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The Effects of Alarm System Errors on Dependence: Moderated Mediation of Trust With and Without Risk

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ABSTRACT

THE EFFECTS OF ALARM SYSTEM ERRORS ON DEPENDENCE: MODERATED MEDIATION OF TRUST WITH AND WITHOUT RISK

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Research on sensor-based signaling systems suggests that false alarms and misses affect operator dependence via two independent psychological processes, hypothesized as two types of trust. These two types of trust manifest in two categorically different behaviors: compliance and reliance. The current study links the theoretical perspective outlined by Lee and See (2004) to the compliance-reliance paradigm, and argues that trust mediates the false alarm-compliance relationship but not the miss-reliance relationship. Specifically, the key conditions to allow the mediation of trust are: The operator is presented with a *salient choice* to depend on the signaling system and the *risk* associated with non-dependence is recognized. Eighty-eight participants interacted with a primary flight simulation task and a secondary signaling system task. Participants were asked to evaluate their trust in the signaling system according to the informational bases of trust: Performance, process, and purpose. Half of the participants were in a high risk group and half were in a low risk group. The signaling systems varied by reliability (90%, 60%) within subjects and error bias (false alarm prone, miss prone) between subjects. Generally, analyses supported the hypotheses. Reliability affected compliance, but only in the false alarm prone group. Alternatively, reliability affected reliance, but only in the miss prone group. Higher reliability led to higher subjective trust. Conditional indirect effects indicated that individual factors of trust mediated the relationship between false alarm rate and compliance (i.e., purpose) and reliance (i.e., process), but only in the high risk groups. Serial mediation

analyses indicated that the false alarm rate affected compliance and reliance through the sequential ordering of the factors of trust, all stemming from performance. Miss rate did not affect reliance through any of the factors of trust. The theoretical implications of this study suggest the compliance-reliance paradigm is not the reflection of two independent types of trust. The practical applications of this research could be to update training and design recommendations that are based upon the assumption of trust causing operator responses regardless of error bias.

*“’*cause Eric Chancey wrote this ~~song~~ *dissertation* for Kelli ~~Brooks~~ *Chancey”*

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INTRODUCTION

As technological capability and sophistication have advanced, "*can that function be automated?*" has been replaced with "*should that function be automated?*" Clearly, the complexity and ubiquity of automation have grown in recent decades. In operational environments, this shift has relegated the human to a monitor of automated systems. To help the human manage numerous complex systems, sensor-based systems that issue signals have also flourished.

Because signaling systems are not always reliable, humans do not always depend upon associated signals. One of the key factors that guides the human's dependence upon signaling systems is operator trust (Bliss, Gilson, & Deaton, 1995; Lee & See, 2004; Meyer, 2001; Rice, 2009). Research suggests that the type of error generated by the signaling system (i.e., false alarm or miss) leads to unique and independent types of trust. These two types of trust induce two categorically different reactions from the human: compliance and reliance (Meyer, 2001). Yet, researchers have not offered an adequate explanation about how each trust mediates the relationship between signaling system errors and the dependence behaviors of compliance and reliance. They have also not thoroughly explored the level of risk associated with evaluating signaling system output.

The purpose of the current research is to provide a theoretical review of human-automation trust, and relate it to the concepts of signaling system compliance and reliance. The concepts and relationships reviewed will then be empirically tested. The review begins with a framework and brief overview of automation to help the reader interpret the outcomes and conclusions appropriately. Subsequent material will include theoretical and practical applications.

Automation

Automation has become pervasive, significantly altering human activities. It may reduce human errors and workload, enhance efficiency, and provide economic advantages (Nickerson, 1999; Wickens & Hollands, 2000). Thus, increased automation has flourished in many domains (e.g., aviation, medicine, military, manufacturing, transportation, households, entertainment).

No matter the function, automated system performance cannot be well predicted by the functionality of the technology alone. Research has shown that automation interacts with human performance in often unexpected or unintended ways (Lee, 2006; Parasuraman & Riley, 1997; Parasuraman, Sheridan, & Wickens, 2000). Automation, therefore, is frequently judged by gauging human performance. The term *human-centered automation* captures the essence of this perspective, where automation is designed to complement the human operator in achieving a common goal (Billings, 1996, p. 3; cf. Jordan, 1963). The extent to which a function is automated is referred to as the level of automation (LOA). The LOA can range from fully manual (Level 1) to fully automated (Level 10) (see Table 1). Although Table 1 provides a reasonable description of LOAs according to the output functions of an automated system, it does not account for "*input*" functions that precede decision making and actions (i.e., information-based automation; see Endsley & Kaber, 1999, and Sheridan & Verplank, 1978, for similar frameworks of LOAs).

Table 1

Levels of automation of decision and action selection.

HIGH	10. The computer decides everything, acts autonomously, ignoring the human.
	9. informs the human only if it, the computer, decides to
	8. informs the human only if asked, or
	7. executes automatically, then necessarily informs the human, and
	6. allows the human a restricted time to veto before automatic execution, or
	5. executes the suggestion if the human approves, or
	4. suggests one alternative
	3. narrows the selection down to a few, or
	2. The computer offers a complete set of decision/action alternatives, or
LOW	1. The computer offers no assistance: human must take all decisions and actions.

Note. Adapted from "*A Model for Types and Levels of Human Interaction with Automation" by R.* Parasuraman, T. B. Sheridan, and C. D. Wickens, IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans, 30 (3), p. 287. *Copyright 2000 by IEEE.*

Parasuraman et al. (2000) suggested that it is possible to modify Table 1 to suit information-based automation, yet did not propose a specific list of steps toward that end. Reflecting a similar perspective, Wickens, Mavor, Parasuraman, and McGee (1998, pp. 15-16, p. 243) proposed that information-based LOAs can reflect how six automated functions are implemented: Filtering information, Information distribution, Information transformation, Confidence expression, Integration checks, and Flexible user-specified information presentation. Degree of feature implementation determines the LOA for information-based automation (e.g., filtering data would represent a lower LOA than if the automation suppresses data it determines are irrelevant).

Parasuraman et al.’s (2000) definition suggests automation replaces, partially or fully, *functions previously carried out by a human*. On this point, Parasuraman et al. (2000) proposed a framework that encompasses LOA’s underlying inputs (i.e., information-based automation) and outputs (i.e., decision selection and action implementation automation). These automated functions are mapped to a simplified version of corresponding stages of human information processing (Figure 1; see Sheridan, 2000, for a similar framework).

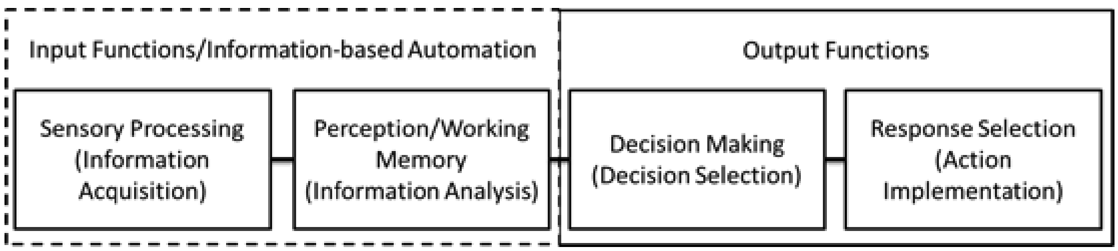

Figure 1. Simplified model of human information processing system based on Parasuraman et al. (2000). *Note*: System functions automated by processing stage are in parentheses.

Stage 1, sensory processing, corresponds to information acquisition automation, which augments or replaces aspects of human selective attention and sensors (e.g., eyes, ears, skin), by selecting, registering, and filtering input data (Parasuraman et al., 2000; Wickens, Lee, Liu, & Becker, 2004; Wickens et al., 1998, p. 14). Stage 2, perception and working memory, corresponds to information analysis automation, which augments or replaces cognitive processes used to integrate information, assess situations, and provide diagnoses. Stage 3, decision making, corresponds to decision selection automation, which augments or replaces cognitive processes associated with deciding among alternatives and selecting appropriate actions. Stage 3 automation departs from information analysis by making assumptions about the costs and values of the decision impact, in a probabilistic and uncertain environment (Parasuraman et al., 2000; Wickens et al., 2004, p. 421). Stage 4, response execution corresponds to control and action execution automation. Generally, Stage 4 automation replaces human actions and manual control (e.g., hand, foot, voice), to some degree (Parasuraman et al., 2000).

Although some forms of automation may represent a single stage, automation may represent more than one stage. A system can incorporate some or all of the stages at various LOAs. To illustrate, some physiological monitoring systems used in hospitals (e.g. automated infusion pump) may alert healthcare workers to a patient's abnormal physiological state (Stage 1), integrate those physiological symptoms and arrive at a diagnosis (Stage 2), recommend a treatment (Stage 3), and then carry out that treatment (Stage 4) (Onnasch, Wickens, Li, & Manzey, 2014).

Automation is often adopted because of an anticipated cost/benefit tradeoff. Designers and management may also be reluctant to trust the human operator to accomplish a function that could be carried out by a machine, resulting in a high LOA (Parasuraman & Riley, 1997). Sometimes, automation may be implemented simply to showcase technological skill (Nickerson, 1999). In many cases, the preference to automate where possible and economically beneficial continues to be a common strategy (Parasuraman & Wickens, 2008; Sheridan & Parasuraman, 2005). This strategy, however, often distances the human operator from the system and requires continuous monitoring (Endsley & Kaber, 1999; Parasuraman & Riley, 1997). Unfortunately, it is well documented that humans are poor monitors (Warm, Parasuraman, & Matthews, 2008).

Human factors literature is replete with examples where operators failed to detect automation breakdowns and intervene (Lee, 2006). Causes include lack of feedback from passive monitoring (Lee, 2006), vigilance (Warm et al., 2008), poor situation awareness (Endsley & Kiris, 1995), and complacency (Bailey & Scerbo, 2007; Parasuraman & Manzey, 2010). To assist the human with monitoring complex or numerous automated systems, alerted-monitor systems are often implemented to provide information about system trends, impending breakdowns, and failures (Sorkin & Woods, 1985). This type of system is the focus of the current work.

Alerted-Monitor Systems

The relationship between sensor-based signaling systems and human monitors has been studied in both lab (e.g., Bliss, 2003; Breznitz, 1984) and field settings (e.g., Wickens et al., 2009), within a multitude of domains and applications, e.g., security monitoring (Bliss & Chancey, 2014), aviation (Pritchett, Vándor, & Edwards, 2002), hospitals (Xiao, Seagull, Nieves-Khouw, Barczak, & Perkins, 2004), dismounted Soldier operations (Dzindolet, Pierce, Beck, Dawe, & Anderson, 2001), ground transportation (Lees & Lee, 2007), and power plants (Carvalho, do Santos, Gomes, Borges, & Guerlain, 2008). The simplest paradigm used to investigate the alerted-monitor system includes two subsystems: the sensor-based signaling system and the task-engaged human monitor (Bliss & Gilson, 1998; Sorkin & Woods, 1985). The following section describes the prototypical sensor-based signaling system. Signaling system reliability and error bias are also reviewed, as these error characteristics impact the attitudes (e.g., trust) and response behaviors of the human monitor differentially. Moreover, this review will inform the design of the experimental tasks and signaling system in the current work.

Sensor-Based Signaling Systems. The sensor-based signaling system represents a broad category of automation that employs stimuli such as alarms, alerts, and warnings (Bliss & Gilson, 1998). Signaling systems are designed to direct the attention of the user to hazards that may require intervention or further inspection (Meyer, 2004). It is not difficult to identify or envision a signaling system that could be classified as Stage 3 automation (e.g., traffic alert and collision avoidance system directing a pilot to “pull up”) or Stage 4 automation (e.g., automatic ground collision avoidance systems that warn of an impending collision and take control of the aircraft; Swihart, 2009). Yet, the prototypical signaling system, at a minimum, is generally an information-based automation that augments Stages 1 (i.e., directs attention) and 2 (i.e., diagnoses a critical event).

Signals generated by these systems do not all require the same reaction from the human monitor, particularly with regard to timeliness. Indeed, the military standard for aircraft alerting systems differentiates between warnings, cautions, and advisories (MIL-STD-411F, 10 March 1997). *Warnings* indicate the existence of a hazardous condition, which requires immediate action to prevent negative consequence (e.g., loss of life, equipment damage). *Cautions* indicate the existence of a condition that does not require immediate action. *Advisories* indicate a safe or normal operating condition, which attracts attention to impart information for routine performance. It should also be noted that, based on military standards, the term *warning* can be used interchangeably with *alarm* and the term *alert* can be used interchangeably with *caution* (MIL-STD-1472G 11 January 2012; MIL-HDBK-1908B 16 August 1999).

Signaling systems have sometimes been referred to as *signal detection systems*, which describe devices that are compatible with signal detection theory (SDT) and analysis (Sorkin & Woods, 1985). From this perspective, the signaling system monitors and analyzes noisy input data for abnormal conditions, or signal events. The purpose of the signaling system is to discriminate between signal-plus-noise events (abnormal conditions) and noise-alone events (normal conditions; Sorkin & Woods, 1985, pp. 52-53). Signal detection theory assumes four potential decision outcomes, a hit (signal present and signaling system responds signal present), a correct rejection (signal absent and signaling system responds signal absent), a miss (signal present and signaling system responds signal absent), and a false alarm (signal absent and signaling system responds signal present). Detection of the signal, within the SDT paradigm, is described by two parameters: sensitivity and response criterion.

The sensitivity parameter describes the effectiveness with which the signaling system is capable of distinguishing between abnormal and normal conditions (i.e., d'; Sorkin & Woods, 1985). Designers should attempt to maximize system sensitivity. This parameter, however, is restricted by technological capability and the knowledge required to inform what constitutes an abnormal condition (Sorkin & Woods, 1985; e.g., knowledge required to design algorithms that detect cardiac arrhythmia, Drew, et al., 2004).

The sensor threshold setting is represented by the signaling system's response criterion (i.e., β or c), or the degree of evidence required to issue a signal event. In the event that the signaling system makes an error, this parameter determines the type of error it is more likely to make (i.e., error bias). Although signaling system algorithms can be complex, the output can be conceptualized as conditional logic based on a preset threshold. For example, in the case of a household smoke detector, if the environmental concentration of smoke exceeds a preset threshold (e.g., black smoke exceeds 10% optical density per foot; Geiman & Gottuk, 2003), then the signaling system issues an alarm (if not then the signaling system remains silent).

Unlike the sensitivity parameter, the threshold setting is not limited by technological capability. Instead, this parameter can be set to any level desired (Sorkin & Woods, 1985). Importantly, if the sensor threshold is set too conservatively (i.e., much evidence is required to issue a signal present), then false alarms will be minimized at the expense of abnormal conditions not being signaled. Alternatively, if the sensor threshold is set too liberally (i.e., minimal evidence is required to issue a signal present), then the chance of signaling an abnormal event will be maximized, at the expense of frequent false alarms.

Commonly, sensor thresholds are set to minimize the chance of missing an abnormal event (Sorkin & Woods, 1985). One reason for adopting this setting, and indeed one of the reasons for adopting signaling systems generally, is legalistic policies associated with manufactures' "obligation to warn" (Bliss & Gilson, 1998). Moreover, the costs associated with a signaling system missing an event often have the potential to be disastrous. To this point, during a series of recent penetration tests conducted by the Department of Homeland Security, undercover investigators were able to smuggle mock explosives and banned weapons through Transportation Security Administration (TSA) checkpoints in multiple United States airports. Airport screeners missed detecting dangerous items in 67 out of 70 tests (Fishel, Thomas, Levine, & Date, 2015). In a statement to Congress, the Inspector General of Homeland Security indicated that these misses were due to a combination of both human and technology-based failures. In a summary of one of these tests, Homeland Security investigators identified technological vulnerabilities associated with explosive detection systems and explosives trace detection equipment. The summary indicated that the TSA does not have a process in place to assess or identify equipment failures or the capability to assess whether explosive detection systems are operating at the correct detection standards (Department of Homeland Security: Office of the Inspector General, 2014).

Yet overly liberal threshold settings, which generate frequent false alarms, can also have severe consequences. For example, hospitals employ a multitude of physiological monitoring systems that signal changes in critical life functions (e.g., cardiac patterns, blood oxygenation).

Because of the criticality of these monitored functions, alarm thresholds are often purposefully set to be extremely liberal (Drew, et al., 2004). This liberal setting, however, produces many false alarms (Welch, 2011). Excessive false alarms have led to instances of clinical alarm fatigue, where healthcare workers have anticipated a false alarm and failed to respond to a serious condition in a timely manner or at all (Keller, 2012). Unfortunately, when alarms are true, delayed or absent responses can result in patient death or injury (Solet & Barach, 2012). To combat the excessive false alarms associated with these devices, some hospitals (e.g., Boston Medical Center) have recently opted to adjust default manufacturer threshold settings to be more conservative, in accordance with clinically significant changes in physiological parameters (Whalen et al., 2014).

Sensitivity and response criterion both determine system reliability, which can significantly impact the human monitor's responses and attitudes such as trust (Chancey, Bliss, Proaps, & Madhavan, 2015a). Sullivan, Tsimhoni, and Bogard (2008) describe three of the dominant perspectives on signaling system reliability. From an *engineering perspective*, reliability is defined by the extent to which the signaling system consistently produces the same results under the same conditions (i.e., a signaling system is reliable if it consistently activates during abnormal events). From a *functional perspective*, reliability is defined by the number of errors (false alarms and misses) that occur during a given time period. Finally, reliability can be defined by the subjective proportion of false alarms per total alarms during a given time period, which is considered the *user perspective.* This is the user's perspective because missed events are simply overlooked if not regularly detected. Reviewing the effects of signaling system reliability on performance, Wickens and Dixon (2007) opted for a functional definition of reliability, because this perspective allows for a simple calculation of proportion or percentage of correct diagnoses and is a scale typically used in reliability engineering. Therefore, to simplify the alerted-monitor paradigm and allow for easier translation, the current work will adopt the functional reliability perspective.

Human Monitor. Considering the signaling system in isolation will not fully reflect alerted-monitor performance. Instead, the error characteristics of the signaling system often affect the decision-making and action implementation processes of the human monitor. The previous section highlighted two signaling system parameters: reliability and error bias. This section describes each of these parameters in terms of their impact on human reactions.

Signaling System Reliability on Human Reactions. In theory, most of the design and training recommendations for signaling systems are based on the assumption that when presented with a signal, the human will acknowledge the authenticity of it and react appropriately (Bliss & Gilson, 1998). Yet this is not always the case, particularly when a system is unreliable. Generally, higher reliability leads to higher response rates toward signals (e.g., Bliss et al., 1995; Chancey et al., 2015a; Manzey, Gerard, & Wiczorek, 2014), quicker signal reaction times (e.g., Chancey et al., 2015a; Getty, Swets, Pickett, & Gonthier, 1995), and greater operator sensitivity (e.g., Chancey et al., 2015a; Rice, 2009).

Wickens and Dixon (2007) published a literature review investigating the effects of signaling system reliability on human performance, specifically reaction time and accuracy. Their results indicated that higher reliability generally led to better performance. The authors reported a “cross-over point” of 70% reliability, below which the human is better off without the aid of a signaling system at all.

Proposing a 70% cutoff implies that systems with reliability levels below this point represent a waste of resources, as they offer no additional value and may impede performance.

Of note, however, the studies included in Wickens and Dixon's review targeted laboratory-based studies with reliability rates above 50%. To illustrate the reliabilities of real world systems, hospital alarms have reported reliability levels of 27% (Chambrin et al., 1999), 5% (Lawless, 1994), and even less than 1% (Tsien & Fackler, 1997). Yet, these systems are often described as "essential to providing safe care to patients" (The Joint Commission, 2013). Bliss and Chancey (2013) reported a study in which participants interacted with a 20% and 40% reliable signaling system. Their results indicated that although participants responded to more alarms in the 40% condition, their accuracy was slightly better in the 20% condition.

Some researchers have noted that, under certain circumstances, the human's response rate tends to match the expected probability of true signals, a response pattern termed *probability matching* (e.g., Bliss et al., 1995; Manzey et al., 2014; Wiegmann, Rich, & Zhang, 2001). The notion of trust calibration, which refers to the degree to which the automation is trusted versus how much it should be trusted, has been used to describe the process that determines probability matching responses. Bliss et al. (1995) were the first to report this type of response pattern toward unreliable signaling systems, where 90% of the participants in this study tended to match their response rate to the reliability of the system (e.g., in the 75% group, participants responded to approximately 75% of the alarms).

Wiegmann et al. (2001) mathematically illustrated how probability matching affects overall alerted-monitor system performance. If a system is 80% reliable and the operator probability matches, then across 100 signals and responses, the alerted-monitor system would arrive at 64 correct diagnoses (i.e., $0.8 \times 80 = 64$). The remaining 20 of the human's responses would be opposite of the signal system responses, arriving at four correct diagnoses (i.e., 0.2 ×

20 = 4). This results in an overall accuracy rate of 68% (i.e., 64 + 4 = 68) for the alerted-monitor system (Wiegmann et al., 2001).

Yet, Bliss et al. (1995) noted a minority of participants (10%) optimized their strategy by responding to every signal, termed an *extreme response pattern*. This is an optimal strategy because if the participant responds to every signal for an 80% reliable system across 100 signals, the alerted-monitor system would be correct 80 times (i.e., 0.8 × 100 = 80 correct; Wiegmann et al., 2001). To clarify when a responder is more likely to adopt an extreme response pattern, Bliss (2003) conducted a retrospective analysis across seven of his own studies. He noted that when the system was transparent (i.e., alarm validity information could be used to crosscheck the output of the signaling system), most participants probability matched. Alternatively, when the system was opaque (i.e., no alarm validity information was presented), a greater percentage of participants adopted an extreme response pattern (see also Manzey et al., 2014).

Across the studies reported by Bliss (2003), participants were always informed of the reliability of the signaling system prior to interacting with it. Wang, Jamieson, and Hollands (2009) tested the effects of reliability disclosure on a metric of signaling system reliance (i.e., response bias difference). Wang et al. reported that participants with reliability information more appropriately varied their reliance upon the aid, in accordance with the reliability level, than those who were not provided with reliability information. Indeed, providing reliability information can greatly affect response rate, irrespective of the true reliability of the system. Bliss, Dunn, and Fuller (1995) reported a study in which participants interacted with a 50% reliable signaling system across two sessions. Before beginning the second session an experimental confederate falsely informed participants that the signaling system was 75% reliable, which resulted in an increased response rate during the subsequent session (see Chancey

& Bliss, 2012, for a similar effect of information reliability disclosure on responses in a navigation task).

Signaling System Error Bias on Human Reactions. Although signaling system reliability clearly affects the reaction strategy of the human monitor, the type of error (i.e., false alarm or miss) also affects reactions. Excessive false alarms often lead to instances in which the operator reduces, slows, or stops their responses (Breznitz, 1984; Getty et al., 1995; Sorkin, 1988). These types of reactions have been often referred to as examples of the *cry-wolf effect*.

Alternatively, if the signaling system has been shown to miss critical events, then the user may be forced to monitor the raw data to ensure that events are not overlooked (Chancey et al., 2015a). This creates a situation in which the operator is forced to divide attention among tasks, leading to increased workload and deterioration in performance indices (Dixon & Wickens, 2006; Dixon, Wickens, & McCarley, 2007). Such protective data monitoring is termed *defensive monitoring* (Adams, Bruyn, Houde, & Angelopoulos, 2003). In some cases, defensive monitoring behavior may be excessive; the operator is then said to be a *skeptical monitor* (Moray & Inagaki, 1999). Alternatively, in situations featuring extremely reliable but miss-prone systems, operators may demonstrate *complacency* by under-sampling the raw data (Dixon & Wickens, 2006; Moray & Inagaki, 1999). Bailey and Scerbo (2007) reported two experiments where increasing the reliability of highly reliable automated systems led to a decrease in monitoring performance.

