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QUANTIFYING TRUST, DISTRUST, AND SUSPICION IN HUMAN-SYSTEM INTERACTIONS

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14. ABSTRACT

In this research effort we used our new usability lab containing a state-of-the art suite of cognitive, physiological, and behavioral measurement devices to isolate and quantify the various low level variables that indicate the level of trust that is present while a person works with his or her computer system. Recent advances in Biomedical Engineering have resulted in the development of extremely non-invasive brain measurement devices. These devices hold great potential for the quantitative, real-time measurement of user states during realistic human-computer interactions. This research effort built upon our previous research; where we developed techniques to enhance usability testing with functional near infrared spectroscopy (fNIRS) and Electroencephalography (EEG). Our primary goal was to apply our research to the AFOSR Denial & Disrupt project, measuring the effects of various interface disruptions on users' cognitive workload.

In this effort, we continued our research with non-invasive brain measurement and explored the quantitative measurement of trust, distrust, and suspicion while a user works with his or her computer system. This timely research holds great potential in the cyber-operations domain, where we

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Quantifying Trust, Distrust, and Suspicion in Human-System Interactions

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Overview

With specialties in HCI and machine learning, our research explores the use of non-invasive brain and physiological sensor measurement to classify user states passively in order to enhance usability testing and adaptive system design. We have a strong record of accomplishment in applying our non-invasive physiological sensor research to avenues of research in the cyber domain.

Lab at Syracuse University

With support from the AFOSR DURIP program, we run a state-of-the-art HCI lab. The lab contains over $500K of non-invasive cognitive, physiological, and behavioral measurement devices. This includes a 52-channel functional near-infrared spectroscopy (fNIRS) device from Hitachi Medical (ETG 4000), Advanced Brain Monitoring's b-alert wireless EEG, a desk mounted faceLab eyetracker, two wireless galvanic skin response sensors from Affectiva, faceReader emotion recognition software, Morae usability testing software, and several computer workstations for use in experiments.

With their potential to monitor people's mental states non-invasively and in real-time, Electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS) have become popular brain imaging techniques, and have been used by researchers to measure a wide range of cognitive and emotional states in operational settings [1-13]. Electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS) are popular, non-invasive, brain imaging techniques. Unlike other brain devices which require subjects to lie in restricted positions (fMRI), or to drink hazardous materials (PET), EEG and fNIRS can non-invasively measure users' brain activity under normal working conditions [1]. This makes EEG and fNIRs appropriate choices for brain measurement in HCI. EEG and fNIRS measure different physiological responses to mental state changes. EEG measures the electrical potentials caused by neurons firing during brain activity. fNIRS measures blood volume and oxygenation changes, reflecting hemodynamic responses to brain activity. The majority of brain measurement research in HCI uses EEG to measure users' states while a smaller body of research uses fNIRS. fNIRS is the only non-invasive device that can be used in operational setting that provides us with functional localizations

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comparable to fMRI. Since fNIRS and fMRI both measure elements of the Blood Oxygen Level Dependent (BOLD) signal. Researchers have recently explored the combination of the two devices to measure brain function [2-5]. This is promising, as combining the two devices can provide information about both the neural activations and the subsequent oxygenation and blood flow changes in the brain. Furthermore, by pairing the low spatial and high temporal resolution of EEG with the high spatial and low temporal resolution of fNIRs, it may be possible to overcome limitations of each measurement technology.

Our high density 52-channel fNIRS has head probe configurations that enable brain measurement across the entire head, rather than being limited to the forehead (Figure 1).

Figure 1: The ETG4000 52-channel fNIRS at Newhouse.

