttman 1983).

SB slips generally precede the detection of a problem while RB and KB mistakes arise during subsequent attempts to find a solution. A defining condition for both RB and KB mistakes is an awareness that a problem exists. The occurrence of a slip is normally associated with a distraction or preoccupation that captures the attention of the individual. However in the case of a mistake, the limited attention focus of the individual will not have deviated far from the problem evaluation. Almost all actions include skill and rule based components, even those relying heavily on KB levels. It is easier to predict SB and RB errors than RB errors. It is expected that total number of SB errors and RB mistakes would be greater than KB mistakes. However, KB mistakes have a greater percentage of occurrences considering the total number of opportunities for error. Reason defines a problem as a "situation that requires a revision of the currently instantiated programme of action." The occurrence of a problem initiates the individual to cycle through the problem solving dynamic as outlined by Reason's GEMS model.

An underlying assumption of GEMS is that individuals are highly biased to finding a preexisting or prepackaged solution using RB associations before elevating to the high level of cognitive effort associated with the resource intensive KB level. Once a problem has been identified, the individual will cycle through pre-established rules in search cues that relate the current problem to rules (and hence solutions) that have been successfully applied to previous problems. The individual moves into the KB level once he/she becomes aware that successive iterations though the rule-based loop has failed to produce an acceptable solution. However, even when in the KB level, the cognitive thought process proceeds on channels analogous to RB-based thinking.

Application of GEMS to an Emergency Operations Center

GEMS is a context free model of erroneous actions that provides a description of the mental cognitive mechanisms behind error occurrences. It is more of a theoretical causal model than a model based on the observable manifestations of error actions. GEMS is useful in defining a basis in evaluating the causes of human error failure. All of the error modes described by the GEMS model would be present in a disaster management situation within an EOC.

As one progresses up the chain of command in an EOC, human behavior progressively becomes increasingly knowledge based. Knowledge based cognitive processes are comparatively more susceptible to misjudgments due the resource limitations of the human cognitive system. Some of the questions raised include: "Are these limitations worsened in an EOC during a disaster situation?" "Does the added effect of information overload and multiple decisions have a negative impact?"

Problem-solving that relies on KB reasoning will take longer than recognition of established routines in rule based cognition. An effective response system is one that can respond quickly to a disaster situation. This indicates that in order to improve disaster management systems focus on reducing much of the KB reasoning and activities to RB behavior is necessary.

Human Reliability Assessment

Reliability is generally defined as "the probability that an item will operate adequately for a specified period of time in its intended application." (Amstadter 1971). Reliability science is well-developed and there are many methods for modeling failure and equipment reliability.

However, these techniques are generally geared towards machines and not humans. As explained below, there are some inherent differences between human and machine which make it, from a reliability standpoint, desirable to treat humans and machines separately.

The following six differences have been adapted from (Franus, Karwowski et al. 1986)

- Different functions of a machine are normally mutually independent, where as interaction effects exist between different human functions and responses.
- The function of a machine has two phases: Inactive and Active. Human activity levels cannot be as clearly demarcated.

- The function of a machine is linear. That is, the end result is a sum of answers of all the signals [or commands] entered, whereas human reactions are the end results of all information received and perceived.
- A machine works at a continuous rate; humans work unevenly.
- A machine can function correctly for extended periods; humans tire and make errors.
- Machine functions perform automatically according to a predefined programs and parameters. However, human reactions can be dynamic and elastic.

Due to these differences, human errors are fundamentally different from machine errors and cannot be treated the same way. The field of human reliability assessment attempts to address these differences and accurately incorporate the human element in system reliability.

Definition of Human Reliability Assessment

Human reliability assessment (HRA) is defined by Kirwan (1996) as "the identification of error opportunities that may affect system risk, the quantification of their likelihoods, and the determination of how to reduce those likelihoods if required". Human reliability assessment models serve the purpose of predicting human error probabilities, identifying the causal factors of human error and providing a framework to mitigate the probability of occurrence.

Several human reliability analysis (HRA) models have been developed since the 1960, and currently, a wide spectrum of human reliability models exist, numbering as high as 50 by some estimates (Thiruvengadachari 2006). HRA was born in the nuclear power industry as part of risk and safety assessment programs and hence a significant proportion of current HRA models are geared towards nuclear power industry. As the importance and awareness of the need for human error analysis in other high consequence industries grew, HRA research has expanded into other industries. Some examples are:

- Nuclear Power plants (Cacciabue, Carpignano et al. 1990; Cacciabue, Carpignano et al. 1991; Cacciabue, Carpignano et al. 1992)
- Aviation industry (Latorella and Prabhu 2000)
- Information Security (Wood and Banks 1993; Mock and Scherrer 2004)
- Chemical and Process Industries (Kirwan 1996)
- Healthcare (Lyons, Adams et al. 2004) (Dhillon 2003)
- Manufacturing Industry (Bubb 2005)

Human reliability assessment techniques can be classified as first generation or second generation depending on the methodology of the HRA techniques and the period in which it is developed (Kim 2001). Kim (2001) defines the following differences between first generation and second generation techniques.

- First generation HRA models are similar to hardware reliability methods. They rely on event trees.
- Human actions are regarded as either success or failure in first generation models, whereas second generation models can adopt partial definitions success and failure.

- First generation HRA models better suited for errors of omission, whereas errors of commission are not addressed as comprehensively as in second generation models.
- Cognitive aspects of error are not given as much importance in first generation techniques as in second generation models.

The focus on first generation models is more on error quantification, whereas, in second generation models, error identification and quantification were both emphasized. However Mosleh and Chang (2004) state that while second generation methods achieve considerable improvement in error identification, they have negligible improvement in error quantification.

Human reliability analysis methods can also be broadly classified into as qualitative or quantitative methods. Qualitative methods are based solely on expert opinion, whereas quantitative methods based on mathematical models and databases of generic human error probabilities. Qualitative techniques normally have the experts directly assess the probabilities of particular scenarios and, hence, tend to be relatively unstructured (Kirwan 1996). The general purpose of these HRA techniques is to reduce the effects of human errors to "tolerable levels" (Kim and Bishu 2006). Quantitative HRA methods form the basis of probabilistic risk assessment (PRA). In PRA event trees or fault trees are used to assign estimates of human reliability to each task element, and traditional probabilistic reliability methods are utilized to calculate overall system/task reliability. These human reliability estimates are calculated on the basis of assigning human error probabilities (HEPs) to task components to determine the probability of failure on an absolute scale (Kim and Bishu 2006).

Figure 5 shows a more detailed mapping of HRA methods that is presented by (Thiruvengadachari 2006). This mapping classifies HRA methods based on how the human errors are modeled.

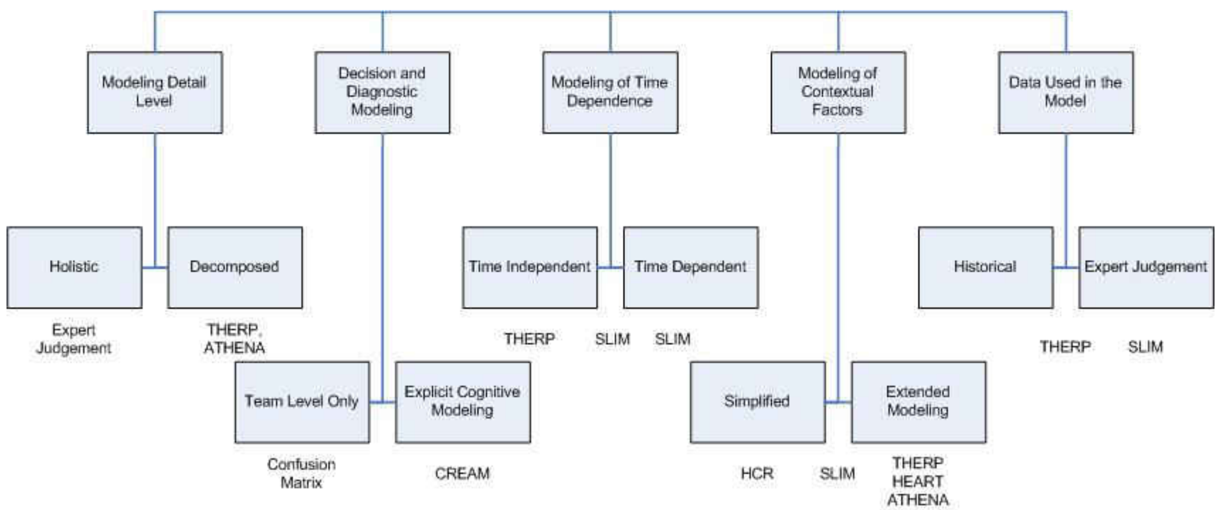


Figure 5: HRA Classification.

Definition of Human Error Probability

Human Error Probability (HEP) is defined as the "probability that an error will occur during the performance of a given task." (Kim and Bishu 2006). Mathematically, it is defined as:

Equation 1: Human Error Probability

$$HEP = \frac{N_e}{N_o}$$

where,

N_e = Number of errors occurred; and

N_o = Number of opportunities for error.

Number of opportunities for error can be difficult to estimate, especially because some the opportunities of error can be covert, unrecorded or not readily observable. Most current methods rely on determining the opportunities of error as a function of task duration. "The central tenet of HRA is that the HEP estimation process must be reasonably accurate, or at least conservative (i.e., tending more towards pessimistic estimate of failure probability rather than optimistic ones" (Kirwan 1996). If the HEP values are not accurate then risk may be under-estimated. This could lead to an inaccurate assessment in which the wrong errors are concluded for reduction.

Gertman & Blackman's Human Reliability & Safety Analysis Data Handbook (1994)

Table 1 lists the HEP tables or datasets available in this handbook, their sources and their applicability to HRA in an EOC (Gertman and Blackman 1994). Specific HEP values for alpha input, alphanumeric input and numeric input are given in Table 2.

Table 1: HEP Values with Applicability in EOCs.

Data Table	Location	Original Source
General Human Failure Rates	Table 5-5, p 125	Williams (1989)
Human Failure Rates for General Task	Table 5-7, p 126	Williams (1989)
Initial screening model of estimated HEPs and EFs for Diagnosis over Time by Control Room Personnel of Abnormal Events Annunciated Closely in Time	Table 5-8, p 128	Swain and Guttman (1983)
Initial screening model of estimated HEPs and EFs for Rule based Actions by Control Room Personnel after Diagnosis of an Abnormal Event	Table 5-9, p 128	Swain and Guttman (1983)
Nominal model of estimated HEPs and EFs for Diagnosis within Time by Control Room Personnel of Abnormal Events Annunciated Closely in Time	Table 5-10, p 128	Swain and Guttman (1983)
Estimated HEP per Item or perceptual unit in preparation of written material	Table 5-12, p 131	Swain and Guttman (1983)
Number of Reactor Operators and Advisors Available to Cope with an Abnormal Event and Their Related Levels of Dependence: Assumptions for PRA	Table 5-11, p 130	Swain and Guttman (1983)
Estimated HEPs Related to Failure of Administrative Control	Table 5-13, p 131	Swain and Guttman (1983)
Estimated Probabilities of Error of Omission per Item of Instruction when Use of Written Procedures is Specified	Table 5-14, p132	Swain and Guttman (1983)
Estimated Probabilities of Errors in Recalling Oral Instruction Items not Written Down	Table 5-15, p 133	Swain and Guttman (1983)
Estimated Probabilities of Errors in Selecting Unannunicated Displays for Quantitative or Qualitative Readings	Table 5-16, p 134	Swain and Guttman (1983)
Estimated HEPs for Errors of commission in reading and recording quantitative information from unannunciated displays	Table 5-17, p 134	Swain and Guttman (1983)
Estimated HEPs for errors of commission in check reading displays	Table 5-18, p 135	Swain and Guttman (1983)
Modifications of Estimated HEPs for Step by Step and Dynamic Processing as a function of stress	Table 5-23, p 139	Swain and Guttman (1983)

Conditional Probabilities of success or failure for task N for the five levels of dependence, given failure on preceding task N-1	Table 5-25, p 141	Swain and Guttman (1983)
Conditional Probabilities of success or failure for task N for the five levels of dependence, given success on preceding task N-1	Table 5-26, p 142	Swain and Guttman (1983)
General Guidelines for estimating Uncertainty Bounds for estimated HEPS	Table 5-27, p 143	Swain and Guttman (1983)
Approximate HEPs for Dependent Tasks given Previous Task Failed	Table 5 -28, p 144	-
Approximate conditional HEPs and their UCBs for dependence levels given failure on the preceding task.	Table 5-29, p 145	Swain and Guttman (1983)
Source categories of action consequence, attitude, response set, and resources and estimates of HEP upper and lower bounds for decision-based errors	Table 5-36, p 150	Gertman et al (1992)
HEP estimates for decision based errors	Table 13-6, p 400 (and associated Table 13-5)	Gertman et al (1992)
Lower bound error rates for skill and rule based behavior	Table 13-9, p 403	-
Lower bound failure rates for knowledge/decisions based errors	Tables 13-10/13-11, p 404-405	-
Data on human failure rates for general tasks	Table 5-7, p126	Williams (1989)

Table 2: General Data Entry Error Rates (Gertman and Blackman 1994)

	5^{th} Percentile Value	Nominal HEP	95^{th} Percentile Value
Alpha Input	4.0×10^{-3}	8.0×10^{-3}	5.0×10^{-2}
Alphanumeric Input	2.0×10^{-3}	5.0×10^{-3}	7.0×10^{-3}
Numeric Input	1.0×10^{-3}	3.0×10^{-3}	8.0×10^{-3}

In addition to the above mentioned data, the following HEP values from A Guide to Practical Human Reliability Assessment by (Kirwan 1994) can also be candidates for utilization in an EOC:

- General rate for errors involving very high stress levels: 0.3
- General error rate for oral communication: 0.03
- General error of omission: 0.01
- Error of omission of an act embedded in a procedure: 0.003

- General error rate for an act performed incorrectly: 0.003
- Error in simple routine operation: 0.001

The empirical data, which are required to carry out a HRA, are collected from a few selected fields of application, normally the armed forces and/or nuclear power plants. In theory, these HEP values can be adapted to other fields of application after a correction adjustment. This adjustment occurs by way of performance shaping factors.

Definition of Performance Shaping / Influencing Factors

Performance shaping factors (PSF's) are defined as: "any factor that influences human behavior." (Swain and Guttman 1983) (Miller and Swain 1987). Performance shaping factors are contextual in nature dependent upon the situation or environment analysis (Kim and Jung 2003). This context factor is referred to by different terms. Some examples are: PSF (performance shaping factor), EPC (error producing condition), CPC (common performance conditions), PIF (performance influencing factors), IF (influencing factor), and PAF (performance affecting factor). The basic function of PSFs is to adapt general HEPs to a specific application.

PSFs can be internal or external in nature. Internal PSF's are factors that are intrinsic characteristics of the human operator. Factors such as level of training, stress levels, experience, motivation level, skill levels, and so forth. External PSFs are dependent on the working environment of the human operator. Demonstrative examples are interface design, noise conditions, illumination, supervision, operating procedures, and workstation layout.

In reviewing the literature on PSFs, a few shortcomings are noted. Logic dictates that there can be interaction effects between distinctive PSFs, however research into PSF interactions lacks development. Also, error taxonomies and PSFs are generally developed for a specific application or industry, with the nuclear power industry as the most common. This may lead to issues of accuracy and applicability especially when using modified techniques which combine error taxonomies and error probabilities from different models.

First Generation HRA Methods

First generation human reliability analysis techniques can be divided into the following three categories (Kim and Bishu 2006):

- Task-based nalysis
- Response time based analysis
- Expert judgment based analysis

Task-based analyses consider the human to be another hardware component of the system and evaluate the human in the same manner as hardware would be evaluated (Kim 2001). The human tasks are cascaded into its lower level sub-tasks, when put together in the correct sequence, complete the task. The probabilities of success of these sub-tasks are then combined to form the overall probability of success for the task. A representative HRA technique would be the Technique for Human Error Rate Prediction (THERP) (Swain and Guttman 1983).

Response time-based analysis methods endeavor to model human error as a function of time after an event has occurred (Kim and Bishu 2006). This differs from tasked based analysis which focuses on errors as a resultant in procedure or process execution. The analysis in response time-based method focuses on how human utilize information obtained from situation and the cognitive process of control behind the response. Time reliability correlations (TRC) are introduced to relate failure probability as a function of human response time interval. Three different types of TRCs are introduced: Skill based performance, rule-based performance, and knowledge-based performance (Hall, Fragola et al. 1982).

However, it is observed that it is difficult to effectively segregate human response clearly into one of the above categories because the cognitive levels are used interchangeably. It is also observed that most TRC-based models, such as human cognitive reliability analysis (HRC), could constitute a task time completion prediction model but did not constitute a model of error (Senders and Moray 1991); (Kantowitz and Fujita 1990). Furthermore, in a study by Kantowiz and Fujita (1990) it is shown that the actual response time curves for different cognitive tasks are almost identical.

Expert judgment-based models rely on subject matter experts to assign probability estimates of human failure. An example is the technique Tecnica Empirica Stima Errori Operatori (TESCO) (Bello 1980). The experts judge and assign error probabilities to five categories: type of activity, stress factor for routine activity, operator quality, activity anxiety factor, and activity ergonomic factor. They are, then, multiplied together to form an overall error probability. Slightly more complex methods are developed later on, but the essence of each method is similar to the method above.

Technique for Human Error Rate Prediction (Swain and Guttman 1983)

The Technique for Human Error Rate Prediction (THERP) is used in the nuclear industry (Swain and Guttman 1983). Validated by Kirwan (1996), it is considered one of the most widely used and popular HRA methods. THERP is based on the basic tenets of machine reliability calculations and works in a similar manner. However, as discussed previously and as pointed out by Kim (2001), humans are unique from machines and, hence, cannot be evaluated in the same manner. One advantage of THERP is that it takes into consideration error correction and recovery factors.

The main steps of the THERP are as follows:

- Decomposition of tasks into task elements.
    - This level of decomposition depends on the assessor.
- Assignment of nominal HEPS to each element
    - Values are selected from the Swain and Guttmann's handbook on human reliability.
- Determination of PSF effects on each element's HEP
    - There are no standard PSF values outlined; they are assigned by the assessor using qualitative analyses and using his or her knowledge of the system.

- Assessment of dependence between different element HEPs
  - A five-level dependence model is explained in the Swain and Guttamann's handbook of human reliability.
- Aggregation of HEPs using an event tree and the multiplicative rule.

Human Error Assessment and Reduction Technique (Williams 1986)

The Human Error Assessment and Reduction Technique (HEART), which a simplified version of THERP, has been predominantly used within the nuclear industry. HEART is validated by Kirwan (1996) to be satisfactory in a nuclear power plant applications. While it follows a similar application methodology as THERP, it does not decompose into as much detail. Instead it classifies the tasks into generic categories. The advantage of HEART over THERP is that is much faster and simpler to apply. However, some of the disadvantages of HEART are that there is no scope for error correction, the final estimate is highly-dependent on the assessor's judgment and it is difficult to quantify the HEP values to other industries (Thiruvengadachari 2006).

The methodology for the HEART technique as summarized by (Williams 1986):

1. The task is classified into one of eight generic categories listed in Table 3.
2. Nominal HEPs are assigned to each task.

Table 3: Heart Nominal HEPs (Williams 1986).

Letter	Generic Task	Nominal HEP (5^{th}-95^{th} percentile)
A	Totally unfamiliar, performed at speed with no real idea of likely consequences.	0.55 (0.35-0.97)
B	Shift or restore system to a new or original state on a single attempt without supervision or procedures.	0.26 (0.14-0.42)
C	Complex task requiring high level of comprehension and skill.	0.16 (0.12-0.28)
D	Fairly simple task performed rapidly or given scant attention.	0.09 (0.06-0.13)
E	Routine, highly-practiced, rapid task involving relatively low level of skill.	0.02 (0.007-0.045)
F	Restore or shift a system to original or new state following procedures with some checking.	0.003 (0.008-0.007)
G	Completely familiar, well-designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly-motivated, highly – trained and experienced person, totally aware of implications of failure, with time to correct potential error, but without the benefit of significant jobs aids.	0.0004 (0.0008-0.009)
H	Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system stage.	0.00002 (0.0-0.0009)

3. Influencing Error Producing Conditions are determined as shown in Table 4. The decision on which EPC to apply is critical to the process and is dependent on the evaluator's assessment.
4. The assessed proportion of effect is calculated for each EPC as shown in Table 5.
5. HEP Calculation, as shown in the last row of Table 5.

Table 4: HEART EPCs (Williams 1986).

Number	Error-producing condition	Nominal amount by which unreliability might change
1	Unfamiliarity with a situation which is potentially important, but which only occurs infrequently, or which is novel	x 17
2	A shortage of time available for error detection and correction	x 11
3	A low signal to noise ratio	x 100
4	A means of suppressing or overriding information or features which is too easily accessible	x 9
5	No means of conveying spatial and functional information to operators in a form which they can readily assimilate	X 9
6	A mismatch between an operator's model of the world and that imagined by a designer	X 8
7	No obvious means of reversing an unintended action	X 8
8	A channel capacity overload, particularly one caused by simultaneous presentation of non- redundant information	X6
9	A need to unlearn a technique and apply one which requires the application of an opposing philosophy	X 6
10	The need to transfer knowledge from task to task without loss	X 5.5
11	Ambiguity in the required performance standards	X 5
12	A mismatch between perceived and real risk	X 4
13	Poor, ambiguous or ill matched system feedback	X 4
14	No clear, direct and timely confirmation of an intended action from the portion of the system over which control is to be exerted	X 4
15	Operator inexperience	X 3
16	An impoverished quality of information conveyed by procedures and person-person interaction	X 3
17	Little or no independent checking or testing of output	X 3
18	A conflict between immediate and long term objectives	X 2.5
19	No diversity of information input for veracity checks	X 2.5
20	A mismatch between the educational-achievement level of an individual and the requirements of the task	X 2
21	An incentive to use other more dangerous procedures	X 2
22	Little opportunity to exercise mind and body outside the immediate confines of a job	X 1.8
23	Unreliable instrumentation	X 1.6
24	A need for absolute judgments which are beyond the capabilities or experience of an operator	X 1.6
25	Unclear allocation of function and responsibility	X 1.6
26	No obvious way to keep track or progress during an activity	X 1.4

Table 5: HEART example calculation (Kirwan 1996).