Human monitor reactions clearly depend upon both the reliability (error rate) and error bias (type of error) of the signaling system. One of the most prominent theoretical constructs thought to mediate the causal connection between the error characteristics of the signaling system and human reactions, is the level of trust the human has in the automation. Because of its role in the proposed study, the remainder of this review will elaborate upon the psychological effects of trust as it relates to human-automation interaction and, more specifically, the alerted-monitor system.

Trust in Automation

The notion that trust in automation influences operator reactions is not new. Sheridan hypothesized the concept of operator trust in supervisory control paradigms frequently over the years (e.g., Sheridan & Verplank, 1978; Sheridan, Fischhoff, Posner, & Pew, 1983; Sheridan & Hennessy, 1984). However, Muir (1987, 1994; Muir & Moray, 1996) is largely credited with the first formal attempt to model trust in automation. She proposed a two-dimensional framework to study human-machine relationships, which were based on existing taxonomies of interpersonal trust (i.e., Barber, 1983; Remple, Holmes, & Zanna, 1985) and has led to a multitude of theoretical perspectives that vary in terms of how trust in automation is conceptualized (see Table 2).

Table 2

Selected Human-Automation Trust Theories Arranged Chronologically.

Human-Automation Trust Theory References	*Description*
Muir (1987, 1994; Muir & Moray, 1996)	Proposed a framework that integrated bases of trust (persistence, technical competence, and responsibility) and dynamics of trust (predictability, dependability, and faith).
Lee and Moray (1992; 1994)	Proposed modified version of Muir's framework, which added leap of faith, understanding, and trial-and-error experience (Zuboff, 1988). Related this updated framework to the concepts of purpose, process, and performance.
Parasuraman and Riley (1997; Riley, 1996)	Cited trust as one of the key components in determining automation use, along with other variables such as workload, perceived risk, and self-confidence.
Cohen, Parasuraman, and Freeman (1998)	Proposed the Argument-based Probabilistic Trust (APT) model, which introduced the use of event-trees that probabilistically model decisions to determine automation dependence.
Seong and Bisantz (1999; Seong, Bisantz, & Gattie, 2006)	Proposed a trust model based on Brunswik's (1952) Lens model, which attempted to account for trust calibration.
Dzindolet et al. (2001)	Proposed a conceptual model of automation use, which cited trust as a key component. Loosely based on concepts proposed by Parasuraman and Riley (1997).
Lee and See (2004)	Proposed a qualitative model that specified how to design trustable automation and presented a review of both interpersonal and human-automation trust theories.
Madhavan and Wiegmann (2007)	Proposed a model of sequential development of trust for automation and humans and, additionally, a framework of factors that affect the development of trust in automation.
Hoff and Bashir (2015)	Proposed a three-layer trust model consisting of dispositional, situational, and learned trust.

Although each perspective has added to the understanding of human-automation trust, some theoretical perspectives are limited in scope and application or do not align with the ideas presented in this work. To illustrate, some models advocate behavioral measurement of trust (e.g., Seong & Bisantz, 1999) or appear indifferent to inferences of trust from behavior (e.g., Dzindolet et al., 2001). Additionally, some models conceptualize trust as a relatively rational thought process (e.g., Cohen et al., 1998) or omit key related concepts associated with trust, such as perceived risk or vulnerability (e.g., Madhavan & Wiegmann, 2007).

The work of Lee and See (2004), however, provides arguably the most comprehensive and integrative perspective on the topic of trust in automation, which is largely based on the work of Muir (1987; 1994; Muir & Moray, 1996) and Lee and Moray (1992; 1994). The framework of Lee and See explains how behavioral reactions, such as compliance and reliance, are related but different from attitudes such as trust. Moreover, this framework also points to key trust-related concepts often overlooked in experimental designs used in the study of signal reaction behaviors, such as the perceived risk associated with compliance or reliance. Therefore, although the current work acknowledges aspects of existing human-automation and interpersonal trust theories, it will generally adopt the theoretical structure and terminology proposed by Lee and See's (2004) conceptualization of trust in automation.

Lee and See (2004) noted that trust has been conceptualized in very different ways across researchers. Some theorize trust as a belief (e.g., Kramer, 1999), an attitude (e.g., Barber, 1983), an intention (e.g., Mayer, Davis, & Schoorman, 1995, 2007), or as a behavior (e.g., Deutsch, 1960; Meyer, 2001). To resolve these conflicting perspectives, Lee and See (2004) utilized the framework developed by Ajzen and Fishbein (1977, 1980). This framework depicts beliefs as the informational basis for attitudes. Beliefs are influenced by experience and the availability of information. Attitudes are affective evaluations of beliefs that lead to the formation of intentions. Intentions then lead to behaviors, which are regulated by environmental and cognitive variables. Lee and See (2004) noted that trust is best conceptualized as an attitude, where beliefs about the characteristics of the automation help form the basis for adopting a particular level of trust. Depending on the level of trust, this may lead a person to adopt an intention that leads to a behavior. Lee and See (2004) suggested that considering trust as a behavior or intention has the potential to confound its effects with other variables that likely affect behavior (e.g., workload, situation awareness, self-confidence). From this perspective, there is a clear distinction between trust as an attitude and behavioral reactions, such as signaling system compliance and reliance.

Lee and See (2004) go on to highlight two important components associated with trust. First, one common theme among most conceptualizations of trust is the notion of vulnerability, where the trustor willingly assumes risk by delegating responsibility to the trustee (cf. Mayer et al., 1995). This responsibility implies that the trustee is advancing the goal of the trustor, which leads to the second component: goal orientation. Although most perspectives of trust do not explicitly include this component, most highlight the importance of allowing a trustee to perform a particular action on behalf of the trustor (i.e., to help advance the trustor's goals; cf. Mayer et al., 1995). Reflecting these perspectives, Lee and See (2004) define trust as "an attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability."

From this definition, Lee and See (2004) described trust in terms of appropriateness, where trust is compared to the capabilities of the automation. Trust appropriateness describes the relationships between the error characteristics of the system and the resulting behavioral reactions. Reaction behaviors can result in either an over dependence or an under dependence upon the automation, described as misuse and disuse respectively (Parasuraman & Riley, 1997). Trust appropriateness is broken down to calibration, resolution, and specificity.

Calibration denotes how close the match is between a human's trust and the automation's capabilities (e.g., reliability level, error bias). Calibration has been used to describe reaction strategies such as probability matching (e.g., Wiegmann et al., 2001) and monitoring behaviors such as complacency (e.g., Bailey & Scerbo, 2007; Moray & Inagaki, 1999). Operators demonstrate poor trust calibration by over trusting the system (i.e., trusting it above its capabilities, generating misuse), or under trusting the system (i.e., trusting the system below its capabilities, generating disuse) (cf. Parasuraman & Riley, 1997; Parasuraman, Sheridan, & Wickens, 2008).

Resolution indicates the sensitivity of automation trust to differentiate among automation capability levels. To illustrate, an operator who trusts a 60% reliable system the same as a 90% reliable system illustrates poor resolution. Presumably, if the operator trusts the 60% and 90% reliable system equally, trust should not cause the operator's response rate to be markedly different between these two systems. An operator who trusts a 90% reliable system slightly more than an 89% reliable system, however, illustrates good resolution and should demonstrate behavior that approximates the reliability levels accordingly (i.e., probability matching).

Specificity denotes the level of trust associated with a particular function at a particular time and situation, which is similar to the concept of system-wide trust (Keller & Rice 2009; Rice & Geels, 2010). Keller and Rice (2009) showed that participants' reactions to an individual perfectly reliable aid depended upon the presence of unrelated unreliable aids. The authors concluded that participants based their reactions on "system-wide trust" rather than trust in a specific component.

Lee and See (2004) described trust as an affective evaluation of the characteristics of the trustee. Moreover, that evaluation helps determine if the trustee can achieve the goals of the trustor. This premise implies two components that form the basis of trust: the focus (i.e., what is to be trusted) and the type of goal-oriented information supporting the trust.

The *focus* of trust is described according to the degree of detail (e.g., trust in an organization versus an individual). This concept is often related to general versus specific trust, which corresponds to trust specificity outlined above. From this perspective, trust might correspond to beliefs about the overall system of automations or beliefs about a particular mode of an automated aid (Lee & See, 2004; p. 58).

Researchers often describe *goal-oriented information* that supports trust in terms of attributional abstraction. From this perspective, trust is initially based on observable behaviors and progresses to being based on more abstract concepts in reference to the trustee. Based on relationships among close partnerships (i.e., couples), Rempel et al. (1985) theorized that interpersonal trust is initially based on direct "coding" of partner behaviors and then, once trust becomes more established, trust is based more on the trustor's belief about the trustee's motivations (p. 98). Rempel et al. (1985) denote this evolution of trust as progressing from *predictability*, which is influenced by the predictability of a partner's behaviors, to *dependability*, which is influenced by the perception of the characteristics of the trustee, to *faith*, which is not "securely rooted" in past behaviors, but is instead based on a belief that the trustee can be depended upon irrespective of the available evidence. Another well cited article among organizational psychology is that of Mayer et al. (1995), which proposed similar bases of trust, describing ability, integrity, and benevolence (each corresponding to predictability, dependability, and faith, respectively).

Based on Rempel et al. (1985), and originally proposed by Lee and Moray (1992), Lee and See (2004) proposed similar bases for trust in automation: performance, process, and purpose. *Performance* describes what the automation does, and corresponds to the current and historical operation of the automation to include reliability, predictability, and ability. This closely resembles the concept of predictability, where trust is based on observable behavior or performance. For this component, automation that readily achieves the operator's goals will lead to greater trust. *Process* describes how the automation operates, and corresponds to the appropriateness of the automation's algorithms in achieving the operator's goals. This closely resembles the concept of dependability, where the focus shifts from observable behaviors of the automation to the characteristics attributed to the automation. For this component, automation that appears capable of achieving the operator's goals and is understandable will lead to greater trust. Finally, *purpose* describes why the automation was developed, and corresponds to how well the designer's intent has been communicated to the operator. This closely resembles the concept of faith, where trust is based on the belief that the automation can be depended upon in the absence of observing past behaviors. For this component, automation that achieves the goals it was designed to achieve (i.e., the operator's goals) will lead to greater trust.

In contrast to interpersonal theories (e.g., Mayer, et al., 1995; Rempel et al., 1985), where trust is hypothesized to evolve sequentially through stages of attributional abstraction (i.e., performance then process then purpose), Lee and See (2004) conceptualized trust as being based on different levels of attribution that do not necessarily follow a pre-defined sequence. Early in the human-automation relationship the operator may not have had the opportunity to observe the automation's behaviors (i.e., performance), yet may have a clear understanding of the purpose of the automation. From this perspective, trust may initially be faith-based or based on purpose, rather than on the coding of observed behavioral performance. It should be noted, however, that although faith-based trust, or purpose, is similar to dispositional trust, it differs in important ways. Whereas dispositional trust is conceptualized as an enduring personality trait (e.g., Rotter, 1967), the attitude of trust is dynamic and evolves as the relationship between a trustee and trustor develops (e.g., from being based on purpose to being based on process; Lee & See, 2004). Additionally, the attitude of trust is "history-dependent" and depends upon information or behavior about a trustee, whereas dispositional trust is determined by generalized past similar experiences (Lee & See, 2004; cf. Bliss, 2009).

Lee and See (2004) proposed that although trust is largely influenced by affective processes, analytical and analogical processes can also determine the assimilation of goal oriented information. From an analytical perspective, trust reflects accumulated knowledge from previous interactions with the trustee. These interactions are used to rationally and probabilistically determine the behavior of the trustee (cf. APT model by Cohen et al., 1998). To illustrate, when given the opportunity to take one exit verses another, a driver may create a rational argument to analyze the expected outcome or probability of reaching their destination quickly when using the directions provided by a Global Positioning Device (GPS) verses a passenger (e.g., GPS provided correct directions 24/33 times during previous trips, weighted against the passenger being correct 7/12 times during previous trips). Lee and See (2004) argued, however, that this perspective overemphasizes the cognitive capability of the human decision maker to effectively engage in conscious calculations or to make exhaustive comparisons among alternatives (p. 62). Analytical processes, therefore, are likely complemented by other processes such as analogical judgments that rely on category membership. From this perspective, trust develops through direct observations, intermediaries who convey their own observations, and assumptions based on existing standards, category memberships, and procedures (p. 62). For example, the driver may have read in the user manual that the GPS is less reliable in bad weather, so he or she decides not to comply with the directive because it is raining (cf. hearsay technique used by Bliss et al., 1995). This process is similar to the concept of rule-based behaviors (Rasmussen, 1983), where behavior is determined by condition-action pairings.

Yet, Lee and See (2004) proposed that affective processes largely influence the effect of trust on behavior, because trust is not only thought about but also felt (Fine & Holyfield, 1996, p. 25). When expectations about the trustee's performance do not conform to predictions, trust may be betrayed and emotions signal the need to change the behavior of the operator. With automation becoming increasingly sophisticated, operators often lack the cognitive resources to rationally predict its behavior. Lee and See (2004) suggest, therefore, that emotions guide behaviors when rules do not apply or when cognitive resources are not available to make a rational choice.

Based on the theoretical perspective outlined by Lee and See (2004), the behaviors observed in reaction to the error characteristics of the signaling systems could plausibly be mediated by trust. Indeed, Lee and See (2004) note that trust's effect on automation dependence is part of a closed-loop process. If the system is not trusted, then the human will not depend upon it; this results in the operator having limited information regarding its capabilities. This further limits trust growth.

Lee and See (2004) suggested, however, that mediation by trust greatly depends upon the type and presentation of automation. Specifically, with information acquisition automation (e.g., sensor-based signaling systems), Lee and See suggested it is possible for the operator to observe the behavior of the system even if they are not depending upon it (yet, this is true only if the system is transparent). On this point, Lee and See (2004) made an important distinction between system states that require the operator to react in response to a signal and those that require acknowledgement of normal operating conditions (e.g., signaling system is silent). This distinction is captured by the concepts of compliance and reliance respectively.

Compliance, Reliance, and Trust

Importantly, the concepts of compliance and reliance reflect separate psychological processes that motivate operator dependence in the alerted-monitor paradigm, proposed as "two types of trust" (Meyer, 2001; Rice, 2009). Research suggests that these two independent types of trust underlie two distinct behaviors toward unreliable signaling systems that produce either false alarms or misses. *Compliance* refers to the human operator responding when the signaling system issues a signal (e.g., in the event of a fire alarm, the human is compliant if he or she leaves the building). *Reliance*, alternatively, refers to the human refraining from a response when the signaling system is silent or indicates normal operating conditions (e.g., if a fire alarm is silent, then the human is reliant if he or she does not leave a building because of a suspected fire). Together, compliance and reliance are referred to as signaling system *dependence*, which can imply either a response (such as compliance) or a non-response (such as reliance). Importantly, however, in some instances reliance can also be a response to a signaling system indicating normal operating conditions or a safe state (e.g., a TSA agent allowing an individual through an airport screening gate when a security scanner does not detect banned substances or items).

Generally, compliance and reliance are described as behaviors, or sometimes the a lack of a behavior in the case of reliance (e.g., Dixon et al., 2007; Meyer, 2001, 2004; Rice, 2009; Rice & McCarley, 2011; Manzey et al., 2014). Yet some researchers describe compliance and reliance as cognitive states (e.g., Dixon & Wickens, 2006; Wickens & McCarley, 2008). To illustrate this perspective, Wickens and McCarley (2008) describe reliance as "…the cognitive state that allows an operator to feel confident that there really is no hazard at the times when the alert is silent" (p. 36). Alternatively, the authors refer to compliance as "…the cognitive state that allows the operator to act confidently in response to an alarm when it occurs" (p. 36). Additionally, Meyer, Wiczorek, and Günzler (2014) interchangeably refer to compliance and reliance as both behaviors and psychological constructs (i.e., two types of trust, cf. Meyer, 2001).

This disagreement leads to a somewhat confusing conceptualization for what compliance and reliance are (cognitive states, behaviors, or both). Although some researchers acknowledge the distinction between psychological trust and dependence behaviors (e.g., Rice, 2009), others appear to suggest compliance and reliance behaviors are themselves two types of trust (e.g., Meyer, 2001; Meyer et al., 2014). Yet, regardless of the perspective taken, compliance and reliance are generally always operationalized as behaviors: e.g., agreement or response rate (e.g., Bustamante, 2009; Chancey, Bliss, Liechty, & Proaps, 2015b; Dixon & Wickens, 2006; Manzey et al., 2014; Rice, 2009; Rice & McCarley, 2011), response time (e.g., Dixon & Wickens, 2006; Rice, 2009; Meyer et al., 2014), secondary-task performance (e.g., Dixon & Wickens, 2006; Dixon et al., 2007), or response criterion (e.g., Meyer, 2001; Meyer et al., 2014). Although there is some discrepancy in the literature as to what compliance and reliance are, the current work takes the perspective that compliance and reliance are behaviors and not cognitive states (or simultaneously behaviors and cognitive states).

If compliance and reliance are behaviors, then it is a straightforward matter to conceptualize two types of psychological trust that influence those behaviors. Meyer's (2001; 2004) initial work implies two notions. First, compliance should be affected when the signaling system issues a signal present, and therefore more likely degraded by the error associated with an issued signal (i.e., false alarm). If the signaling system is unreliable and false alarm prone (FP), then it will likely lead to a manifestation of the cry-wolf effect via one type of trust. Second, reliance should be affected when the signaling system indicates normal operating conditions, and therefore more likely degraded by the error associated with a signal not being issued (i.e., miss). If the signaling system is unreliable and miss prone (MP), then it will likely lead to defensive monitoring via a second type of trust.

Rice (2009) suggested that an extreme version of Meyer's (2001) original conceptualization for the relationship between error bias and dependence takes the form of Model B in Figure 2. In this model, trust in alerts mediates the relationship between false alarms and compliance through a single process. Alternatively, trust in nonalerts mediates the relationship between misses and reliance through a single process. From this perspective, compliance and reliance are independent and there are two separate forms of trust.

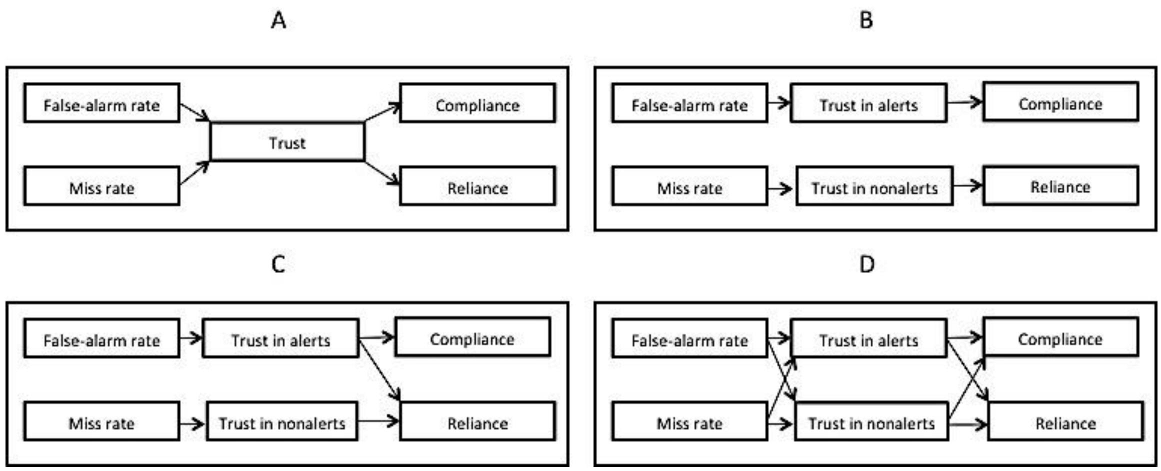

Figure 2. Signaling system errors on dependence: (A) Single-process model, (B) selective two-process model, (C) Mandler's two-process model, and (D) nonselective two-process model. Adapted from "Examining single- and multiple-process theories of trust in automation," by S. Rice, *The Journal of General Psychology*, 13(3), p. 307. Copyright 2009 by Heldref Publications. Models originally adapted from Dunn and Kisner (1988).

Dixon and Wickens (2006) reported a study where participants were aided by unreliable signaling systems that were either FP or MP. As Dixon and Wickens hypothesized, the results indicated that the FP system degraded compliance, whereas the MP system degraded reliance. Moreover, the MP system did not affect compliance. Yet, the FP system affected both compliance and, to a lesser degree, reliance. Based on these results, it is unclear whether false alarms and misses affect compliance and reliance independently (i.e., Figure 2B) or false alarms non-selectively affect both compliance and reliance (i.e., Figure 2C).

Confirming the non-selectivity of false alarms on both behavioral categories, Dixon et al. (2007) reported that a FP system affected both compliance and reliance (i.e., Figure 2C). Rice (2009) suggested that this type of non-selective effect of false alarms on compliance and reliance implies that trust in alerts also affects reliance, whereas the trust in nonalerts only affects reliance. Dixon et al. (2007) suggested, however, that false alarms may have affected both dependence behaviors because false alarms were accompanied by a more salient perceptual event (i.e., auditory alert), and were simply more noticeable and memorable errors than misses (p. 571).

On this point, Rice and McCarley (2011) conducted an experiment in which signaling system misses and false alarms were matched for perceptual salience. The results from this experiment indicated that FP systems led to lower performance and dependence (compliance and reliance) than MP systems of matched reliability. Meyer et al. (2014) also found that false alarms affected compliance and reliance, whereas misses only affected reliance, when misses and false alarms were matched for perceptual salience. Rice and McCarley (2011) suggested that, above any perceptual saliency differences, false alarms might also be more cognitively salient than misses (i.e., false alarms are weighted heavier in determining operator judgments than misses). Indeed, a second experiment conducted by Rice and McCarley (2011) showed that when false alarms were framed as neutral messages (i.e., the system indicated only target present, but not target absent events), the false alarm and miss asymmetry was reduced.

Rice (2009), however, provided a somewhat different perspective regarding the compliance-reliance distinction. Rice described a study (Rice & McCarley, 2008) in which misses, in addition to false alarms, affected both compliance and reliance. Rice suggested that these results could indicate one of two possibilities: there is a singular type of trust affecting both dependence behaviors (Figure 2A) or there are two types of trust that non-selectively affect both compliance and reliance (Figure 2D). Rice's analysis indicated that there are two forms of trust (i.e., Figure 2D). Specifically, false alarms have a strong effect on compliance and a weaker effect on reliance. Alternatively, misses have a strong effect on reliance and a weaker effect on compliance.

The preceding review provides compelling evidence to suggest that false alarms and misses affect compliance and reliance differentially, and that those relationships are likely mediated by two seemingly different or even independent psychological processes. Unfortunately, prior research has not specified the nature of those processes. A common theme within alerted-monitor system research is that the roles of operator trust are assumed and inferred from the behavior observed. Indeed, an alternative explanation might be that a singular trust is formed in a qualitatively different way (or absent), depending upon the error bias of an unreliable signaling system. This, however, is difficult to discern from the observations of dependence behaviors alone. By assuming the role of trust as a singular explanation in determining the behavior, researchers may be oversimplifying the alerted-monitor system and overlooking important aspects associated with the human monitor subsystem.

Differentiating Trust from Compliance-Reliance Behaviors. There are several perspectives from which to question the value of assuming the effects of trust based on the observation of a behavior. One perspective is that there is a circular logic associated with inferring trust from behaviors alone. A second perspective is that by operationalizing psychological trust as a behavior, there is a plausible oversimplification of the process.

Justifying trust as the sole determinant of compliance or reliance is untenable because these behaviors may be affected by other processes (e.g., workload, self-confidence, perceived risk; Chancey et al., 2015b; Lee & Moray, 1994; Lee & See, 2004; Mayer et al., 1995, 2007; Parasuraman & Riley, 1997). Interestingly, interpersonal trust research and human-automation trust research share an offset but parallel historical evolution. Early studies concerning interpersonal trust frequently used a prisoner's dilemma game and operationalized trust as cooperative behavior between participants (e.g., Deutsch, 1960, 1958; Loomis, 1959; Solomon, 1960). Additionally, some researchers equated cooperative behavior with trust when defining the construct, e.g., trust is "the probability that he will perform an action that is beneficial or at least not detrimental to us is high enough to consider engaging in some form of cooperation with him" (Gambetta, 1988, p. 217).