Furthermore, the high spatial resolution of our fNIRS enables us to study functional brain regions that contribute to information processing. For example, we have used fNIRS to differentiate between verbal search load, response inhibition load, verbal working memory load, and spatial working memory load [1, 7]. We have also successfully localized brain regions such as the dorsolateral prefrontal cortex as it relates to emotion regulation, the paracingulate cortex as it relates to suspicion, and Broca's area as it relates to highly alarming and stressful situations [14]. These findings are expanded upon next. As an example of the high spatial resolution afforded by the fNIRS device, Figure 2 depicts the results of statistical tests using fNIRS and fMRI when subjects viewed the same stimulus [15].

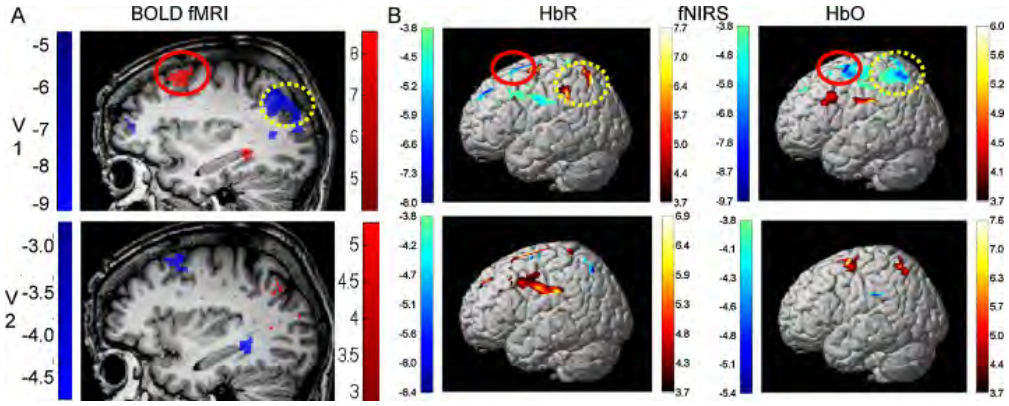

Figure 2: Example showing the statistical test results of a particular stimulus on one subject [15].

Our Prior Related Work (2007-2010)

Dr. Leanne Hirshfield has established a portfolio of work in the cyber domain. Since beginning work with AFOSR as a PhD student in 2007, her research has focused on:

1) Using fNIRS to accurately measure cognitive load in real time during usability studies. One end goal of this research was to conduct usability studies with fNIRS to measure the workload of select D5 techniques on unsuspecting computer users [1, 7, 16-19].
2) Defining the construct of suspicion as it relates to the IT (information technology) environment[20].
3) Using a suite of non-invasive sensors to measure correlates relating to trust, distrust, and suspicion in computer users working in the IT domain [6, 14, 21].

Dr. Hirshfield's earliest AFOSR 6.1 research began in 2007 while she was a graduate student at Tufts University as part of the AFOSR Denial and Disrupt (D&D) project. Much has changed in the cyber landscape since 2007. The D&D project aimed to take an offensive stance toward adversarial computer operators in cyberspace. At the time, cyber-operations techniques had been developed by personnel at Assured Information Security (AIS) to monitor or disrupt an adversarial operator's computer. By introducing subtle – and hopefully undetectable - disruptions into an adversary's computer system, the D&D project aimed to increase user workload, cause distractions, and increase user error rates.

Some examples of disruptions are disabling copy and paste functionality, changing the effects of pressing various keyboard keys, causing pop-ups to appear on the screen, and slowing down program response time. By introducing these subtle disruptions into an adversary's computer system the D&D project aimed to continually reduce the adversary's threat potential while monitoring his actions. Understanding the effects that sequences of disruptions have on operators was essential to the success of the D&D project. Fundamental questions stemming from the D&D project were:

- How do we measure the effectiveness of various interface disruptions?
- What kinds of disruptions should we choose when:
    - We want to increase a computer operator's error rate?
    - We want to make a computer operator less efficient?
    - We want to overload or distract a computer operator?
- What human performance characteristics do we measure?
- How do we conduct usability experiments to acquire the necessary metrics?