EPC	Maximum Effect	Assessed portion of affect	Calculation
Inexperience	X 3	0.4	((3-1)0.4) + 1 = 1.8
Unlearn Technique	X 6	1.0	((6-1)1.0)+1 = 6.0
Low Morale	X 1.2	0.6	((1.2-1)0.6) + 1=1.12
HEP = 0.003 x 1.8 x 6.0 x 1.12 = 0.036			

Second Generation HRA Methods

First generation HRA models suffer from several limitations. To improve the quality of HRA models over first generation models, researchers have focused on four different avenues of advancement (Hollangel 1993). These are:

- Enhancement of probabilistic safety assessment event trees.
- Extension of error modes beyond simple binary failure/success classification and errors of omission/commission into cognitive errors.
- Multistage information processing models.
- And consideration of PSFs qualitatively as well as quantitatively.

Cognitive Reliability and Error Assessment Method (Hollangel 1998)

Developed by Hollangel (1998), the Cognitive Reliability and Error Assessment Method (CREAM) is a popular second generation method. CREAM differs from first generation models by taking into account the cognitive profile of the human under assessment and by utilizing common performance conditions (CPC) instead of performance shaping factors. CPCs are applied at an earlier stage of assessment and include the context in which the task is performed.

Figure 6 shows the operational procedure of CREAM. First, the task for assessment is selected and analyzed in detail. Next, the nine CREAM CPCs are evaluated for the task and the results of this analysis indicate the mode in which the operator is functioning. These modes are strategic mode, tactical mode, opportunistic mode and scrambled mode. Strategic mode is when the human under assessment has the greatest amount of control of the situation (as determined by the CPC assessment), whereas scrambled mode is when the human has the lease amount of control over the situation.

In parallel, from the outcomes of the task analysis, the cognitive profile of the operator required to complete the task successfully is also constructed. This profile is then compared to the actual mode evaluated and the probable cognitive failures are identified. Finally, based on these values, the final probability of error is calculated.

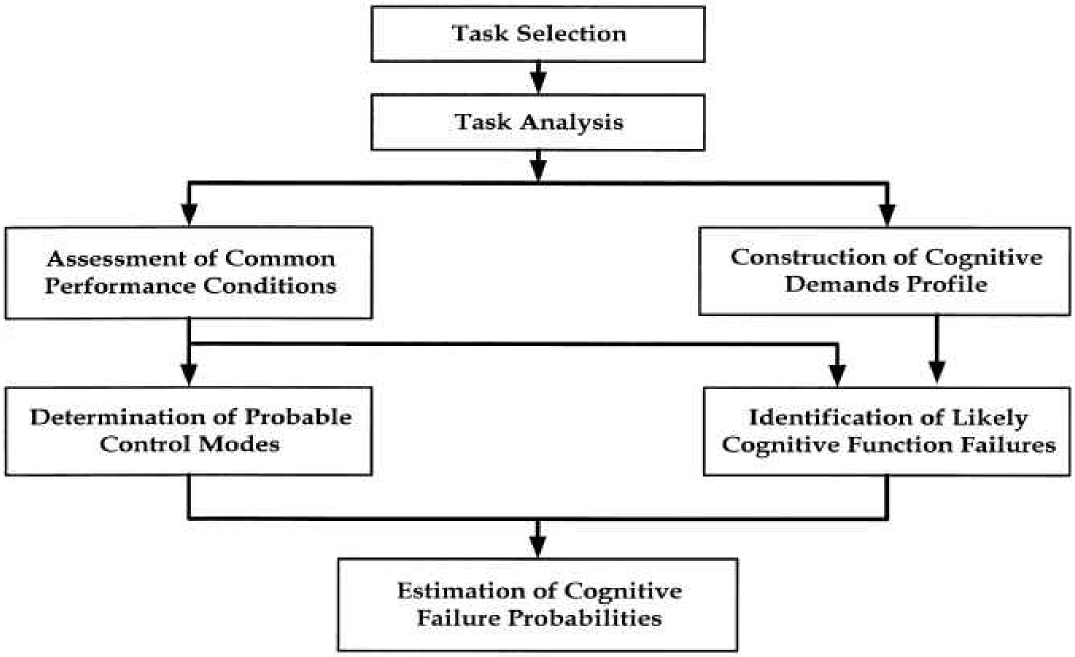


Figure 6: CREAM Methodology (Thiruvengadachari 2006)

List of CREAM Common Performance Conditions

Adequacy of Organization

The adequacy of the organization, its policies and issues (e.g., motivational policies) are assessed and assigned into the four sets of deficient, inefficient, efficient and very efficient. Then, based on the assessor's judgment, one of the above four terms is assigned to this CPC as a whole.

Working Conditions

Conditions such as lighting, noise levels, and other work conditions, including adherence to ergonomic and industrial hygiene standards are assessed using worker surveys and interviews. The working conditions are then assigned as incompatible, compatible or advantageous.

Adequacy of MMI and Operational Support

Human machine interfaces are evaluated in terms of usability. Classifications are inappropriate, tolerable, adequate and supportive.

Availability of Procedures/Plans

The availability of procedures/plans for accomplishing a given task are classified as inappropriate, acceptable or appropriate.

Number of Simultaneous Goals

If the operator performs more than one activity at the same time, it may lead to additional stress on the human, leading to an ultimate reduction in work accuracy and quality. Based on the assessment of number of activities and types of activities, this factor is classified as either more than actual capacity, or matching the current capacity, or less than the actual capacity.

Available Time

The available time to accomplish the task is classified into as either continuously inadequate, or temporarily inadequate, or adequate.

Time of Day

The working hours of the operator are considered as either night or day. Night hours are from midnight till 7 am and from 5 pm till midnight. Day hours are considered as 6 am till 6 pm.

Adequacy of Training and Preparation

Training methods, training time, retraining requirement, and training feedback are considered as either inadequate, or adequate with limited experience, or adequate with high experience.

Crew Collaboration Quality

The quality of crew collaboration, in terms of efforts between operators, supervisors, and so forth are classified as either deficient, or inefficient, or efficient, or very efficient.

A Technique for Human Error Analysis (Cooper, Ramey-Smith et al. 1996)

A Technique for Human Error Analysis was developed using funding from the naval forces by Cooper et al in 1996 and utilizes performance shaping factors (PSF). It is generally considered a good method for retrospective, not predictive analysis (Kim 2001).

ATHEANA utilizes error forcing contexts (EFC), which are assessed on a combination of plant conditions and performance shaping factors by expert opinion. Figure 7 illustrates the iterative process of ATHENA. The starting point of ATHENA is a previously developed probabilistic risk assessment (PRA) model of the system under scrutiny. An accident occurrence or scenario is identified from the PRA model, which is then analyzed for the probable unsafe action committed by a worker. The process is repeated until an acceptable EFC is reached or until the EFC remain unchanged. Once the all final EFCs are identified, probability values are estimated based on the frequency of occurrence of each EFC.

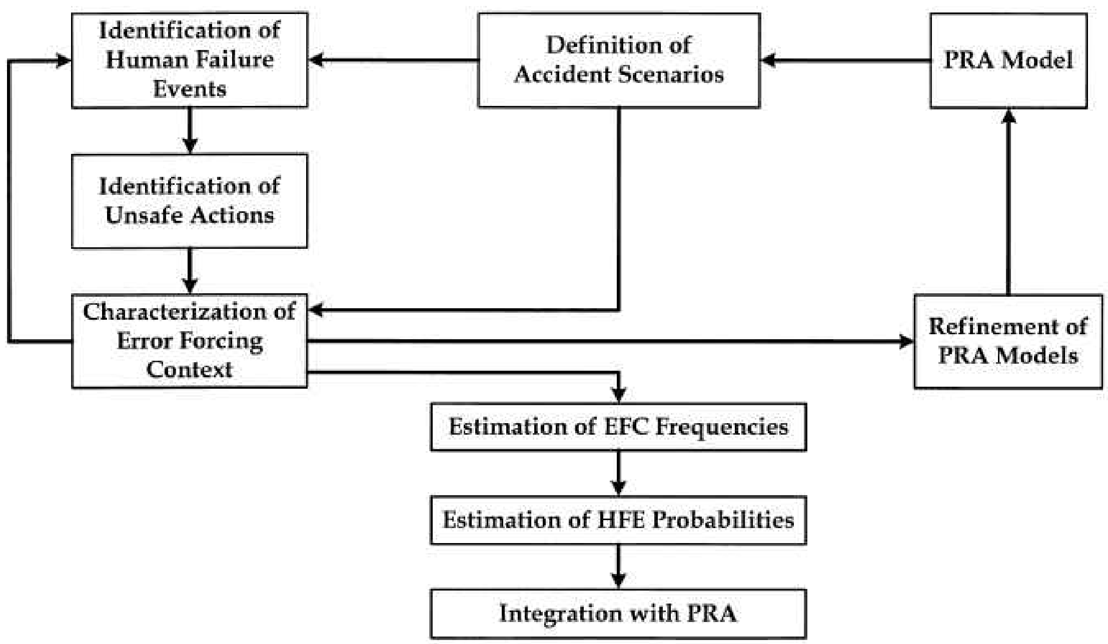


Figure 7: ATHENA Methodology (Thiruvengadachari 2006).

Crisp Limitations of HRA Methods

Human reliability assessment (HRA) has so far been limited to high budget/high risk environments such as nuclear power plants or the armed forces. This is, in part, due to limitations of the HRA techniques themselves. Bezdek (1991) states these limitations as(Bezdek 1981):

- They normally require vast amounts of historic data for previous calculations,
- They are analytical in nature; difficult to apply on situations where failures are subjective in nature and thus performance measures are difficult to define,
- And uncertainties in the system due to human randomness, vagueness and inaccuracy.

The last two limitations cannot be overcome by classic crisp methods. "In order to be able to make significant assertions about the behavior of humanistic systems, it may be necessary to abandon the high standards of rigor and precision that we have become conditioned to expect of our mathematical analyses of well structured mechanistic systems, and become more tolerant of approaches which are approximate in nature." (Karwowski and Mital 1986). Also according to Karwowski & Mital a "...formal treatment of vagueness is an important and necessary step toward more realistic handling of imprecision and uncertainty due to human [uncertainties]." (Karwowski and Mital 1986).

This leads the discussion towards the application of fuzzy set theory to human reliability assessment. Fuzzy set theory allows for interpretation and manipulation, recognition and hence evaluation of vague information and data. In a recent study of fuzzy model application to HRA, Kolarik states that "A fuzzy performance reliability model is a better choice than a crisp performance reliability model in a complex system where performance measures are difficult to measure precisely and/or the relationship between performance measures and failure modes [human error] cannot be represented though analytical [crisp] models." (Kolarik 2004)

Zadeh, the founder of fuzzy set theory, published his first paper on fuzzy sets in 1965. "One of Zadeh's main insights was that mathematics can be used to link language and human intelligence. Many concepts are better defined by words than by mathematics, and fuzzy logic and its expression in fuzzy sets provide a discipline that can construct better models of reality". (McNeill and Thro 1994)

In conventional set theory, an element x either belongs or does not belong to a set **X**. The concept of fuzzy set extends the range of membership values for the function and allows graded membership, usually defined on an interval [0,1]. Hence, an element may belong to a set with a certain degree of membership, not necessarily just zero or one. The "excluded middle" concept is then abandoned, and more flexibility is given in specifying the characteristic function (Bezdek 1981).

Why Fuzzy Set is Suited to Human Reliability Analysis

Uncertainty due to vagueness (or fuzziness) has to do with the complexity of the system under investigation and the human thought and perception processes (Zadeh 1973). The degree of fuzziness refers to the extent of membership of an element to a class or category.

Three types of "fuzziness" are present in systems involving humans. These are:

- Fuzziness stemming from our inability to acquire and process adequate amounts of information about the behavior of a particular subsystem.
- Fuzziness due to vagueness of the relationships between people and their working environments, and complexity of the rules and underlying principles related to such systems.
- And, fuzziness inherent in human thought processes and subjective perceptions of the outside world (Karwowski and Mital 1986).

Fuzzy HRA Modeling Recent Research

While there are many instances of fuzzy set application to different aspects of ergonomics, there is considerable less literature available on its application to human reliability assessment. One example to this particular field is "Human Performance Reliability: on-line assessment using fuzzy logic." by Kolarik, et al. (2004). An overview and analysis of the paper follows.

The paper proposes that "human performance measures/metrics are physical variables/signals that are highly correlated with performance. The critical limits are clearly defined boundaries for the human performance measures/metrics that separate unacceptable performance from acceptable performance." (Kolarik 2004). It goes on to state that humans can experience different types of errors and that these errors are "affected by several performance measures/metrics." (Kolarik 2004). Hence, human reliability can be based on forecasted results of performance measures. A Human Performance Reliability Prediction Model is proposed that will use the above mentioned performance measures as inputs and will use multivariate time series forecasting methodologies to predict human reliability in real time. "Compared to traditional human reliability models, the proposed human performance reliability models differ in several critical respects: (i) each working individual is the subject of modeling; (ii) the model is implemented in real-time, using on-line sensors; (iii) the model is driven by a time-varying function that can accommodate continuously changing situations and/or environments; and (iv) the model can influence operational decisions in real time." (Kolarik 2004). The performance metrics are chosen on basis of the tasks and requirements. These metrics must meet the following criteria:

- "The performance metrics selected must characterize unimportant aspect of human performance for the task under study.
- For each performance metric, there must be a clearly defined criterion (failure mode function) that separates un-acceptable performance from acceptable performance.
- Metrics must be measurable and monitored in real-time." (Kolarik 2004)

According to the paper, there are two basic methods for failure definition: analytical and fuzzy. In the analytical method, "failure is defined in the form of mathematical functions in terms of performance measures, such as $s_i(y_1, y_2, \ldots, y_p)$ where $y_i \ldots y_p$ are performance measures." (Kolarik 2004). On the other hand, fuzzy failure definition is to be used where an explicit critical limit is hard to define. In fuzzy logic, "if-then" rules, based on the experience and/or knowledge of experts are used to compile a fuzzy reliability estimator. "The core of the fuzzy reliability estimator is a linguistic description of conditional reliability under a given input performance state." (Kolarik 2004).

Normalization, the first step, is used to perform scale transformations in which the performance variables are mapped into a common-normalized variable of the same magnitude. The next step is fuzzification, in which the normalized variables are transferred into a fuzzy set. Next, in rule inference, the fuzzy rule data base is interpreted and applied to the fuzzy set. Finally the output is defuzzified into a crisp variable and denormalized into its original magnitude.

The rest of the paper deals with the mathematical application of the crisp and fuzzy algorithm to real time monitoring and control. While this paper provides some valuable insights into the basic methodology of fuzzy application to human reliability prediction, it lacks treatment of the human factors side of human reliability assessment or how PSFs would be interpreted as fuzzy sets. The paper is primarily concerned with the mathematics of real time human reliability assessment.

Overview of Disaster Management

The primary goal of emergency management or disaster management is to ensure the preparation "to respond to, recover from, and mitigate the impact of the many consequences that may be generated by an emergency/disaster situation." (Florida 2004). Most small scale incidents are generally handled on the local, single jurisdiction level by primary first responders. However, disaster may occur with little or no warning, and may escalate more rapidly than the ability of any single local response organization or jurisdiction can manage. The National Incident Management System states that "there are important instances in which successful domestic incident management operations depends on the involvement of multiple jurisdictions, functional agencies, and emergency responder disciplines." (DHS 2004).

The levels of disasters are defined as follows:

- Minor Disaster: Any disaster that is likely to be within the response capabilities of local government and results in only minimal need for state or federal assistance.
- Major Disaster: Any disaster that will likely exceed local capabilities and require a broad range of state and federal assistance. The Federal Emergency Management Agency will be notified and potential federal assistance will be predominantly recovery-oriented.
- Catastrophic Disaster: Any disaster that will require massive state and federal assistance, including immediate military involvement. Federal assistance will involve response as well as recovery needs (Florida 2004).

The Federal Government developed the National Incident Management System (NIMS) framework in 2004 (DHS 2004). NIMS outlines a set of "doctrine, concepts, principles, terminology and organizational processes to enable effective, efficient and collaborative incident management at all levels." (DHS 2004). NIMS does not provide operational or resource allocation plans, but instead provides a general framework of what an operational plan should consist. Each local government is responsible for developing their own emergency plan, commonly referred to as a Comprehensive Emergency Management Plan, or CEMP.

One of the concepts outlined in NIMS a unified command structure named Incident Command Structure (ICS). "Unified Command overcomes much of the inefficiency and duplication of effort that can occur when agencies from different functional and geographic jurisdictions, or agencies at different levels of government, operate without a common system or organizational framework." (DHS 2004). Some of the advantages of using unified command are as follows:

- A single set of objectives is developed for the entire incident.
- A collective approach is used to develop strategies to achieve objectives.
- Information flow and coordination is improved between agencies involved in the incident
- All agencies with responsibility for the incident have an understanding of joint priorities and restrictions.
- The combined efforts of all agencies are optimized as they perform their respective assignments under a single Incident Action Plan.

Incident Command Structure

According to NIMS "the incident command organizational structure (ICS) develops in a top-down, modular fashion that is based on the size and complexity of the incident, as well as the specifics of the hazard environment created by the incident." (DHS 2004). When needed, separate functional elements can be established, each of which may be further subdivided to enhance internal organizational management and external coordination. The ICS structure is dynamic and expands from the top down as complexity in the emergency response increase and functional responsibilities are delegated. An example of a typical ICS command structure is shown in Figure 8.

The ICS organization has five major functions: Command, Operations, Planning, Logistics, and Finance and Administration (DHS 2004).

- <u>Command:</u> Consists of the incident commanding officer and his/her support staff. They provide a central, single top level decision making function.
- <u>Operations:</u> Responsible for all activities focused on reduction of the immediate hazard, saving lives and property, establishing situational control and restoration of normal operations.
- <u>Planning:</u> Collects, evaluates and disseminates incident situation information and intelligence to incident management personnel, prepares status reports, displays situation information, maintains status of resources assigned.

- Logistics: Responsible for all support requirements needed to facilitate effective and efficient incident management, including ordering resources from off-incident locations. It also provides facilities, transportation, supplies, equipment maintenance and fuel, food services, communications and information technology support, and emergency responder medical services.
- Finance/Administration: This function is established when the agency involved in incident management activities requires Financial and other administrative support services.

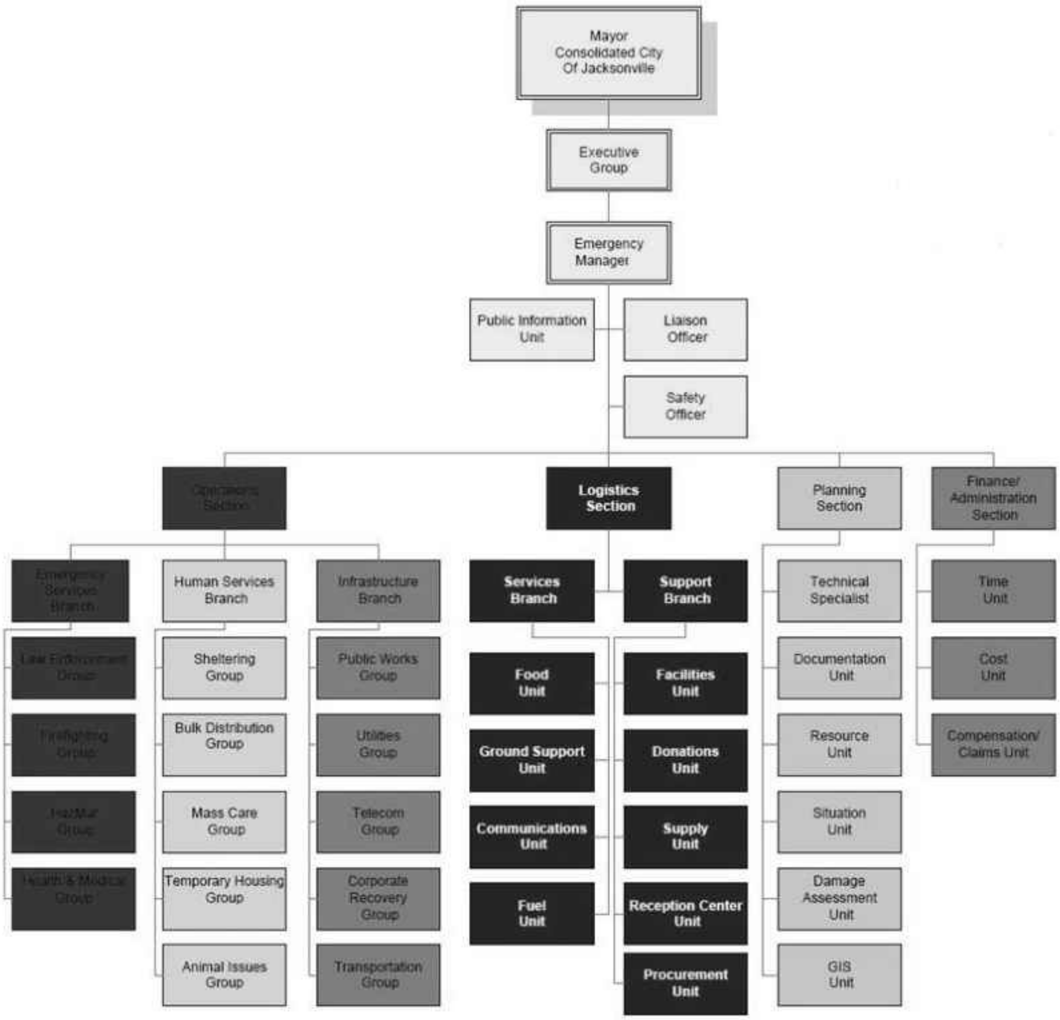


Figure 8: ICS command structure (Jacksonville 2007).