Yet, this perspective led to a general critique among interpersonal trust researchers concerning the oversimplification of the effect of trust on behavior. Key and Knox (1970) questioned the value of studies that used the prisoner's dilemma game and cooperation to quantify trust. Key and Knox (1970) argued that it is possible to observe cooperative behavior with the plausible absence of trust, where the behavior may be based on other motives or rationales (e.g., in the absence of perceived risk and vulnerability).

Mayer et al. (1995) proposed that it is conceivable to cooperate with a person whom one does not trust, particularly if there are external control mechanisms that punish the trustee for deceitful behavior. Chancey, Proaps, and Bliss (2013) made a similar argument in the case of trust in automation, where pilots may be procedurally mandated to comply with certain alarms irrespective of their trust (although in this case, the control mechanism is placed upon the trustor not the trustee). Wiegmann et al. (2001) noted two instances in which trust may plausibly dissociate from behavior: the automation may be unreliable, but more accurate than the operator; and the operator may not have the information required to inform a diagnosis (i.e., the system is opaque). Rice (2009) proposed that an operator might not trust an automated aid but still depend upon it, because he or she is overloaded and does not have the time to crosscheck the aid's accuracy.

Some interpersonal trust researchers, however, still conceptualize trust as an observable choice behavior. One of these perspectives conceptualizes trust behavior as relatively rational, introduced largely from sociological, economic, and political fields (Kramer, 1999). This perspective characterizes the trusting individual as motivated to make a rational, efficient choice to maximize gains or minimize losses. Similar to normative decision models, this perspective is left open to criticisms countering the assumption that humans are rational decision makers (cf. Kahneman & Tversky, 1979, 1984; Simon, 1956). Clearly, humans do not always make rational choices, as decisions are often influenced by fallible heuristics (Tversky & Kahneman, 1974), framing effects (Kahneman & Tversky, 1979), and emotions (Loewenstein & Lerner, 2003).

Generally, interpersonal trust research has conceptualized trust-based behaviors as a manifestation of psychological trust (Costa, Roe, & Thailleau, 2001). As such, trust behaviors are not themselves characterized as trust, but the outcome of a particular level of psychological trust (e.g., Mayer et al., 1995; McAlister, 1995). Some researchers, however, have gone further to reject trust behaviors entirely. For example, one meta-analysis on the role of trust in leadership excluded articles that operationalized trust as a behavior, due to the "problematic" nature associated with this practice (Dirks & Ferrin, 2002).

Muir (1994) argued trust cannot be observed but only inferred, and indeed some researchers advocate trust be measured more directly via subjective assessment (e.g., Chancey et al., 2015a; Key & Knox, 1970; Wiegmann et al., 2001). In response to this, several researchers have tested for subjective trust as a mediator between signaling system error characteristics (reliability, error bias) and dependence behaviors (e.g., compliance, reliance, reaction time, response/agreement rate).

Bustamante (2009) noted that for trust to be a mediator between system characteristics and dependence behaviors, at least two criteria must be met: association and temporal precedence. There is ample evidence to claim an association among system error characteristics, dependence behaviors, and trust, theoretically (Cohen et al., 1998, Hoff & Bashir, 2015, Lee & See, 2004, Madhavan & Wiegmann, 2007, Muir, 1987, 1994) and empirically (Chancey et al., 2015a; Lee & Moray, 1992, 1994; Muir, 1996; Wang et al., 2010). Bustamante (2009) suggested, however, that empirical research has generally not accounted for temporal precedence in experimental design, because researchers tend to measure trust after the behaviors have been collected (however, see Lee & Moray, 1992, 1994 and Bliss, Hunt, Rice, & Geels, 2014, who modeled trust development using time-series analysis techniques).

Bustamante (2009) conducted two experiments in which participants interacted with either a FP or MP signaling system. To experimentally establish that trust preceded compliance and reliance he measured trust halfway through the experimental sessions and analyzed only the behaviors collected after the trust measure. The results from both experiments indicated lack of mediation. Bustamante (2009) concluded that, although trust is related to compliance and reliance, it might simply be a byproduct rather than a causal construct.

Using a similar paradigm, Wiczorek and Manzey (2009) allowed participants to interact with unreliable FP signaling systems before measuring trust. The results from their study indicated that the perceived reliability predicted the rate of compliance, with no mediating effect of subjective trust. Similarly, Chancey et al. (2013) reported a study in which a more reliable FP signaling system led to higher response rate and higher subjective trust, yet did not find evidence to suggest trust mediated the relationship between reliability and response rate. Unfortunately, Chancey et al. (2013) measured trust following the behavioral reactions, making it difficult to establish temporal precedence.

Recently, however, Chancey et al. (2015a) reported a study in which participants interacted with unreliable signaling systems that were FP or MP. In this study trust was measured halfway through the session and only the dependence behaviors following this measurement were analyzed. Their results indicated that subjective trust partially mediated the relationship between signaling system reliability and response rate. Trust did not, however, mediate the relationships between error bias (FP, MP) and response rate or reaction time, nor between reliability and reaction time. However, higher reliability led to a higher response rate, quicker reaction time, and higher subjective trust.

Baron and Kenny (1986) noted that one of the assumptions of mediation is that the mediator should be measured without error. Muir (1994) makes the cogent argument that it is difficult to research trust experimentally, because it is a hypothetical construct and cannot physically be observed or measured directly (p. 1909). It may be that the preceding studies failed to find a strong mediating effect of subjective trust on behavior due to the measures employed. Chancey et al. (2013) and Chancey et al. (2015a) used the 12-item questionnaire developed by Jian, Bisantz, and Drury (2000), which was generated empirically rather than based on any specific theory. Bustamante (2009) used three items from the Jian et al. (2000) questionnaire. Wiczorek and Manzey (2010) used a single-item questionnaire, assessing trust in alarms.

Certainly, the ambiguity of trust reflects the extensive history in which trust has been conceptualized as intuitive to the point of under-specification. This under-specification may have led researchers to overlook instances in which trust is not the likely operant variable in the compliance-reliance paradigm. Additionally, trust is qualitatively different depending upon the circumstances. The following section argues *how* the "two types of trust" observed in compliance-reliance research may be different and concludes with the purpose of the current work. Specifically, trust may be less robust in the MP-reliance relationship than the FP-compliance relationship.

Study Purpose: Trust and the Compliance-Reliance Paradigm

From established theories, unreliable systems should degrade trust, which should then lead to a reduction in or absence of reactions from the operator. Yet, as Lee and See (2004) suggested, the robustness or stability of trust depends upon the degree to which the goal-oriented information (i.e., performance, process, purpose) of the automation provides the basis to form that trust. The degree to which the informational bases of trust are available (i.e., purpose, process, performance) determines the appropriateness of trust (i.e., calibration, resolution, specificity), which subsequently guides the appropriateness of reaction behaviors (i.e., either misuse, disuse, or appropriate use of automation). The way in which this information is conveyed, however, depends on the type of automation, how the automation is contextualized, and, pertinent to the current work, the differences between systems that are compliant or reliant oriented (Lee & See, 2004).

Salient Choice. Clearly, FP systems are qualitatively different from MP systems, particularly in relation to error saliency (Rice & McCarley, 2011). Laboratory context may have underplayed the causal nature of trust and its ability to distinguish compliance from reliance. To demonstrate that trust is a more robust predictor of behavior under certain conditions, Chancey et al. (2015b) reanalyzed the data from Chancey et al. (2015a) to distinguish compliance from reliance. As expected, the FP system affected compliance but not reliance. Alternatively, the MP system affected reliance but not compliance. Interestingly, however, subjective trust partially mediated the relationship between reliability and compliance for the FP systems, but not the relationship between reliability and reliance for the MP systems. This suggests that the subjective evaluation of the operator's own attitude toward the system is qualitatively different depending on the error bias.

Chancey et al. (2015b) noted that false alarms present a salient, explicit choice to comply or not. Alternatively, misses give a non-salient, implicit choice to rely or not.
For an operator to intervene in spite of the absence of a signal, such as in the MP-reliance relationship, requires the operator to notice the absence of a cue (e.g., alarm, alert, advisory), a task that humans perform poorly (Hearst, 1991). The absence of a cue represents the key compliance-reliance distinction. It should be noted, however, in some cases the operator may notice an alternative cue from the alarm, which could then trigger a reaction behavior (e.g., if a building occupant smells smoke and evacuates, even though the fire alarm has not sounded). Yet if the monitored system is opaque (due to the complexity or absence of raw data), the operator will not be afforded the opportunity to evaluate alternative cues.

To this point, the user perspective of reliability proposed by Sullivan et al. (2008) is the subjective proportion of only false alarms, because missed events are unnoticed. Mirroring this, one of the characteristics of trust that distinguish it from other constructs such as confidence, is that the individual must choose one action in preference to another (Luhmann, 1988; Mayer et al., 1995). Lee and See (2004) proposed that trust develops from observations of automation behavior (i.e., performance). The observation of performance can contribute to evidence that buffers or develops existing trust based on alternative levels of attributional abstraction (i.e., process, purpose). Yet, the clear faulty behavior associated with a false alarm is more likely to act causally through operator trust because of its salience to the operator. From this perspective, trust is likely more sensitive to signaling system false alarms than misses because it provides salient information to evaluate whether or not the system can achieve an operator's goals (i.e., performance). This leads to the second component, the notion of perceived risk and vulnerability toward the automation in achieving the operator's goals.

Risk of Dependence. A plausible reason why Chancey et al. (2015a) did not find trust to be a strong mediator is because the strength of this effect depends upon the vulnerability of the operator toward the automation (Lee & See, 2004; Mayer et al., 1995, 2007). If participants do not feel risk when ignoring signals, trust has less influence upon the dependence behavior. Mayer et al. (1995, 2007) argued that risk is an essential component in modeling trust, where trust was characterized as a willingness to be vulnerable to another party. Simply having a willingness to be vulnerable, however, does not require an individual to take on any risk. Specifically, risk is integral in the behavioral demonstration of trust, whereby the trustor is not only willing to be vulnerable (i.e., trust) but actually assumes the risk (i.e., automation dependence; see bolded "Risk" moderating relationship in Figure 3).

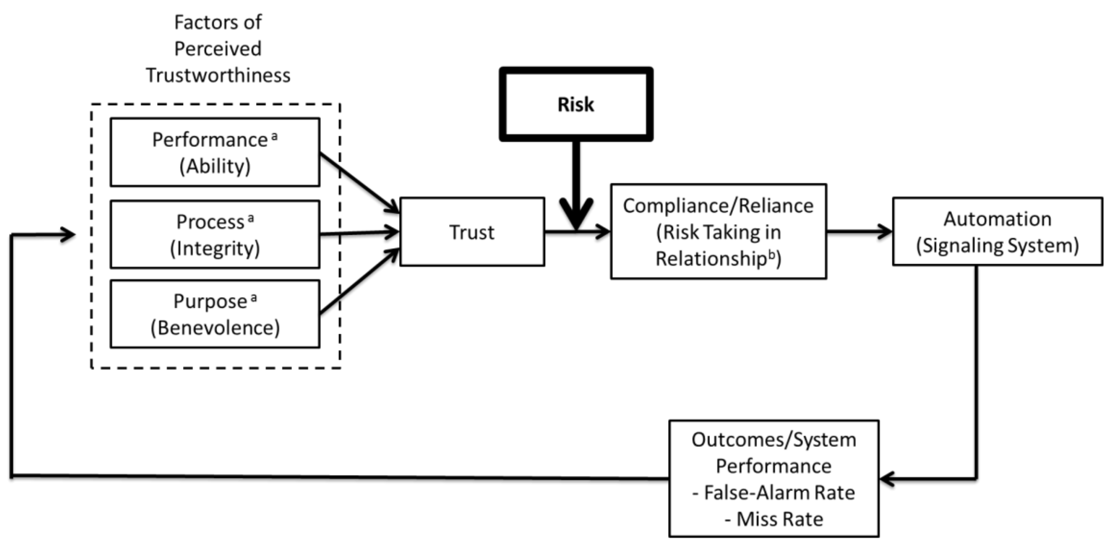

Figure 3. Modified "Proposed Model of Trust" by Mayer et al., (1995). [a]Lee and See's (2004) dimensions describing the bases of trust. [b]Automation compliance and reliance described as behavioral manifestations of trust.

Conditions for Dependence. Based on the preceding argument, the key conditions that allow trust to mediate the relationship between the error characteristics of signaling systems and dependence behaviors are: (condition 1) The operator is presented with a *salient choice* to depend on the signaling system and (condition 2) the *risk* associated with non-dependence is recognized. If these two conditions exist then one of two outcomes is possible: 1.) If trust in the system is higher than the risk of non-dependence, then the operator will depend upon the system or 2.) If trust in the system is lower than the risk of non-dependence, then the operator will not depend upon the system.

An example of this would be a pilot who engages in a violent course correction following a collision avoidance alarm. The pilot, in this case, trusts the alarm (condition 1) more than the risk associated with not complying with it, potentially leading to a midair collision (condition 2).

Moreover, by taking evasive action the pilot receives performance feedback. Trust should then grow if the pilot can confirm loss of separation (i.e., hit), or decline if the loss of separation cannot be confirmed (i.e., false alarm). Comparably, early instantiations of Ground Proximity Warning Systems produced a large number of false alarms, which led pilots to report a lack of trust in the system and to describe their evasive maneuvers as safety hazards (Pritchett et al., 2002, p. 194).

Alternatively, if the user does not recognize a choice (condition 1), and thus possibly does not recognize the risk involved in deviating from the current state (condition 2), then trust is less likely to act as a causative factor. In the case of signaling system misses, where the operator is not presented with a signal, there is no apparent or salient choice and the status quo should be maintained (barring instances of alternative non-alarm cues). Therefore, trust may be less impactful in the MP-reliance relationship (cf. Chancey et al. 2015b). This is not to suggest that trust does not or cannot mediate the relationship between misses and reliance, particularly if the trustor is aware of how the automation is likely to behave (i.e., process) or if it is being used for what it was designed to do (i.e., purpose). What is lacking is the cue for the operator to evaluate the behavior (i.e., performance) of the automation and recognize that it is missing signal events (i.e., trust is more volatile due to the informational basis deficiency). Moreover, if trust were to play a role in determining behavior, dispositional trust might be more predictive than affective trust.

Additionally, even if presented with a salient choice (condition 1), if the user is not made vulnerable by depending or not depending upon a signaling system (condition 2), then trust is also less relevant. Consequently, trust can fluctuate from high to low but not strongly determine the dependence behavior (cf., Mayer et al., 1995). Again, this is a plausible alternative explanation for the results reported by Bustamante (2010), Chancey et al. (2013), and Wiczorek and Manzey (2011). These studies were conducted in controlled laboratory conditions, in which risk of response behaviors was minimal. Such paradigms, though convenient and controllable, lack ecological validity (Sheridan & Parasuraman, 2005).

The primary purpose of the current work is to empirically test the preceding argument to determine how the bases of trust (i.e., performance, process, purpose) mediate the relationships between FP or MP systems and dependence behaviors (i.e., compliance and reliance). Moreover, risk likely modifies the degree to which trust mediates these relationships at all. Specifically, the second goal of this research is to investigate if the vulnerability of participants in high and low risk groups modifies the mediating influence of trust.

Hypotheses

The following hypotheses reflect the preceding theoretical and empirical review of signaling system characteristics and dependence behavior:

Moderated Mediation Hypotheses:

In reference to the models in Figure 4, the criteria of a mediator is often conveyed in terms of the *causal steps approach*: "(a) variations in levels of the independent variable significantly account for variations in the presumed mediator (i.e., Path a), (b) variations in the mediator significantly account for variation in the depended variable (i.e., Path b), and (c) when Paths a and b are controlled, a previously significant relation between the independent and dependent variables is no longer significant, with the strongest demonstration of mediation occurring when Path c′ is zero" (Baron & Kenny, 1986, p. 1176).

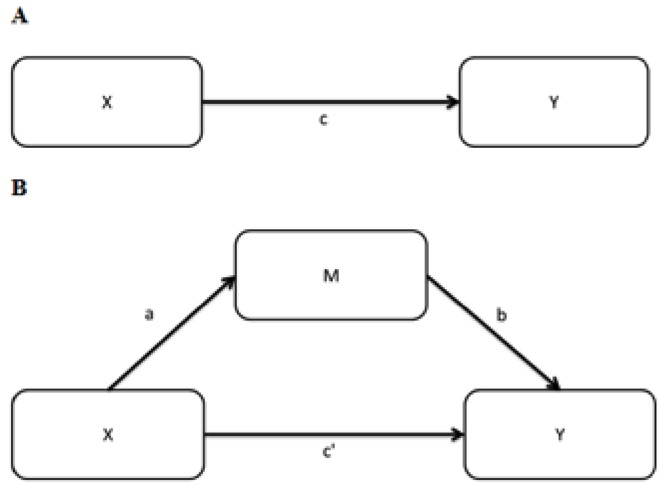

Figure 4. Graphical representation of a direct effect and simple mediation model. **A** illustrates a total effect and **B** illustrates a mediation design. Adapted from "*Asymptotic and Resampling Strategies for Assessing and Comparing Indirect Effects in Multiple Mediator Models*," by K. J. Preacher and A. F. Hayes, Behavior Research Methods, 40 (3), p. 880. Copyright 2008 by Psychonomic Society, Inc.

However, to test whether trust mediates the relationships between reliability and compliance for the FP systems or between reliability and reliance for the MP systems, a method advocated by Preacher and Hayes (2004, 2008; Hayes, 2009) will be used. This method employs bootstrapping to determine if the indirect effect of the mediator is significant (i.e., the product of path a and b in Figure 4). Although the traditional perspective on mediation assumes that path c was initially significant, an indirect effect does not. It is possible, therefore, to find a significant indirect effect without an initially significant total effect (i.e. Figure 4A). Some researchers suggest that a significant indirect effect can be interpreted as a mediator, even in the absence of the initially significant total effect (MacKinnon, Krull, & Lockwood, 2000; Hayes, 2009; Shrout & Bolger, 2002). For example, if a model has two mediators working in opposite directions, this could result in two significant indirect effects in the absence of a total effect. Hayes (2009) argued that failing to test for indirect effects in the absence of a total effect may lead researchers to miss instances where X affects Y through unanticipated mechanisms. Therefore, based on the pervasive theoretical presumption that trust mediates the relationships between error characteristics and dependence behaviors, the current work will interpret significant indirect effects as evidence of mediation. Moreover, although researchers generally refer to mediational processes as full or partial, the current work will consult the effect size calculation of κ^2 (proportion of maximum observed indirect effect) proposed by Preacher and Kelley (2011) for simple mediation analyses. For this effect size parameter, $\kappa^2 = 0$ implies that there is no linear indirect effect and $\kappa^2 = 1$ implies that the indirect effect is as large as it potentially could have been. Additionally, the ratio of indirect to total effect will also be consulted (P_m), which is the most commonly reported effect size measure for mediation analyses.

To determine if the indirect effect of trust is significant, bootstrap confidence intervals are created whereby the middle 95% of the resampled means are retained and the upper 2.5% and lower 2.5% of the means are dropped. The 95% confidence intervals will be examined to determine if the indirect effect is significantly different from 0 (i.e., signficance is $p < .05$, two-tailed), which indicates a mediated process. It should be noted that in small samples the assumption of normality is not generally met, yet the proposed bootstrap method is a nonparametric technique that does not require this assumption. Moreover, Preacher and Hayes (2008) recommend the use of the bootstrapping approach over other methods (e.g., Sobel test, causal steps approach), on the grounds that this approach has higher power while maintaining reasonable control over Type I error rate (p. 880).

Extending the analysis of mediation, the current work will employ a moderated mediation model to test if risk modifies the degree to which trust mediates the tested relationships, by looking at conditional indirect effects for participants in a high risk group versus a low risk group. Preacher, Rucker, and Hayes (2007) define a conditional indirect effect as "the magnitude of an indirect effect at a particular value of a moderator" (p. 186). In addition to probing for moderated mediation by looking at conditional indirect effects, indexs of moderated mediation will also be reported. Hayes (2015) proposes that "a mediation process can be said to be moderated if the proposed moderator variable has a nonzero weight in the function linking the indirect effect of X on Y through M to the moderator" (p. 7). Hayes (2015) goes on to propose that moderated mediation can be tested by whether this weight, called the index of moderated mediation, is different from zero. Again, bootstraped 95% confidence intervals for the index of moderated mediation can be created, where the mediational process is considered moderated if the confidence intervals do not contain zero (i.e., signficance is $p < .05$, two-tailed).

The theoretical framework used in the current study specifies that risk modifies the degree to which trust affects the outcome behavior, where error characteristics may cause trust to fluctuate from high to low without then causing the outcome behavior in the absence of risk (see Figure 3). This conceptualization places the moderating effect on the mediator on path b (the effect of M on Y), wich is refered to as a second stage moderation model (Hayes, 2015; Figure 5). Additionally, trust factors of performance, process, and purpose, will be analyzed in a parallel multiple-mediation model. With the parallel model, there is no assumption as to the possible causal influence between each factor (e.g., the performance factor does not necessarily affect the process factor before affecting the dependence behavior). The theoretical justification for this is specified by Lee and See's (2004) proposal that, unlike interpersonal trust development (cf.

Mayer et al., 1995; Rempel et al., 1985), human-automation trust does not necessarily follow a pre-defined sequence of atributional abstraction. Yet, although Lee and See (2004) do not propose a specified causal flow among the bases, they do not necessarily suggest the bases cannot or will not affect each other. Therefore, follow-up serial mediation models specifying the causal flow of performance on process and then purpose will also be conducted.

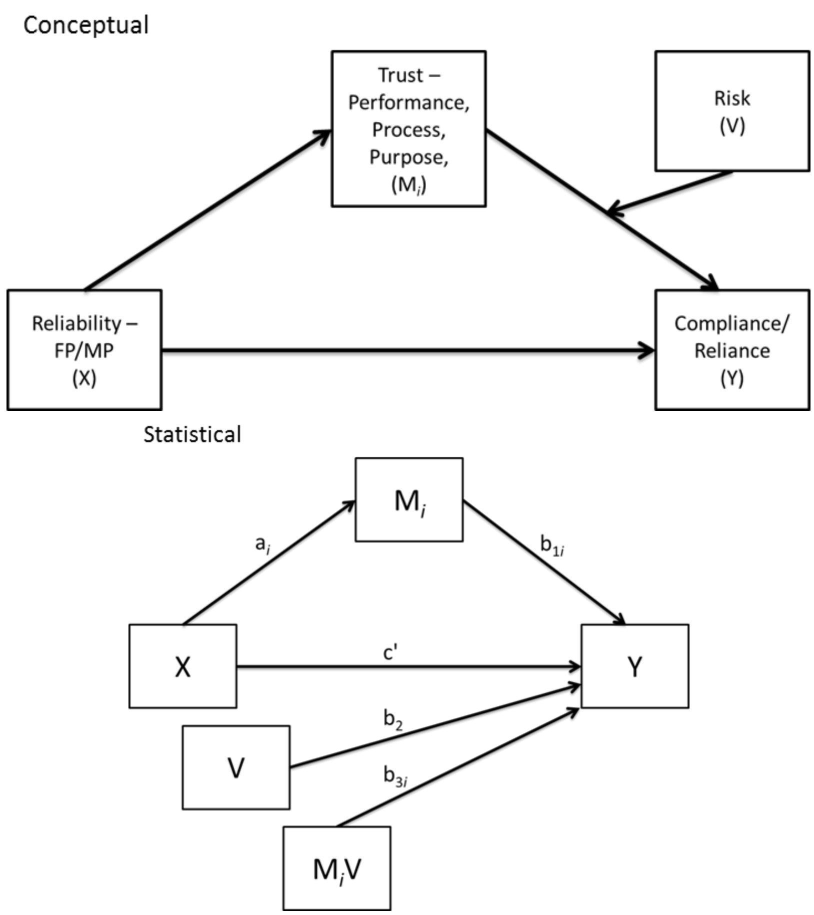

Figure 5. Moderated mediation depicted conceptually and statistically.