Ideally, these usability tests could be conducted to evaluate the effects of the D&D disruptions on computer users. While usability tests can acquire objective, real-time metrics of a user's speed and accuracy while working with an interface, acquiring additional metrics about the user's workload while working with a computer system involved the use of surveys. These surveys are highly subjective, are often prone to subject biases, and are administered after a task has been completed, lacking valuable insight into the user's changing experiences during a task.

The novelty of our original AFOSR 6.1 research stemmed from the use of fNIRS to measure and quantify cognitive load. We developed machine learning techniques that enabled us to predict workload on a single trial basis, while users completed computer tasks. We were then able to measure accurately the effect that certain D5 techniques had on the cognitive load of computer users. In particular, we examined cognitive load, overload, and distraction as effected by pop-ups, dropped keystrokes, switched keystrokes.

Through our work conducting this initial 6.1 research project, we were among the first to pair fNIRS data with machine learning techniques, and among the first researchers to demonstrate the potential of fNIRS as a non-invasive technique for the real-time assessment of cognitive load for usability tests and adaptive systems. We enhanced usability testing and the measurement of user states in general, and more specifically, we applied the findings from our basic research to the usability testing problems stemming from the Denial & Disrupt project [1, 7, 16, 17, 19, 21].

Accomplishments of this Research Project (2011 – 2014)

The research described in this final report was a follow-up effort to the research described above. While conducting the initial D&D research on cognitive load, the critical notion of 'suspicion' emerged. It was obvious that a disruption was only useful if it did not cause suspicion in adversarial operators. From the defensive point of view, it was also apparent that many complacent workers would have an initial onset of suspicion when they noticed something amiss with the computer, but they would never end up becoming suspicious (this would result in a successful cyber attack occurring on blue forces in the operational domain). Dr. Hirshfield worked with Dr. Phil Bobko and Lt. Col. Alex Barelka to better understand the role of suspicion in the IT domain. It was clear from the start that the construct of suspicion was poorly defined in the literature, and that the scant literature that described manipulations of suspicion in experimental settings was of variable quality.

The result of this exploration into the suspicion domain was a recent Human Factors publication [20]. In that publication, studies that consider suspicion were reviewed and integrated. These

interdisciplinary literature areas included communication, psychology, human factors, management, marketing, information technology, and brain/neurology. We first developed a generic model of state-level suspicion. Research propositions were then derived within IT contexts. Our findings indicated that fundamental components of suspicion include (i) uncertainty, (ii) increased cognitive processing (e.g., generation of alternative explanations for perceived discrepancies), and (iii) perceptions of (mal)intent. We therefore defined "state suspicion" as the simultaneous occurrence of these three components. Our analysis also suggested that trust inhibits suspicion, while distrust can be a catalyst of state-level suspicion. Based on a three-stage model of state-level suspicion (Figure 3), associated research propositions and questions were developed.