Emergency Operations Center

The Emergency Operations Center is the facility that is used to coordinate a response to any major emergency or disaster situation. An EOC is the physical location at which the coordination of information and resources to support incident management activities normally takes place. An Incident Command Post (ICP) is different from an EOC. An ICP is located at or in the immediate vicinity of an incident site. The function of an ICP is primarily focused on tactical on-scene response functions. EOCs are more central facilities; at a strategic level of organization. EOCs can be internally organized dependent on by major functional discipline (e.g., ICS structure), by jurisdiction or by some other methodology. Florida Emergency Operations Centers operate at different levels of activation. These are (Florida 2004):

- Level III - Monitoring Activation: Level III is typically a monitoring phase.
- Level II - Partial Activation: This is limited agency activation. All primary support functions are notified as defined by the local CEMP.
- Level I – Full-Scale Activation: This is a full-scale activation with 24-hour staffing of the EOC. All primary and support agencies under the local CEMP are notified.

The Emergency Operations Center, when notified of the possibility of a disaster/emergency situation, will be activated to Level III monitoring the situation. This could be the notification of a tropical storm. This activation level allows for the monitoring of the situation and possible warning declarations. When an emergency situation occurs that does not require the full response of the EOC, the activation will be Level II and only the staff members needed to resolve the emergency situation will be called up to respond. This activation level represents an emergency situation such as a severe car crash on a major roadway or a wildfire that threatens only a small number of the citizens in Orange County. Upon notification that a disaster/emergency situation is imminent, the EOC will be fully-activated (Level I), all staff members and support agency are to report to duty. This level of activation is for a major hurricane on the way or another such imminent disaster.

Timeline of Disaster Management

When an emergency/disaster event is detected or is imminent, the first 72 hours before and after the event constitutes the critical timeline that defines an effective response operation. To improve the effectiveness of the response, the operational objectives may be initiated along a critical timeline in 24-hour intervals to ensure an effective response operation. The following timeline is adapted from the State of Florida Comprehensive Emergency Management Plan (FL-CEMP) (Florida 2004). The agency or person responsible is highlighted in brackets with each activity.

72 hours to 48 hours Before Event Impact

- A functional 24-hour State Warning Point is issued to alert and notify all appropriate local, state and/or federal officials and staff of an emergency/disaster situation.

- The activation of a State public information system to ensure the appropriate medial releases, live media broadcasts, and activation of the Florida Emergency Information Line.

- Ensure the activation and operational readiness of the State Emergency Operations Center. The EOC is activated fully (Level I) or partially (Level II) depending on the event and may be activated.

- The activation of an event monitoring and reporting process, i.e., technical data, situation, and chronology of events reports, weather tracking, etc.

48 hours to 24 hours Before Event Impact

- The activation of a protective actions planning process to develop Incident Action plans to guide response operations.

- The activation of the process to determine the need to request a federal emergency declaration.

- The activation of a process to ensure the deployment of the appropriate technical liaisons in the impact area, i.e., hurricanes, forest fires, terrorist events, repatriation, etc.

- The activation of a communication system that will effectively deploy necessary communication systems and initiate amateur radio operations at the state EOC.

- The activation, if necessary, of the Intergovernmental Relations Team to ensure that timely information is being shared with local elected, State Legislative, and United States Congressional officials.

- The activation of a conference call process to share information between the appropriate state, county, multi-state, and federal agencies and organizations to address protective action measures.

- The activation of an effective and efficient mutual aid process to augment local, state, and federal resources.

- The activation of a process to monitor protective action measures taken by the counties such as evacuation and sheltering.

- The activation of an efficient and effective field operations response process.

- The activation of an effective and efficient impact assessment process to determine disaster impact to infrastructure, emergency services, human needs, etc.

24 hours to Event Impact

- The activation, if applicable, of an Impact-Area Tour process for the Governor and other appropriate local, state, and federal officials.

- The activation of a process to assist local governments with re-entry activities.

- The activation of the Preliminary Damage Assessment process with local, State, and federal officials.

- The activation of the process, if applicable, to request a federal Presidential Disaster Declaration.

Event Impact to 24 hours After Event Impact

- Initiate process to re-establish communications and determine disaster impact (i.e., life-threatening conditions, debris clearance, transportation, security) with impacted areas.

24 hours to 48 hours After Event Impact

- The activation of the process for Response/ Recovery transition including EOC return to monitoring Level III.

As can be seen from the timeline above, a high level of coordination and communication between various agencies is required. It would be prudent to further discuss the importance communication and information management in disaster management.

Communication and Information Management in Disaster Management

Effective information exchange during a disaster event is vital to ensure the coordination of response efforts, manage the allocation of resources and prevent further harm from occurring. An accurate, reliable and consistently available information exchange system is required to deliver secure and relevant information when and where it is needed. “The faster emergency responders are able to collect, analyze, disseminate and act on key information, the more effective and timely will be their response, the better needs will be met and the greater the benefit to the affected populations.” (Walle and Turoff 2007).

In an EOC the majority of communication is verbal. Although written computer-based systems have been implemented, they are currently used more for record keeping than for real-time communication (Interview with Marion County and Orange Country officials). Verbal communication challenges have been found to be a critical component in a variety of industries (Gibson, Megaw et al. 2005). Past research has in particular focused on communication errors and their subsequent contribution to incidents in the air and rail industries. For example it was found that 92% of railway maintenance incidents were directly attributed to communication errors (Murphy 2001).

Handheld Data Entry

Researchers have found that handheld devices offer a numerous advantages over paper based data collection methods. These advantages include reduced effort, transcription errors, time and cost (Saleh, Radosevich et al. 2002), (Shaw and May 2004). Some clinical cases studies have shown that using handheld computers can save nurses close to two hours a day (Shelby-James, Abernethy et al. 2007). However, they have also shown that data entry rates using handheld devices can infringe on unacceptable levels. (Shelby-James, Abernethy et al. 2007) found in a study that error rates in handheld computers used for medical data entry were as high as 67.5 errors per 1000 fields as compared to the accepted error rate of 10 per 10,000 fields for paper-based double data entry. They also found that error rates were highest in those fields containing a default value.

The most commonly researched aspect of handheld devices is usability, especially in terms of how well individuals are able to perform tasks using the various types of current mobile device interfaces. (Silfverberg, MacKenzie et al. 2000) created models to predict the data entry rate on numeric keypads using different entry methods. Multi-press, two-key, and linguistic-based (predictive text entry) keypad text entry methods were researched. It was found that expert users could achieve rates of up to 27 words per minute using one handed thumb or two index finger input with the multi-press and two-key methods. The predicted speeds increased to 46 wpm for expert users using two handed (index fingers) combined with the linguistic based, predictive text entry method.

(Mizobuchi, Mori et al. 2002) found that data entry speed and accuracy of stylus based text entry is similar to data entry using a four-way navigation key input. Using squares on a grid as targets, the sizes of target were varied to examine the speed and accuracy of target selection. They found that the subjects could select targets with a pen as accurately as with a key at a target width of 5mm. This figure prescribes a minimum soft keyboard button size for stylus input.

A similar study to investigate the effect of key size on handheld data entry while walking and standing was conducted. The research also focused on determining if data entry increased in difficulty due to the (possible) increased mental workload of walking. The researchers found that there was no significant increase n data entry difficulty; however, the test subjects indicated a decreased rate of walking and data entry for every test case. From this is can be assumed that walking and text entry are largely independent, except for a “fixed cost” reflected in the slower rates of walking and texting (Mizobuchi, Chignell et al. 2005).

Summary

The majority of research found on handheld device data entry is for comparison of different input types, including handwriting recognition pen input, soft (virtual) keyboards, numeric keypads and minute keyboards. Even within these, research is focused mostly on improving user experience/satisfaction levels. Very little published research was found on determining error rates and external error causing conditions as they relate to handheld data entry, specifically in emergency operations centers or other related high stress environments. However, while current work in this field does not directly relate to this research, it still provides valuable insight and knowledge. Additionally, the following observations are made from the literature review.

- Existing HRA methods do not incorporate handheld devices in their evaluation. Human error probability values have not been found for data entry in handheld devices, however, generalized values for alphanumeric input do exist.
- Interaction effects between PSFs are generally not considered.
- Published research related to human factors evaluation in disaster management is largely lacking. Of particular interest to study is determining what performance shaping factors/error causing conditions are present in EOCs and how they affect human performance under those conditions.

Table 6 provides a matrix that relates the sources and authors that have been discussed in this chapter to the literature research topics.

Table 6: Source-Research Matrix

Source	Disaster Management	Human Error	Human Reliability Assessment	Communication Error Modeling/Handheld Data Entry
Amstadter			x	
Bello			x	
Bezdek	x			x
Bubb		x	x	
Cacciabue		x	x	
Carver	x	x		
Cooper			x	
Dhillion			x	
DHS-NIMS	x			
FL-CEMP	x			
Franus			x	
Fromkin				x
Gertman			x	
Gibson		x		
Hagen			x	
Hall			x	
Hollangel			x	
C.O.Jacksonville	x			
Kantowitz		x	x	
Karwowski			x	
Kim, B.J.		x		
Kim, I.S.			x	
Kim, J.W.	x	x		
Kirwan			x	
Kolarik			x	
Latorella		x		
Lyons			x	
MacKenzie				x
Meister			x	
Miller		x	x	
Mizobuchi				x
Mock			x	
Mosleh			x	
Murphy				x
Park			x	
Rankin			x	
Reason		x	x	
Saleh				x
Senders		x		
Shappell			x	
Silfverberg				x
Swain		x	x	
Thiruveng.		x	x	
Tufecki	x			x
Walle	x			x
Williams			x	
Wood		x		

CHAPTER THREE: PRELIMINARY ANALYSIS

Following the literature review and preceding the experimental investigations, work was conducted on further understanding the emergency management and EOC processes. This work is presented as a separate chapter because it does not fall into the main scope and focus of the dissertation. However, these studies provide important background information on which the dissertation objectives and experimental procedures were derived, and as such should be discussed. This chapter presents the research process that was followed and the relevant knowledge that was obtained.

Preliminary Analysis Activities

The following activities were conducted:

- Review of emergency management documentation including the Comprehensive Emergency Management plans of the State of Florida, Orange County Florida, Lake County Florida, and the National Incident Management System. State of Florida, Orange County and Lake County are chosen to represent emergency management entities of various size, resources and complexity.
- Site visits to the Orange County and Seminole County EOCs.
- Informal discussions with subject matter experts from the following Florida counties and the State of Florida.
    - Glades County
    - Hardee County

    - Marion County
    - DeSoto County
    - Duval County
    - Collier County
    - Gulf County
    - Hernando County
    - Walton County
    - Franklin County
    - Okeechobee County
    - Orange County
    - Seminole County
- Interaction with emergency management personnel at the annual Florida Governor's Hurricane Conference.
- Attendance at the following training sessions for emergency management operations at the Florida Governor's Hurricane Conference, Orange County EOC and Orlando Fire Department.
    - Communications Unit Leader Training (24 hours)
    - Emergency Operations Center Management & Operation Training (24 hours)
    - Community Emergency Response Team Training (32 hours)
    - Florida First Responders Course (128 hours)

- Observational analysis of full activation (Level III) training exercises at the State of Florida EOC and Orange County EOC. Pictures of EOCs are presented as Figure 9, Figure 10, and Figure 11.

Figure 9: Orange County EOC.

Figure 10: State of Florida EOC.

Figure 11: Seminole County EOC.

<u>EOC Communication Channels</u>

Communication and information exchange are the central objectives of the EOC. Information is received from impact assessment teams, media outlets, 911 centers, state or county personnel, community information lines and many other sources. This information is then analyzed, recorded, and appropriate actions are initiated. EOC communications affect operations not only within the EOC, but operations at the state level. To better understand these relationships, a concept map of the communication between entities typically involved with a large EOC during emergency activation is developed. Figure 12 describes the flow of communication to and from entities that share information with the EOC.

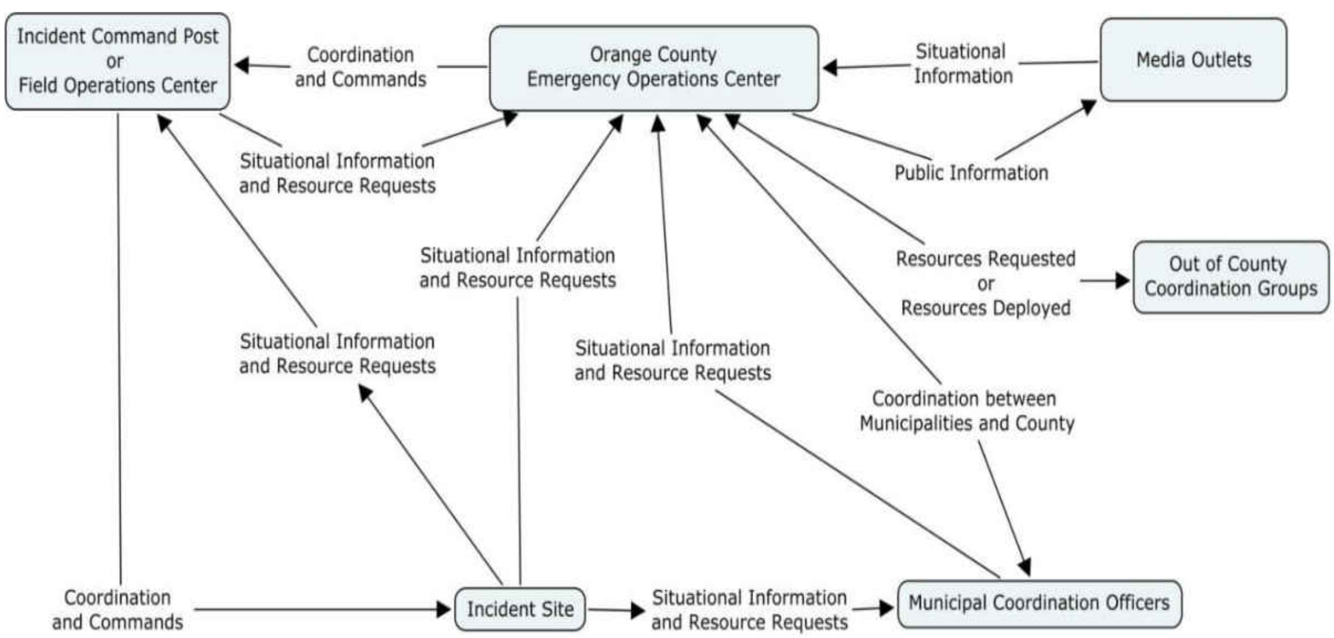


Figure 12: EOC Communication.

This structure presents a generic model that represents external EOC communication in a large Florida County. However, the activation or scale of these entities will vary depending on the size of the incident, the size of the community affected, and the number of responders and other personnel activated. Some of these components may be combined or perhaps even further divided.

EOC Error Framework

Based on the information flow in this concept map, communication tasks within an EOC might be broadly categorized as data entry, data perception, or data processing. Data in this case describe any form of information such as situational reports, execution orders, resource requests, weather updates, and so forth. Data entry and data perception tasks are further associated with some form of communication technology. The technology may be computers, including desktops and laptops, touch-screen devices such as personal data assistants (PDA), handheld keyboard devices, such as RIM Blackberry or Sprint Treo smartphones, paper forms, including those transmitted by fax and verbal communication, either in person or via telephone (satellite, landline or cellular) shortwave radio or 2 way radio. The difference between data entry and perception is a function of directionality. Data following an outbound vector from a station is considered as data entry, i.e., the individual is entering data into the system, whereas data perception is an inbound vector in which the observer is perceiving data from the system. The terms entry and perception are specifically chosen as they describe measurable processes that can be evaluated to test for accuracy.

After data have been perceived by an individual, a decision regarding what needs to be done with that data or what needs to be done on basis of that data is made. The incoming data could require further approval or it could have been misrouted. In either case, the decision would be made to transfer the data to another individual. Frequently, incoming messages are requests for resources or support, or they can be situation reports, on the basis of which individual would deploy resources to a locality. These resources could be anything from personnel, such as law enforcement officers, to food supplies to support hardware, such as communication equipment. Sometimes, the required quantity of resources is not available, in which case the individual would make the decision to request more resources. Similarly, incoming information might not provide the individual with all the information required; in this instance, the decision would be made to search for or to request more information.

A multitude of EOC tasks are reduced to 15 generalized combinations, as shown in Figure 13 under the heading "Tasks". These 15 combinations have been independently validated by subject matter experts and thus can be applied to describe any data related process within an EOC. The theoretical basis of this framework is rooted in Reason's Generic Error Modeling System (1990) and the modeling of the human error as portrayed by Gertman and Blackman (1994).

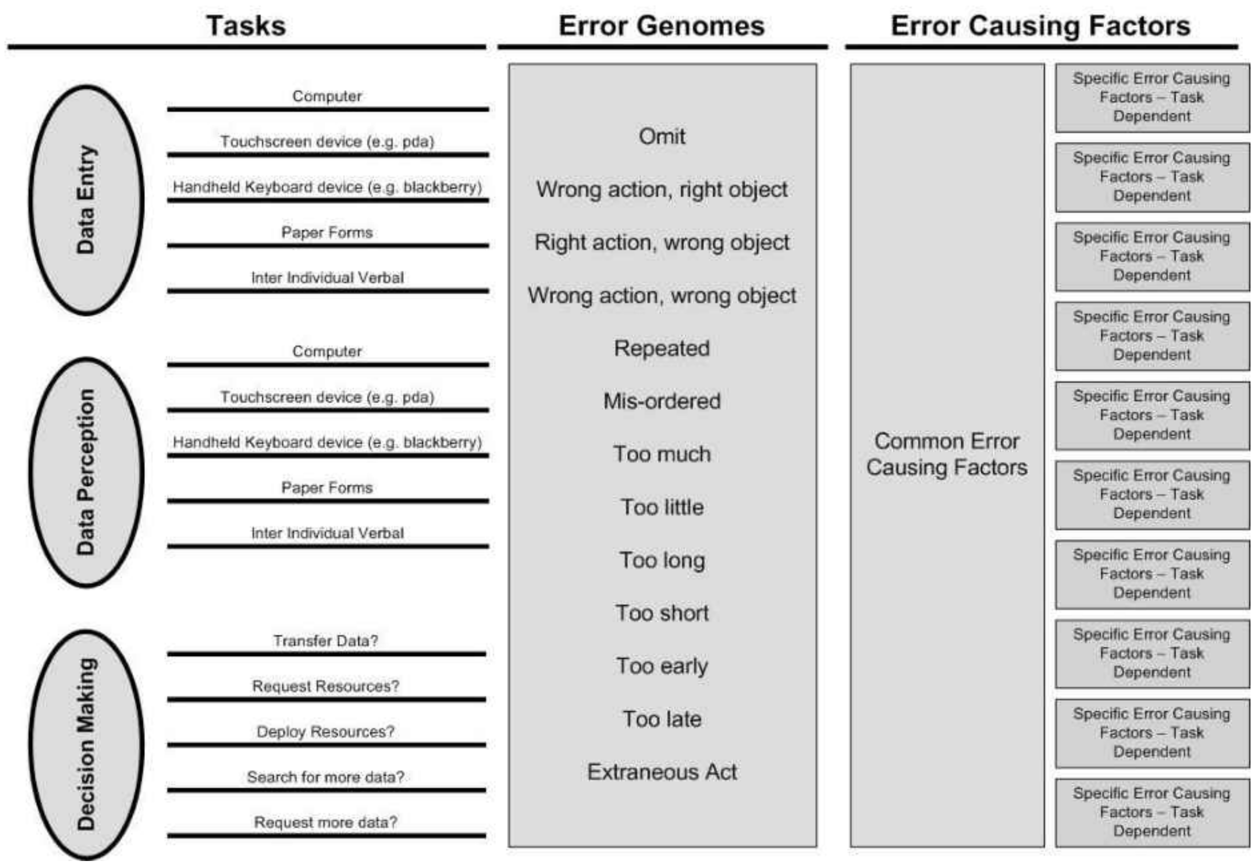


Figure 13: EOC Error Framework.

As also shown in Figure 13, error genomes, based on external the error modes of Shorrock and Kirwan (2002) and on the recent work of Gibson, et al. (2006) have been identified for each combination. Combined with the generalized task descriptions, these error genomes can be used to fully describe human errors in an EOC environment. An example is: data entry – blackberry text – omit, i.e. that one or more characters are omitted when entering data into a blackberry text message.

Having developed a generic categorization method, the next stage in this process is to determine the causes of human error within the system. This approach presupposes that human errors are due to system induced conditions. When researching the causes for human error in an EOC it was noted that the certain factors, such as noise or heat which affected human performance regardless of the specific task performed while other factors, such as the software interface that influenced only a specific task or subtask. From this observation, as shown in Figure 13 it is possible to categorize all error causing conditions as either “common”, those that affect all tasks or “specific”, and those that only affect one particular subtask or technology.