H1 – As reflected in Figure 6-H1, trust will mediate the relationship between signaling system reliability and compliance for FP systems (Lee & See, 2004; Meyer, 2001; Rice, 2009). This is similar to Meyer's (2001) initial conceptualization of the FP-Compliance relationship (see Figure 2B). Supporting this hypothesis, recent empirical evidence showed that trust partially mediated this relationship (Chancey et al. 2015b). Yet, some researchers have suggested trust in an unreliable system is not a strong determinant of compliance, based on several studies that found trust did not mediate this relationship (Bustamante, 2009; Chancey et al., 2013; Wiczorek & Manzey, 2010). It is unclear if this is due to the atheoretical questionnaires employed in these studies. To investigate this possibility, the current study assesses trust from a theoretical perspective via subjective evaluations based on signaling system performance, process, and purpose (Lee and See, 2004). Moreover, this lack of evidence may be due to the absence of risk in depending upon the automation (see H3 below).

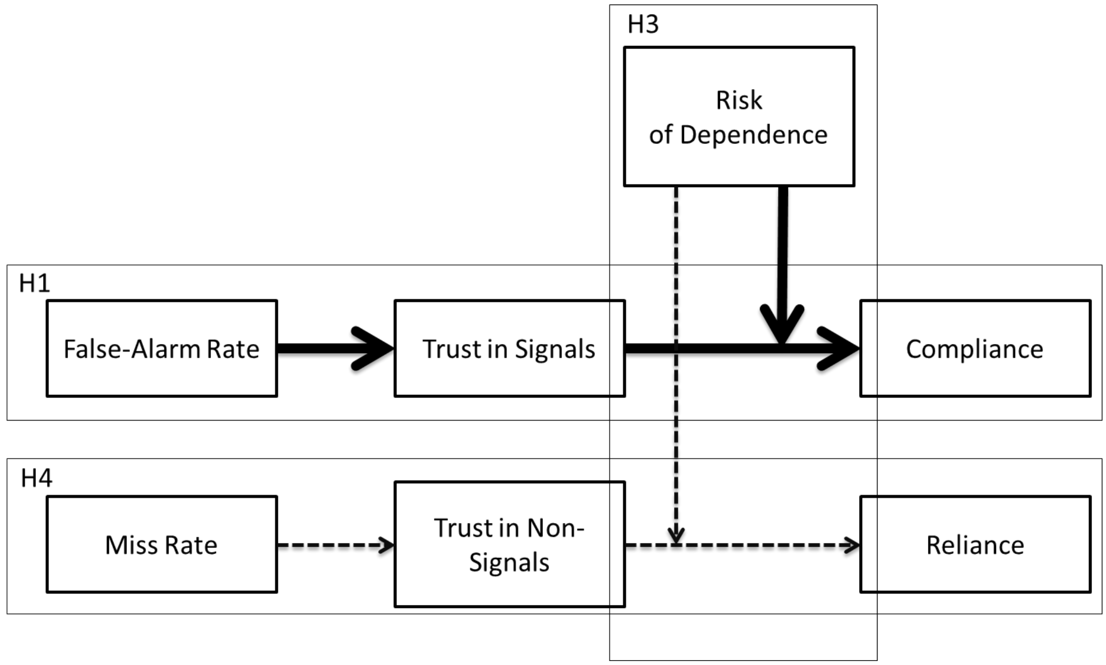

Figure 6. Hypothesized model reflecting signaling system errors on dependence (Similar to the model in Figure 2B, with the addition of risk moderating the effect of trust; i.e., model in Figure 3). Solid arrows indicate strong effect, whereas dashed arrows indicate weak affect.

H2 – Similar to the first hypothesis, trust will mediate the relationship between reliability and dependence rate for the FP signaling system (Chancey et al., 2015b; Lee & See, 2004).

H3 – As reflected in Figure 6-H3, the degree to which trust mediates any of the tested relationships will depend upon the degree of risk associated with not maintaining a high level of performance on the experimental tasks (Lee & See, 2004; see Figure 3). Specifically, risk will moderate the mediating effect of trust in the tested relationships (Mayer et al., 1995; Parasuraman & Riley, 1997; Sheridan & Parasuraman, 2008).

H4 –Trust based on performance will not mediate the relationship between reliability and reliance for the MP system. Moreover, because of this, trust will not mediate the relationship at all (cf. Bustamante, 2009; Chancey et al., 2015b; see Figure 6-H4).

H5 – Similar to the fourth hypothesis, trust will not mediate the relationship between reliability and dependence rate for the MP signaling system (Chancey et al., 2015b).

Effects of Reliability, Error Bias, and Risk Hypotheses. (H6) Higher reliability will lead to higher subjective ratings of trust (Chancey et al., 2015a; Lee & See, 2004). An interaction is expected, where higher reliability should lead to higher compliance and reliance, yet this will depend on the error bias. Specifically, the FP system will more directly impact compliance (**H7**) and the MP system will more directly impact reliance (**H8**) (Dixon, 2001; Chancey et al., 2015b; Rice, 2009). **(H9)** Finally, as a manipulation check, participants in the high-risk group will report higher perceived risk ratings than those in the low-risk group.

METHOD

Design

This study employed a 2 (error bias: FP or MP signaling system) × 2 (reliability: 90% or 60% reliable signaling system) × 2 (risk: high risk or low risk) split-plot design. The signaling system task was modeled after the tank-spotting tasks used in similar studies of compliance and reliance (e.g., Bustamante, 2009; Rice, 2009). For the tank-spotting task, participants made judgments about the presence or absence of a tank embedded in a series of aerial pictures. Participants completed this task with the aid of a signaling system that issued an alarm if it suspected that a tank was in the picture. This represented a transparent system, because it allowed participants to visually cross-check the accuracy of the signaling system. In addition to the signaling system task, participants were also required to perform two additional tasks from the Multi-Attribute Task Battery (MATB II; i.e., resource management and the compensatory tracking tasks; Santiago-Espada, Myer, Latorella, & Comstock, 2011). This experimental paradigm approximated flight simulation and accommodated contextual elements that allowed for independent variable manipulation and sensitive recording of participant responses and attitudes (e.g., transparent automation, multi-tasking, manipulation of signaling system reliability and error bias).

Independent Variables. Error bias of the signaling system was a fixed, between-subjects variable with two levels. The false alarm prone (FP) system committed false alarm errors only. The missed alarm prone (MP) system committed misses only. Reliability was a fixed, within-subjects variable with two levels: 90% reliable and 60% reliable. Reliability indicated the percentage of trials in which the signaling system was programmed to correctly indicate a tank present or tank absent out of the total number of aerial pictures presented.

Before interacting with each of the 60% and 90% reliable signaling systems, participants were informed that the systems are not perfectly reliable. Participants were not informed of the *specific* reliability or error bias, to ensure that trust levels resulting from the independent variable manipulations were given equal chances to develop across groups and conditions. Therefore, if specific error characteristic information were disclosed, trust could reflect information associated with each error bias rather than from direct automation interactions and observations. Participants were told that the 90% reliable automation “tends to be pretty reliable, so it probably won’t make a lot of mistakes” and that the 60% reliable automation “tends to be pretty unreliable, so it probably will make a lot of mistakes.”

To elicit measurable response differences, the reliability levels of 60% and 90% were chosen to be above and below the 70% crossover point reported by Wickens and Dixon (2007). Reliability of the signaling system was manipulated similar to previous studies using the FP/MP manipulation (e.g., Bustamante, 2009; Chancey et al., 2015a; Dixon et al. 2007, Meyer et al., 2014; Rice, 2009). Additionally, 50% of the aerial pictures had a tank (i.e., signal present) and 50% did not (i.e., signal absent). The signal detection response matrix according to error bias and reliability appears in Table 3.

Table 3

Detection response matrix for the false alarm prone (FP) and miss prone (MP) systems according to reliability for the signaling system task

	90% FP	*60% FP*	*90% MP*	*60% MP*
Hits	30 (.50)	30 (.50)	24 (.40)	6 (.10)
False Alarms	6 (.10)	24 (.40)	0 (.00)	0 (.00)
Misses	0 (.00)	0 (.00)	6 (.10)	24 (.40)
Correct Rejections	24 (.40)	6 (.10)	30 (.50)	30 (.50)

Note. Numbers outside of parentheses represent the raw number of responses per category that will occur during the session. Numbers in parentheses represent the proportions of responses (out of the total number of responses during each session).

Risk was a fixed, between-subjects variable with two levels: High risk, where the consequences of performing poorly on the experimental tasks was additional time in the experimental session without class credit to cover the additional time spent participating; and low risk, where performing poorly on the experimental tasks carried no direct consequences. The experiment always took approximately 1.5 hours to complete, regardless of the risk manipulation (i.e., participants were informed of only the additional time). Participants were randomly assigned to error bias and risk groups and reliability conditions were counterbalanced across groups.

Dependent Variables. To ensure that the trust measure temporally preceded dependence behaviors, subjective trust was assessed halfway through each session. For the moderated-mediation and mediation analyses, only the dependence behaviors obtained after the trust questionnaire were used in the analyses (cf. Bustamante, 2009; Chancey et al., 2015a). The proportions of signaling system errors were equated for pre- and post-questionnaire administration, to ensure that an experimental artifact was not mistaken for a particular effect. A modified version of the "human-computer trust questionnaire" developed by Madsen and Gregor (2000) was used to determine levels of operator trust (see Appendix B). A modified version of the perceived risk questionnaire developed by Simon, Houghton, and Auino (1999) was used to assess the perceived risk of performing poorly on the experimental tasks (see Appendix C).

Compliance was operationally defined as the number of times the participant responded "Tank Found" when the signaling system issued an alarm, out of the total number of alarms the signaling system issued (cf. Chancey et al., 2015b; Rice, 2009). Reliance was operationally defined as the number of times the participant responded "No Tank" when the signaling system remained silent, out of the total number of times the signaling system remained silent (cf. Chancey et al., 2015b; Rice, 2009). Because manipulating error bias and reliability creates an unequal number of opportunities for the participant to be reliant or compliant, overall dependence rate was also collected (e.g., in the 90% FP group there were 36 opportunities for a compliant response and 24 opportunities for a reliant response, whereas in the 90% MP group there were 24 opportunities for a compliant response and 36 opportunities for a reliant response). Therefore, dependence rate was operationally defined as the number of times the participant's response matched the advice of the signaling system (i.e., signal present or signal absent) out of the total number aerial pictures presented to the participant.

Performance measures were recorded for all of the experimental tasks. For the signaling system task, response bias (c), sensitivity (d′), and reaction time (RT; seconds from onset of the choice to respond “Tank Present” or “Tank Absent”) were recorded. For the compensatory tracking task, the root mean square deviation of a reticle from the center point of a crosshair was used to determine performance. For the resource management task, the amount of time that fuel levels deviated from a pre-specified amount of 2,500 units was used to determine performance.

Participants

The R program PowMedR (Kenny, 2014) was used to conduct a power analysis based on the standardized beta path coefficients reported by Chancey et al. (2015b; PowMedR downloaded from http://www.davidakenny.net/progs/PowMedR.txt; coefficients were a = .745, b = .444, c' = .403). The analysis indicated that a total of 39 participants would be required to achieve a power of .80 with a .331 effect size (standardized path coefficient) at an alpha level of .05, to observe a significant indirect effect (*ab*) of trust on compliance for an unreliable FP system (reliability 60% and 90%). Therefore, 88 participants were tested (56 females, 32 males), where half were presented with FP systems (n = 44) and half were presented with MP systems (n = 44). Participants self-reported an average age of 19.28 (*SD* = 2.13, *Min* = 18, *Max* = 28), playing video games an average of 2.69 hours-per-week (*SD* = 5.08), and using computers (work and recreation) an average of 17.55 hours-per-week (*SD* = 13.09). All participants reported having normal (or corrected-to-normal) visual acuity at the time of participation. No participant indicated having color deficiency or hearing impairment.

A convenience sample of college students from Old Dominion University (ODU) was used in the current study. Participants were enlisted through SONA, an online recruitment management program used by the ODU Psychology Department (see Appendix D for recruitment advertisement). Participants received research credits for participating in the 1.5-hour-long study, which could be applied toward course credit at the instructors' discretion. Approval from ODU's Institutional Review Board was obtained before data collection and written informed consent was obtained from all participants before participation (see Appendix A).

Materials/Apparati

Instruction Sheet. Participants were provided with an instruction sheet that contained information about how to complete the MATB II tasks and the signaling system task (see Appendix E). The experimenter read the instructions aloud to each participant, and the participant was asked to read along with his or her own copy.

MATB II. The MATB II is a battery of programmable tasks that simulate pilot responsibilities during flight (Santiago-Espada et al., 2011). Participants were responsible for two of these tasks: the compensatory tracking task and the resource management task.

Compensatory Tracking Task (Figure 7). This task simulates the pilot's function of maintaining level flight while competing with environmental variables such as wind. Using a joystick, participants attempted to keep a continuously drifting blue reticle at the center of a pair of crosshairs. Performance was calculated as the root mean square deviation of the reticle from the center point, which was sampled every 15 seconds and compiled in an output file.

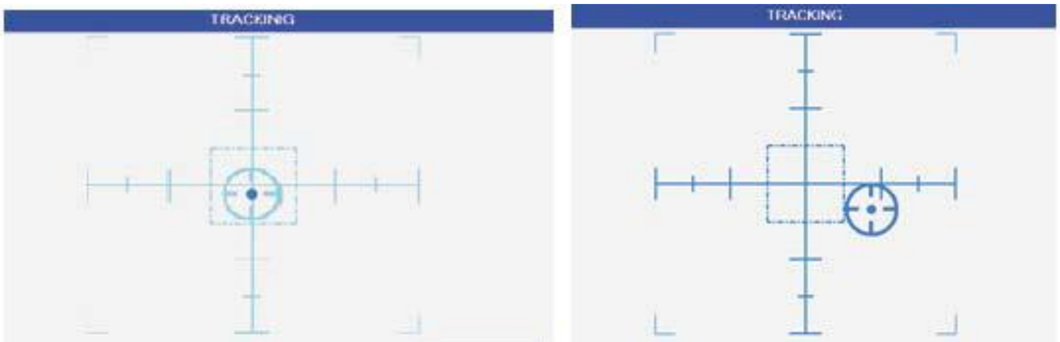

Figure 7. Screenshot of the compensatory tracking task.

Resource Management Task (Figure 8). This task represents a fuel management system. Six tanks labeled A through D contain green fuel, which depletes over the course of the task. Participants were tasked with transferring fuel from the supply tanks (E and F, which do not deplete) to tanks A and B. Participants were asked to maintain the fuel levels in tanks A and B as close to 2,500 units as possible (not above and not under). This task was accomplished by activating pumps that connect each tank (labeled 1-6). Pumps were activated and deactivated by pressing the corresponding number on a standalone ten-key number pad. Randomly, however, these pumps temporarily turned red and no longer transferred fuel. The fuel levels in tanks A and B were recorded every 30 seconds, where performance was determined by the difference from 2,500 units of fuel at these time points.

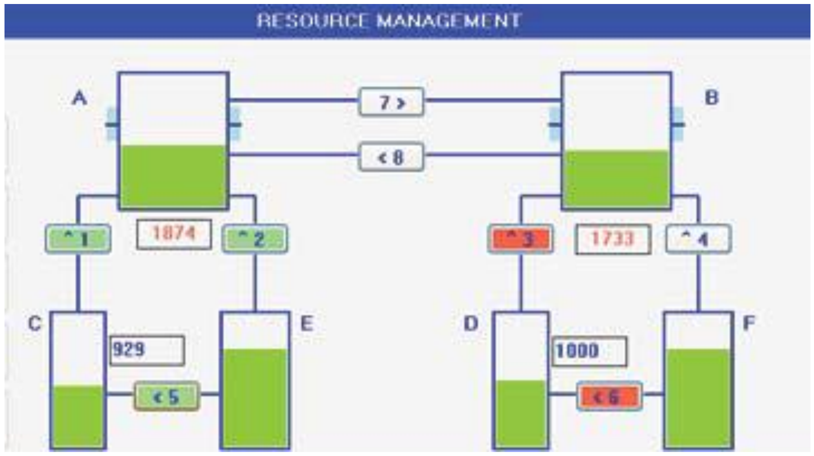

Figure 8. Screenshot of the resource management task.

Signaling System Task. Using SuperEdit 4.7™, the researcher developed the signaling system task, which was presented using SuperCard 4.7™ software hosted on a Macintosh desktop computer. The signaling system task was modeled after the tank spotting tasks used in similar compliance-reliance studies (e.g., Bustamante, 2009; Rice, 2009). Participants were required to view a series of aerial pictures and judge whether a tank was present or absent within each picture. The images were 30 aerial pictures of Bagdad, Iraq, collected using GoogleMaps. Images of tanks (see Figure 9) were embedded within each of these aerial pictures (see Figure 10). Across conditions, participants were exposed to the same 30 pictures with and without an imbedded tank (resulting in 60 aerial pictures).

Figure 9. Five types of embedded tanks.

Figure 10. Picture of tank embedded in an aerial photograph.

There was a delay between each aerial picture (randomized at 10, 14, or 18 seconds). Aerial pictures appeared for 3 seconds before moving to a screen that asked for the participants’ response. Participants were aided by a "Tank Spotting Aid," which diagnosed the presence of a tank in one of four quadrants of the image by surrounding it in red. If the aid diagnosed the presence of a tank it also sounded an auditory alarm. If the aid diagnosed the absence of a tank it did not sound an alarm and did not surround any quadrant in red. At the response screen, the image was replaced by text indicating the tank spotting aid's diagnosis (i.e., "Tank Found" or "No Tank"). Additionally, participants were required to click a button labeled "No Tank" if they did not believe the aerial picture contained a tank and click a button labeled "Tank Found" if they believed the aerial picture contained a tank. Participants were not able to move to the next picture until they clicked one of the two buttons. If a tank was in the picture, the aid never erred by alarming an incorrect quadrant; participants were explicitly informed of this. This aid represents the prototypical signaling system described in the section titled *Sensor-based Signaling Systems* in the current work, in that it both aids with information acquisition by selecting and filtering data (i.e., Stage 1 automation) and analyzes the available data to provide a diagnosis (i.e., Stage 2 automation; see Figure 11).

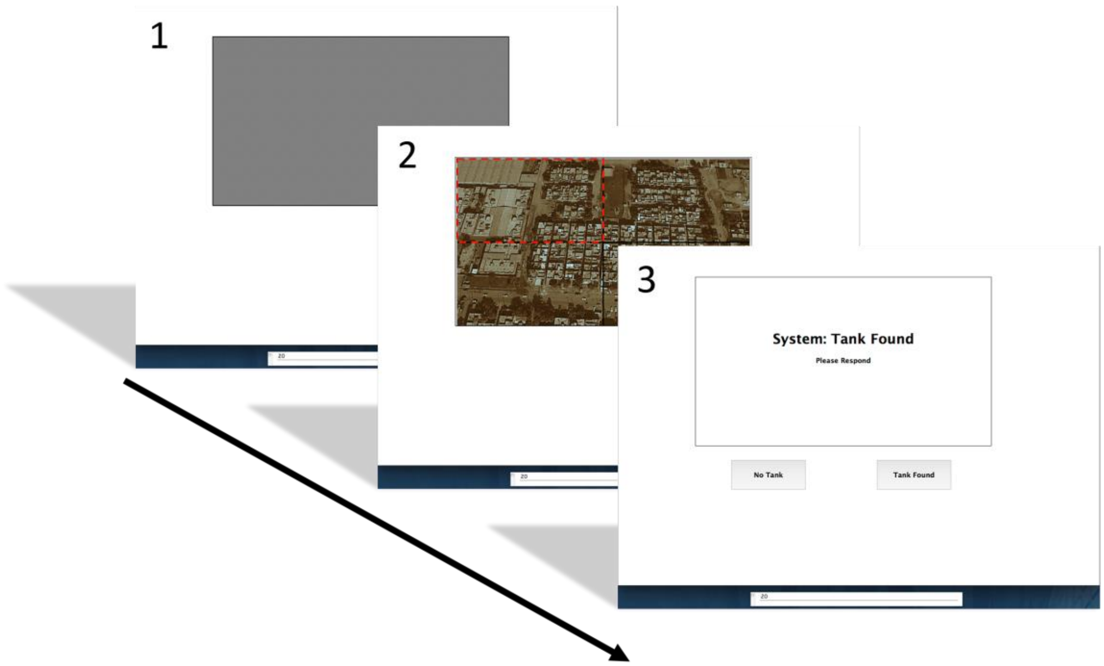

Figure 11. Signaling system task graphical depiction. 1) Delay between images randomized at 10, 14, and 18 seconds. 2) Aerial image presented for 3 seconds with visual and auditory alarm. 3) Screen presented after aerial image indicating the tank spotting aid's diagnosis and requesting the participant's response.

The color red was chosen for the signaling system visual diagnostic cue, to comply with the military standard for an alarm indicating hostile target identification (MIL-STD-1472G 11 January 2012). Tank Present alarms were accompanied by a tone that increased in frequency from 700 to 1,700 Hz in 0.85 seconds, with an interruption interval of 0.12 seconds, to comply with the military standard for aircrew station alerting systems indicating the existence of a condition requiring immediate action (MIL-STD-411F March 1997). To help participants evaluate their own performance on this task, a point bank was provided at the bottom of the task window. Correct decisions (i.e., clicking Tank Found when a tank is in the photograph or clicking No Tank when a tank is not in the photograph) resulted in a 1-point increase to the bank. Incorrect decisions (i.e., clicking Tank Found when a tank was not in the photograph or clicking No Tank when a tank was in the photograph) resulted in a 1-point decrease to the bank. Participants began each experimental session with 20 points, to avoid negative values. Points were not associated with any substantial benefits, other than to provide participants with an indication to monitor their own performance.

Trust questionnaire. A modified version of the "human-computer trust questionnaire" developed by Madsen and Gregor (2000) was used to determine levels of operator trust (see Appendix B). Importantly, this questionnaire closely matches the factors of performance, process, and purpose identified by Lee and See (2004), where Madsen and Gregor (2000) instead labeled similar factors of reliability, understandability, and faith, respectively (cf., Mayer et al., 1995; Rempel et al., 1985). The questionnaire consisted of 15 statements accompanied by a 12-point Likert scale asking participants to indicate their agreement from "Not at all" to "Very Much." In this study, the questionnaire showed adequate internal consistency for overall trust ($\alpha_{\text{Cronbach's}} = .97$), as well as for the individual factors of performance ($\alpha_{\text{Cronbach's}} = .96$), process ($\alpha_{\text{Cronbach's}} = .91$), and purpose ($\alpha_{\text{Cronbach's}} = .93$).

Perceived risk questionnaire. A modified version of the risk perception questionnaire used by Simon et al. (1999) was used to measure the perceived risk associated with consequences for performing poorly on the experimental tasks (see Appendix C). Simon et al. (1999) reported that this measure showed an adequate internal consistency ($\alpha_{\text{Cronbach's}} = .85$) and a factor analysis determined that the measure was unidimensional. The questionnaire showed an adequate internal consistency in the current study as well ($\alpha_{\text{Cronbach's}} = .85$).

Demographic form. Participants completed a demographic form at the beginning of the experiment (see Appendix F); participants indicated their sex, age, computer experience, videogame experience, hearing capability, visual acuity, color deficiency, and (if applicable) whether they had corrective hearing or visual devices with them to complete the experiment.

Apparati. The MATB II and signaling system tasks were hosted on two separate desktop computers (see Appendix G for picture of experimental setup). Participants performed the MATBII tasks on a Dell OptiPlex 990, Intel® Core™ i5 – 2500K CPU, with a Windows 7 operating system. Participants operated the compensatory tracking task with a Microsoft SideWinder Precision 2 Joystick and indicated their responses to the resource management tasks by pressing number keys (1-6) on a ten-key number pad. The signaling system task was hosted on a Macintosh desktop computer, which utilized OS X Yosemite version 10.10.3. Signaling system auditory alarms were presented by RadioShack® PRO-100 Communications Headset headphones. Two separate 12-inch Gateway FDP monitors (1730 for the PC and 1765 for the Mac) visually presented both tasks.