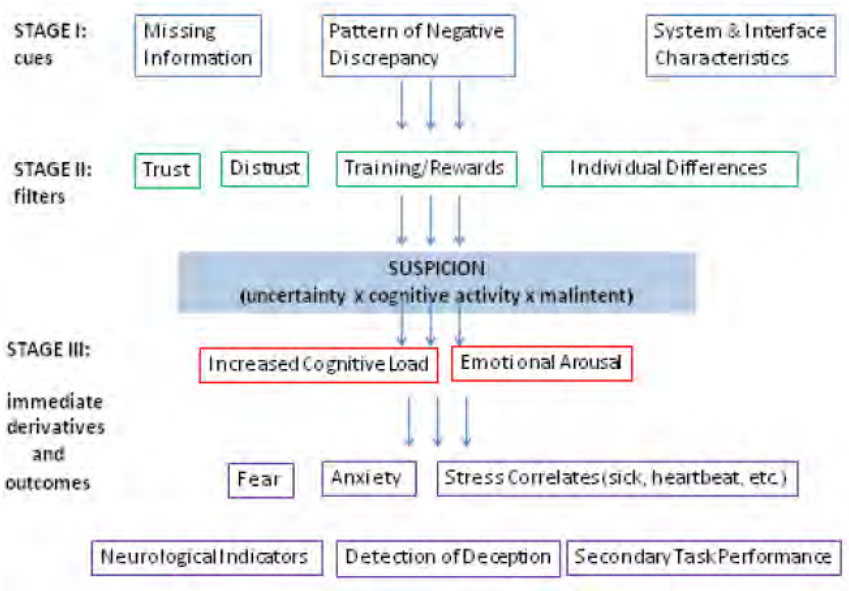

Figure 3: Our three stage model of suspicion [20].

These propositions and questions were intended to help guide future work on the measurement of suspicion (self-report and neurological), as well as the role of the construct of suspicion in models of decision-making and detection of deception[20].

In addition to the theoretically-based work on suspicion and trust described above, Dr. Hirshfield has remained focused on the use of machine learning methods to accurately predict mental states that are of particular interest in the cyber domain using physiological (fNIRS, EEG, eyetracking, and GSR) and behavioral (keypress and mouse movement) sensors. A practical – and generally useful - byproduct of these experiments and research was the development of custom machine learning algorithms that predict mental states with cognitive, physiological, and behavioral data [1, 6, 17, 28]. Unlike traditional statistical techniques (which complement the results of machine learning), accurate machine learning classifiers are essential in order to predict the presence, or effects, of cyber techniques in real-time on blue and red force cyber operators.

Model of the Physiological Correlates of Trust, Distrust, and Suspicion

Another valuable result from Dr. Hirshfield's AFOSR research is a model describing the physiological correlates of trust, distrust, and suspicion (Figure 4). The model is grounded in the theoretical suspicion and trust work done by Bobko, Barelka and Hirshfield [20], and it combines the findings from Dr. Hirshfield's prior AFOSR physio- sensor experiments mentioned above [1, 6, 7, 14]. Although the model has implications for interpersonal communications, the focus of the model is on the physiological correlates of trust, distrust, and suspicion within the IT domain. The rest of this section describes Figure 4 in detail.