Observed Common EOC Conditions

During the site visits and SME discussions it was discovered that certain commonly occurring EOC conditions could be causal to increased human error probability. Personnel within an EOC are exposed to increased room temperature, noise levels, communication workload and cognitive loading. These factors could be attributed to increasing the likelihood of human error. Room temperatures would increase throughout the activation period as the latent heat from human bodies and computer equipment would accumulate within the enclosed space of an EOC. Additionally this condition would often be exacerbated by underpowered air conditioning units and power outages. It was noted that EOC room temperatures reached an excess of 95^{o} after a few hours of full activation.

Similarly, noise was another factor that was constantly present throughout the EOC. EOCs at full activation can be staffed by several dozens to a few hundred personnel during full activation, most of who are engaged in communication and information exchange. While there are periods of lull and relative quiet, the noise imparted by telephone bells, multiple simultaneous conversations, announcements, and other office noises, such as typing, photocopiers and such is fairly constant, with the volume, complexity and intensity of the noise varying over time.

EOC personnel are exposed to multiple simultaneous communication channels. An example is responding to an individual (verbal face-to face communication) while transcribing written data into a computer. Concurrent communications are short term and are normally limited to two simultaneous communication channels. If an eventuality arose arises in which the individual is exposed to a third channel or to an extended second channel, then he or she will terminate or temporarily suspend one of the previous channels. The exposure to this factor is characterized as intermittent yet highly repetitive, with observed exposure duration lasting approximately 10 seconds and repeating every few minutes. Similar to communication loading, EOC personnel are exposed to repetitive and intermittent cognitive loading in which decisions regarding their next actions are made, as well as well deciding which individuals or agencies need to contacted or informed.

CHAPTER FOUR: METHODOLOGY

The dissertation objectives listed in chapter one will be accomplished through a three factor between subjects randomized full factorial experiment. The experimentation consists of two parts. In the first part of the experiment, each test volunteer is asked to copy text from a computer monitor into the test instrument, a Blackberry Curve 8330, shown in Figure 14. This portion of the test will be utilized to determine the basic human error probability value (BHEP) for handheld data entry error. In the second portion of the experiment, each volunteer is exposed to a combination of the three test factors. The test responses from this part of the experimentation are used in determining the individual and interaction affects of the test factors.

Figure 14: Blackberry Curve 8330.

Factors

The three factors tested are ambient conditions, communication workload, and cognitive loading. Each factor is assigned two levels: "low" and "high". The factors' high levels are designed to mimic the conditions prevalent in an emergency operations center during full activation. Table 7 summaries the factors and factor definitions.

The factors to be tested are as follows:

- Environmental factors as influenced by ambient noise and temperature.
- Communication workload as influenced by the number of concurrent incoming communication channels
- Decision alternative as influenced by the number of active simultaneous communication paths

Table 7: Factor Definitions

Factor Name	Description	Low Level Conditions	High Level Conditions	Loading Duration
Environmental Conditions	Noise	No noise	Multiple conversations/office noises continuously varying between 80-90 dBa	Continuous with varying intensity
	Temperature	Normal Room Temperature (approx 75^{o})	95-100^{o}	Continuous
Communication Workload	Comm. Channels	One Channel	Two Channels	Intermittent, 10 seconds every minute
Cognitive Loading	Number of Alternatives Available	One Alternative	Seven Alternatives	Intermittent
	Secondary Task	None	10 seconds to solve a math problem in each minute	Intermittent, 10 seconds every minute

Dependent Variable

The dependent, measured variables are the number of *data entry errors* that occur. A data entry error occurs when one of the following conditions is met.

- Omitting a character
- Incorrectly entered character
- Unnecessary characters entered

At this time it would be prudent to discuss some of the assumptions made insofar. These are as follows.

Assumptions

- Self correcting behavior is still considered an error because the error itself still occurred.
- Individual errors are independent with no carry over effects. Error x at time t does not influence or cause error $x+1$ at time $t+\Delta t$.
- All errors are of equal importance.
- Each communication channel is the same in terms of mental commitment.
- A space is a character and constitutes an opportunity for error.

Experimental Design

A three factor between subjects randomized full factorial experiment is conducted. There are a total of eight test groups, with each group consisting of 11 volunteers, as shown in Figure 15.

Test groups are only to determine which set of conditions the volunteer will be exposed to. Each volunteer is tested individually.

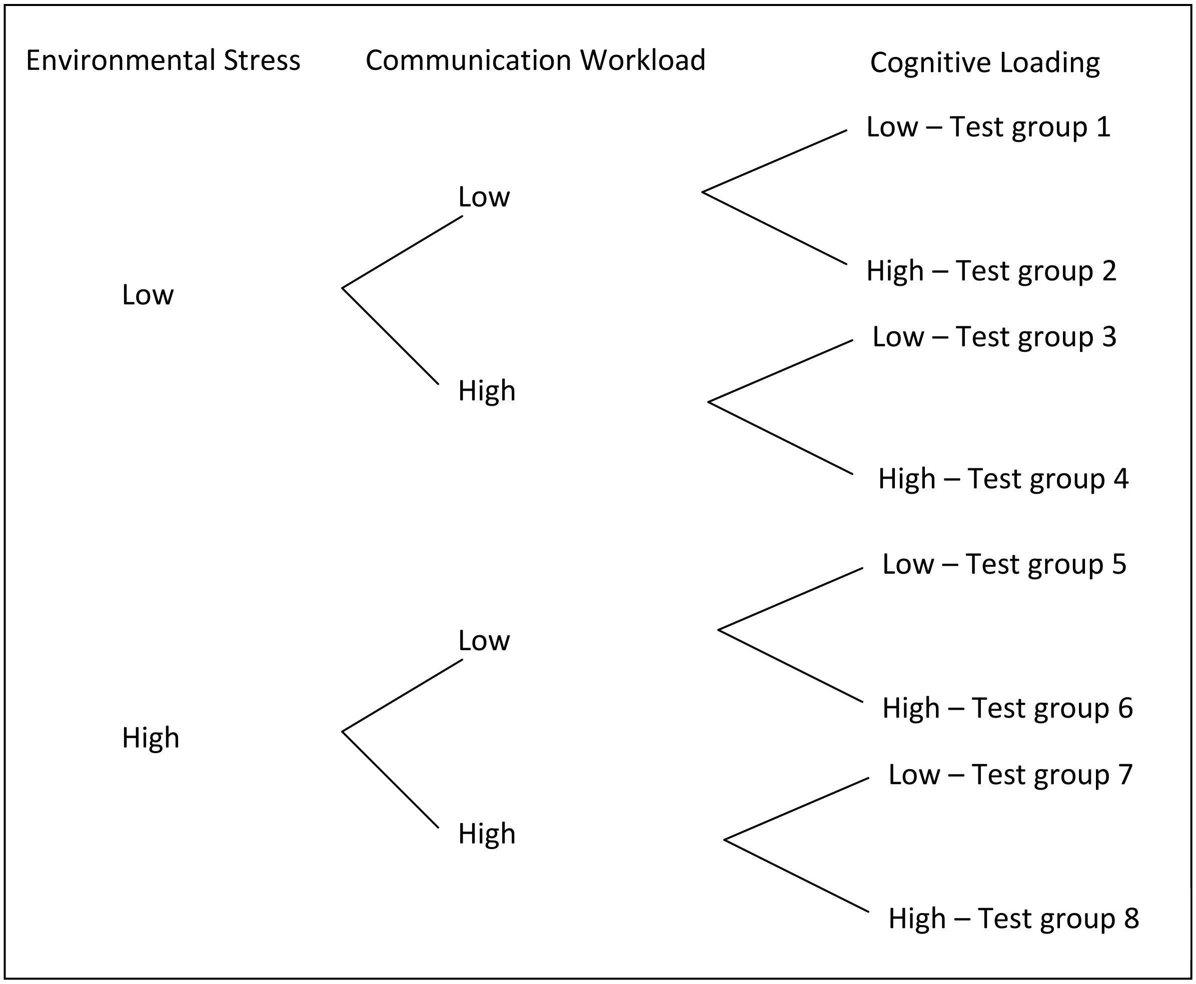


Figure 15: Experimental Design.

Experimental Procedure

The experimental procedure is as follows:

The test room is preconditioned to required temperature at least 30 minutes prior to beginning the experiment to assure uniformity of room temperature. The test volunteer is asked to review and sign the IRB approved consent form. The volunteer is informed that he/she can discontinue testing at any time.

The volunteer is then asked to complete a brief demographic questionnaire. The questionnaire will establish the subject's familiarity with hand held mobile computing devices.

The subject is given time to familiarize themselves with the handheld device. He/She is asked to type in his/her names, e-mail address, addresses and phone numbers. The purpose of this is to ensure the subject's ability to access special characters and numbers in the blackberry. To test his/her ability to enter text into the handheld device, and to ensure a measure of equality in ability between test subjects, the volunteer is asked to type and e-mail the following paragraph to hetestverify@gmail.com in under seven minutes. If the volunteer does not complete the data entry within seven minutes, then he/she is allowed to practice on the handheld device until he/she feels confident enough to try again.

"Florida coastal cleanup needs volunteers for Saturday, October 25 from 9 to 11 a.m. Be part of the 22nd annual international coastal cleanup coordinated by the Ocean Conservancy and supported locally by the City of Orlando and Keep Orlando Beautiful. Sites include Lakes Ivanhoe, Dot, Lorna Doone, Lucerne, and Park Lake. T-shirt, breakfast and cleanup supplies provided. Dress for a mess! To register, call 407-758-6931"

Afterwards the volunteer is asked to type four standard paragraphs of approximately 500 characters each into the blackberry and to e-mail each paragraph to hetestac@gmail.com. Each paragraph is sent to a different individual. The total length provides a predetermined number of opportunities for error. The subject is allowed five minutes per paragraph to complete this task. The data from this activity is used towards establishing a base HEP.

The standard paragraphs were designed to model actual status reports from the Florida State EOC and to maintain an equal number of characters per paragraph. The paragraphs are as follows:

"Tropical Strom Woodward has formed 250 miles off the coast of Africa. Computer models predict that the tropical storm has the potential to form into a category 5 hurricane within the next four days. The storm is too far away to accurately predict the trajectory of the storm. However, emergency officials in the State of Florida are preparing for a possible East Coast landfall sometime early next week. The National

Hurricane Center in Miami is actively monitoring the storm. This is the third named storm of the season." (Character count: 521)

"*Tropical Storm Woodward is on the verge of forming into a hurricane. Computer models predict that Woodward will become a hurricane within the next four to six hours. The projected path is predicted to pass through Cuba and then turn North towards South Florida. State of Florida Emergency Response Team has requested the federal government for support. The National Hurricane Center has issued a hurricane watch for most of South Florida. US ships at sea have been asked to return to port immediately.*" (Character count: 501)

"Hurricane Woodward made landfall in Cuba two hours ago as a category 3 hurricane.. Woodward has now completed passed over Cuba and is back in the Atlantic heading northwest at 50 miles per hour. The National Hurricane Center predicts Woodward to strengthen to a Category 5 storm impacting the lower East Coast of Florida in approximately 10 hours. The State of Florida Emergency Operations Center has been full activated and emergency officials have been called in. A mandatory evacuation of residents in the projected impact zone has been ordered." (Character count: 550)

"Hurricane Woodward made landfall at the city of Taylor at 10:00pm tonight. Approximately 50% of the city is flooded. Fortunately Florida Highway Patrol was able to

successfully evacuate the residents of the city and no loss of life is reported. However, Frontier Dam located to the south of the city is possibly on the verge of failure. All land routes leading into the city have been rendered useless by flooding or debris. First responders are conducting aerial reconnaissance in attempts to devise an action plan."

(Character count: 516)

The volunteer is next allowed a 10 minute rest period after which he/she is asked to enter into the pre-conditioned test room. In this stage of the experiment, the volunteer is exposed to their test conditions and are asked to receive information, process it and then relay the information to the required recipient. The exact process will depend on which test factor(s) the individual is exposed to.

General process (for test groups 1 & 5) is as follows:

Six text paragraphs are e-mailed to the volunteer at five minute intervals via a personal computer. The text paragraphs contain e-mail instructions and a message. The volunteer is asked reproduce the message into the handheld device and e-mail it as per the instructions. The following are the text paragraphs.

" *Send the following e-mail to Public Works.*

Information regarding the city sewage system is required to effectively plan for flooding relief. A map of the pipe network indicating the location of major storm drains along *with capacity figures for the network and retention basins will need to be delivered to the EOC immediately. Also, first responders entering flooded areas are expressing concerns regarding downed power lines. Please confirm that the Taylor city electric power grid has been fully deactivated and safety precautions have been implemented to prevent unauthorized grid electrification.*" (Character Count: 558)

" *Send the following e-mail to Law Enforcement.*

Over the last half hour, fifteen 911 calls have been received indicating widespread trespassing and looting in the Simpson neighborhood of East Taylor. Reports indicate that several residents have armed themselves in attempts to protect their personal property and safety. However, this has lead to an unstable situation in which gun battles are erupting uncontrollably. Several injuries have been reported. It is requested that units be immediately dispatched to the Simpson area to deal with the situation." (Character Count: 507)

" *Send the following e-mail to the State Governor.*

The City of Taylor requires further support for its firefighting, law enforcement, search and rescue, emergency care and flooding containment. Current city resources have been overwhelmed and are unable to cope with the magnitude of the disaster. If the city is to survive the impact of Hurricane Woodward then further resources must be forthcoming on an urgent basis. Resource requests indicating required requisitions and quantities *have been entered into the WebEOC system under the appropriate categories.”* (Character Count: 508)

“ Send the following e-mail to Search and Rescue.

Aerial reconnaissance helicopters have reported approximately 8 to 9 individuals stranded in areas of high flooding. The survivors are clustered on the roofs of three buildings. The addresses are: 14567 Woodbridge St., 5567 Icon Ave., and 434 Lyon Circle. Water depths are estimated 10 to 12 feet. Two of the survivors seem to be injured and may require immediate medical assistance. The survivors should be airlifted out immediately. Food, water and safe shelter arrangements will also need to be made.” (Character Count: 504)

“ Send the following e-mail to Emergency Care.

A shelter needs to be arranged for 35 survivors who have been rescued from the City of Taylor during the last 12 hours. Among the survivors there are 10 adult males, 12 adult females, 3 infants, and 10 children. One of the adult survivors requires wheelchair access and another requires diabetic supplies. Arrangements should be made to provide for the survivors for one week. The shelter should have adequate facilities to accommodate the individuals with a personal space allocation of 60 square feet of usable space. ” (Character Count: 519)

“ *Send the following e-mail to Public Announcements.*

Flooding has subsided and officials have declared the City of Taylor safe for rehabilitation. The power grid will be re-electrified at midnight tonight. The fire department will be on stand –by to respond to any electrical fires. Announcements need to me made through all mainstream media channels to inform evacuated individuals that at 8am tomorrow, emergency officials will allow evacuated individuals to return to the city. Law enforcement will need to increase its presence along all major road arteries to ensure public safety. ” (Character Count: 533)

The process for *decision making – high level* (test groups # 2, 4, 6, & 8) is the same as the general process outlined above with two differences, (1) the volunteer is not provided with the individual or agency to which the message needs to be sent. This causes the volunteer to use rule based cognitive processes to determine where the message needs to be sent. And (2), the volunteer is asked to perform a secondary task of solving a mathematical question every minute.

The process for communication workload – high level (test groups # 3, 4 ,7, & 8) includes an additional communication channel that is opened with the volunteer via telephone every minute. The conversation lasts approximately 10 seconds. The volunteer is given strict instructions not to stop typing during the telephone conversation.

Test groups 5, 6, 7, & 8 are exposed to noise and warm room temperatures. The noise features 15 simultaneous conversations superimposed with office sounds such as copiers. The noise loop varies in volume from 80 to 90 dba and plays during the duration of the experiment. The OSHA safety standard specifies that individuals should be exposed to 85dba of continuous noise for no more than 10 hours and 5 minutes. This experiment is well inside the safety zone.

Room temperature is be set between 95^o and 100^o. This temperature at half an hour of exposure should not cause the volunteer to experience any ill effects. However, the volunteer will is closely monitored, both in terms of physical appearance and heart rate to ensure his or her safety.

Sample Size

A priori power analysis was performed to determine the sample size for the study. The level of statistical significance for the study was set at the conventional value of $\alpha = .05$. Statistical power of .80 and the effect size of "large" (ES=.40) were also selected. The variables presented seven degrees of freedom. Using the standard tables for ANOVA tests the sample size was determined to be 11 participants for each of the eight experimental groups (Cohen, 1977, p384).

The test subjects will be students attending at the University of Central Florida. Study participants should be familiar with the use of a mobile device and desktop computer with moderate to high computer skills and Internet skills (measurement/eligibility criteria). Both male and female students of all ethnicities will be invited to participate in the study. Participating students will be informed that their test results will remain anonymous and that participation is purely voluntarily. The subjects will also be they have the option to withdraw from the study at anytime without consequence. To help solicit volunteers, several UCF professors will be requested to offer extra credit to students which successfully complete testing.

Data Collection

To avoid interference with the test subjects, a video camera situated behind the subject will be used for data collection. The camera will set to zoom in on the blackberry and the image on the camera screen or remote monitor will be used to count the number of mistakes that the subject makes.

Controls

- Time: Each subject will be allocated the same amount of time to enter data.
- Instruction: Each subject will be provided the same instruction by the same tester.
- Device: Each subject will utilize the same mobile handheld keyboard device
- Location: Each subject will be tested in the same location to eliminate untested ambient conditions

- Seating position: Subjects will be influenced by seating position and table height, to minimize these, the subject will be asked to adjust the seat position and height to the most comfortable position for him/her.

CHAPTER FIVE: RESULTS AND DISCUSSION

This chapter presents the data collected and explains how the data was analyzed. A discussion of the analysis and findings is also presented. The dependent variable data was collected by counting the number of errors that occur for each paragraph, to find a total number of data entry errors per paragraph per individual. This figure was then converted to error rates by dividing the cumulative errors that occurred by the total number of opportunities for error. The opportunities for error were found by counting the number of characters which were completed in the allocated time and subtracting the number of characters that may have been omitted due to *read errors*.

As mentioned in chapter four, a total of 88 subjects were required for the experimentation. Volunteers were solicited from among undergraduate and graduate students at the University of Central Florida. A total of 101 subjects appeared for the experiments, corresponding to a total of 202 hours of testing. Out of these, 14 subjects were excluded from the final data leading to a final number of 87 participants. The 14 subjects were excluded for the following reasons.

- The initial nine subjects were excluded because of testing refinement and improvement.
- Two subjects did not complete the experiment because they were unwilling or unable to tolerate the heat levels required for the environmental stress test.

- Two subjects were removed from the data set because they exhibited obvious signs of poor motivation and effort. Their test results did not represent realistic error rates.
- One subject was not included in the data set due to observation error.

Subject Demographics

As can be seen from Table 8, there is an equal spread between male and female test subjects. However, as shown in Table 9 and Table 10, the age and education levels of the subjects are skewed towards younger, college going individuals. Because of this, it is possible that the results obtained within this research do not fully represent individuals of different age or education backgrounds.

Table 8: Subject Demographics: Gender

Characteristic	Percentage
Male	49.43%
Female	50.57%

Table 9: Subject Demographics: Age

Characteristic	Percentage
18-30 years old	96.55%
31-50 years old	03.45%
Above 50 years old	00.00%

Table 10: Subject Demographics: Education

Characteristic	Percentage
High School Education	91.95%
Bachelors Education	06.90%
Masters Education	01.15%
Doctorate	00.00%

From Table 11 it is seen that all the participants have had previous handheld messaging experience, with approximately 38% of the participants having previous experience on handheld QWERTY style devices. Intuitively, it would seem that individuals who have previous experience with handheld QWERTY devices would experience better performance as compared to their counterparts and that analysis should be conducted to determine the relationship between error rates and previous experience. However, to counter this, as explained later, this experimentation is designed to factor out the affects of individual differences, including previous experience.

Table 11: Subject Demographics: Previous Handheld Messaging Experience

Characteristic	**Percentage**
Never used any mobile device messaging	00.00%
Novice at numeric keypad messaging	10.34%
Intermediate at numeric keypad messaging	35.63%
Expert at numeric keypad messaging	16.09%
Novice at mobile QWERTY	11.49%
Intermediate at mobile QWERTY	13.79%
Expert at mobile QWERTY	12.64%

Observer Error

One of the concerns during this experimentation was the possibility of observation error. Errors in observation could occur from a variety of reasons, including observer inattention and inability to maintain observational pace with the subject's error rate. To check the quality of the data, three test subjects were independently co-observed by a third party. Presented in Table 12 is the data from the co-observation.

Table 12: Observer Error Data

Text Block	# Errors Independent Observed	# Errors Sami Observed	Absolute Difference
65-B1	4	4	0
65-B2	8	6	2
65-B3	6	9	3
65-B4	14	14	0
68-B1	66	62	4
68-B2	30	31	1
68-B3	34	38	4
68-B4	37	34	3
57-B1	44	50	6
57-B2	39	46	7
57-B3	41	37	4
57-B4	37	44	7
		Average	3.42
		Total	41

These 12 text blocks correspond to a total of 6474 characters to be observed, which each character presenting an opportunity for error. The numbers of errors are defined as the value of the absolute difference between the two observer sets. Over these 6474 opportunities for error, a total of 41 errors were found. This corresponds to a difference of 0.63%. It is also important to find if there is any statistical difference between the two observer sets. This was done through the use of a non-parametric independent means comparison (Mann-Whitney) test. The results are presented in Table 13 and Table 14.