SPSS PROCESS Macro. To test the proposed moderated mediation and mediation models, a macro developed by Hayes (2013), referred to as PROCESS (v2.13), was used. This macro is compatible with SPSS and can be downloaded from *http://www.afhayes.com*, and has been used in other studies to test for mediation (Chancey et al., 2015a; Chancey et al., 2013; Merritt & Ilgen, 2009).

Procedure

After arriving at the testing location, participants were asked to complete the Informed Consent Form (Appendix A) and then the demographics form (Appendix F). Participants then received the experimental instructions, which were also read aloud by the researcher (Appendix

E). To accommodate the between-subjects variable of risk, half of the participants (randomized) received instructions indicating a “high risk” of adverse consequences associated with poor performance and the other half received instructions indicating a “low risk” of adverse consequences associated with poor performance. Following instructions, participants were then asked to practice the MATB II tasks alone and in combination (approximately 5 minutes). Participants were then asked to search through 10 aerial images that had a single tank embedded and indicate where in the image the tank was. All participants were required to find the tank before proceeding to the next image. Following the familiarization session, participants were asked to fill out the perceived risk questionnaire (Appendix C). Following this, participants completed a 10-minute practice session with the three tasks, where the signaling system was 100% reliable. Aerial images used in the practice session where not used in the experimental sessions.

Following the practice session, all participants then completed two 20-minute experimental sessions, where the signaling system varied in reliability for each session (90% and 60%). Participants were informed of the general reliability qualities of the signaling system before each session; the order of presentation was counterbalanced across participants. To accommodate the between-subjects variable of error bias, half of the participants experienced signaling systems that were FP only and the other half experienced signaling systems that were MP only (randomized). Halfway through all sessions, participants were presented with the trust questionnaire (Appendix B). Following the completion of this questionnaire, participants then completed the remainder of the session (see Figure 12).

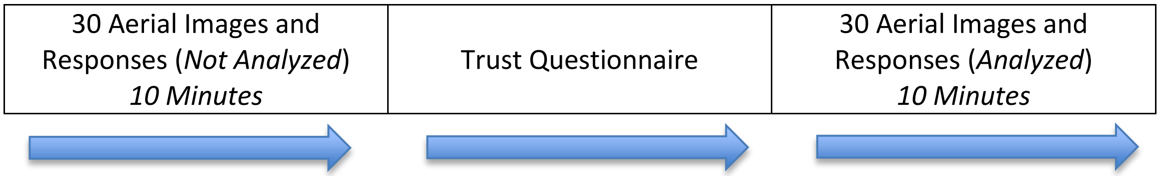

Figure 12. Graphical depiction of experimental process.

Following the two 20-minute sessions, participants were debriefed. For participants in the High-Risk group, this included informing them of the risk manipulation. Participants in the High Risk group were asked not to disclose this manipulation to other students who may participate in the study. Participants were then thanked and awarded research credit for their participation. The session lasted approximately 1.5 hours per participant.

RESULTS

Descriptive statistics were calculated and are presented in Appendix H. Data were transformed to be scaled from 0 as the *min* and 1 as the *max*. For example, a dependence rate (or compliance/reliance rate) of 0 indicates no agreements with the alarm system, whereas a dependence rate (or compliance/reliance rate) of 1 indicates perfect agreement with the alarm system. Similarly, a trust rating of 0 indicates no trust in the alarm system, whereas a trust rating of 1 indicates perfect trust in the alarm system.

The data were inspected for outliers, equal numbers among conditions and groups, and histograms were created to visually observe if the variables were generally normally distributed. Analysis of variance (ANOVA), however, is generally robust to violations of the normality assumption (Maxwell & Delaney, 2004, p. 112). Levene's tests were consulted to address the assumption of homogeneity of variance for the between subjects manipulations, which was not violated for any of the reported ANOVAs. The parallel moderated-mediation and mediation (simple and serial) analyses used a non-parametric bootstrapping method that did not require the assumption of normality. The moderated-mediation and mediation analyses employed standard errors that were based on the HC3 estimator, to address the assumption of homoscedasticity (Hayes & Cai, 2007). The moderated-mediation and mediation analyses were separated into FP systems (n = 44) and MP systems (n = 44), and analyzed separately. An outlier-labeling rule with a multiplier of 2.2 was consulted to identify outliers, and ensure that the results were not due to anomalous data (Hoaglin & Iglewicz, 1987). Two lower limit outliers were identified for reliance (outlier labeled as reliance rate values less than .04), in which reliance rate was 0 for both outliers. These data were adjusted to .32 to be .01 below the identified next lowest value of .33.

To minimize the chances of making a Type I error, $p < .05$ was established to indicate statistical significance. It should be noted that the selection of $p < .05$, which is heavily weighted to minimize a Type I error, was selected because of the experimentally controlled nature of this study and the existence of numerous studies and research supporting the ideas and proposed hypotheses (i.e., less controlled applied studies are often underpowered and novel research is often exploratory in nature, plausibly warranting an upward *p* value adjustment; Wickens, 1998). Moreover, the *p* value is often rigidly interpreted dichotomously as “all-or-none,” which leaves no room for interpretations of “practical significance” and thus increases the risk of a Type II error. Yet it is more appropriately expressed as a level of confidence, which is better represented as a continuous product (Wickens, 1998). Therefore, importantly, numerical effect sizes and power estimates accompany analyses, and are consulted to interpret the degree to which variables affected each other. To apportion power appropriately, hypotheses were tested before omnibus higher order interactions were investigated. Non-hypothesized interactions were interpreted by α corrected simple effects, where $\alpha = .05/b$ was used to establish significance of the simple effect of independent variable (IV) *a* within specific levels of IV *b* (Maxwell & Delaney, 2004, pp. 307-308).

Main Effects and Interactions

Perceived Risk. A two-way between-subjects ANOVA revealed a significant main effect of risk on perceived risk, $F(1, 84) = 12.457$, $p = .001$, *partial* $\eta^2 = .129$, observed power = .937, where participants in the high risk group ($M = .584$, $SE = .032$) assigned higher perceived risk ratings to poor task performance than the low risk group ($M = .426$, $SE = .032$). Neither a significant main effect of error bias, $F(1, 84) = .048$, $p = .827$, nor interaction between error bias and risk group, $F(1, 84) = 3.025$, $p = .086$, was observed.

Trust. A split-plot ANOVA revealed a significant main effect of reliability on subjective trust, $F(1, 84) = 185.795$, $p < .001$, *partial* $\eta^2 = .689$, observed power = 1.00, where participants in the 90% reliability condition ($M = .724$, $SE = .017$) rated the signaling system significantly more trustworthy than those in the 60% reliable condition ($M = .465$, $SE = .018$). Significant effects were not observed for the main effect of error bias, $F(1, 84) = 3.092$, $p = .082$, main effect of risk, $F(1, 84) = .893$, $p = .347$, interaction between error bias and risk, $F(1, 84) = 1.054$, $p = .208$, interaction between reliability and risk, $F(1, 84) < .001$, $p = .997$, interaction between error bias and reliability, $F(1, 84) = 1.151$, $p = .286$, nor interaction among reliability, risk, and error bias, $F(1, 84) = .428$, $p = .515$.

Performance. A split-plot ANOVA revealed a significant main effect of reliability on the performance factor of trust, $F(1, 84) = 176.138$, $p < .001$, *partial* $\eta^2 = .677$, observed power = 1.00, where participants in the 90% reliability condition ($M = .700$, $SE = .019$) rated the performance factor of trust higher than when in the 60% reliable condition ($M = .396$, $SE = .020$). There was also a significant main effect of error bias, $F(1, 84) = 4.090$, $p = .046$, *partial* $\eta^2 = .046$, observed power = .516, where participants in the FP group ($M = .580$, $SE = .022$) rated the performance factor of trust higher than the MP group ($M = .516$, $SE = .022$). Significant effects were not observed for the main effect of risk, $F(1, 84) = .335$, $p = .564$, interaction between error bias and risk, $F(1, 84) = 1.140$, $p = .289$, interaction between reliability and risk, $F(1, 84) = .043$, $p = .176$, interaction between error bias and reliability, $F(1, 84) = 1.862$, $p = .176$, nor interaction among reliability, risk, and error bias, $F(1, 84) = 1.729$, $p = .192$.

Process. A split-plot ANOVA revealed a significant main effect of reliability on the process factor of trust, $F(1, 84) = 103.695$, $p < .001$, *partial* $\eta^2 = .552$, observed power = 1.00, where participants in the 90% reliability condition ($M = .776$, $SE = .017$) rated the process factor of trust higher than when in the 60% reliable condition (*M* = .582, *SE* = .022). Significant effects were not observed for the main effect of error bias, $F(1, 84) = 1.628$, $p = .205$, main effect of risk, $F(1, 84) = .874$, $p = .352$, interaction between error bias and risk, $F(1, 84) = 1.047$, $p = .309$, interaction between reliability and risk, $F(1, 84) = .431$, $p = .513$, interaction between error bias and reliability, $F(1, 84) = .837$, $p = .363$, nor interaction among reliability, risk, and error bias, $F(1, 84) = .089$, $p = .766$.

Purpose. A split-plot ANOVA revealed a significant main effect of reliability on the purpose factor of trust, $F(1, 84) = 195.869$, $p < .001$, *partial* $\eta^2 = .700$, observed power = 1.00, where participants in the 90% reliability condition (*M* = .696, *SE* = .018) rated the purpose factor of trust higher than when in the 60% reliable condition (*M* = .471, *SE* = .019). Significant effects were not observed for the main effect of error bias, $F(1, 84) = 2.187$, $p = .143$, main effect of risk, $F(1, 84) = 1.069$, $p = .304$, interaction between error bias and risk, $F(1, 84) = .453$, $p = .503$, interaction between reliability and risk, $F(1, 84) = .144$, $p > .05$, interaction between error bias and reliability, $F(1, 84) = .393$, $p = .705$, nor interaction among reliability, risk, and error bias, $F(1, 84) = .417$, $p = .520$.

Dependence Rate. A split-plot ANOVA revealed a significant interaction between reliability and error bias on dependence rate, $F(1, 84) = 17.762$, $p < .001$, *partial* $\eta^2 = .175$, observed power = .986. A follow-up analysis on simple effects indicated that there was a significant effect of reliability in both the FP, Wilk's $\lambda = .219$, $F(1, 84) = 300.370$, $p < .001$, *partial* $\eta^2 = .780$, observed power = 1, and the MP group, Wilk's $\lambda = .394$, $F(1, 84) = 129.299$, $p < .001$, *partial* $\eta^2 = .606$, observed power = 1. Alternatively, for the 60% reliable condition, participants in the MP group agreed with the alarm system more often than those in the FP group, $F(1, 84) = 45.383$, $p < .001$, *partial* $\eta^2 = .351$, observed power = 1 (see Figure 13).

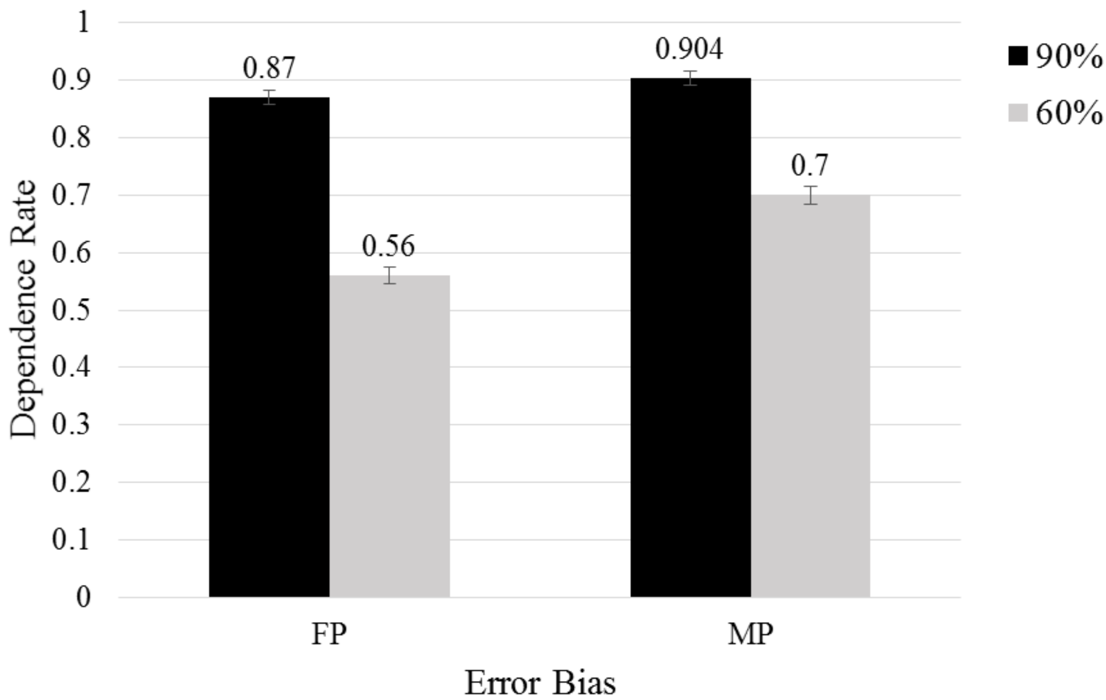

Figure 13. Average dependence rate as a function of reliability (90% and 60%) and error bias.

Significant effects were not observed for the main effect of risk, $F(1, 84) = .600$, $p = .441$, interaction between error bias and risk, $F(1, 84) = .006$, $p = .936$, interaction between risk and reliability, $F(1, 84) = .022$, $p = .882$, nor interaction among reliability, risk, and error bias, $F(1, 84) = 2.145$, $p = .147$.

Compliance. A split-plot ANOVA revealed a significant interaction between reliability and error bias on compliance rate, $F(1, 84) = 77.446$, $p < .001$, *partial* $\eta^2 = .480$, observed power = 1. A follow-up analysis on simple effects indicated that there was a significant effect of reliability on compliance rate, but only in the FP group, Wilk's $\lambda = .346$, $F(1, 84) = 158.940$, $p < .001$, *partial* $\eta^2 = .65$, observed power = 1 (Figure 14).

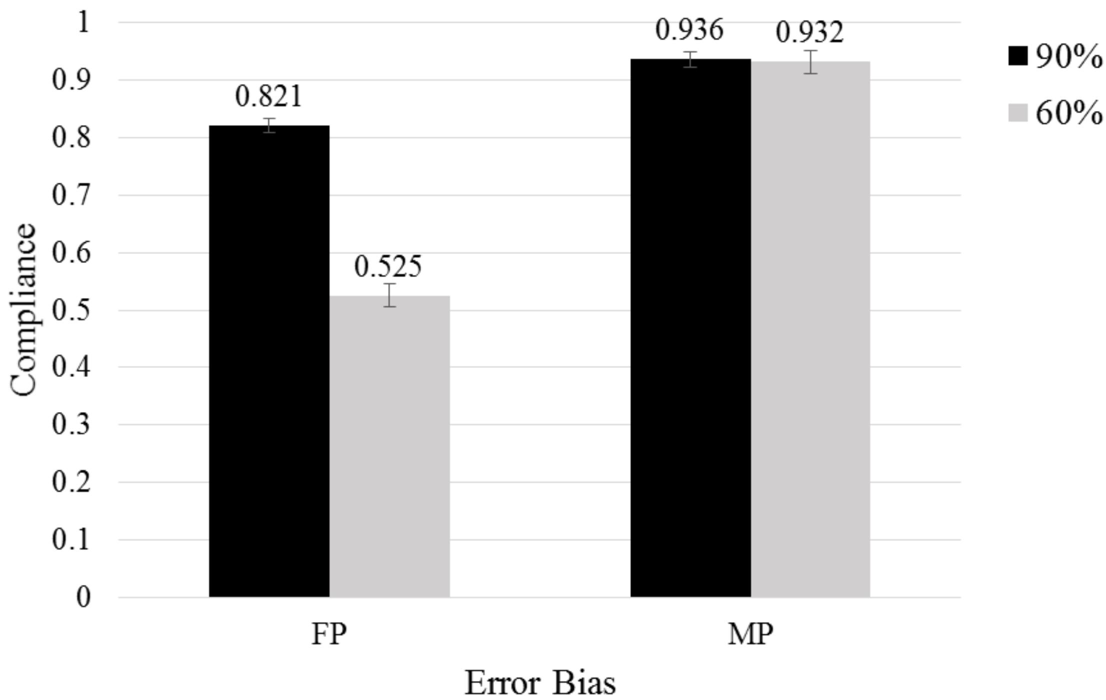

Figure 14. Average compliance rate as a function of reliability (90% and 60%) and error bias.

Significant effects were not observed for the main effect of risk, $F(1, 84) = .095$, $p = .759$, interaction between error bias and risk, $F(1, 84) = 1.522$, $p = .221$, interaction between risk and reliability, $F(1, 84) = .581$, $p = .448$, nor interaction among reliability, risk, and error bias, $F(1, 84) = .581$, $p = 448$.

Reliance. A split-plot ANOVA revealed a significant interaction between reliability and error bias on reliance rate, $F(1, 84) = 15.934$, $p < .001$, *partial* $\eta^2 = .150$, observed power = .972. A follow-up analysis on simple effects indicated that there was a significant effect of reliability on reliance rate, but only in the MP system, Wilk's $\lambda = .583$, $F(1, 84) = 60.179$, $p < .001$, *partial* $\eta^2 = .417$, observed power = 1. It should be noted, however, the effect of reliability on reliance in the FP group approached significance, Wilk's λ = .945, $F(1, 84) = 4.879$, $p = .030$ (greater than the alpha corrected .025), *partial* $\eta^2 = .055$, observed power = .588. Alternatively, the FP and MP groups were significantly different for both the 90% condition, $F(1, 84) = 6.366$, $p = .014$, *partial* $\eta^2 = .070$, observed power = .703, and 60% condition, $F(1, 84) = 33.613$, $p < .001$, *partial* $\eta^2 = .286$, observed power = 1 (Figure 15).

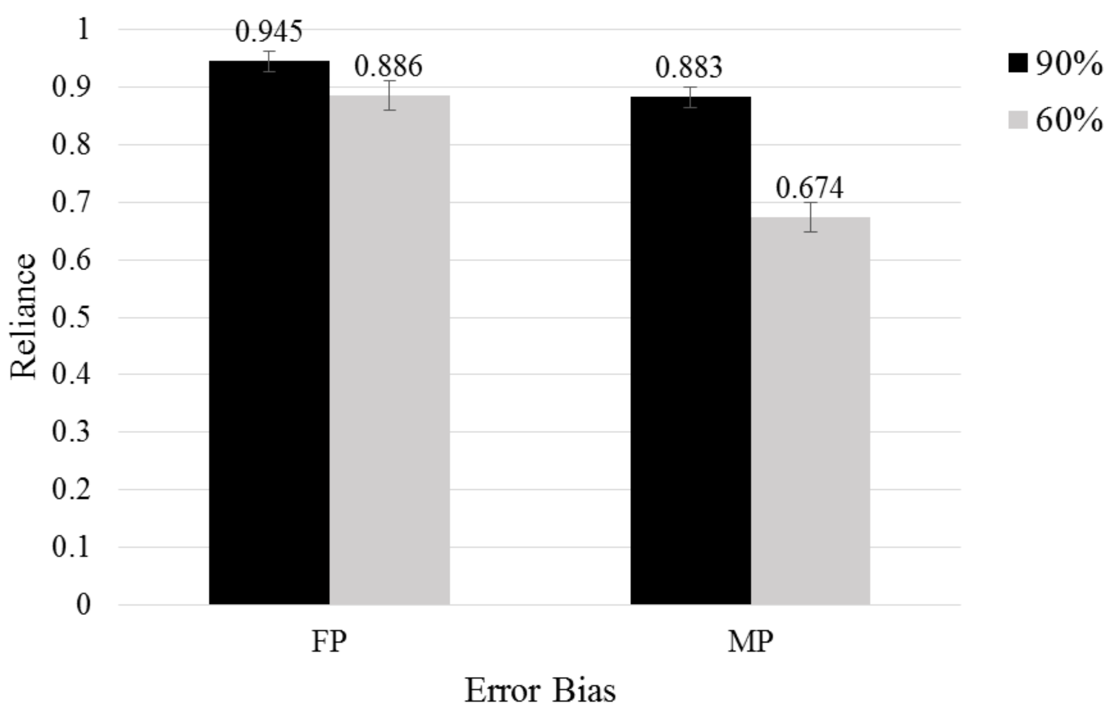

Figure 15. Average reliance rate as a function of reliability (90% and 60%) and error bias.

Significance was not observed for the main effect of risk, $F(1, 84) = .047$, $p = .829$, interaction between error bias and risk, $F(1, 84) = .606$, $p = .438$, interaction between risk and reliability, $F(1, 84) < .001$, $p = .987$, nor interaction among reliability, risk, and error bias, $F(1, 84) = 1.240$, $p = .269$.

Primary task performance. A significant main effect of risk on tracking task performance was observed, $F(1, 84) = 10.418$, $p = .002$, *partial* $\eta^2 = .110$, observed power = .891. Participants in the high risk group (*M* = 39.893, *SE* = 1.372) kept the drifting reticle significantly more stable than those in the low risk group (*M* = 46.157, *SE* = 1.372). No other main effects or interactions were observed for tracking task performance ($p > .05$). For resource management performance, no significant main effects or interactions were observed ($p > .05$).

Secondary task performance. A significant interaction between reliability and error bias on sensitivity (i.e., d′) was observed, $F(1, 84) = 19.724$, $p < .001$, *partial* $\eta^2 = .190$, observed power = .992. A follow-up analysis on simple effects indicated that there was a significant effect of reliability on sensitivity for both the FP, Wilk's $\lambda = .757$, $F(1, 84) = 26.986$, $p < .001$, *partial* $\eta^2 = .243$, observed power = 999, and MP groups, Wilk's $\lambda = .389$, $F(1, 84) = 131.688$, $p < .001$, *partial* $\eta^2 = .611$, observed power = 1. Alternatively, there was a significant effect of error bias, but only in the 60% reliability group, $F(1, 84) = 19.310$, $p < .001$, *partial* $\eta^2 = .187$, observed power = 991 (see Figure 16). No other main effects or interactions were observed for sensitivity ($p > .05$).

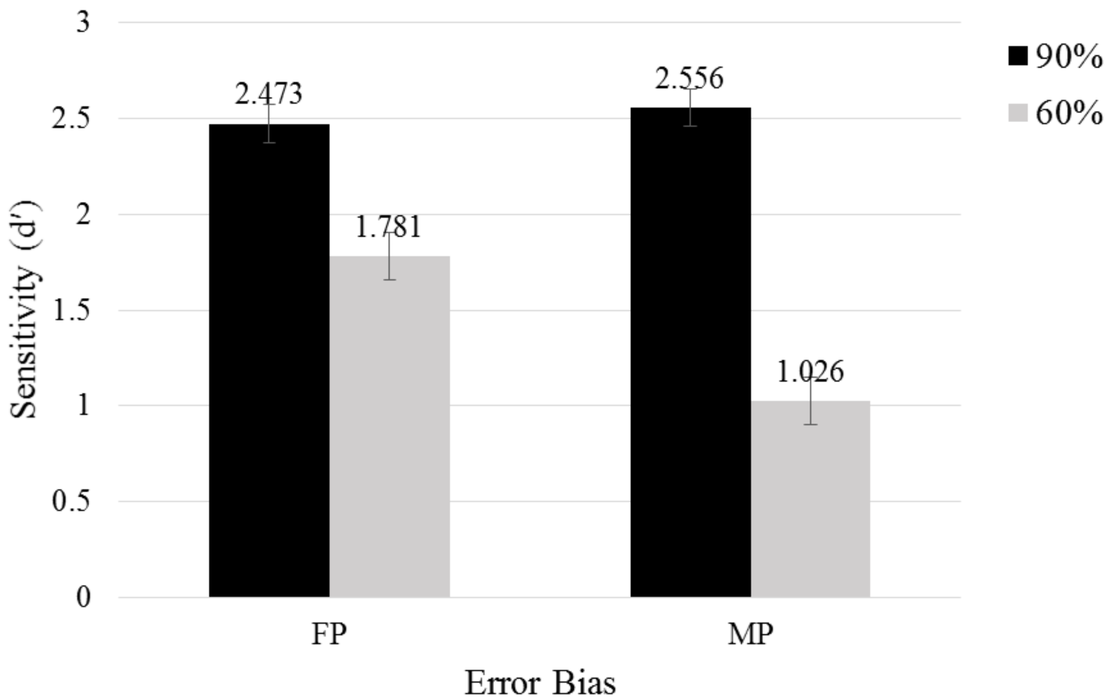

Figure 16. Average sensitivity (d′) as a function of reliability (90% and 60%) and error bias.