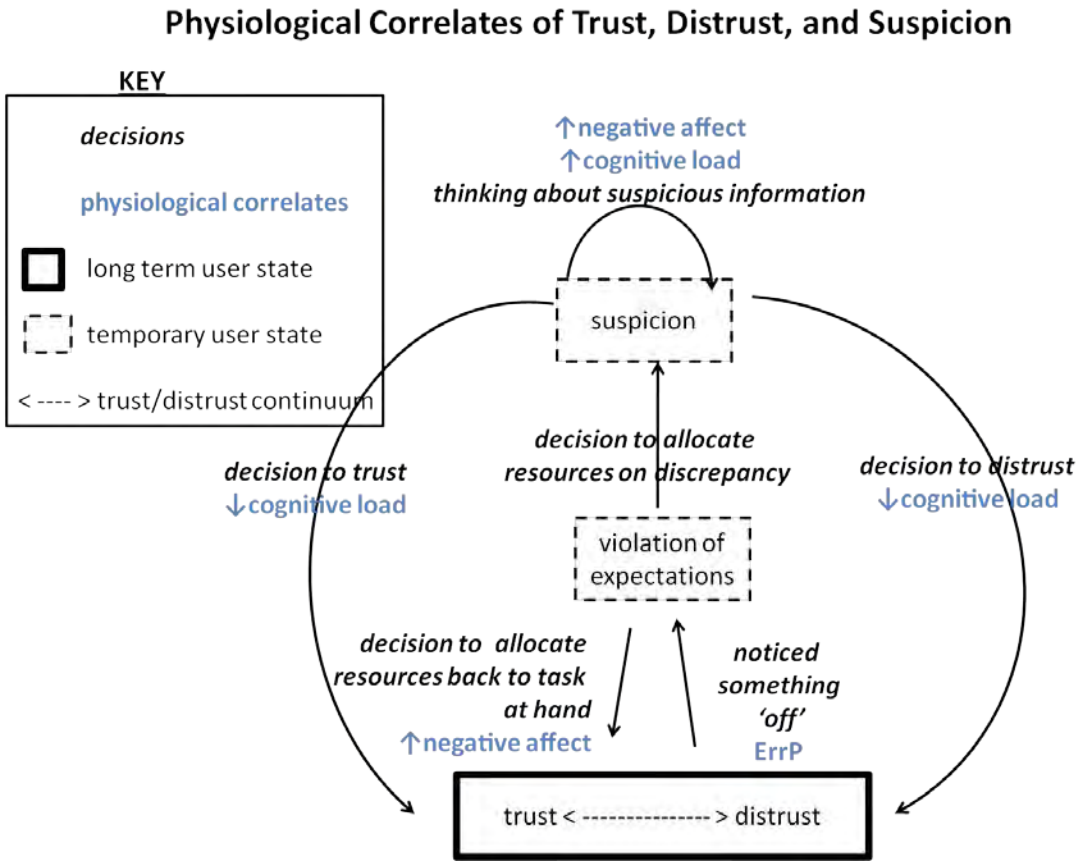

Figure 4: Hirshfield's hypothesized physiological correlates of trust, distrust, and suspicion.

At a high level, the model in Figure 4 depicts the mental states that a computer operator transitions between when encountering problems (likely caused by D5 techniques) with their computer system. These computer operators spend most of their time in long term user states of trust and distrust (bottom of Fig 4). While the literature does not fully agree on the relationship between trust and distrust, this model views trust and distrust as uni-dimensional or, at the very least, highly overlapping multi-dimensional, constructs. In practical terms, computer operators are continually updating their levels of trust based on interactions with their environment.

Many operators are predisposed to have a high level of trust (or distrust) that usually serves as a lens by which they view their interactions in their environment (called *propensity to trust*). Most computer operators tend to be cognitive misers; they prefer to spend their time focusing their

cognitive resources on the task at hand, rather than spending effort interpreting interactions from the computer system or an external agent [7]. For example, operators with a high propensity to trust view interactions with others as honest and straightforward, enabling them to adapt a truth heuristic that can limit workload during interactions with their environment. Viewing the environment through a predisposed 'high trust' lens is one piece of information built into people's *mental model* (i.e., one's internal model of how the world around them works) that helps them to interact with their environment with minimal cognitive load.

When something occurs that violates an operator's mental model (such as a program crash, or an obviously deceitful email allegedly from a coworker) that operator's expectations are violated. In that case, something called an error potential (ErrP) occurs in the computer user's brain [6, 22, 23]. This can, and has been, detected with EEG, even when the violation of expectations is extremely subtle [6]. Once a violation of expectations has occurred, the user can either 1) attend to that item and become suspicious or 2) return to the task at hand.

If a computer user becomes suspicious, he experiences a "feeling of uncertainty and perceived malintent about the underlying information or actions of an external agent" [20]. This involves an increase in negative affect as well as an increase in cognitive load as he generates hypotheses about the source, and meaning of, the discrepancy. The suspicious state ends when the user decides either to re-enter a trustful state (go back to the task at hand) or to become distrustful (which likely involves an action such as making a call to the IT department, or running antivirus software).

If the user does not become suspicious (and many computer users experience violations in expectations time and time again without ever becoming suspicious), then that user will remain in his long term state residing somewhere within the trust/distrust continuum. It is worth noting that the Bobko, Barelka, Hirshfield theory states that distrust increases likelihood to become suspicious while trust buffers suspicion [20]. This means that a person who is predisposed to view the world with high distrust will be quicker to become suspicious than will his highly-trusting peer. In the case where the user experiences a violation in expectations without becoming suspicious, there will likely be an increase in negative affect (thought not always) if the user believes the discrepancy is a result of his or her own human error. Or, the user may attribute the discrepancy to problems with the computer system (i.e., "this program is so slow!") and trust may be lowered.