Table 13: Observer Error Mann-Whitney Test

	Group	N	Mean Rank	Sum of Ranks
Observations	1	12	12.04	144.50
	2	12	12.96	155.50
	Total	24		

Table 14: Observer Error Mann-Whitney Test

	Dif
Mann-Whitney U	66.500
Wilcoxon W	144.500
Z	-.318
Asymp. Sig. (2-tailed)	.750
Exact Sig. [2*(1-tailed Sig.)]	.755

From Table 14, it can be seen that p>0.05 and hence we fail to reject the hypothesis that the means of the two sets are statistically different. Hence a reasonable assumption can be made that observer error is statistically negligible.

Base HEP

The first objective of the research is to determine a base HEP value. This base HEP value is important for the following reasons:

- It provides a baseline from which to study the improvement or decrease in human performance or error levels as performance shaping factors are varied.
- The bHEP value is required when conducting a Human Reliability Assessment of tasks involving the use of Blackberries.

To determine the bHEP value, the four "base paragraphs" are used as the data set. The first step in the analysis process is to determine if there are any statistically significant within subjects differences between the paragraphs. This is to determine when the subjects have reached a “steady state” error rate i.e. when effect of learning curve ends. This is done using repeated measures ANOVA on the four basic error data sets. Repeated measures is when the same subjects are repeated across a number of treatments. In this case, each paragraph would represent a different treatment.. The hypothesis tested is that there is no difference between the paragraphs, i.e. that the individual has achieved a steady error rate.

However before this is done, a condition for running a repeated measures ANOVA is that the assumption of sphericity is met. A spherical data set is one in which the variances across the repeated measures are considered equal. Formally, it tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix. From
Table **15** we can see that the Mauchly’s Test is not significant with a p-value of 0.209. Since this is greater alpha (0.05), we fail to reject the null hypothesis and can hence assume that the condition of sphericity has been met.

Next, the repeated measures ANOVA was conducted to test the null hypothesis for each individual test subject, i.e there is no difference between the mean error rates of the paragraphs. The results of the repeated measure ANOVA is presented in Table 16 and APPENDIX C: BASE REPEATED MEASURES SPSS OUTPUT, which indicates a p-value of 0.512.

Hence, with a 95% level of confidence, we have failed to reject the null hypothesis and can assume that the mean error rates across the paragraphs are not significantly different.

Table 15: Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Paragraph	.919	7.160	5	.209	.946	.982	.333

Table 16: Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Paragraph	Sphericity Assumed	.000	3	.000	.718	.542

Using the knowledge that there is no statistical difference between the paragraphs, a HEP value is calculated for each individual using a cumulative value of errors over the four base paragraphs divided by the cumulative number of opportunities for error over the same four base paragraphs. An average figure for HEP was calculated across the 87 subjects. This HEP figure is found to be 0.0296 with a standard deviation of 0.015. Figure 16 presents a histogram of the distribution.

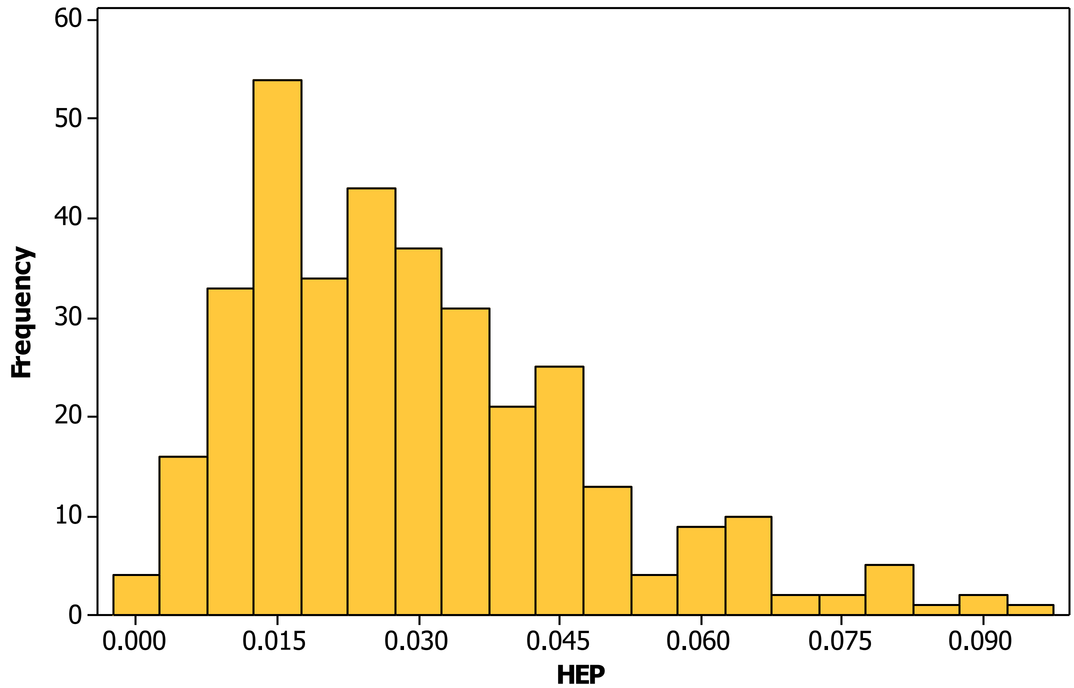


Figure 16: Base HEP Histogram

Comparing this Blackberry bHEP to the general bHEP value for an act performed incorrectly, 0.003, the Blackberry bHEP is relatively high (Kirwan 1994). However, an interesting comparison is to the general error rate for oral communication, which is nearly identical at 0.03 (Kirwan 1994). The general bHEP value for alphanumeric input is 0.005, which is within the same order as the Blackberry bHEP. From this, it can be concluded that research has resulted in a bHEP value which agrees with existing literature. In fact, the similarity poses an interesting question: Is similarity of these figures a coincidence or does all communication error have a similar error rate that is influenced by some internal cognitive mechanism? If this is the case then that would suggest that, generally speaking, error in human communication is medium independent.

Effect of Cognitive, Environmental and Communication Factors

The second research objective is to determine if EOC specific levels of cognitive stress, environmental stress and communication workload have a significant effect on Blackberry data entry error rate. The collected data are first analyzed utilizing repeated measures ANOVA to determine if there is a significant difference between the mean error rates of each of the six paragraphs. The complete analysis is presented as APPENDIX D: TEST CONDITIONS REPEATED MEASURES SPSS OUTPUT. No significant differences were found between the mean error rates of each of the six paragraphs. This indicates that the different paragraphs did not affect the data entry error rates and can be considered as an insignificant factor for this analysis.

To increase the robustness of the analysis, the data are combined across the paragraphs to result in a single error rate for each individual. The next step is an ANOVA analysis to determine the main and interaction effects of the three factors. The tested hypotheses are:

1. Test for main effect of environment

   H_0: Population means are equal across all levels of the environment factor.
   H_a: Population means are not equal across all levels of the environment factor.

2. Test for main effect of communication workload

   H_0: Population means are equal across all levels of the communication factor.
   H_a: Population means are not equal across all levels of the communication factor.

3. Test for main effect of cognitive load

   H_0: Population means are equal across all levels of the cognitive factor.
   H_a: Population means are not equal across all levels of the cognitive factor.

4. Test for interaction effect of env*cog

   *H_0: Population means are equal across all levels of the env*cog interaction.*
   *H_a: Population means are not equal across all levels of the env*cog interaction.*

5. Test for interaction effect of env*com

   *H_0: Population means are equal across all levels of the env*com interaction.*
   *H_a: Population means are not equal across all levels of the env*com interaction.*

6. Test for interaction effect of com*cog

   *H_0: Population means are equal across all levels of the com*cog interaction.*
   *H_a: Population means are not equal across all levels of the com*cog interaction.*

7. Test for interaction effect of env*cog*com

   *H_0: Population means are equal across all levels of the env*cog*com interaction.*
   *H_a: Population means are not equal across all levels of the env*cog*com interaction.*

The complete ANOVA analysis is presented as APPENDIX E: TEST CONDITIONS GLM-ANOVA SPSS OUTPUT. Presented in Table 17 are the mean HEP values and HEP standard deviations found for each test condition. Table 18 presents the between subject F statistics and *p*-values, from which we reject the null hypotheses 1, 2 and 3, i.e. the main effects of environment (*p*=0.014), cognitive (*p*=0.002), and communication (*p*=0.00) are all statistically significant. This indicates that each of the tested factors affect the Blackberry data entry error rate. Figure 17 visually portrays and compares the mean data error rates between the stressed and unstressed conditions. The mean error rates increase from the unstressed, low conditions to the stressed, high conditions for all three factors. Communication effects represent the largest increase in mean error rate.

Table 17: HEP Values for Different Test Conditions

Test Conditions	Mean HEP	Std. Deviation
Cog	.033765367545	0146844733578
Com	.041222317455	.0210226354948
Cog + Com	.034380675455	.0136381902938
Env	.027534458400	.0079108030937
Env+Cog	.038015159182	.0109715589505
Env+Com	.036376775273	.0130261990047
Env+Cog+Com	.058309163909	.0193252988774

Table 18: Tests of Between Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.009[a]	7	.001	6.538	.000
Intercept	.114	1	.114	551.432	.000
Env	.001	1	.001	6.289	*.014*
Cog	.002	1	.002	10.206	*.002*
Com	.004	1	.004	17.127	*.000*
*Env * Cog*	.001	1	.001	4.255	*.042*
Env * Com	7.126E-5	1	7.126E-5	.345	.559
Cog * Com	.000	1	.000	.558	.457
*Env * Cog * Com*	.001	1	.001	6.783	*.011*
Error	.016	79	.000		
Total	.140	87			
Corrected Total	.026	86			

a. R Squared = .367 (Adjusted R Squared = .311)

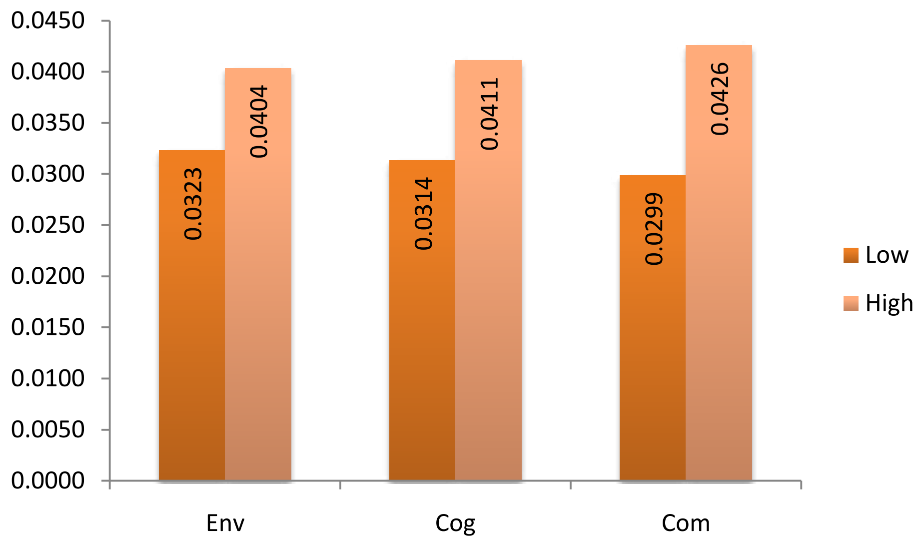


Figure 17: Bar Chart of Factor Means

The results presented in Table 18 also indicate that there are two significant interactions, the two-way interaction of env*cog and the three way interaction of env*cog*com. Hence, we reject hypotheses 4 & 7 and fail to reject hypotheses 5 & 6. Figure 18 visually presents the env*cog interaction, in which difference in slopes between the blue line (only environmental effect) and the green line (env*cog interaction) is evident. For comparison purposes the other two-way interactions are also presented as Figure 19 and Figure 20. In each of these two figures, it can be seen that the slopes of the trend lines are almost parallel.

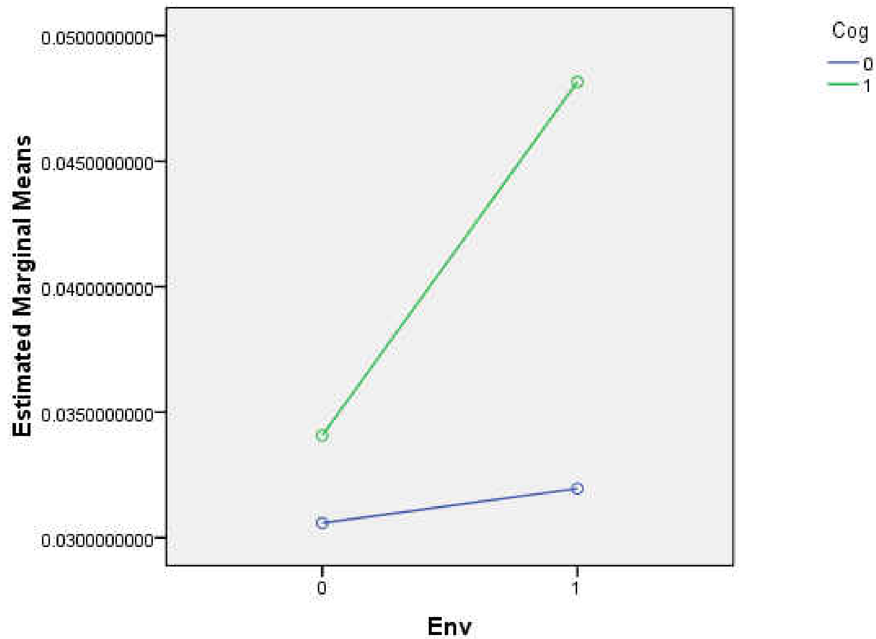


Figure 18: Env*Cog Marginal Means

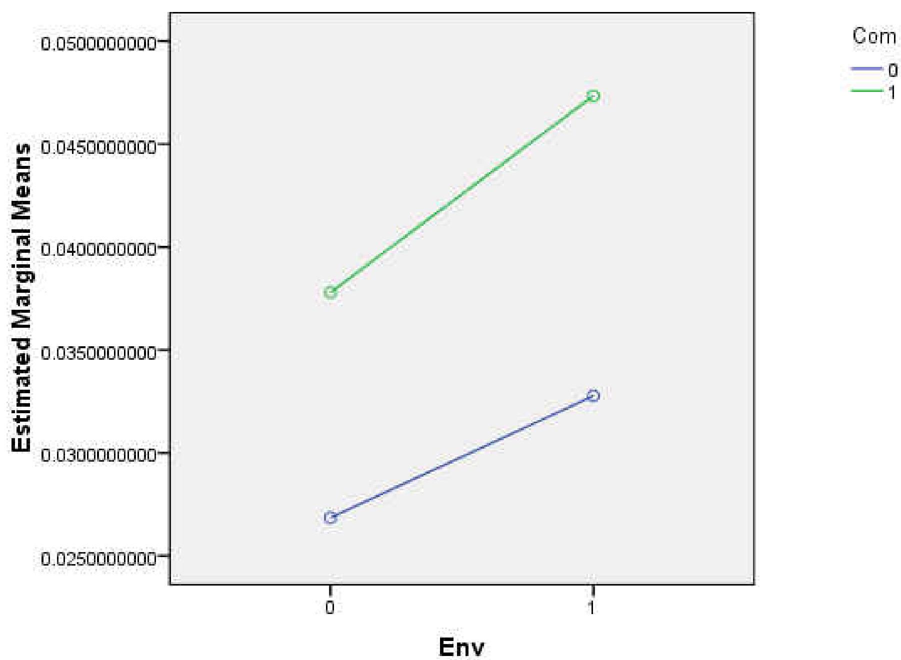


Figure 19: Env*Com Marginal Means

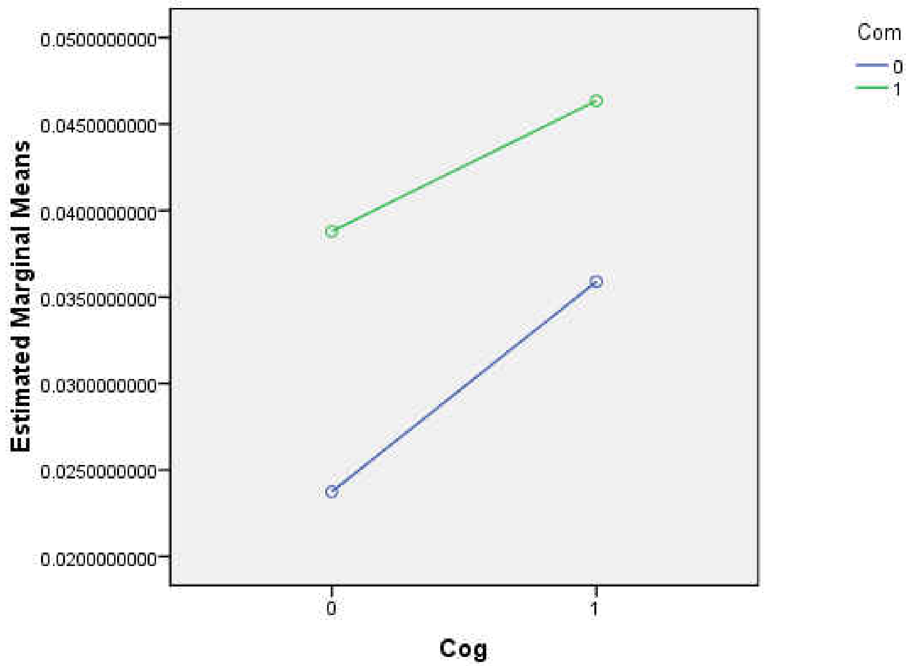


Figure 20: Com*Cog Marginal Means

To better understand the effects of the factors, the data are also analyzed by an ANOVA in which the different groups are regarded as treatments. Group number 1 is the control group which represents the base, low stress conditions for all three factors. Groups 2 to 8 are combinations of stresses as outlined in Figure 15 of Chapter 4. The hypothesis for the ANOVA analysis is that the means of the error rate differences are the same between the different test conditions. However as shown in Table 19, we reject this hypothesis because the p-value is less than 0.05. Tukey's pairwise comparisons were run as post-hoc tests to determine where the differences in means lie. A complete listing of pairwise comparisons is given in Table 20 from which we can see that groups 3, 6, and 8 are significantly different from group 1 (the control group) at an alpha of 0.10. This post-hoc result reinforces the original between subjects ANOVA results in regards to the interaction effects.

Table 19: ANOVA Analysis on Test Groups

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.009[a]	7	.001	6.538	.000
Intercept	.114	1	.114	551.432	.000
TestGroup	.009	7	.001	6.538	.000
Error	.016	79	.000		
Total	.140	87			
Corrected Total	.026	86			

a. R Squared = .367 (Adjusted R Squared = .311)

Table 20: Tukey's Pairwise Comparisons

(I) TestGroup	(J) TestGroup	Mean Difference (I-J)	Sig.
1	2 (cog)	-.0138	.331
	3 (com)	-.0213	.018
	4 (cog+com)	-.0144	.278
	5 (env)	-.0076	.927
	6 (cog+env)	-.0181	.076
	7 (com+env)	-.0164	.144
	8 (com+cog+env)	-.0384	.000

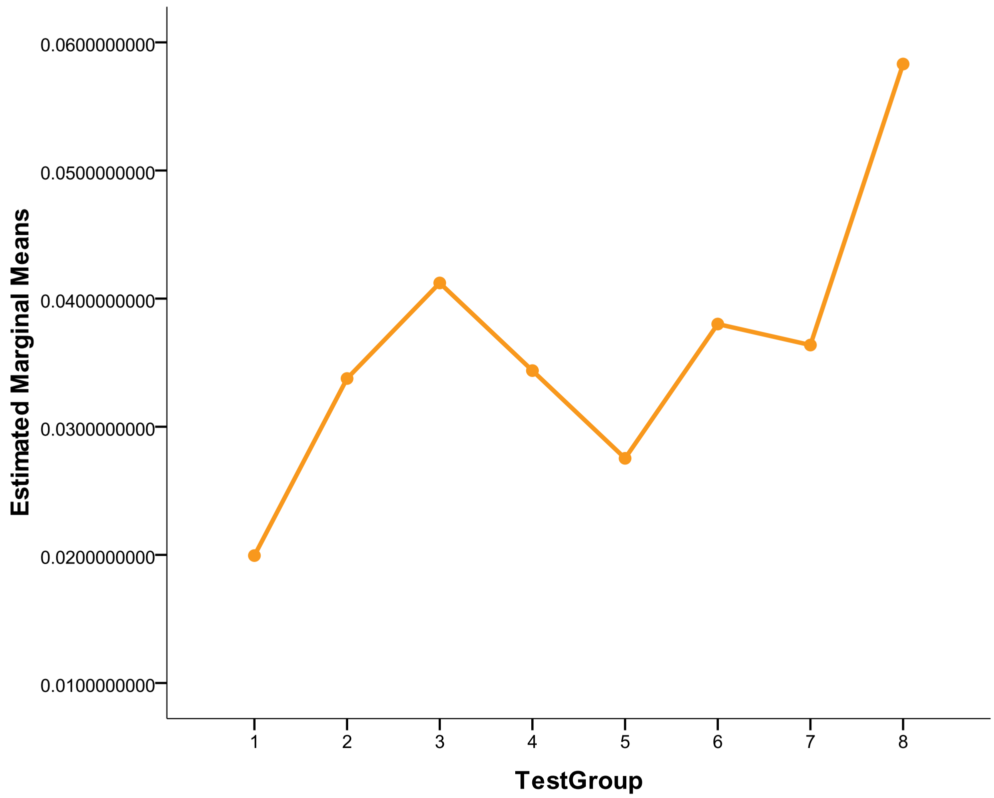


Figure 21: Mean Error Rate per Group

Figure 21 visually indicates the mean error rate for each group. As can be seen from this figure, group 8 (3-way interaction) represents the largest increase in error rates over the control group, followed by groups 6, 7 and 4 (2-way interactions) and then groups 2 and 5 (single factors). Group 3 (communication workload factor) is a notable exception to this trend. From this trend the conclusion can be drawn that the effects of the factors are additive.