A significant interaction between reliability and error bias on alarm score was observed, $F(1, 84) = 22.464$, $p < .001$, *partial* $\eta^2 = .211$, observed power = .997. A follow-up analysis on simple effects indicated that there was a significant effect of reliability on score for both the FP, Wilk's $\lambda = .782$, $F(1, 84) = 23.470$, $p < .001$, *partial* $\eta^2 = .218$, observed power = 998, and MP groups, Wilk's $\lambda = .386$, $F(1, 84) = 133.342$, $p < .001$, *partial* $\eta^2 = .614$, observed power = 1. Alternatively, there was a significant effect of error bias, but only in the 60% reliability group, $F(1, 84) = 22.528$, $p < .001$, *partial* $\eta^2 = .211$, observed power = 997 (see Figure 17). No other main effects or interactions were observed for score ($p > .05$).

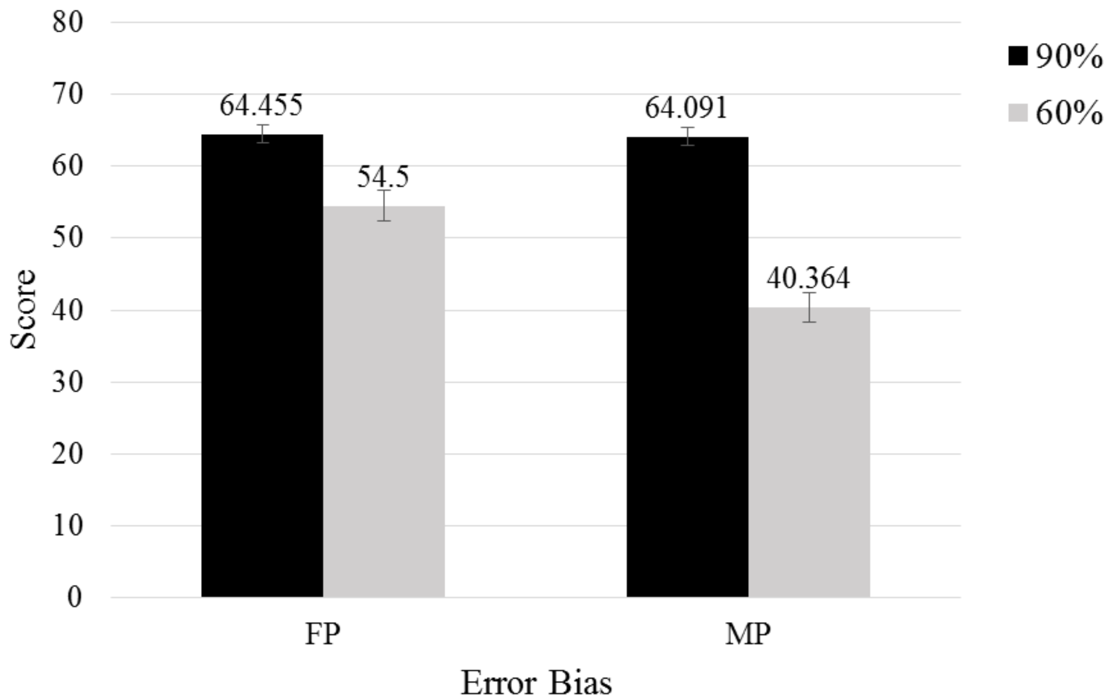

Figure 17. Average secondary alarm-task score as a function of reliability (90% and 60%) and error bias

A significant interaction between reliability and error bias on RT was observed, $F(1, 84) = 3.982$, $p = .049$, *partial* $\eta^2 = .045$, observed power = .505. A follow-up analysis of simple effects indicated that there was a significant effect of reliability on RT, but only in the FP group, Wilk's $\lambda = .934$, $F(1, 84) = 5.902$, $p = .017$, *partial* $\eta^2 = .066$. Alternatively, there was a significant effect of error bias, but only in the 60% reliability group, $F(1, 84) = 11.155$, $p = .001$, *partial* $\eta^2 = .117$, observed power = 910 (see Figure 18). No other main effects or interactions were observed for RT ($p > .05$).

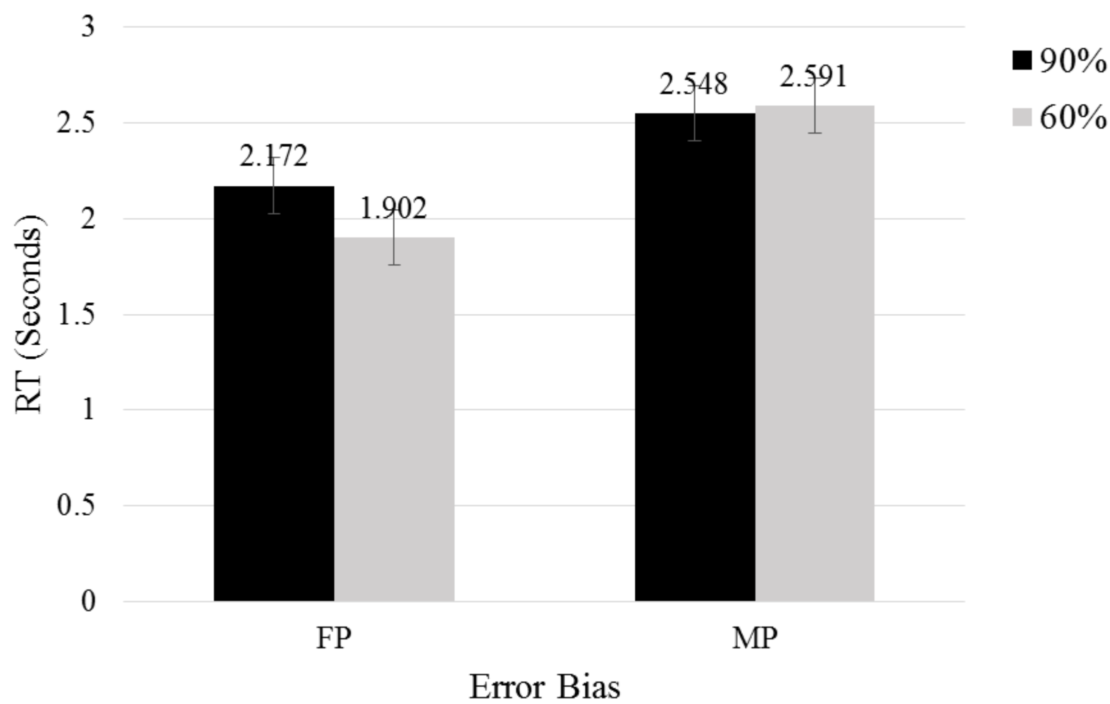

Figure 18. Average RT (seconds) as a function of reliability (90% and 60%) and error bias.

A significant interaction between reliability and error bias on response bias (i.e., c) was observed, $F(1, 84) = 10.609$, $p = .002$, *partial* $\eta^2 = .112$ observed power = .896. A follow-up analysis of simple effects indicated that there was a significant effect of reliability on response bias, but only in the FP group, Wilk's $\lambda = .876$, $F(1, 84) = 11.906$, $p = .001$, *partial* $\eta^2 = .124$. Specifically, the 90% condition tended to respond as though a tank was present ($M = -.078$, $SE = .046$) and the 60% condition tended to respond as though there was no tank ($M = .114$, $SE = .042$). Alternatively, there was a significant effect of error bias for both the 90% condition, $F(1, 84) = 49.419$, $p < .001$, *partial* $\eta^2 = .370$, observed power = 1, and the 60% condition, $F(1, 84) =$

12.242, p = .001, *partial* η^2 = .127, observed power = .933 (see Figure 19). No other main effects or interactions were observed for response bias (p > .05).

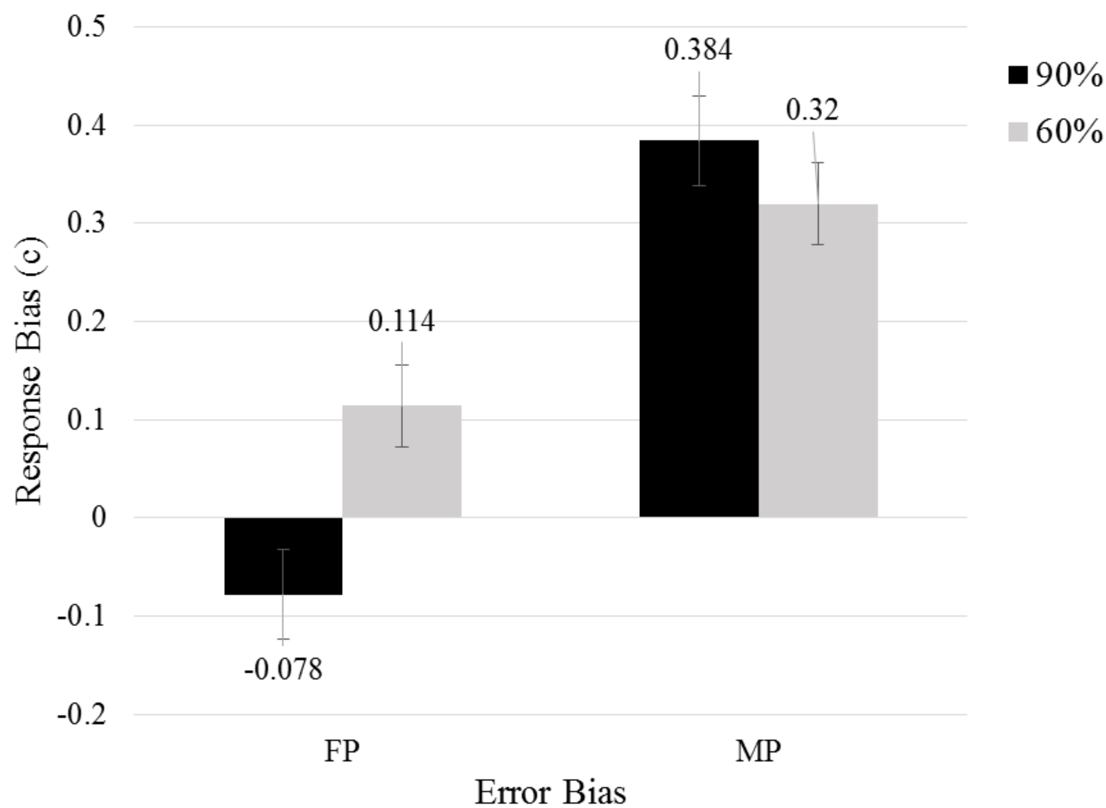

Figure 19. Average response bias (c) as a function of reliability (90% and 60%) and error bias.

False Alarm Prone Systems: Mediation Analyses

Trust. For the FP systems, general trust (i.e., performance, process, and purpose) did not mediate the relationships between reliability and compliance, reliance, nor dependence rate, for either the high or low risk groups. Follow-up simple mediation analyses, not accounting for the moderating effect of risk, are presented below (see Tables 4 and 5). Although no significant effects were found, effect sizes for simple mediation analyses were consulted to allow for a comparison with Chancey et al. (2015b), which reported significant indirect effects of trust on both compliance and dependence rate. For the mediating effect of trust between reliability and compliance, the proportion of the maximum observed indirect effect was $\kappa^{2 =}$ .112 (*SE* = .056, 95% *CI* [.009, .222]). Additionally, for the mediating effect of trust between reliability and dependence rate, the proportion of the maximum observed indirect effect was $\kappa^{2 =}$ .088 (*SE* = .054, 95% *CI* [.005, .203]).

Table 4

Path coefficients for the false alarm prone system simple-mediation models.

Source	***Compliance***	***Reliance***	***Dependence Rate***
a	.239***	.239***	.239***
	(.036)	(.036)	(.036)
b	.097	.062	.069
	(.058)	(.129)	(.055)
c	.295***	.074	.311***
	(.019)	(.043)	(.019)
c′	.274***	.059	.294***
	(.024)	(.053)	(.023)

* $p < .05$; ** $p < .01$; *** $p < .001$

Note: Standard errors in parentheses. See Figure 4 for corresponding model paths (X = Reliability, M = trust, Y = Compliance, Reliance, Dependence Rate).

Table 5

Indirect effects of trust for false alarm prone system reliability on compliance, reliance, and dependence rate through subjective estimates of signaling system trust.

Source	***Point Estimate***	***SE***	***Bootstrapping 95% CI***	
			Lower	**Upper**
Compliance	.023	.014	-.002	.053
Reliance	.015	.027	-.039	.067
Dependence Rate	.017	.014	-.009	.046

Note. *Data bootstrapped (10,000).*

Performance. For the FP systems, the performance factor of trust did not mediate the relationships between reliability and compliance, reliance, nor dependence rate, for either the high or low risk groups.

Process. For the FP systems, the process factor of trust did not mediate the relationships between reliability and compliance nor dependence rate, for either the high or low risk groups. The process factor did, however, mediate the relationship between reliability and reliance, but only for the high risk group (i.e., risk moderated the mediating effect of the process component of trust). Specifically, a significant conditional indirect effect was observed in the high risk group, *ab* = .057, *SE* = .033, 95% *CI* (.006, .136), but not in the low risk group, *ab* = -.062, *SE* = .066, 95% *CI* (-.047, .215). For the high risk group, participants in the 90% reliability condition relied on the system at a rate of .057 times more than those in the 60% reliability condition, as a result of the process factor of trust. However, the conditional indirect effects between the high and low risk groups were not significantly different from each other, *index of moderated mediation* = .005, *SE* = .071, 95% *CI* (-.0124, .162).

A follow-up simple mediation analysis, not accounting for the moderating effect of risk, indicated that the proportion of the maximum observed indirect effect was $\kappa^{2\,=}$ .064 (*SE* = .039, 95% *CI* [.006, .163]) for the mediating effect of the process component of trust between reliability and reliance. Yet, when not accounting for the moderating effect of risk, a significant indirect effect of the process component of trust was not observed (*ab* = .028, *SE* = .019, 95% *CI* [-.0004, .082]).

Purpose. For the FP systems, the purpose factor of trust did not mediate the relationships between reliability and reliance nor dependence rate, for either the high or low risk groups. The purpose factor did, however, mediate the relationship between reliability and compliance, but only for the high risk group (i.e., risk moderated the mediating effect of the purpose component of trust). Specifically, a significant conditional indirect effect was observed in the high risk group, *ab* = .088, *SE* = .043, 95% *CI* (.002, .172), but not in the low risk group, *ab* = .044, *SE* = .062, 95% *CI* (-.083, .166). For the high risk group, participants in the 90% reliability condition complied with the system at a rate of .088 times more than those in the 60% reliability condition, as a result of the purpose factor of trust. However, the conditional indirect effects between the high and low risk groups were not significantly different from each other, *index of moderated mediation* = .044, *SE* = .075, 95% *CI* (-.104, .194).

A follow-up simple mediation analysis, not accounting for the moderating effect of risk, indicated that the proportion of the maximum observed indirect effect was $\kappa^{2\,=}$ .131 (*SE* = .054, 95% *CI* [.025, .238]) for the mediating effect of the purpose component of trust between reliability and compliance. Not accounting for the moderating effect of risk still revealed a significant indirect effect of the purpose component of trust (*ab* = .028, *SE* = .014, 95% *CI* [.004, .060]).

Follow-up Serial Mediation Analyses. Serial mediation analyses, using the risk group as a covariate, revealed that the indirect effect of performance, process, and then purpose, significantly indirectly affected compliance rate through all three of the bases of trust sequentially (*indirect effect* = .009, *SE* = .005, 95% *CI* [.0003, .021]). In other words, higher reliability led to higher ratings of performance (a_1 = .273, *SE* = .040, $p < .001$), which led to higher ratings of process (d_{21} = .645, *SE* = 125, $p < .001$), which led to higher ratings of purpose (d_{32} =.190, *SE* = .046, $p < .001$), and ultimately resulted in a higher compliance rate (b_3 =.264, *SE* = .129, $p = .043$). For this analysis, the ratio of indirect to total effect of reliability on compliance rate was P_m= .029 (*SE* = .018, 95% *CI* [.001, .072]). However, a stronger effect was observed for the sequential indirect effect of performance through purpose on compliance rate (*indirect effect* = .053, *SE* = .027, 95% *CI* [.002, .106]). Independent of the effect of the process component, higher reliability resulted in a higher performance rating (a_1 = .273, *SE* = .040, $p < .001$) which led to a higher purpose rating (d_{31} = .740, *SE* = .060, $p < .001$) and ultimately led to a higher compliance rate (b_3 = .264, *SE* = .129, $p = .043$). For this analysis, the ratio of indirect to total effect of reliability on compliance rate was P_m= .194 (*SE* = .099, 95% *CI* [.007, .398]).

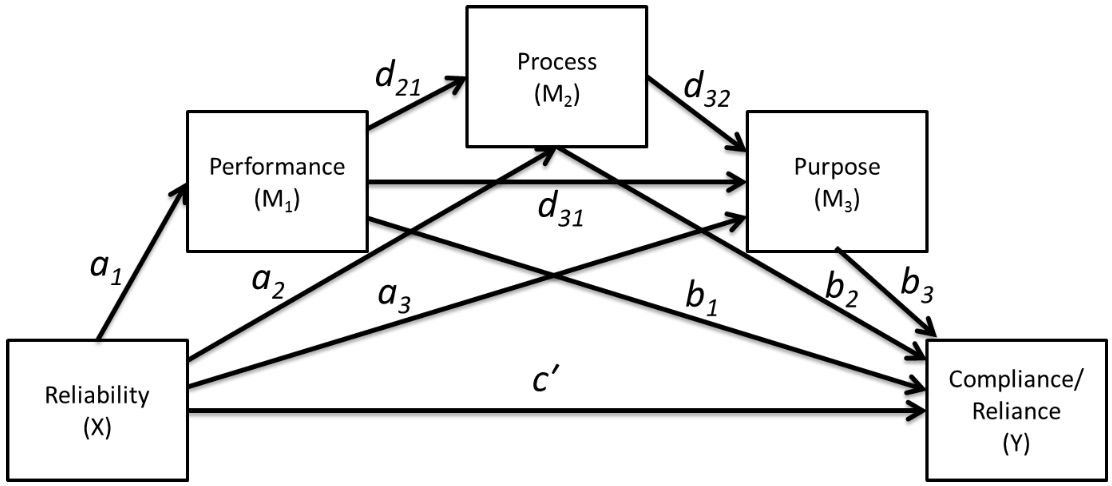

Figure 20. Serial mediation process model. *Note*: Adapted from "Introduction to Mediation, Moderation, and Conditional Process Analysis," by A.F. Hayes, p. 145. Copyright 2013 by The Guilford Press.

Additionally, a significant indirect effect of performance through process on reliance rate was observed (*indirect effect* = .057, *SE* = .034, 95% *CI* [.005, .139]). Independent of the effect of the purpose component, higher reliability resulted in a higher performance ratings (a_1 = .273, *SE* = .040, $p < .001$) which led to a higher process ratings (d_{21} = .645, *SE* = 125, $p < .001$) and ultimately led to a higher reliance rate (b_2 = .329, *SE* = 162, $p = .045$).

Miss Prone Systems: Mediation Analyses

Trust. For the MP systems, general trust (i.e., performance, process, and purpose) did not mediate the relationships between reliability and compliance, reliance, nor dependence rate, for either the high or low risk groups. Follow-up simple mediation analyses, not accounting for the moderating effect of risk, are presented below (see Tables 6 and 7).

Table 6

Path coefficients for the miss prone system, simple-mediation models.

Source	***Compliance***	***Reliance***	***Dependence Rate***
a	.279***	.0279***	.279***
	(.034)	(.034)	(.034)
b	.154	.133	.109
	(.083)	(.076)	(.062)
c	.004	.208***	.204***
	(.026)	(.024)	(.019)
c′	-.039	.171***	.173***
	(.035)	(.032)	(.026)

* $p < .05$; ** $p < .01$; *** $p < .001$

Note: Standard errors in parentheses. See Figure 4 for corresponding model paths (X = Reliability, M = trust, Y = Compliance, Reliance, Dependence Rate).

Table 7

Indirect effects of trust for miss prone system reliability on compliance, reliance, and dependence rate through subjective estimates of signaling system trust.

Source	***Point Estimate***	***SE***	***Bootstrapping 95% CI***	
			Lower	**Upper**
Compliance	.043	.025	-.004	.092
Reliance	.037	.022	-.004	.084
Dependence Rate	.031	.018	-.004	.067

Note. *Data bootstrapped (10,000).*

Performance. For the MP systems, the performance factor of trust did not mediate the relationships between reliability and compliance, reliance, nor dependence rate, for either the high or low risk groups.

Process. For the MP systems, the process factor of trust did not mediate the relationships between reliability and compliance, reliance, nor dependence rate, for either the high or low risk groups.

Performance. For the MP systems, the performance factor of trust did not mediate the relationships between reliability and compliance, reliance, nor dependence rate, for either the high or low risk groups.

Follow-up Serial Mediation Analyses. For the MP systems, serial mediation analyses did not reveal any indirect effects of performance, process, nor purpose, on compliance rate or reliance rate.

Summary of Results

Main Effects and Interactions.

- Perceived Risk: Supporting the manipulation check, the high risk group indicated higher perceived risk associated with poor task performance (supporting H9).
- Trust: Higher reliability led to higher subjective trust (supporting H6).
- Dependence Rate: Higher reliability led to a higher dependence rate. An interaction revealed that this effect was more pronounced in the FP group.
- Compliance: An interaction revealed that higher reliability led to a higher compliance rate, but only for the FP group (supporting H7).
- Reliance: An interaction revealed that a higher reliability led to a higher reliance rate, but only in the MP group (supporting H8). Yet, although not statistically significant due to the alpha correction, a higher false alarm rate led to a marginal reduction in reliance.
- Primary task performance: Participants in the high risk group performed better on the tracking task than those in the low risk group. No other significant effects on primary task performance were observed.
- Secondary task performance: Higher reliability led to higher sensitivity, yet an interaction indicated that this effect was more pronounced in the MP group. Similarly, higher reliability led to higher alarm scores, yet an interaction indicated this effect was more pronounced in the MP group. Participants in the MP group responded slower than those in the FP group. Moreover, participants responded quicker in the less reliable condition, but only for the FP

group. Finally, there was a significant effect of reliability on response bias, but only in the FP group. Specifically, participants in the higher reliable condition tended to respond as though a tank was present more often.

FP systems: Moderated-mediation and mediation analyses. Although the single factor of trust did not mediate any of the tested relationships, individual factors or bases of trust differentially mediated the relationships between false alarm rate for both compliance and reliance. The purpose factor of trust mediated the FP-compliance relationship (partially supporting H1) and, although a weaker effect, the process factor of trust mediated the FP-reliance relationship. Moreover, conditional indirect effects showed that those factors of trust only mediated those relationships for participants in the high risk group (supporting H3, according to Preacher et al., 2007). Yet, the index of moderated mediation was not significantly different from zero, indicating those conditional indirect effects were not significantly different from each other (failing to support H3, according to Hayes, 2015).