As stated previously, the model in Figure 5 represents the culmination of all of Dr. Hirshfield's prior theoretical and experimental work in this domain. **The importance of this model is that it is not only grounded in theoretical work from research on trust, distrust, suspicion, cognitive load, and cognitive heuristics, but it shows how transitions between states of trust and suspicion can be measured in experimental settings with physiological sensors**. This model will play an important role in the proposed work discussed in this document.

The end goal of measuring the effects that a given cyber technique has on computer operators has been a common thread throughout these research efforts. Table 1 provides a brief overview of the specific D5 techniques that have been tested in this prior work, and the effects of the D5 techniques as measured by non-invasive physiological sensors.

Table 1: Overview of cyber techniques that have been tested with non-invasive sensors in Dr. Hirshfield's prior AFOSR work.

D5 Effect	Measured Effect on Operator
Dropped keystrokes	Increased WL measured w/ fNIRS[19].
Broken links (on web)	Error potential in EEG data[6].
Introduction of random music (on web)	Error potential in EEG data[6].
Introduction of sudden animation (on web)	Error potential in EEG data[6].
Improper symbol/metaphor mapping (on web)	Error potential in EEG data[6].
Pop-ups	Increased WL measured with fNIRS [19].
Slow internet	Increased WL and increased 'frustration' measured with fNIRS[14].
System crash	Increased WL and increased 'distress' measured with fNIRS[14].

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Abstract

In this research effort we used our new usability lab containing a state-of-the art suite of cognitive, physiological, and behavioral measurement devices to isolate and quantify the various low level variables that indicate the level of trust that is present while a person works with his or her computer system. Recent advances in Biomedical Engineering have resulted in the development of extremely non-invasive brain measurement devices. These devices hold great potential for the quantitative, real-time measurement of user states during realistic human-computer interactions.

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In this effort, we continued our research with non-invasive brain measurement and explored the quantitative measurement of trust, distrust, and suspicion while a user works with his or her computer system. This timely research holds great potential in the cyber-operations domain, where we can use cognitive measures to understand the level of suspicion and trust that adversarial computer operators (who we are monitoring and/or disrupting) have toward their computer system. We can also use these measures defensively, training our own military personnel to develop the cognitive awareness and skill set needed to

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Archival Publications (published) during reporting period:

Sommer, N., Hirshfield, L., Velipasalar, S., Our Emotions as Seen Through a Webcam. Accepted in Proc. of the International Conference of Human Computer Interaction, Crete, Greece. (HCII 2014).

Escalante, J. Butcher, S. Hirshfield, L.M. Using the EEG Error Potential to Identify User Interface Design Flaws. the International Conference of Human Computer Interaction (HCII 2013).

Haas, M., Hirshfield, L., Ponangi, P. , Kidambi,P., Rao, D., Edala, N., Armbrust, E., Fendley, F., Narayanan. S.. Decision-making and emotions in the contested information environment. Accepted into ICST Journal Transactions (2013).

Hirshfield, L.M., Barelka, A. Bobko, P. Paverman, D., Hirshfield, S.., Using Non-Invasive Brain Measurement to Explore the Psychological Effects of Computer Malfunctions On Users During Human-Computer Interactions. Accepted in the Journal of Advances in Human-Computer Interaction , 2014.

Changes in research objectives (if any):

Change in AFOSR Program Manager, if any:

This project was in Bob Herklotz's portfolio, and it now falls under Tristan Nguyen.

Extensions granted or milestones slipped, if any:

Slipped milestone: Final report was submitted late.

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

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