In this experiment it has been found that the combination of environmental stress and cognitive multitasking has a significant impact on the human error probability of Blackberry data input. In addition, high levels of communication workload should be avoided. However environmental stress does not significantly increase the human error rate. A possible explanation of this the possibility that individuals are able to adapt to, and thus “tune out” physical stressors like heat and noise. But if that adaption process is interrupted by repeated cognitive loading, it hampers the individual’s ability to adapt to external circumstances. Communication loading may present such a high effect because it is an interference task which diverts the individual’s attention from the typing task. However it is interesting to note that communication, when coupled with other stressors such as cognitive loading or environmental stress does not present as large an effect on error rate. This indicates that communication workload is the most important stressor within the EOC environment. The fact that communication loading increases the error rate is not very surprising because it increases the requirements on the individual’s working memory and hence degrades the performance of both tasks. This finding agrees with the current literature on this topic, such as Mizobuchi, Chignell et al. (2005).

The results are also very interesting because it was found that the interaction effects between error causing factors are statistically important. Currently human error models and human reliability assessment techniques do not consider interaction affects. Although this does not mean that existing models are incorrect, it does raise doubt their comprehensiveness.

Correlation Between Time and Error Rate in Base Group

Although it is not part of the research objectives, a correlation analysis is conducted to determine if a relationship exists between error rates and entry rate. As shown in Table 21, a significant correlation of -0.336 exists with p-value of 0.002. Figure 22 demonstrates this correlation visually. The importance of this finding is that it provides a correlation figure between typing speed and error rates, i.e. as typing speed decreases, less errors are made. This result is intuitive, lending further evidence towards the validity of the experimental results.

Table 21: Pearson Correlation between entry rate and error rate

		b1tob4time	b1tob4errorrate
b1tob4time	Pearson Correlation	1	-.336**
	Sig. (2-tailed)		.002
	N	85	85

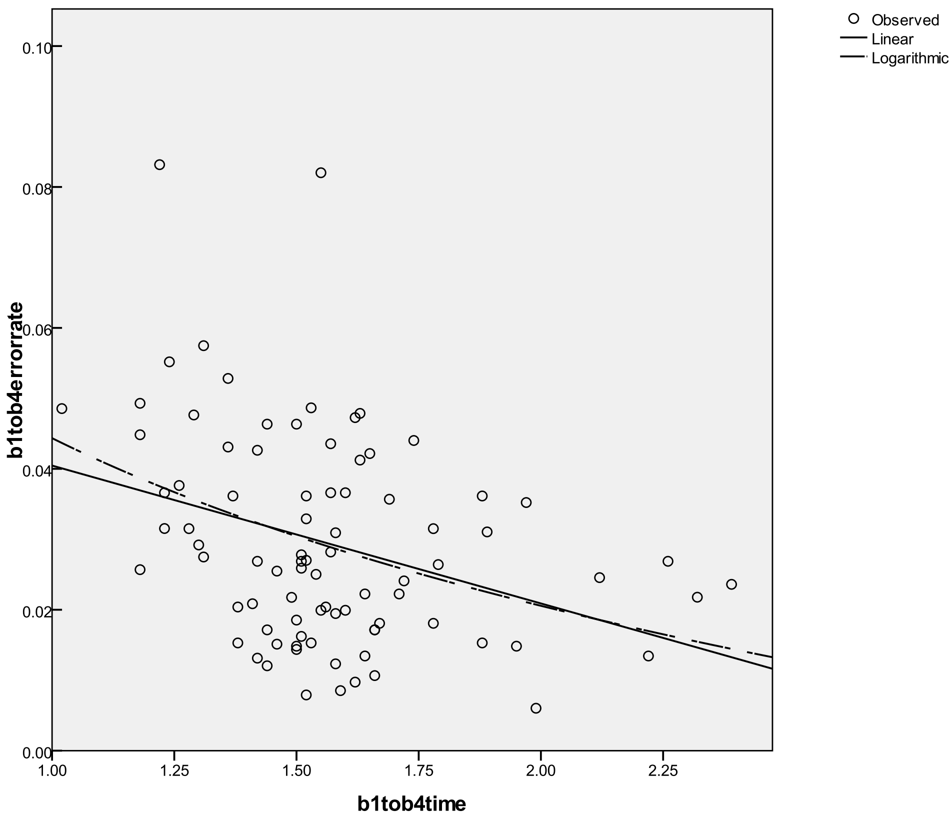


Figure 22: Graph of Error Rate to Data Entry Rate

CHAPTER FIVE: CONCLUSIONS AND FUTURE WORK

The research objectives were twofold. First to define an accurate human error probability for Blackberry data entry tasks and second to determine if increased environmental stress, cognitive loading and communication multi-tasking, are detrimental to human performance in an EOC environment, as measured by a change in blackberry data entry HEP.

For this purpose a preliminary analysis was conducted using ethnographic task analysis methods to determine an EOC communication network and EOC research framework. From the EOC research framework it was learned that all tasks within an EOC can be categorized as data entry, data perception or decision making. It was also discovered from the preliminary analysis that personnel within an EOC are exposed to high levels of heat, noise, cognitive loading and communication multi-tasking. This knowledge was used in designing an experimental methodology to achieve the research objectives. A Blackberry bHEP value of 0.0296 with a standard deviation of 0.015 was found. Also, it was found that (1) communication multitasking and (2) combinations of cognitive and high environmental stress were statistically significant in causing an increase in the probability of human error in data entry. Table 22 relates the research findings and conclusions to the research gaps listed in Chapter 1.

Table 22: Research Conclusions

Research Gap	**Research Finding**	**Conclusion**
The need to identify a research framework for EOCs. This includes identifying the processes and systems with human involvement.	SME reviewed EOC Research Framework in Figure 13.	The framework presents an outline which can be utilized to guide future research.
Determining if performance shaping factors (PSF) present in an EOC have a significant impact of human error.	The main effects of each factor and interaction effects of cognitive and environmental effects were found to be significant.	PSFs present in an EOC do have an impact on human error. While this was demonstrated on data entry task, it is not unreasonable to assume that all tasks within an EOC would be similarly affected.
Do interactions between performance shaping factors or error causing conditions have a significant effect on human error?	The combination of cognitive loading and high environmental stress was statistically significant.	From this experimentation, it was found that only interaction effects are significant. This implied that interaction effects can possibly play a significantly greater role than only single factor effects.
Determining if data entry errors occur when using a handheld device and if they can measured and quantified.	bHEP value of 0.0296 with a standard deviation of 0.015	Data entry errors occur and can be measured and quantified.
Can the bHEP value be influenced by external performance shaping factors present in an EOC?	The main effects of each factor and interaction effects of cognitive and environmental effects were found to be significant.	The error rate is influenced by external conditions present in an EOC. Controlling these conditions would help in reducing the overall number of errors made in an EOC.

Other significant results that were found during the course of this research are:

1. The similarity between the general alphanumeric bHEP, verbal communication bHEP and Blackberry data entry. This would suggest the possibility that human

communication may be medium independent and as such, a function of some intrinsic cognitive mechanism.

2. There is a correlation of -0.336 between typing speed and error rate. A logical value that agrees with intuition; typing slower yields less mistakes.

3. Observer error in this research can be considered to be statistically negligible. This suggests that it possible to accurately monitor and detect data entry error.

The final conclusion from this effort is that errors occur in handheld data entry and that the conditions present in an EOC conductive to an increase in errors. Because these same conditions are present throughout the EOC, the possibility exists that errors are being induced in other tasks as well. However, by managing these factors, for example by keeping noise and heat at the low level as defined in Chapter 3, the number of handheld data entry errors can be reduced.

Benefits of Research

The benefits of conducting this research extend to both the scientific community and to practitioners in the domains of disaster management and human reliability assessment. Specifically these benefits are:

- Disaster Management
  - Scientific Knowledge: It has been proven that human communication errors occur in data entry tasks within disaster management environments, which in turn suggests that human errors occur in other tasks as well. This research provides evidence to justify the development of a comprehensive human reliability model for disaster management.

  - Practitioners: Communication error due to human error in data entry occurs within the EOC. Data validation systems should be implemented to confirm all critical data.

  - Practitioners: Current levels of communication workload, cognitive workload and lack of environmental control induce higher rates of error in EOC personnel, and hence, should be controlled.

- Human Reliability Assessment
  - Scientific Knowledge: The research finds that handheld devices need to be included in human error databases.

- Scientific Knowledge: Evidence is also provided that interaction effects between performance shaping factors are significant and should be addressed in human reliability models.

- Practitioners: A Blackberry text data entry base HEP value is provided for application in current HRA models.

Future Work

This research is a first step in exploring a compilation of pertinent topics. Listed below are suggestions for future work stemming as extensions of this effort.

1. Effect of Other Performance Shaping Factors: Several factors were not included in this study. It is very possible that these factors would affect human performance in EOCs. Most notably, fatigue was not considered. The first question raised is: Does fatigue come into play at all? Individuals in an EOC are set to 8 hour shifts and they are not typically working continuously, although that largely depends on what position/station they work. Another interesting factor to explore would the EOC design and layout. However to study this, an initial study would first need to be required to develop a layout classification system.

2. Different Levels of Stress: Although the single factors themselves are not statistically significant, the question still remains if high levels or cognitive loading, communication loading or environmental stress would have statistically significant effects. Determining this would also help in developing a regression model to quantify the impact of each factor.

3. Blackberry Data Entry Performance Curves: Further research can be conducted to correlate typing speeds to data entry error rates. Several data points would be set at specified typing speeds and the number of errors that occur at each speed can be correlated to determine performance curves.

4. Other Mobile Devices: An assumption was made throughout this research that other similar handheld QWERTY mobile devices would have the same error rate. This assumption should be tested and validated by comparing the data entry error rates between Blackberries and similar devices such as TREOs or Sidekicks. This presents a potentially immense research area in which handheld devices can be examined on a microscopic design level. For example: *"What effect does inter-button spacing have on data entry error rates?" "If there is a statistically significant correlation, can a performance curve be found relating error rates to inter-button spacing?" "At what point does this factor cease being statistically significant?"* Similarly, other non QWERTY mobile devices should be considered. Handheld devices employ many interface modalities and

present a variety of spatial and dimensional layouts. Examples include soft keyboards, touch screens, numeric keypads.

5. Individual differences. Investigations should be conducted to determine if handheld data entry error or human error under EOC conditions in general can be modeled as a function of some inherent physiological, psychological or behavioral aspect. For example, do introverts exhibit a statistically different data entry error rate as compared to extroverts? Knowledge gained form this research could be used for training purposes.

APPENDIX A: IRB APPROVAL

University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901, 407-882-2012 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Notice of Expedited Initial Review and Approval

From : **UCF Institutional Review Board**
FWA00000351, Exp. 6/24/11, IRB00001138

To : **Samiullah K. Durrani** and Co-PI: **Pamela R. McCauley-Bush**

Date : **October 28, 2008**

IRB Number: **SBE-08-05852**

Study Title: **Human Error in Mobile Keyboard Device Usage Subject to Environmental and Workload Factors of Emergency Operating Centers at Full Activation**

Dear Researcher:

Your research protocol noted above was approved by **expedited review** by the UCF IRB Chair on 10/27/2008. **The expiration date is 10/26/2009.** Your study was determined to be minimal risk for human subjects and expeditable per federal regulations, 45 CFR 46.110. The categories for which this study qualifies as expeditable research are as follows:

4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed they must be cleared/approved for marketing.

6. Collection of data from voice, video, digital, or image recordings made for research purposes.

7. Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

The IRB has approved a **consent procedure which requires participants to sign consent forms.** Use of the approved, stamped consent document(s) is required. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Subjects or their representatives must receive a copy of the consent form(s).

All data, which may include signed consent form documents, must be retained in a locked file cabinet for a minimum of three years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained on a password-protected computer if electronic information is used. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

To continue this research beyond the expiration date, a Continuing Review Form must be submitted 2 – 4 weeks prior to the expiration date. Advise the IRB if you receive a subpoena for the release of this information, or if a breach of confidentiality occurs. Also report any unanticipated problems or serious adverse events (within 5 working days). Do not make changes to the protocol methodology or consent form before obtaining IRB approval. Changes can be submitted for IRB review using the Addendum/Modification Request Form. An Addendum/Modification Request Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

Failure to provide a continuing review report could lead to study suspension, a loss of funding and/or publication possibilities, or reporting of noncompliance to sponsors or funding agencies. The IRB maintains the authority under 45 CFR 46.110(e) to observe or have a third party observe the consent process and the research.

On behalf of Tracy Dietz, Ph.D., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 10/28/2008 04:09:16 PM EST

APPENDIX B: DATA COLLECTION FORMS

Demographic Questionnaire

"Human Error in Mobile Keyboard Device Usage Subject to Cognitive, Environmental and Communication Workload Stressors Present in Fully Activated Emergency Operating Centers"

Samiullah Durrani, sdurrani@mail.ucf.edu 407-823-1095

Participant #__________________

1) Gender
   a) Male
   b) Female

2) Age
   a) 18-30
   b) 31-50
   c) Above 50

3) Education Completed
   a) None
   b) High School/GED
   c) Bachelors
   d) Masters
   e) Doctorate

4) Please select the category that best describes you.
   a) Never used any type of mobile device for messaging.

   b) Novice at using regular cell phone (numeric keypad) for messaging, but have not used a QWERTY keyboard on a mobile device.

   c) Intermediate at using regular cell phone (numeric keypad) for messaging, but have not used a QWERTY keyboard on a mobile device.

   d) Expert at using regular cell phone (numeric keypad) for messaging, but have not used a QWERTY keyboard on a mobile device.

   e) Novice at using QWERTY keyboard on a mobile device for messaging.

   f) Intermediate at using QWERTY keyboard on a mobile device for messaging.

   g) Expert at using QWERTY keyboard on a mobile device for messaging.

Error Rate Data Collection Form

"Human Error in Mobile Keyboard Device Usage Subject to Environmental and Workload Factors of Emergency Operating Centers at Full Activation"

Samiullah Durrani, sdurrani@mail.ucf.edu 407-823-1095

Participant #___________________ Group #_______________________

	Omit Character	Incorrectly Entered Character	Unnecessary Characters Entered	Sending Error
Base Paragraph 1				
Base Paragraph 2				
Base Paragraph 3				
Base Paragraph 4				
Test Paragraph 1				
Test Paragraph 2				
Test Paragraph 3				
Test Paragraph 4				
Test Paragraph 5				
Test Paragraph 6				

APPENDIX C: BASE REPEATED MEASURES SPSS OUTPUT

Within-Subjects Factors

Measure:MEASURE_1

Paragraph	Dependent Variable
1	ErrorRateB1
2	ErrorRateB2
3	ErrorRateB3
4	ErrorRateB4

Descriptive Statistics

	Mean	Std. Deviation	N
ErrorRateB1	.02861142218	.020316300073	87
ErrorRateB2	.03100352656	.020278089177	87
ErrorRateB3	.03056621246	.017787368539	87
ErrorRateB4	.02901083975	.017318294503	87

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.
Paragraph	Pillai's Trace	.029	.842[a]	3.000	84.000	.475
	Wilks' Lambda	.971	.842[a]	3.000	84.000	.475
	Hotelling's Trace	.030	.842[a]	3.000	84.000	.475
	Roy's Largest Root	.030	.842[a]	3.000	84.000	.475

a. Exact statistic

b. Design: Intercept
Within Subjects Design: Paragraph

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
	a			
Paragraph	.919	7.160	5	.209

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
 Within Subjects Design: Paragraph

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square
Paragraph	Sphericity Assumed	.000	3	.000
	Greenhouse-Geisser	.000	2.839	.000
	Huynh-Feldt	.000	2.946	.000
	Lower-bound	.000	1.000	.000
Error(Paragraph)	Sphericity Assumed	.042	258	.000
	Greenhouse-Geisser	.042	244.136	.000
	Huynh-Feldt	.042	253.337	.000
	Lower-bound	.042	86.000	.000

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		F	Sig.
Paragraph	Sphericity Assumed	.718	.542
	Greenhouse-Geisser	.718	.535
	Huynh-Feldt	.718	.540
	Lower-bound	.718	.399

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source	Paragraph	Type III Sum of Squares	df	Mean Square	F	Sig.
Paragraph	Linear	2.519E-6	1	2.519E-6	.014	.906
	Quadratic	.000	1	.000	2.571	.113
	Cubic	1.274E-5	1	1.274E-5	.070	.792
Error(Paragraph)	Linear	.015	86	.000		
	Quadratic	.011	86	.000		
	Cubic	.016	86	.000		

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	.309	1	.309	326.324	.000
Error	.081	86	.001		

Estimated Marginal Means

Paragraph

Estimates

Measure:MEASURE_1

Paragraph	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.029	.002	.024	.033
2	.031	.002	.027	.035
3	.031	.002	.027	.034
4	.029	.002	.025	.033

Pairwise Comparisons

Measure:MEASURE_1

(I) Paragraph	(J) Paragraph	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.002	.002	1.000	-.008	.003
	3	-.002	.002	1.000	-.007	.003
	4	.000	.002	1.000	-.006	.005
2	1	.002	.002	1.000	-.003	.008
	3	.000	.002	1.000	-.005	.006
	4	.002	.002	1.000	-.003	.007
3	1	.002	.002	1.000	-.003	.007
	2	.000	.002	1.000	-.006	.005
	4	.002	.002	1.000	-.003	.006
4	1	.000	.002	1.000	-.005	.006
	2	-.002	.002	1.000	-.007	.003
	3	-.002	.002	1.000	-.006	.003

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.029	.842[a]	3.000	84.000	.475
Wilks' lambda	.971	.842[a]	3.000	84.000	.475
Hotelling's trace	.030	.842[a]	3.000	84.000	.475
Roy's largest root	.030	.842[a]	3.000	84.000	.475

Each F tests the multivariate effect of Paragraph. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

APPENDIX D: TEST CONDITIONS REPEATED MEASURES SPSS OUTPUT

Within-Subjects Factors

Measure: MEASURE_1

paragraph	Dependent Variable
1	T1
2	T2
3	T3
4	T4
5	T5
6	T6

Between-Subjects Factors

		N
Env	0	44
	1	43
Cog	0	43
	1	44
Com	0	43
	1	44

Descriptive Statistics

	Env	Cog	Com	Mean	Std. Deviation	N
T1	0	0	0	.019681349636	.0086719096350	11
			1	.033214014818	.0178908815658	11
			Total	.026447682227	.0153686264331	22
		1	0	.028045743182	.0172453056071	11
			1	.037447524091	.0178212626576	11
			Total	.032746633636	.0177765814987	22
		Total	0	.023863546409	.0139911923972	22
			1	.035330769455	.0175599446296	22
			Total	.029597157932	.0167281108415	44
	1	0	0	.026100362500	.0100376829729	10
			1	.033318421727	.0167616020305	11
			Total	.029881250667	.0141230582535	21
		1	0	.037907238455	.0153464848253	11
			1	.062965966273	.0320567710425	11
			Total	.050436602364	.0276760002451	22
		Total	0	.032284916571	.0141282417655	21
			1	.048142194000	.0292120748514	22

			Total	.040397942233	.0242084481711	43
	Total	0	0	.022738022429	.0096815415200	21
			1	.033266218273	.0169177413396	22
			Total	.028124541233	.0147001548092	43
		1	0	.032976490818	.0167104495527	22
			1	.050206745182	.0284804775462	22
			Total	.041591618000	.0246669016331	44
		Total	0	.027976308581	.0145282476120	43
			1	.041736481727	.0246845658448	44
			Total	.034935476609	.0213453569012	87
T2	0	0	0	.017324185273	.0082164636292	11
			1	.045969125091	.0329219356917	11
			Total	.031646655182	.0276255320286	22
		1	0	.041325887273	.0220756941250	11
			1	.031358829818	.0121221476297	11
			Total	.036342358545	.0181123604615	22
		Total	0	.029325036273	.0203737866138	22
			1	.038663977455	.0253377538112	22
			Total	.033994506864	.0232070187755	44
	1	0	0	.029056603900	.0174339803748	10
			1	.037229002000	.0249242592518	11
			Total	.033337383857	.0215609860834	21
		1	0	.034728247909	.0146038200314	11
			1	.055564628636	.0209381908012	11
			Total	.045146438273	.0205920062222	22
		Total	0	.032027465048	.0158693183672	21
			1	.046396815318	.0243440996622	22
			Total	.039379225651	.0216577736797	43
	Total	0	0	.022911051286	.0143729220250	21
			1	.041599063545	.0288434767103	22
			Total	.032472359884	.0245700193676	43
		1	0	.038027067591	.0185747998189	22
			1	.043461729227	.0207893136493	22
			Total	.040744398409	.0196755572451	44
		Total	0	.030644827070	.0181476000008	43
			1	.042530396386	.0248648162202	44
			Total	.036655919598	.0224875606270	87
T3	0	0	0	.018250042636	.0099663769088	11
			1	.041261583909	.0264079072860	11
			Total	.029755813273	.0227611647473	22
		1	0	.032450240455	.0195898775964	11
			1	.032727863909	.0159960019926	11
			Total	.032589052182	.0174530359635	22
		Total	0	.025350141545	.0168183157368	22
			1	.036994723909	.0217485966087	22
			Total	.031172432727	.0200954469301	44