Follow-up serial mediation analyses gave a different perspective on the effect of false alarm rate on compliance and reliance through performance, process, and then purpose. Specifically, trust mediated the relationship between false alarm rate and compliance, by affecting each factor in a sequential order. From this perspective H1 was supported, because the effect of the FP system reliability on compliance was the result of each factor building off of each other. Yet, a stronger mediating effect in the FP-compliance relationship was observed through performance and then purpose. Additionally, the effect of false alarm rate on reliance was mediated by the sequential effect of performance on process. Neither trust nor any of its individual bases mediated the relationship between false alarm rate and general dependence rate (failing to support H2).

MP systems: Moderated-mediation and mediation analyses. Although factors of trust mediated some of the FP-compliance/reliance relationships, none of those factors mediated any of the MP-reliance (or dependence rate) relationships (supporting H4 and H5).

DISCUSSION

Generally, the results supported the proposed hypotheses and observed differences did not trade off with primary task performance (see Appendix I). Similar to other studies exploring the compliance-reliance paradigm, predicted main effects and interactions were observed (Chancey et al., 2015b; Dixon, 2001; Meyer, 2001, 2004; Rice, 2009). Yet, bases or factors of trust indirectly affected response behaviors in the FP relationships, and not the MP relationships. Moreover, trust only mediated those FP relationships for participants in the high risk group. For the MP system, although trust was related to reliance (i.e., main effects of miss rate on trust and reliance), the results indicated that the effect on trust was a byproduct of miss rate rather than a causal mechanism affecting reliance behavior (cf. Bustamante, 2009).

Although there is somewhat compelling evidence to suggest that there are two different cognitive processes underlying the FP-compliance and MP-reliance relationships, these relationships lack theoretical and empirical specificity. The results from the current work suggest that researchers may need to re-conceptualize the notion of two independent types of trust. The following sections will first discuss how these results contribute theoretically to the compliance-reliance paradigm, discuss the practical implications, and describe some limitations of the current study and ideas for future research.

Theoretical Implications

The FP systems had a more direct effect on trust affecting behavior than the MP systems. Although this indicates two independent psychological processes stemming from FP and MP system reliability, the more plausible explanation is that trust more strongly affects behavior in one relationship than the other (i.e., *there are not two types of trust*). Instead, other candidate psychological constructs need to be explored to predict and explain the MP-reliance relationship, such as confidence and state-based suspicion (explored in Figure 21 below). Additionally, the non-selective mediation stemming from false alarm rate on compliance and reliance suggests that different combinations of the bases of trust, rather than two types of trust, likely affect these behaviors. Figure 21 graphically represents the results obtained from the current study and includes two candidate constructs to explain the MP-reliance relationship. The theoretical contributions of this work will first be discussed from the effects of false alarm rate on compliance and reliance, and then from the effects of miss rate on reliance.

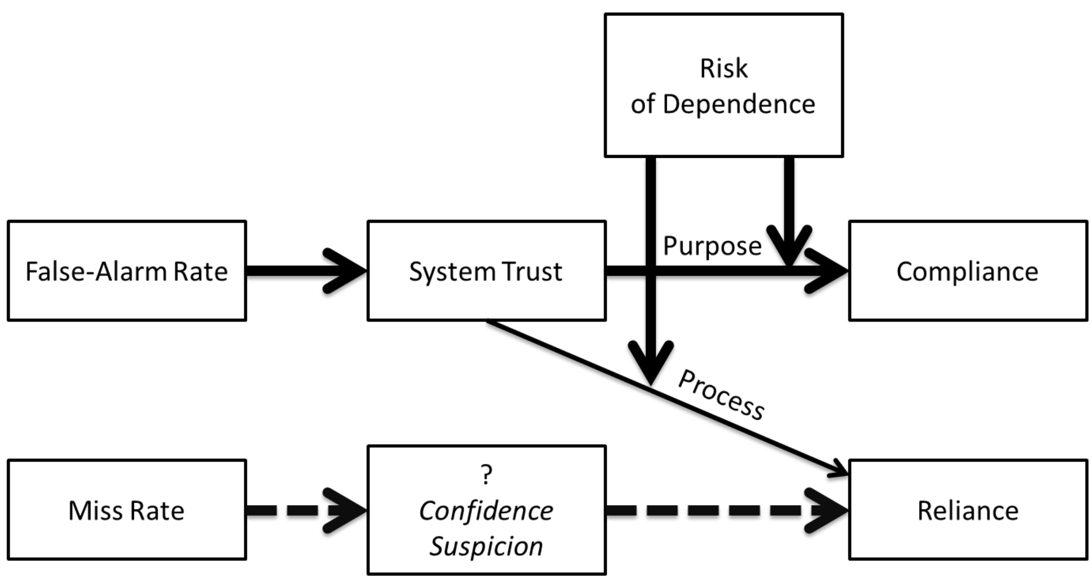

Figure 21. Graphical depiction of study results (similar to model in Figure 2C). *Note*: Solid lines represent significant effects, thin line represent weak effect, dashed lines represent hypothesized mediational processes.

FP-compliance/reliance relationship: Non-selective effects of trust and the role of risk. Although the initial compliance-reliance model proposed by Meyer (2001) was the suspected outcome (i.e., the model in Figure 2B), the results suggested that false alarm rate had a non-selective effect on both compliance and reliance (i.e., more closely resembling the model in Figure 2C). This outcome aligns well with the results of recent studies (e.g., Dixon et al. 2007; Dixon & Wickens, 2006; Meyer et al., 2014; Rice & McCarley, 2011). Yet, the results of the current study provide a more detailed account of the psychological processes of trust, according to its bases, involved in determining the effect of FP system reliability on compliance and reliance.

Contrary to earlier explanations, compliance and reliance are likely affected by two non-independent forms of trust, stemming mainly from FP systems. The current study found that the purpose basis of trust mediated the relationship between false alarm rate and compliance, whereas the process basis of trust mediated the relationship between false alarm rate and reliance. Yet, each of these mediating processes were the effect of the performance basis of trust. Therefore, with FP systems, compliance and reliance are likely the manifestation of different bases of trust acting upon each other (i.e., two manifestations of the same construct), rather than two independent types of trust as suggested in the original compliance-reliance distinction (i.e., Meyer, 2001).

According to the serial mediation analyses, the performance factor of trust was affecting the degree to which purpose was leading to compliance and process was leading to reliance. This aligns well with the argument proposed earlier in the current work, where trust should develop from the observation of automation behavior (i.e., performance; cf. Lee & See, 2004). Moreover, the observation of automation performance should then provide evidence that tempers or develops trust based on alternative levels of attributional abstraction (i.e., process, purpose). The faulty behavior associated with false alarms, as opposed to misses, in the current study, was predicted to act causally through operator trust because of its salience.

For the FP-compliance relationship, the evaluation of the alarm systems' performance led to a significant effect on participants' evaluation of the purpose of the automation. The results of the current study indicate that if a system produces false alarms too often, the operator may question the automation's ability to achieve the goals it was designed to achieve. This effect subsequently leads to non-compliant behavior when it does sound an alarm. In other words, false alarms degrade the operator's trust in *why the automation was created in the first place*. This perspective endorses the idea that a system that warns an operator of everything ultimately results in a system that warns the operator of nothing (i.e., the system has no apparent purpose; cf. Lee & See, 2004).

Alternatively, for the FP-reliance relationship, evaluation of the alarm systems' performance led to a significant effect on participants' evaluation of the process of the automation. If a system produces false alarms too often, when the system does remain silent after consistently signaling target present events, this may contribute to a lack of understanding for what caused the sudden silence. This sudden silence subsequently leads to non-reliant behavior in the absence of an alarm. In other words, false alarms degrade the operator's trust in the apparent capability of how the automation is contributing to the achievement of the operator's goals (cf. Lee & See, 2004).

Risk of dependence. The results of the current study were somewhat conflicting, as to whether risk moderated the mediating effect of trust on compliance and reliance. To test for moderated mediation, Preacher et al., (2007) proposed the use of conditional indirect effects. Using this approach, there was evidence to support the conclusion of moderated mediation in the current study, because factors of trust were mediating the relationship between false alarm rate and compliance/reliance for only those in the high risk group. Alternatively, Hayes (2015) proposed a more formal test of moderated mediation, by investigating if the path linking the conditional indirect effect to the moderator is significantly different from zero (i.e., index of moderated mediation). Based on this approach, the 95% confidence intervals for this path contained zero (i.e., $p > .05$), indicating the two conditional indirect effects were not significantly different from each other (i.e., the indirect effect of trust in the high risk group resembled the same effect in the low risk group).

Regardless, risk is a critical factor in the majority of human-automation and interpersonal theories of trust (however, see other models that omit risk, e.g., Madhavan & Wiegmann, 2007; Seong & Bisantz, 2000; Seong et al., 2006). Therefore, researchers wishing to draw causal links between trust and behaviors should consider the role of risk, if their conclusions are to remain consistent with a majority of theoretical perspectives of trust (e.g., measure risk, account for risk, manipulate risk). This work is not the first to make this suggestion or attempt to impose an element of risk upon participants (cf. Lyons, Stokes, Eschleman, Alacron, & Barelka, 2011). Indeed, the impetus to use time investment penalties in the current study was adopted from the work of Bliss et al. (1995; see also Bliss & Dunn, 2001). Because the sample participants in the current study were college students, additional time investment was suspected to be personally negative to participants. Although it is unclear how effectively the technique was implemented in the current study, it did lead to conditionally significant indirect effects of trust according to risk group assignment.

There are other ways in which risk may be manipulated in laboratory studies. Lyons et al. (2011) manipulated risk perception in a simulated combat environment by having participants base their decisions on conflicting information that compromised the safety of a convoy. Although this manipulation requires some imagination on the part of the participant, the sample used by Lyons et al. (2011) was partially made up of military personnel who may have had to make similar life-and-death decisions in the real world. Hanson, Bliss, Harden, and Papelis (2014) used a similar technique to successfully manipulate task criticality, by telling participants in that the cost of poor performance was the death of hypothetical team members. Bliss and McAbee (1995) manipulated criticality in an alarm-response task by deducting more points for the high criticality group as compared to the low criticality group.

Although the outcome from the current study is somewhat conflicting regarding risk, it does indicate that risk was affecting the degree to which trust mediated the significant relationships tested. Admittedly, the risk manipulation in the current study was minimally effective, leaving room for improvement. Although students in the high-risk group may have assigned higher risk ratings than those in the low risk group, there is a clear research opportunity to explore individual differences that likely play a role here. Anecdotally, some individuals in the high-risk group rated the consequences of poor performance as low, and alternatively some individuals in the low risk group rated the consequences of poor performance as high. This particular difference might be due to individual students' differential need for achievement or other underlying personality traits (Phillips & Gully, 1997). Future research should investigate the moderating role of operator traits in similar paradigms (cf. Merritt & Ilgen, 2008).

Comparison with Chancey et al. (2015b). The current results aligned with those reported by Chancey et al. (2015b). Interestingly, the main effects of reliability on trust and the interaction of FP reliability on compliance had virtually identical effect sizes. Yet, there were some noticeable differences in the degree to which subjective trust mediated the tested relationships.

Specifically, in the current study trust as a single factor did not mediate the relationship between reliability and compliance. Moreover, the associated mediating effect was noticeably smaller ($\kappa^2 = .112$) than the one reported by Chancey et al. (2015b; i.e., $\kappa^2 = .325$). Even the significant sequential indirect effects of the trust components on compliance (i.e., performance, process, and purpose; $P_m = .029$; performance and purpose; $P_m = .099$) were still much smaller than the indirect effect reported by Chancey et al. (2015b; $P_m = .451$).

The current results provide a unique opportunity to observe scientific research replication. Specifically, not only were the experimental designs and analytical techniques similar, so were many other aspects (e.g., same monitors, controls, headphones, primary tasks, session durations, ODU students). Drawing comparisons between these studies may be valuable in terms of directing future research endeavors and identifying variables that potentially contribute to the degree to which subjective trust mediates particular relationships in alerted-monitor paradigms. Obviously, however, there are some differences that cannot be easily accounted for, such as testing locations and potential differences in participants due to time and seasonality differences.

Trust Questionnaire. The current study used a version of Madsen and Gregor’s (2000) human-computer trust questionnaire, which was theoretically derived and modified to reflect Lee and See’s (2004) bases of trust (i.e., performance, process, and purpose). Alternatively, Chancey et al. (2015b) used Jian et al.’s (2001) empirically derived trust questionnaire. Clearly, the main advantage of the questionnaire used in the current study is that it targets a specific theoretical perspective of trust. As with the measurement of any construct, researchers should select a measurement tool that reflects how the researcher conceptualizes the construct (see similar argument by Salmon et al., 2009, on the measurement of situation awareness).

It makes little sense to provide a theoretical argument for how trust should affect a behavior given certain constraints, and subsequently measure trust in a way that is not congruent with the theory backing the argument. In the current study, trust is characterized as an attitude, which is an affective evaluation of beliefs. The informational bases of performance, process, and purpose are beliefs about the automation, which are influenced by experience and information. Therefore, it makes theoretical sense to measure trust by asking participants to subjectively evaluate their beliefs about the system.

In the current study, trust mediated the FP-compliance/reliance relationships only when the bases were ordered in a theoretically plausible way, rather than as a single factor of general trust. Although this result supports the theoretical positions outlined in the current work, it may also indicate important differences between each questionnaire. It is possible that the empirically derived Jian et al. (2000) questionnaire measures more than just trust, as it is not aligned with any particular theory of trust *per se*. This possibility, however, is not necessarily an altogether undesirable trait. Indeed if the stronger mediating effect were due to the questionnaire, then this provides researchers a starting point to discover what aspects of the questionnaire are leading to this outcome. Additionally, this would indicate that researchers should be devoting more effort into ascertaining what other constructs predict the FP-compliance/reliance relationships aside from trust.

Transparency and workload. One of the clear differences between each study is that the systems tested in the current study were more transparent than the entirely opaque systems tested by Chancey et al. (2015b). Interestingly, however, a more transparent system should theoretically lead to a stronger mediating effect of trust (cf. Chancey et al., 2015a). Specifically, with a transparent system the operator has the ability to cross-validate system diagnoses with the underlying raw data, which allows for a more clear observation of automation behavior and error characteristics (i.e., performance; Lee & See, 2004). Yet, on the topic of transparency, Adams et al. (2003) argued that it might be more difficult for an operator to evaluate the quality of the diagnostic output of a system that provides information (i.e., signaling system) rather than higher stage automation that may provide a physical product. Adams et al., therefore, suggested that differences in the ability to evaluate the quality of output could affect trust calibration in the long run, which may account for the effect size differences observed between this study and Chancey et al. (2015b).

Alternatively, because the system in the current study was transparent, this may have led to differences in workload between each study. Specifically, participants in the current study may have invested cognitive resources and visual attention to evaluate individual images in an attempt to improve their performance. Conversely, with the opaque system used by Chancey et al. (2015b), participants lacked the opportunity to crosscheck the system's output to perform better. Instead, participants had to rely on the stated reliability and feedback from the system, potentially allowing for a workload difference between each study. Consequently, in the current study, participants may have trusted (or distrusted) the system's diagnoses but were too busy to consistently evaluate the image and provide an informed decision to agree (or disagree) with the system (cf. Rice, 2009; i.e., workload may have suppressed the mediating effect of trust). Further research should investigate the mediating effect of workload and trust using a parallel multiple mediator model, to evaluate which construct is better accounting for dependence behaviors. Hayes (2013) advocates this method to test competing theories. Indeed, Wickens and McCarley's (2013) theoretical description of the compliance-reliance paradigm relies more heavily on performance constructs such as workload and divisions of attentional resources than trust as a singular explanation.

Specificity of error characteristics disclosure. The current study supplied participants very little information about the error characteristics before they interacted with each system. Alternatively, Chancey et al. (2015b) provided participants with both the exact reliability level and the error bias. Participants were also quizzed about those error characteristics before each session, requiring all correct responses before allowing the session to begin. The differential strength of the mediating effect of trust across both studies might be due in part to the difference in error characteristic disclosure specificity. Lee and See (2004) propose that trust can develop through analogical processes such as hearsay. Moreover, studies have shown that error disclosure can have a significant impact on response behaviors (e.g., Bliss et al., 1995; Chancey & Bliss, 2010; Wang et al., 2009).

Clearly, error disclosure should add to a more complete mental model associated with the alarm system, particularly if the participant has had limited interactions with the system to observe error rates first hand. Further research should be conducted to assess if the mediating effect of trust is moderated by the specificity of error disclosure. Results could have broad practical applications, as disseminating the error characteristics of a particular alarm system via intended (e.g., training) or unintended (e.g. hearsay) methods likely significantly impact trust and subsequent response strategy of the operator (cf. Bliss et al., 1995).

Perceptual saliency of errors and performance feedback. There were clear differences between the saliency of false alarms and misses in the current study: false alarms were accompanied by both a visual cue and an auditory alert, whereas misses were accompanied by neither cue. Yet, the alarm systems reported by Chancey et al. (2015b) were more similar in terms of error saliency: false alarms were accompanied by a red “Failure” and the fire bell of a Boeing 747, whereas misses were accompanied by a green “OK” and a 1000 Hz tone. Moreover, the performance feedback for a correct and incorrect decision was somewhat different between the studies. In Chancey et al. (2015b), correct and incorrect decisions were accompanied by both an on-screen point bank and a voice that announced “correct” and “incorrect” after each decision. The current study provided more subtle performance feedback, offering only an on-screen point bank.

Although Chancey et al. (2015b) demonstrated that false alarm rate affected only compliance and miss rate affected only reliance, the current study showed a non-selective effect of false alarm rate on compliance and reliance and a selective effect of miss rate on reliance. These results align with the saliency hypothesis and results reported by Dixon and Wickens (2006), which were replicated by Dixon et al. (2007). Moreover, the current results found a non-selective mediating effect of trust on compliance and reliance for the FP system, whereas Chancey et al. (2015b) found a selective mediating effect of trust on compliance for only the FP system.

However, because both error saliency and performance feedback was different between each study, it is difficult to parse out which (if either) effect was driving the mediating effect of trust. Future researchers should consider manipulating error saliency and feedback systematically. Clearly, outside of laboratory conditions these errors are usually different in terms of both perceptual saliency and in the degree to which they offer the user a chance to learn from their occurrence (see reliability defined by user perspective earlier in this document).

MP-reliance relationship: Confidence and state-based suspicion. Similar to Chancey et al. (2015b), trust mediated the FP-compliance relationship but not the MP-reliance relationship, suggesting trust is not the operant variable in the MP relationship. Indeed, from a theoretical perspective, there are plausible arguments to suggest that other constructs might be better candidates. For example, recently the construct of state-based suspicion has been proposed and may offer an alternative explanation to describe the MP-reliance relationship (Bobko, Barelka, & Hirshfield, 2014). Importantly, one of the hypothesized components associated with increased suspicion is missing information, which can lead to a reduction in performance indicies due to the greater cognitive workload associated with searching for more information. This scenario mirrors the results obtained by Dixon and Wickens (2006; Dixon et al., 2007), where participants experienced an increase in workload when dividing attention among tasks to offset the errors produced by the MP system. Moreover, the current study found that performance was significantly worse for the MP system, which is plausibly the result of participants unsuccessfully searching for additional information.

Another candidate construct that may be useful in describing the relationship between misses and reliance is confidence (Chancey et al., 2015b). As suggested previously, one of the differences between confidence and trust is that trust requires one choice in preference to another, but confidence does not (Luhman, 1988). Systems that are MP do not offer salient choices to deviate from the status quo. Differentiating between confidence and trust, Smith (2005) proposed that confidence is living with everyday dangers, where a person can routinely “bracket” life’s contingencies so that they can go about their business without continuous uncertainty/anxiety (p. 307). Smith (2005) suggested that confidence is at play when people take for granted expert knowledge and systems that control, predict, or keep contingent events from happening (p. 307). This scenario could be easily used to describe the concept of complacency, where individuals assume that the “expert system” will work properly and engage in other activities without worrying that the system will make an error that will go undetected.

Moreover, trust requires the acceptance and acknowledgement of risk, whereas confidence does not (Luhman, 1988; Mayer et al., 1995). In the case of misses, if one does not even recognize that he or she is at risk, then this is a state of confidence rather than trust. In the current study, trust in MP systems did not significantly affect reliance even for those in the high risk groups. Supporting this point, in a review of trust in automation, Adams et al. (2000) defined a confident judgment as, “…a discrete reason-based judgment related to the probability of a specific event that occurs outside the domain of risk, and is distinct from a trust judgment” (p. 30).

From the perspective that trust mediates the FP-compliance relationship, whereas alternative constructs may mediate the MP-reliance relationship, Meyer’s (2001) initial proposal of two types of trust may be accurate. Indeed, it may be more correct to conceptualize trust as mediating one process and confidence or suspicion mediating the other. Yet, there is a current dearth of available theoretically grounded measures to test for these alternative constructs (however, see state-based suspicion questionnaire from Lyons et al., 2011).

One potential measure of signaling system confidence could be to simply have participants rate the probability that a signaling system will make a false alarm, miss, correct rejection, or hit. However, as argued throughout this work, one of the defining characteristics of a miss is the absence of a cue. Therefore, asking operators or participants to evaluate the occurrence of something they theoretically and plausibly should not be aware of may not be successful. Alternatively, physiological measures associated with state-based suspicion have also been proposed. Specifically, Bobko et al. (2014) suggested that state-based suspicion is associated with increased anterior cingulate cortex activity (ACC). Researchers, therefore, could theoretically test for an increase in ACC for participants responding to a MP system. However, such physiological activity could result from multiple factors.

Comparing FP and MP system task performance. The now increasingly common finding of a non-selective effect of false alarm rate on both compliance and reliance, has led to a general conclusion that false alarms negatively impact operator performance to a greater degree than misses (Rice & McCarley, 2011). Interestingly, in this research FP systems affected compliance and reliance more, but MP hindered secondary task performance more. When compared to the FP group, participants in the MP group (particularly the 60% condition) took longer to select tank present or absent and were worse at correctly indicating if a tank was present or absent (i.e., alarm score), even independent of their response bias (i.e., d′).

The RT difference is likely due to the fact that the FP group had more auditory signals to direct the attention of the participants away from the primary tasks. To illustrate, out of 60 total aerial images, the FP 60% system had 54 auditory signals, the FP 90% system had 36 auditory signals, the MP 90% system had 24 auditory signals, and the 60% MP system had just 6 auditory signals. Supporting this idea, even within the FP group there was a significant effect of reliability: more reliable systems led to longer RTs. This result is the opposite of what is generally found in the existing literature (e.g., Chancey et al., 20015a; Getty et al., 1995; Wickens & Dixon, 2008). Yet, there are multiple studies that have reported inconsistencies in the relationship between reliability and RT for alerted-monitor systems (e.g., Bliss & Chancey, 2014; Rice, 2009; Wang et al., 2009). Because the signaling system was a secondary task, participants plausibly did not consistently divert attentional resources away from the primary task to support the secondary task. Instead, the auditory signal was likely heavily relied upon to support task switching. Additionally, RT was collected for only those responses that matched the system's diagnosis. This indicates that participants may have missed the picture entirely, and simply agreed with the system when they finally did notice that their response was required.

From this perspective, the MP system may have been more akin to an opaque system, as participants were not able to crosscheck the output by evaluating the image. This may also partially explain why the FP group was better able to separate the tank present pictures from tank absent pictures (i.e., the auditory signal afforded participants the ability to scan the picture for a tank). If the MP system was less transparent than the FP system, then this may have also contributed to the fact that trust did not mediate any of the MP-dependence relationships. Interestingly, Wiegmann et al. (2001) proposed that subjective trust in a signaling system may dissociate from the observed behavior when the operator lacks the information needed to inform a diagnosis (see also Bliss, 2003, and Chancey et al. 2015a).