	1	0	0	.027954971900	.0150471174311	10
			1	.039269909182	.0154509686126	11
			Total	.033881843810	.0159619670418	21
		1	0	.040632090727	.0215774216799	11
			1	.054835470091	.0301591323594	11
			Total	.047733780409	.0266021229279	22
		Total	0	.034595367476	.0194105690130	21
			1	.047052689636	.0247036085013	22
			Total	.040968881140	.0228964400923	43
	Total	0	0	.022871437524	.0132747538377	21
			1	.040265746545	.0211377761683	22
			Total	.031770851442	.0196141841709	43
		1	0	.036541165591	.0205422549561	22
			1	.043781667000	.0261338658460	22
			Total	.040161416295	.0235168916554	44
		Total	0	.029865251884	.0185123672632	43
			1	.042023706773	.0235566875393	44
			Total	.036014355506	.0219592682144	87
T4	0	0	0	.021041835091	.0107661175908	11
			1	.047497940000	.0315615655471	11
			Total	.034269887545	.0266993911612	22
		1	0	.034459411000	.0196131143350	11
			1	.043657488636	.0263579233208	11
			Total	.039058449818	.0231552413424	22
		Total	0	.027750623045	.0168974607940	22
			1	.045577714318	.0284436328823	22
			Total	.036664168682	.0248164002904	44
	1	0	0	.031878894800	.0109450867860	10
			1	.034586466182	.0137882336831	11
			Total	.033297146476	.0122835426085	21
		1	0	.041136327909	.0127365554167	11
			1	.064266447455	.0273160598874	11
			Total	.052701387682	.0239308359381	22
		Total	0	.036728026429	.0125484219695	21
			1	.049426456818	.0260107873635	22
			Total	.043224897791	.0213193080199	43
	Total	0	0	.026202339714	.0119424010706	21
			1	.041042203091	.0246686247013	22
			Total	.033794827953	.0207007488107	43
		1	0	.037797869455	.0164955083132	22
			1	.053961968045	.0282380046216	22
			Total	.045879918750	.0242723306945	44
		Total	0	.032134936326	.0154389582679	43
			1	.047502085568	.0270058428365	44
			Total	.039906827897	.0232547361654	87
T5	0	0	0	.020610661182	.0109259550805	11

			1	.039613940455	.0188670572290	11
			Total	.030112300818	.0179146240557	22
		1	0	.032457811636	.0203263807404	11
			1	.032707249182	.0152394669725	11
			Total	.032582530409	.0175314320186	22
		Total	0	.026534236409	.0170396384388	22
			1	.036160594818	.0171053251730	22
			Total	.031347415614	.0175612579103	44
	1	0	0	.030215026500	.0109119767021	10
			1	.036312954364	.0122973545477	11
			Total	.033409179190	.0117870003299	21
		1	0	.034716369364	.0138741033311	11
			1	.053169471091	.0270972560472	11
			Total	.043942920227	.0230324445943	22
		Total	0	.032572872762	.0124552866221	21
			1	.044741212727	.0222728149487	22
			Total	.038798535070	.0189681454664	43
	Total	0	0	.025184168476	.0117230287199	21
			1	.037963447409	.0156324427211	22
			Total	.031722404209	.0151461603831	43
		1	0	.033587090500	.0170218080414	22
			1	.042938360136	.0238725687158	22
			Total	.038262725318	.0210284303066	44
		Total	0	.029483337884	.0151121255853	43
			1	.040450903773	.0200997374598	44
			Total	.035030152816	.0185458858812	87
T6	0	0	0	.022727272727	.0112972758299	11
			1	.041039895364	.0155306184877	11
			Total	.031883584045	.0162315423832	22
		1	0	.035239509818	.0206222911821	11
			1	.031386791364	.0257068748822	11
			Total	.033313150591	.0228273666329	22
		Total	0	.028983391273	.0174439671265	22
			1	.036213343364	.0213060896289	22
			Total	.032598367318	.0195876471584	44
	1	0	0	.021043165500	.0112176014520	10
			1	.037769784455	.0128190861472	11
			Total	.029804727810	.0145624758875	21
		1	0	.039384971455	.0169065657656	11
			1	.061046062091	.0204374993207	11
			Total	.050215516773	.0213985414570	22
		Total	0	.030650778143	.0169603074393	21
			1	.049407923273	.0204706776758	22
			Total	.040247457047	.0208926931756	43
	Total	0	0	.021925316905	.0110082969354	21
			1	.039404839909	.0139967781021	22

	Total	.030868328674	.0152911964631	43
1	0	.037312240636	.0185236339164	22
	1	.046216426727	.0272759669353	22
	Total	.041764333682	.0234775008226	44
Total	0	.029797696488	.0170245222996	43
	1	.042810633318	.0216998694799	44
	Total	.036378951897	.0204892633094	87

Box's Test of Equality of Covariance Matrices(a)

Box's M	346.165
F	1.740
df1	147
df2	7506.734
Sig.	.000

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.
a Design: Intercept + Env + Cog + Com + Env * Cog + Env * Com + Cog * Com + Env * Cog * Com
Within Subjects Design: paragraph

Multivariate Tests(b)

Effect		Value	F	Hypothesis df	Error df	Sig.
paragraph	Pillai's Trace	.117	1.984(a)	5.000	75.000	.091
	Wilks' Lambda	.883	1.984(a)	5.000	75.000	.091
	Hotelling's Trace	.132	1.984(a)	5.000	75.000	.091
	Roy's Largest Root	.132	1.984(a)	5.000	75.000	.091
paragraph * Env	Pillai's Trace	.026	.398(a)	5.000	75.000	.849
	Wilks' Lambda	.974	.398(a)	5.000	75.000	.849
	Hotelling's Trace	.027	.398(a)	5.000	75.000	.849
	Roy's Largest Root	.027	.398(a)	5.000	75.000	.849
paragraph * Cog	Pillai's Trace	.056	.895(a)	5.000	75.000	.489
	Wilks' Lambda	.944	.895(a)	5.000	75.000	.489
	Hotelling's Trace	.060	.895(a)	5.000	75.000	.489
	Roy's Largest Root	.060	.895(a)	5.000	75.000	.489
paragraph * Com	Pillai's Trace	.025	.377(a)	5.000	75.000	.863
	Wilks' Lambda	.975	.377(a)	5.000	75.000	.863
	Hotelling's Trace	.025	.377(a)	5.000	75.000	.863
	Roy's Largest Root	.025	.377(a)	5.000	75.000	.863
paragraph * Env * Cog	Pillai's Trace	.038	.593(a)	5.000	75.000	.705
	Wilks' Lambda	.962	.593(a)	5.000	75.000	.705
	Hotelling's Trace	.040	.593(a)	5.000	75.000	.705
	Roy's Largest Root	.040	.593(a)	5.000	75.000	.705
paragraph * Env * Com	Pillai's Trace	.066	1.053(a)	5.000	75.000	.393

	Wilks' Lambda	.934	1.053(a)	5.000	75.000	.393
	Hotelling's Trace	.070	1.053(a)	5.000	75.000	.393
	Roy's Largest Root	.070	1.053(a)	5.000	75.000	.393
paragraph * Cog * Com	Pillai's Trace	.089	1.457(a)	5.000	75.000	.214
	Wilks' Lambda	.911	1.457(a)	5.000	75.000	.214
	Hotelling's Trace	.097	1.457(a)	5.000	75.000	.214
	Roy's Largest Root	.097	1.457(a)	5.000	75.000	.214
paragraph * Env * Cog * Com	Pillai's Trace	.056	.891(a)	5.000	75.000	.492
	Wilks' Lambda	.944	.891(a)	5.000	75.000	.492
	Hotelling's Trace	.059	.891(a)	5.000	75.000	.492
	Roy's Largest Root	.059	.891(a)	5.000	75.000	.492

a Exact statistic
b Design: Intercept+Env+Cog+Com+Env * Cog+Env * Com+Cog * Com+Env * Cog * Com
Within Subjects Design: paragraph

Mauchly's Test of Sphericity(b)

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon(a)		
	Greenhouse-Geisser	Huynh-Feldt	Lower-bound	Greenhouse-Geisser	Huynh-Feldt	Lower-bound	Greenhouse-Geisser
paragraph	.722	25.157	14	.033	.888	1.000	.200

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.
a May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.
b Design: Intercept+Env+Cog+Com+Env * Cog+Env * Com+Cog * Com+Env * Cog * Com
Within Subjects Design: paragraph

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
paragraph	Sphericity Assumed	.001	5	.000	1.539	.177
	Greenhouse-Geisser	.001	4.442	.000	1.539	.184
	Huynh-Feldt	.001	5.000	.000	1.539	.177
	Lower-bound	.001	1.000	.001	1.539	.218
paragraph * Env	Sphericity Assumed	.000	5	8.61E-005	.464	.803
	Greenhouse-Geisser	.000	4.442	9.70E-005	.464	.782
	Huynh-Feldt	.000	5.000	8.61E-005	.464	.803
	Lower-bound	.000	1.000	.000	.464	.498
paragraph * Cog	Sphericity Assumed	.001	5	.000	.817	.538
	Greenhouse-Geisser	.001	4.442	.000	.817	.526

	Huynh-Feldt	.001	5.000	.000	.817	.538
	Lower-bound	.001	1.000	.001	.817	.369
paragraph * Com	Sphericity Assumed	.000	5	5.33E-005	.287	.920
	Greenhouse-Geisser	.000	4.442	6.00E-005	.287	.903
	Huynh-Feldt	.000	5.000	5.33E-005	.287	.920
	Lower-bound	.000	1.000	.000	.287	.594
paragraph * Env * Cog	Sphericity Assumed	.001	5	.000	.601	.700
	Greenhouse-Geisser	.001	4.442	.000	.601	.680
	Huynh-Feldt	.001	5.000	.000	.601	.700
	Lower-bound	.001	1.000	.001	.601	.441
paragraph * Env * Com	Sphericity Assumed	.001	5	.000	.895	.485
	Greenhouse-Geisser	.001	4.442	.000	.895	.476
	Huynh-Feldt	.001	5.000	.000	.895	.485
	Lower-bound	.001	1.000	.001	.895	.347
paragraph * Cog * Com	Sphericity Assumed	.002	5	.000	1.672	.140
	Greenhouse-Geisser	.002	4.442	.000	1.672	.149
	Huynh-Feldt	.002	5.000	.000	1.672	.140
	Lower-bound	.002	1.000	.002	1.672	.200
paragraph * Env * Cog * Com	Sphericity Assumed	.001	5	.000	.832	.528
	Greenhouse-Geisser	.001	4.442	.000	.832	.516
	Huynh-Feldt	.001	5.000	.000	.832	.528
	Lower-bound	.001	1.000	.001	.832	.365
Error(paragraph)	Sphericity Assumed	.073	395	.000		
	Greenhouse-Geisser	.073	350.890	.000		
	Huynh-Feldt	.073	395.000	.000		
	Lower-bound	.073	79.000	.001		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	paragraph	Type III Sum of Squares	df	Mean Square	F	Sig.
paragraph	Linear	4.41E-005	1	4.41E-005	.199	.657
	Quadratic	.000	1	.000	2.063	.155
	Cubic	2.86E-006	1	2.86E-006	.015	.902
	Order 4	.000	1	.000	1.224	.272
	Order 5	.001	1	.001	4.647	.034
paragraph * Env	Linear	5.41E-005	1	5.41E-005	.244	.623
	Quadratic	4.25E-005	1	4.25E-005	.228	.635
	Cubic	4.03E-005	1	4.03E-005	.213	.646
	Order 4	.000	1	.000	.718	.399
	Order 5	.000	1	.000	1.045	.310
paragraph * Cog	Linear	5.78E-005	1	5.78E-005	.260	.611
	Quadratic	.000	1	.000	.923	.340
	Cubic	2.42E-005	1	2.42E-005	.128	.722

	Order 4	.000	1	.000	2.187	.143
	Order 5	.000	1	.000	.922	.340
paragraph * Com	Linear	2.26E-006	1	2.26E-006	.010	.920
	Quadratic	9.35E-007	1	9.35E-007	.005	.944
	Cubic	9.44E-006	1	9.44E-006	.050	.824
	Order 4	.000	1	.000	.904	.345
	Order 5	.000	1	.000	.645	.424
paragraph * Env * Cog	Linear	7.39E-005	1	7.39E-005	.333	.566
	Quadratic	.000	1	.000	.853	.358
	Cubic	7.19E-007	1	7.19E-007	.004	.951
	Order 4	.000	1	.000	1.891	.173
	Order 5	2.55E-005	1	2.55E-005	.147	.702
paragraph * Env * Com	Linear	4.07E-005	1	4.07E-005	.183	.670
	Quadratic	.001	1	.001	2.838	.096
	Cubic	.000	1	.000	.975	.326
	Order 4	4.02E-005	1	4.02E-005	.255	.615
	Order 5	3.51E-005	1	3.51E-005	.203	.654
paragraph * Cog * Com	Linear	.000	1	.000	.466	.497
	Quadratic	.000	1	.000	.574	.451
	Cubic	.001	1	.001	5.870	.018
	Order 4	.000	1	.000	1.114	.294
	Order 5	5.54E-005	1	5.54E-005	.321	.573
paragraph * Env * Cog * Com	Linear	1.01E-005	1	1.01E-005	.045	.832
	Quadratic	.000	1	.000	.705	.404
	Cubic	.000	1	.000	.561	.456
	Order 4	.000	1	.000	1.573	.214
	Order 5	.000	1	.000	1.600	.210
Error(paragraph)	Linear	.018	79	.000		
	Quadratic	.015	79	.000		
	Cubic	.015	79	.000		
	Order 4	.012	79	.000		
	Order 5	.014	79	.000		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	.690	1	.690	543.448	.000
Env	.008	1	.008	6.005	.016
Cog	.013	1	.013	10.317	.002
Com	.022	1	.022	17.103	.000
Env * Cog	.005	1	.005	4.040	.048
Env * Com	.000	1	.000	.304	.583
Cog * Com	.001	1	.001	.492	.485
Env * Cog * Com	.009	1	.009	6.757	.011
Error	.100	79	.001		

APPENDIX E: TEST CONDITIONS GLM-ANOVA SPSS OUTPUT

Between-Subjects Factors

		N
Env	0	44
	1	43
Cog	0	43
	1	44
Com	0	43
	1	44

Descriptive Statistics

Dependent Variable:TotalTestErrorRate

Env	Cog	Com	Mean	Std. Deviation	N
0	0	0	.019945215000	.0082276079353	11
		1	.041222317455	.0210226354948	11
		Total	.030583766227	.0190067410893	22
	1	0	.033765367545	.0146844733578	11
		1	.034380675455	.0136381902938	11
		Total	.034073021500	.0138330560682	22
	Total	0	.026855291273	.0135992897073	22
		1	.037801496455	.0176432352277	22
		Total	.032328393864	.0165225191737	44
1	0	0	.027534458400	.0079108030937	10
		1	.036376775273	.0130261990047	11
		Total	.032166148190	.0115533426835	21
	1	0	.038015159182	.0109715589505	11
		1	.058309163909	.0193252988774	11
		Total	.048162161545	.0185210038789	22
	Total	0	.033024349286	.0108221008712	21
		1	.047342969591	.0196118933355	22
		Total	.040350155023	.0173358388455	43
Total	0	0	.023559140429	.0087802594792	21
		1	.038799546364	.0172453812606	22
		Total	.031356557419	.0156470578440	43
	1	0	.035890263364	.0128348904038	22
		1	.046344919682	.0204052084742	22
		Total	.041117591523	.0176566372405	44
	Total	0	.029868087047	.0125688637388	43
		1	.042572233023	.0190565554278	44

Descriptive Statistics

Dependent Variable:TotalTestErrorRate

Env	Cog	Com	Mean	Std. Deviation	N
0	0	0	.019945215000	.0082276079353	11
		1	.041222317455	.0210226354948	11
		Total	.030583766227	.0190067410893	22
	1	0	.033765367545	.0146844733578	11
		1	.034380675455	.0136381902938	11
		Total	.034073021500	.0138330560682	22
	Total	0	.026855291273	.0135992897073	22
		1	.037801496455	.0176432352277	22
		Total	.032328393864	.0165225191737	44
1	0	0	.027534458400	.0079108030937	10
		1	.036376775273	.0130261990047	11
		Total	.032166148190	.0115533426835	21
	1	0	.038015159182	.0109715589505	11
		1	.058309163909	.0193252988774	11
		Total	.048162161545	.0185210038789	22
	Total	0	.033024349286	.0108221008712	21
		1	.047342969591	.0196118933355	22
		Total	.040350155023	.0173358388455	43
Total	0	0	.023559140429	.0087802594792	21
		1	.038799546364	.0172453812606	22
		Total	.031356557419	.0156470578440	43
	1	0	.035890263364	.0128348904038	22
		1	.046344919682	.0204052084742	22
		Total	.041117591523	.0176566372405	44
	Total	0	.029868087047	.0125688637388	43
		1	.042572233023	.0190565554278	44
		Total	.036293172368	.0173072238389	87

Levene's Test of Equality of Error Variances[a]

Dependent Variable:TotalTestErrorRate

F	df1	df2	Sig.
3.522	7	79	.002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Env + Cog + Com + Env * Cog + Env * Com + Cog * Com + Env * Cog * Com

Tests of Between-Subjects Effects

Dependent Variable:TotalTestErrorRate

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.009[a]	7	.001	6.538	.000
Intercept	.114	1	.114	551.432	.000
Env	.001	1	.001	6.289	.014
Cog	.002	1	.002	10.206	.002
Com	.004	1	.004	17.127	.000
Env * Cog	.001	1	.001	4.255	.042
Env * Com	7.126E-5	1	7.126E-5	.345	.559
Cog * Com	.000	1	.000	.558	.457
Env * Cog * Com	.001	1	.001	6.783	.011
Error	.016	79	.000		
Total	.140	87			
Corrected Total	.026	86			

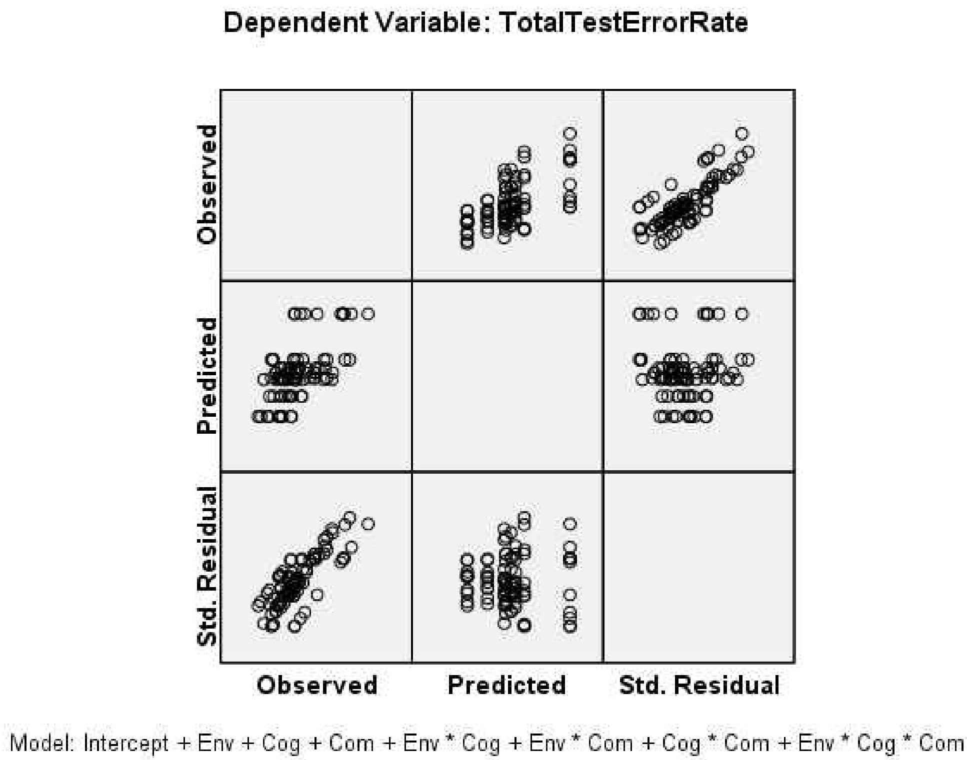
a. R Squared = .367 (Adjusted R Squared = .311)

Estimated Marginal Means

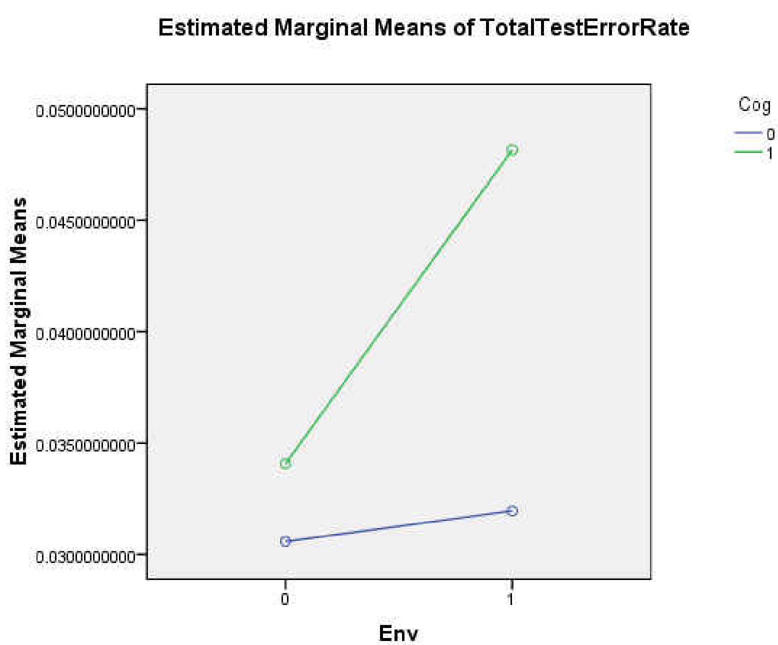
Grand Mean

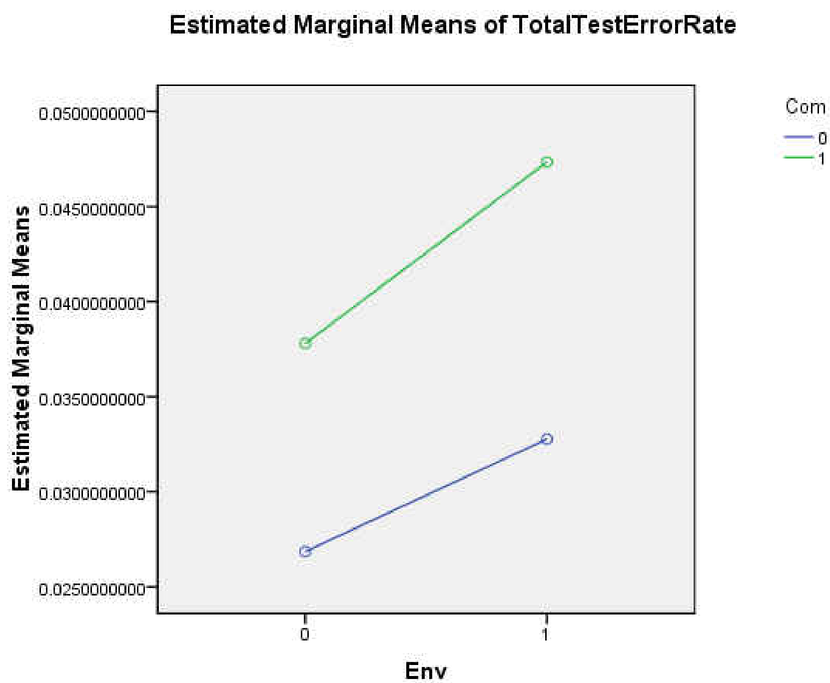
Dependent Variable:TotalTestErrorRate

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
.036	.002	.033	.039



Profile Plots




Estimated Marginal Means of TotalTestErrorRate
Estimated Marginal Means
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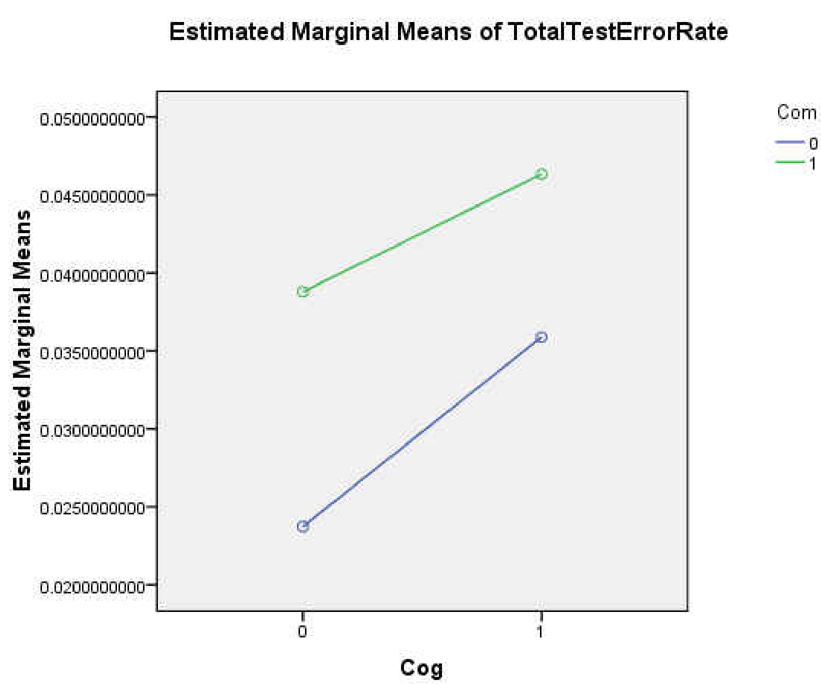
0.0450000000
0.0400000000
0.0350000000
0.0300000000
0.0250000000
0
1
Env
Com
0
1


Estimated Marginal Means of TotalTestErrorRate
Estimated Marginal Means
0.0500000000
0.0450000000
0.0400000000
0.0350000000
0.0300000000
0.0250000000
0.0200000000
0
1
Cog
Com
0
1

APPENDIX F: TEST CONDITIONS BY GROUP ANOVA SPSS OUTPUT

Between-Subjects Factors

		N
TestGroup	1	11
	2	11
	3	11
	4	11
	5	10
	6	11
	7	11
	8	11

Descriptive Statistics

Dependent Variable:TotalTestErrorRate

TestGroup	Mean	Std. Deviation	N
1	.019945215000	.0082276079353	11
2	.033765367545	.0146844733578	11
3	.041222317455	.0210226354948	11
4	.034380675455	.0136381902938	11
5	.027534458400	.0079108030937	10
6	.038015159182	.0109715589505	11
7	.036376775273	.0130261990047	11
8	.058309163909	.0193252988774	11
Total	.036293172368	.0173072238389	87

Tests of Between-Subjects Effects

Dependent Variable:TotalTestErrorRate

Source	Type III Sum of Squares	df	Mean Square	F	Sig.

Corrected Model	.009[a]	7	.001	6.538	.000
Intercept	.114	1	.114	551.432	.000
TestGroup	.009	7	.001	6.538	.000
Error	.016	79	.000		
Total	.140	87			
Corrected Total	.026	86			

a. R Squared = .367 (Adjusted R Squared = .311)

Post Hoc Tests

Multiple Comparisons

TotalTestErrorRate

Tukey HSD

(I) TestGroup	(J) TestGroup	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
1	2	-.013820152545	.0061270131297	.331	-.032897486830	.005257181739
	3	-2.127710245455E-2	.0061270131297	.018	-.040354436739	-.002199768170
	4	-.014435460455	.0061270131297	.278	-.033512794739	.004641873830
	5	-.007589243400	.0062783201883	.927	-.027137693916	.011959207116
	6	-.018069944182	.0061270131297	.076	-.037147278467	.001007390103
	7	-.016431560273	.0061270131297	.144	-.035508894558	.002645774012
	8	-3.836394890909E-2	.0061270131297	.000	-.057441283194	-.019286614624
2	1	.013820152545	.0061270131297	.331	-.005257181739	.032897486830
	3	-.007456949909	.0061270131297	.924	-.026534284194	.011620384376
	4	-.000615307909	.0061270131297	1.000	-.019692642194	.018462026376
	5	.006230909145	.0062783201883	.974	-.013317541371	.025779359662
	6	-.004249791636	.0061270131297	.997	-.023327125921	.014827542648

	7	-.002611407727	.0061270131297	1.000	-.021688742012	.016465926558
	8	-2.454379636364E-2	.0061270131297	.003	-.043621130648	-.005466462079
3	1	.021277102455*	.0061270131297	.018	.002199768170	.040354436739
	2	.007456949909	.0061270131297	.924	-.011620384376	.026534284194
	4	.006841642000	.0061270131297	.951	-.012235692285	.025918976285
	5	.013687859055	.0062783201883	.375	-.005860591462	.033236309571
	6	.003207158273	.0061270131297	1.000	-.015870176012	.022284492558
	7	.004845542182	.0061270131297	.993	-.014231792103	.023922876467
	8	-.017086846455	.0061270131297	.113	-.036164180739	.001990487830
4	1	.014435460455	.0061270131297	.278	-.004641873830	.033512794739
	2	.000615307909	.0061270131297	1.000	-.018462026376	.019692642194
	3	-.006841642000	.0061270131297	.951	-.025918976285	.012235692285
	5	.006846217055	.0062783201883	.957	-.012702233462	.026394667571
	6	-.003634483727	.0061270131297	.999	-.022711818012	.015442850558
	7	-.001996099818	.0061270131297	1.000	-.021073434103	.017081234467
	8	-2.392848845455E-2	.0061270131297	.005	-.043005822739	-.004851154170
5	1	.007589243400	.0062783201883	.927	-.011959207116	.027137693916
	2	-.006230909145	.0062783201883	.974	-.025779359662	.013317541371
	3	-.013687859055	.0062783201883	.375	-.033236309571	.005860591462
	4	-.006846217055	.0062783201883	.957	-.026394667571	.012702233462
	6	-.010480700782	.0062783201883	.707	-.030029151298	.009067749734
	7	-.008842316873	.0062783201883	.851	-.028390767389	.010706133644
	8	-3.077470550909E-2	.0062783201883	.000	-.050323156025	-.011226254993
6	1	.018069944182	.0061270131297	.076	-.001007390103	.037147278467
	2	.004249791636	.0061270131297	.997	-.014827542648	.023327125921
	3	-.003207158273	.0061270131297	1.000	-.022284492558	.015870176012
	4	.003634483727	.0061270131297	.999	-.015442850558	.022711818012
	5	.010480700782	.0062783201883	.707	-.009067749734	.030029151298

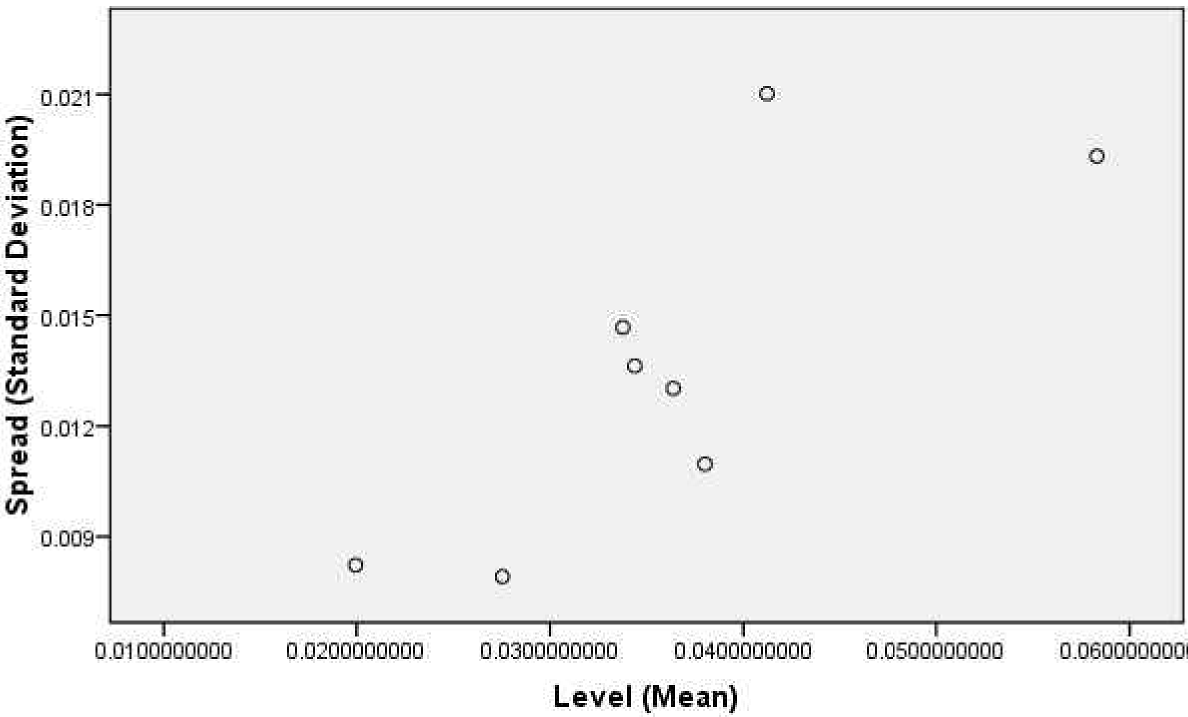
	7	.001638383909	.0061270131297	1.000	-.017438950376	.020715718194
	8	-2.029400472727E-2	.0061270131297	.029	-.039371339012	-.001216670442
7	1	.016431560273	.0061270131297	.144	-.002645774012	.035508894558
	2	.002611407727	.0061270131297	1.000	-.016465926558	.021688742012
	3	-.004845542182	.0061270131297	.993	-.023922876467	.014231792103
	4	.001996099818	.0061270131297	1.000	-.017081234467	.021073434103
	5	.008842316873	.0062783201883	.851	-.010706133644	.028390767389
	6	-.001638383909	.0061270131297	1.000	-.020715718194	.017438950376
	8	-2.193238863636E-2	.0061270131297	.013	-.041009722921	-.002855054352
8	1	.038363948909*	.0061270131297	.000	.019286614624	.057441283194
	2	.024543796364*	.0061270131297	.003	.005466462079	.043621130648
	3	.017086846455	.0061270131297	.113	-.001990487830	.036164180739
	4	.023928488455*	.0061270131297	.005	.004851154170	.043005822739
	5	.030774705509*	.0062783201883	.000	.011226254993	.050323156025
	6	.020294004727*	.0061270131297	.029	.001216670442	.039371339012
	7	.021932388636*	.0061270131297	.013	.002855054352	.041009722921

Based on observed means.

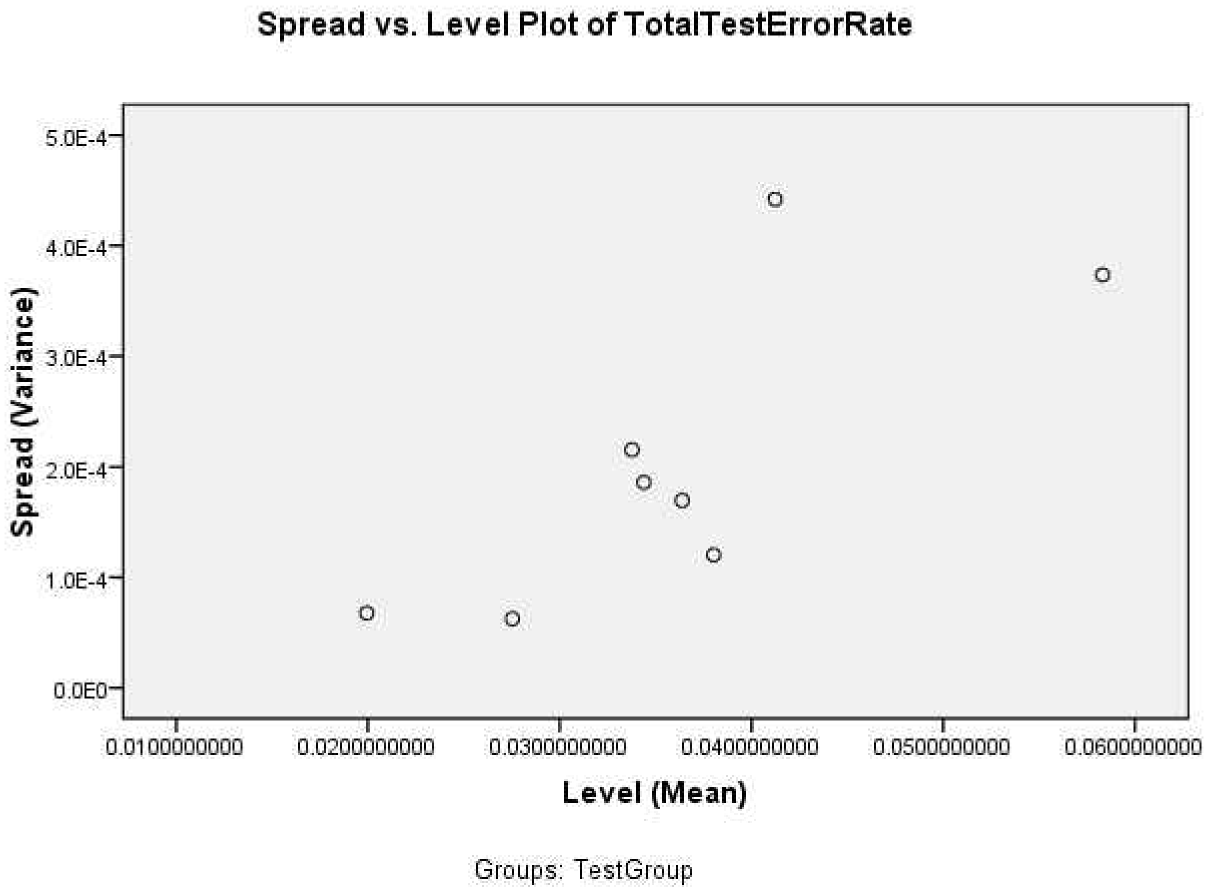
The error term is Mean Square(Error) = .000.

*. The mean difference is significant at the .05 level.

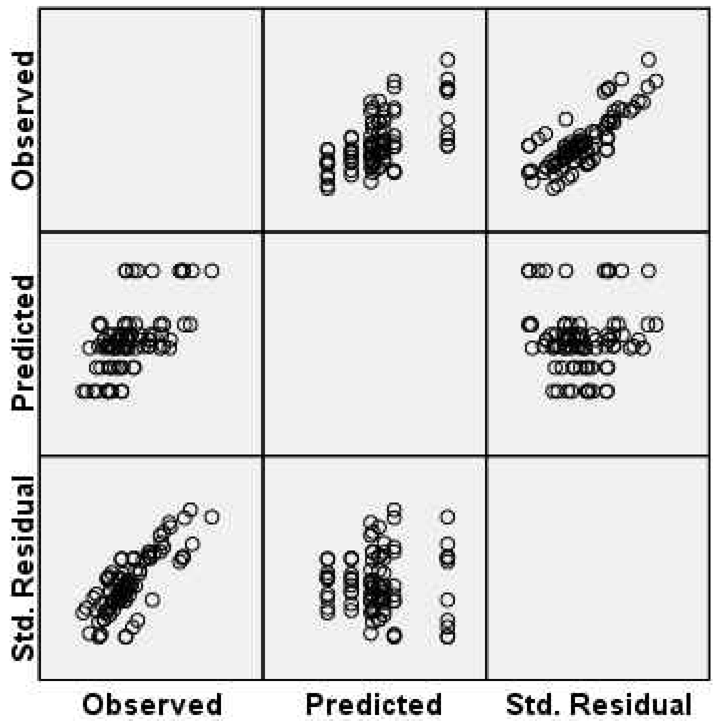
Spread vs. Level Plot of TotalTestErrorRate



Groups: TestGroup

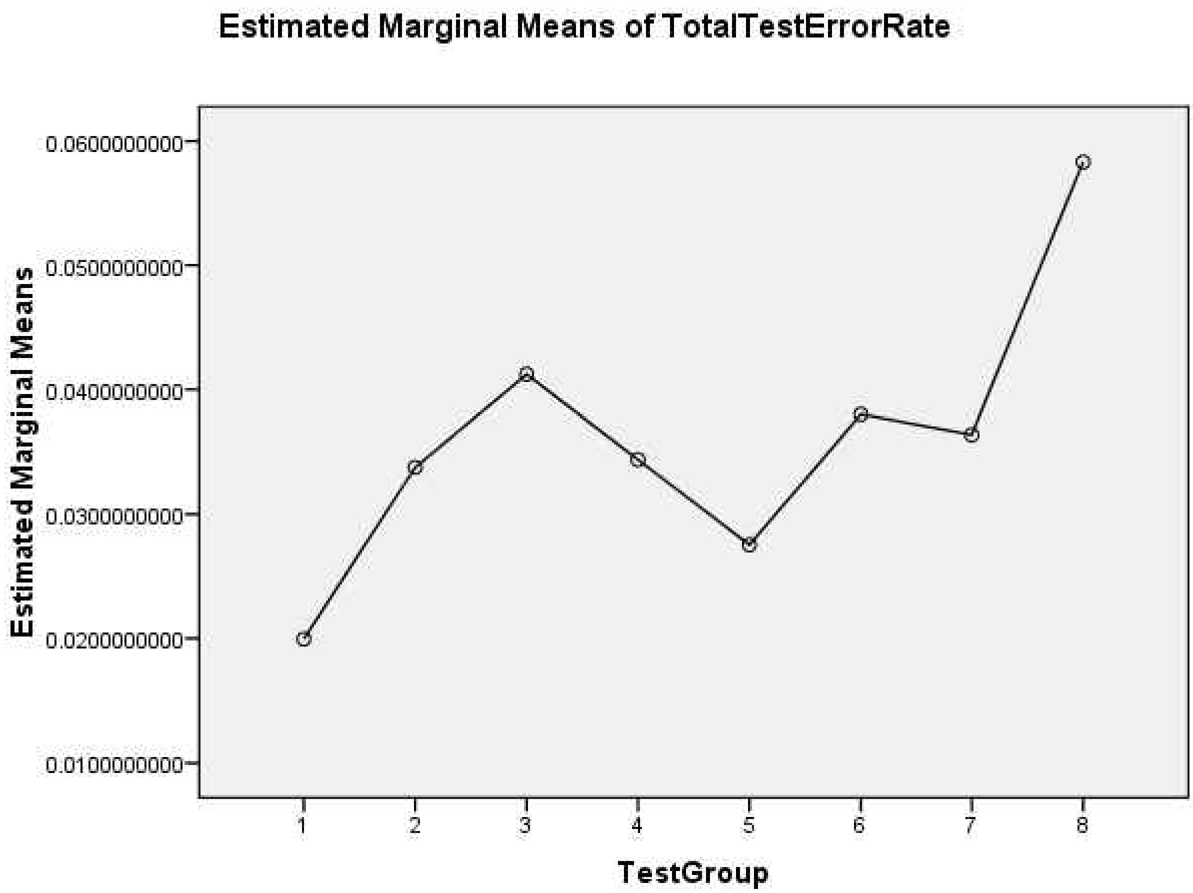

Spread vs. Level Plot of TotalTestErrorRate
Spread (Variance)
5.0E-4
4.0E-4
3.0E-4
2.0E-4
1.0E-4
0.0E0
0.0100000000
0.0200000000
0.0300000000
0.0400000000
0.0500000000
0.0600000000
Level (Mean)
Groups: TestGroup

Dependent Variable: TotalTestErrorRate



Model: Intercept + TestGroup

Profile Plots



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