To this point, the only main effect of error bias on trust was observed for the performance factor (i.e., the FP group indicated higher ratings than the MP group). As previously argued in the current work, the performance basis of trust is the likely missing piece to provoke the mediation of trust in the MP-reliance relationship. Moreover, the serial mediation analysis indicated that the performance factor was significantly affecting other bases of trust, which led to both compliant and reliant behaviors in the FP systems. Again, this perspective may also provide marginal support for Rice and McCarley's (2011) conclusion that false alarms are more cognitively salient errors than misses, above perceptual saliency differences. Yet, there were clear perceptual saliency differences between misses and false alarms in the current study. Therefore, additional research is required to make a more definitive conclusion on the role of cognitive and perceptual error saliency differences on the mediating effect of trust in the compliance-reliance paradigm.

An additional reason the FP group outperformed the MP group may also be due to the fact that the visual cue helped participants more efficiently search images. If the system made an error it was either a false alarm or a miss, it never signaled the wrong quadrant to search (i.e., if the system highlighted a quadrant, it was either in that area or not in the image at all). This gave participants using FP systems a distinct performance advantage over those using the MP system. Yet, for the MP system these results makes ecological sense. The essence of a MP system is that it is automation that generally leaves a majority of the monitoring task to the human. If the human monitors poorly, then this will be reflected in many missed events. Second, *response* time requires that there is something to respond to (i.e., an alarm, alert, or advisory). With an MP system, unless the operator notices non-signal related cues (e.g., smoke from a fire, patient calling for help, engine backfiring), they would not be expected to respond quickly or at all to potential problems.

Practical Applications

Although the tasks in the current study were described as simulating pilot responsibilities during flight, the experimental paradigm used in the current study approximated a complex task environment that was relatively abstract from actual pilot responsibilities (cf. experiment 1 from Wickens et al., in press). Indeed, others have used similar tasks and paradigms to study and comment on a variety of multi-tasking domains in which an operator must engage with an unreliable reliable signaling system (cf. Bliss & Dunn, 2000; Bustamante, 2009; Dixon & Wickens, 2006). The results from this study, therefore, are not necessarily restricted to aviation applications alone. The remainder of this section discusses how several domains can benefit from the current work and concludes with some general implications.

Hospital physiological-based alarm systems. The current work did not find that trust mediated the relationship between reliability and responses for the MP systems (cf. Chancey et al., 2015b). This finding is particularly relevant to physiological-based alarming thresholds (e.g., pulse-oximetry), in which some hospitals have altered criterions to be more conservative (i.e., MP) to combat excessive false alarms leading to clinical alarm-fatigue (Whalen et al., 2015; Chancey et al., 2015b). Practitioners investigating and implementing threshold changes may want to consider that those adjustments will not only differentially impact response behaviors, but also system evaluations that may not be related to system trust. Instead, practitioners may want to consult other theoretical frameworks, such as state-based suspicion or confidence. These constructs may provide greater insight into predicting operator behavior or determining why the behavior occurred.

Additionally, with pulse-oximetry based monitoring systems some healthcare practitioners may not understand the technological limitations of the system, which arise from calibration assumptions, optical interferences, and signal artifacts leading to false alarms (Sinex, 1999; e.g., blue or black nail polish may interfere with accurate readings). Training healthcare workers to understand the underlying process of these systems, in addition to the medical aspects associated with the patient, may help buffer the deterioration of trust associated with the observable performance based errors of trust that are likely salient due to the frequent false alarms. Yet, it should be noted, in the case of multitasking and overload, workers may trust the system and intend to comply but be too busy (cf. Rice, 2009).

Automotive collision warning systems. Collision warning systems have emerged as an application of signaling system technology intended to lessen vehicle crashes. Yet, as with other sensor-based signaling systems, these systems can produce errors (Lees & Lee, 2007; Scott & Gray, 2008). The error bias of these systems depend upon driving style, where drivers with shorter headways experience more misses and drivers with longer headways experience more false alarms (Lees, 2010, p. 38; Ben-Yaacov, Maltz, & Shinar, 2002 Maltz & Shinar, 2004). Moreover, research has shown that automotive collision warning system errors (misses and false alarms) differentially impact driver responses and trust (Abe & Richardson, 2006; Bliss & Acton, 2003; Shah, Bliss, Chancey, & Brill, 2015). Yet, in the context of the results from the current study, trust may be more impactful on affecting response behaviors for drivers who adopt longer headways, and experience more false alarms, than those who adopt shorter headways, and experience more misses. If this were the case, sensor thresholds could be tailored to individual driving styles, as false alarms would more negatively impact system compliance and also reliance to a lesser degree (see Lees & Lee, 2007, and Lees, 2010, who discuss collision avoidance alarm errors on trust according to performance, process, and purpose).

Process control and complacency. Process control is often studied in relation to operator complacency (Bahner, Elepfandt, & Manzey, 2008; Bahner, Hüper, & Manzey, 2008; Moray & Inagaki, 1999). Earlier in this work misses were said to be associated with complacency. Yet, it should be noted that complacency is not often investigated in process control where the monitor is aided by a signaling system. Instead, the operator is generally in charge of monitoring automated processes and asked to intervene when a fault occurs. The same type of sampling strategy, however, would likely occur even with the presence of a signaling system. Again, humans are not generally well suited to notice the absence of events and objects

(Hearst, 1991). Therefore, the role of trust in these paradigms deserves some discussion, as the notion of “over-trust” is frequently invoked when describing complacency in process control tasks.

As argued throughout this work, and empirically demonstrated across this and one other study (i.e., Chancey et al., 2015b), misses are less impactful on affecting behavior through (subjective) trust. Indeed, in a review of complacency and automation bias, Parasuraman and Manzey (2010) acknowledge the lack of convincing empirical links between poor automation monitoring and “high trust” (cf. Lee & See, 2004). Instead, Parasuraman and Manzey cite the work of Baily and Scerbo (2007) as “the only, somewhat tentative, evidence” for a link between trust and monitoring behaviors (p. 389). Parasuraman and Manzey suggest that the weak empirical demonstration within the literature is likely due to a discrepancy between subjective and objective measures of trust. The author would agree with this conclusion, as it is difficult to ask participants to evaluate something they should not have conscious access to (i.e., a missed event). In disagreement with Parasuraman and Manzey’s conclusion, the answer to linking complacency with trust should not be to operationalize trust as a behavior. Results from the current study indicate that researchers studying process control and complacency may want to consider the role of confidence and suspicion in determining monitoring behaviors, rather than trust.

General implications. The error biases of signaling systems are determined by sensor threshold settings, which can be set to any level desired (Sorkin & Woods, 1985). System designers must determine which error is more critical to the task (Rice, 2009). As demonstrated in this work, not only will error bias differentially affect operator responses, it also affects subjective evaluations of the signaling system (cf. Chancey et al., 2015b). The results of the current work could be used to determine threshold settings and predict the effects of those settings on the operator.

Additionally, from a practical perspective, it is unclear how enlightening the conclusion that "the operator did not comply with the alarm because of a lack of trust," really is. In the context of Lee and See's (2004) theoretical perspective, if the components of trust are targeted according to system error bias (i.e., MP, FP), then the practitioner can give more targeted recommendations to support the specific individual goal-oriented informational bases that are lacking. In line with this reasoning, the current work goes beyond the simple idea that "trust" mediates the relationship between error characteristics and reaction behaviors, and proposes the use of testable theoretically grounded mechanisms that can inform the design and training programs associated with signaling systems.

Limitations and Future Research

Although the current work offers an alternative perspective from which to conceptualize and study the compliance-reliance paradigm, it is not without limitations. It is admittedly difficult to replicate real world risk in the laboratory. Also, the college students tested may not have had adequate experience interacting with alarm systems to provide an accurate depiction for how trust affects response behaviors in real world situations.

The questionnaire used in the current study is also not without issue. Although Adams et al. (2001) appreciated the theoretical nature of the questionnaire developed by Madsen and Gregor (2000); the authors did take some issue with the analytical technique used to derive the factors. Adams et al. (2001) suggested a confirmatory factor analysis should have been used to make a fair assessment of the hypothesized factors. The recommendations of the current work are not only to further psychometrically vet this questionnaire, but also implement its use in more studies.

Finally, although the use of ordinary least squares (OLS) regression to estimate simple mediation models is relatively accepted, some researchers suggest that structural equation modeling (SEM) programs (e.g., LISREL, AMOS, or Mplus) are required for more complex modeling such as the ones described in the current work (e.g., Iacobucci, Saldanha, & Deng, 2007). Yet, Preacher (2013) suggests that there are no consequential differences between the results obtained by OLS regression and SEM programs. Instead, Preacher suggests that differences observed between these techniques are due to algorithmic differences, program-specific defaults, and decimal rounding differences (to name a few), rather than data-specific differences (p. 160). Preacher also suggests that SEM programs may be more likely to slightly err in small samples and that the OLS regression procedure is more appropriate (for discussion on this topic see Preacher, 2013, p. 159-162).

The analytical techniques used in the current study are relatively new, and offer behavioral scientists a way to analyze data that was previously largely prohibitive, due to the constraints of small samples (e.g., experimental research often requires testing participants individually in experimental sessions that may take an hour or more). Clearly, ANOVA is an extremely effective tool for discovering how variables affect each other. Yet investigating mediation, moderation, and conditional processes provides an alternative view of empirical data that can be used to describe how variables affect each other according to a specific theory (or competing theory). Describing the current data through process analyses allowed for very specific theoretical aspects to be tested (i.e., the conditional effects of error characteristics through trust on outcome behaviors with and without risk). If only main effects and interactions were interpreted, the explanations offered in this work would have been very similar to previous conclusions and added very little to the understanding of the compliance-reliance paradigm. Therefore, researchers should take advantage of these emerging techniques to complement existing analytical methods, which could result in a better understanding of established effects and outcomes.

Conclusion

The predominant explanation linking the error characteristics of signaling systems and dependence behaviors is based on the presupposition that two independent forms of trust mediate the FP-compliance and MP-reliance relationships. Yet, the results of the current work suggest that trust mediates the FP-compliance and FP-reliance relationships and not the MP-reliance relationship, leading to the conclusion that there are not two independent types of trust. By linking the compliance-reliance paradigm to a specific theory of trust in automation and a theoretically congruent questionnaire, researchers can more effectively and systematically investigate this alerted-monitor paradigm.

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APPENDIX A

INFORMED CONSENT FORM

INFORMED CONSENT DOCUMENT
The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES.

TITLE OF RESEARCH: User Performance with Flight Simulation Tasks

RESEARCHERS:
James P. Bliss, Ph.D., Professor, Responsible Project Investigator, College of Sciences, Psychology Department
Eric T. Chancey, M.S., Graduate Student, College of Sciences, Psychology Department.

DESCRIPTION OF RESEARCH STUDY:

Ninety participants will be tested in this experiment. Those who agree to be tested will complete a background information form. Following this, you will be asked to perform a familiarization session with multiple tasks that simulate tasks similar to those that aircraft pilots perform. After training, you will be asked to perform the simulated aircraft tasks in several experimental sessions. To simulate maintaining stable flight, you will use a joystick to complete a tracking task. You will also monitor and manage depleting fuel of the aircraft by pressing keys on a keyboard. Finally, you will view aerial images that will occasionally have tanks imbedded in them. You will be asked to decide if a tank is in the image or if it is not, with the help of a "tank spotting aid." After the experimental sessions, you will complete an opinion questionnaire to indicate your strategy for responding. You will then be debriefed and dismissed. The entire experiment should almost 2 hours.

You will receive 2 SONA credits for participating in this study.

EXCLUSIONARY CRITERIA:
To participate, you must be over the age of 18. You must have normal vision or corrected-to-normal vision. You must also have normal or corrected-to-normal hearing. Therefore, if you normally wear eyeglasses, contact lenses or hearing aids you will need to wear them to participate.

RISKS AND BENEFITS:
RISKS: If you decide to participate in this study, then you may face a risk of eyestrain similar to the eyestrain experienced during normal computer usage. The researcher tried to reduce these risks by limiting the experimental participation time to less than two hours. And, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.
BENEFITS: There are no direct benefits for participation in this study. However, you may learn valuable information about how research is conducted.

COSTS AND PAYMENTS:
The researchers want your decision about participating in this study to be absolutely voluntary. The main benefit to you for participating in this study is the extra credit or course credit points that you will earn for your class. Although they are unable to give you payment for participating in this study, if you decide to participate in this study, you will receive 1 Psychology Department research credit, which may be applied to course requirements or extra credit in certain Psychology courses. Equivalent credits may be obtained

in other ways. You do not have to participate in this study, or any Psychology Department study, to obtain this credit.

CONFIDENTIALITY:
Your participation is completely confidential. The researcher will remove all identifiers from the information. The results of this study may be used in reports, presentations, and publications; but the researcher will not identify you individually in such publications.

WITHDRAWAL PRIVILEGE:
It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time. Your decision will neither affect your relationship with Old Dominion University, nor cause a loss of benefits to which you might otherwise be entitled. The researchers reserve the right to withdraw your participation in this study, at any time, if they observe potential problems with your continued participation.

COMPENSATION FOR ILLNESS AND INJURY:
If you agree to participate, then your consent in this document does not waive any of your legal rights. However, in the event of harm, injury, or illness arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in any research project, you may contact Dr. James P. Bliss at 757-683-4051, Dr. George Maihafer (IRB Chair) at 757-683-4520, or the ODU Office of Research, 757-683-3460.

VOLUNTARY CONSENT:
By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, please contact the researcher at the number above.

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. George Maihafer (IRB Chair) from the Old Dominion University Office of Research, 757-683-4520, or the ODU Office of Research, 757-683-3460.

By signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.

------------------------------------	------------------------------------	------------------------
Participant’s Name	Participant’s Signature	Date

------------------------------------	------------------------------------	------------------------
Investigator’s Name	Investigator’s Signature	Date

APPENDIX B

TRUST QUESTIONNAIRE

Structure of trust questionnaire:

Performance (Predictability; Ability): What does the automation do? (Trust is in the actions of the agent)

- The tank spotting aid always provides the advice I require to help me perform well.
- The tank spotting aid's advice reliably helps me perform well.
- The tank spotting aid's advice consistently helps me perform well.
- For me to perform well, I can rely on the tank spotting aid to function properly.
- The tank spotting aid adequately analyzes the pictures consistently, to help me perform well.

Process (Dependability; Integrity): How does the automation work? (Trust is in the agent, not the actions)

- Although I may not know exactly how the tank spotting aid works, I know how to use it to perform well.
- I will be able to perform well the next time I use the tank spotting aid because I understand how it behaves.
- I understand how the tank spotting aid will help me perform well.
- It is easy to follow what the tank spotting aid does to help me perform well.
- To help me perform well, I recognize what I should do to get the advice I need from the tank spotting aid the next time I use it.

Purpose (Faith; Benevolence): Why was the automation developed? (Trust is in the agent, irrespective of past behaviors)

- To help me perform well, I believe advice from the tank spotting aid even when I don't know for certain that it is correct.
- To help me perform well, when I am uncertain about deciding "Tank Present" or "Tank Absent" I believe the tank spotting aid rather than myself.
- If I am not sure about whether to click "Tank Present" or "Tank Absent," I have faith that the tank spotting aid will provide the correct solution to help me perform well.
- Even when the tank spotting aid gives me unusual advice, I am certain that the aid's advice will help me to perform well.
- Even if I have no reason to expect that the tank spotting aid will function properly, I still feel certain that it will help me to perform well.

TRUST QUESTIONNAIRE

Part. #: ______ Group: ________ Session: ________ Date:_____ Time:______

Below is a list of statements for evaluating trust between people and automated systems. Please circle the number that best describes your feeling or your impression of the tank spotting aid you used during the task.

1. Even when the tank spotting aid gives me unusual advice, I am certain that the aid's advice will help me to perform well.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

2. For me to perform well, I can rely on the tank spotting aid to function properly.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

3. To help me perform well, when I am uncertain about deciding "Tank Present" or "Tank Absent" I believe the tank spotting aid rather than myself.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

4. It is easy to follow what the tank spotting aid does to help me perform well.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

5. The tank spotting aid's advice reliably helps me perform well.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

6. The tank spotting aid's advice consistently helps me perform well.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

7. I understand how the tank spotting aid will help me perform well.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

8. Even if I have no reason to expect that the tank spotting aid will function properly, I still feel certain that it will help me to perform well.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

9. Although I may not know exactly how the tank spotting aid works, I know how to use it to perform well.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

10. To help me perform well, I believe advice from the tank spotting aid even when I don't know for certain that it is correct.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

11. To help me perform well, I recognize what I should do to get the advice I need from the tank spotting aid the next time I use it.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

12. I will be able to perform well the next time I use the tank spotting aid because I understand how it behaves.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

13. If I am not sure about whether to click "Tank Present" or "Tank Absent," I have faith that the tank spotting aid will provide the correct solution to help me perform well.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

14. The tank spotting aid always provides the advice I require to help me perform well.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

15. The tank spotting aid adequately analyzes the pictures consistently, to help me perform well.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

APPENDIX C

PERCEIVED RISK QUESTIONNAIRE

Part. #: _______ Group: ________ Session: ________ Date:______ Time:_______

The following questions are about how you perceive the level of risk associated with maintaining a high level of performance during the experiment.

I believe that…

1. The consequences for performing poorly on these tasks are substantial.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

2. The overall risk of performing poorly on these tasks is high.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

3. Overall I would label the consequences of performing poorly on these tasks as something negative.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

4. I would label the consequences of performing poorly on these tasks as a significant loss.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

5. Performing poorly on the experimental tasks could have negative ramifications.

Not descriptive: 1 2 3 4 5 6 7 8 9 10 11 12 : Very Descriptive

APPENDIX D

SONA RECRUITMENT ADVERTISEMENT

User Performance with Flight Simulation Tasks

James P. Bliss and Eric T. Chancey, of the ODU Psychology Department are currently conducting an experiment.

Brief research overview: The purpose of this research is to investigate how operators react to various flight simulation tasks.

Research overview

Ninety participants will be tested in this experiment. Those who agree to be tested will complete a background information form. Following this, you will be asked to perform a familiarization session with multiple tasks that simulate tasks similar to those that aircraft pilots perform. After training, you will be asked to perform the simulated aircraft tasks several experimental sessions. To simulate maintaining stable flight, you will use a joystick to complete a tracking task. You will also monitor and manage depleting fuel of the aircraft by pressing keys on a keyboard. Finally, you will view aerial images that will occasionally have tanks imbedded in them. You will be asked to decide if a tank is in the image or if it is not, with the help of a "tank spotting aid." After the experimental sessions, you will complete an opinion questionnaire to indicate your strategy for responding. You will then be debriefed and dismissed. The entire experiment should last almost 2 hours.

You will receive 2 SONA credits for participating in this study.

APPENDIX E

INSTRUCTION SHEET

Welcome to project PROCESS, please put away your cell phone and turn it on silent.

HIGH RISK: The following experiment should take almost 2 hours, at the end of which you will receive 2 SONA credits. Though, participants that perform well on these tasks generally take much less time (about 1 hour or less). However, because some students have not been trying very hard in these sessions we are enforcing some consequences for students who do not, or choose not to, maintain a high level of performance for all of the tasks during the experimental sessions. Performing poorly on the experimental tasks will result in having to spend extra time beyond the 2-hour session until your performance reaches an adequately high level (up to 30 minutes longer). Even if you do go over time, you will still only receive 2 SONA credits for participating today. Again, if you don't perform well on these tasks you will have to stay longer and you won't get additional SONA credit. If you do perform well you will get out much earlier.

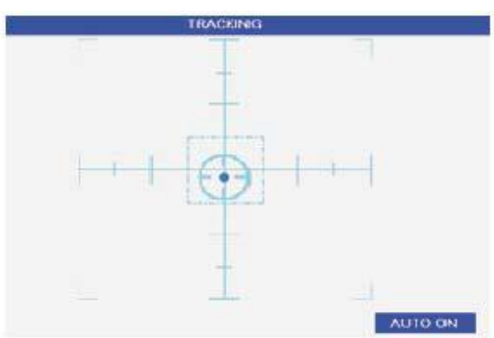
LOW RISK: The following experiment should take almost 2 hours, at the end of which you will receive 2 SONA credits.

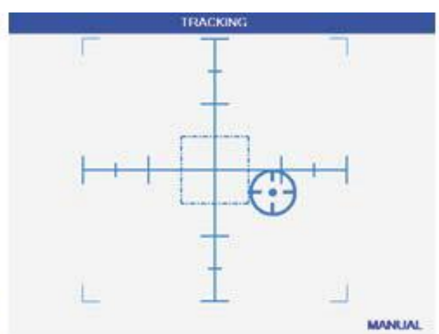
You will be asked to take part in several flight simulation tasks. The tasks you will be expected to respond to will be the tracking task, resource management task, and the tank spotting task. These tasks must be completed the entire time. Your performance will be recorded and monitored by the experimenter during each session.

Do you have any questions so far?

Tracking Task

For the tracking task your job is to keep the target in the center of the rectangular box. The overall purpose of this task is to keep the aircraft (represented by the blue circle) within the dotted rectangular area in the center of this task. Try to maintain this at all times. You control the aircraft with movements of the joystick. If you do not control the aircraft with the joystick, it will drift away from the center. If the aircraft leaves the rectangular area try to bring the aircraft back to center as quickly as possible.





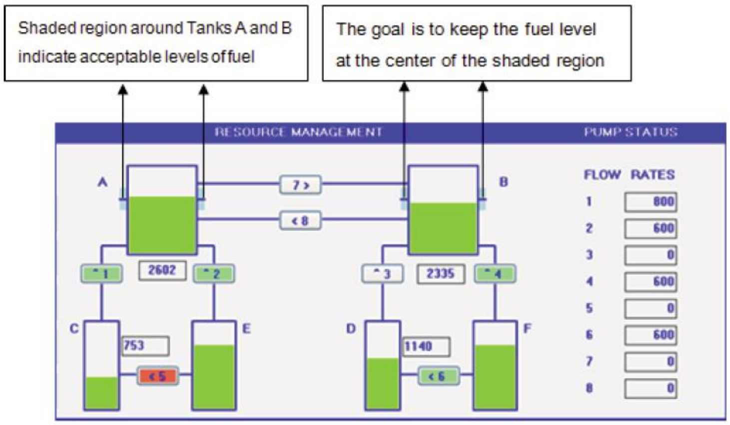
Resource Management task

The lower right region of the main window contains the resource management task. The rectangular regions identified with the letters A-F represent fuel tanks. The green levels within the tanks represent fuel levels. Along the lines, which connect the tanks, are pumps that transfer fuel from one tank to another in the direction indicated by the arrows.

There are 8 pumps labeled with the numbers 1-8. A rectangular box represents each one of the pumps with a number inside it that identifies the pump, and an arrow that indicates the direction of the fuel. The pumps are used to transfer fuel from the supply tanks to the main tanks.

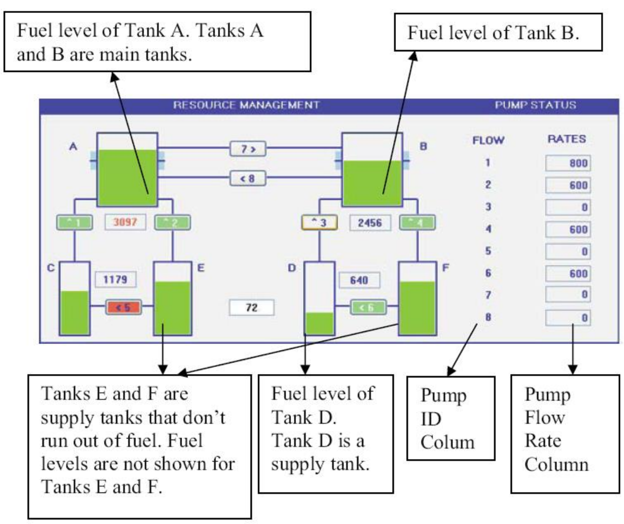
Deactivated pumps are colored in gray  , activated pumps are green  , and failed pumps are red 

. Note in the figure that pumps 1, 2, 4, and 6 are active, pumps 3, 7, and 8 are inactive, and pump 5 is failed.



When a pump activates, the numbers change in the “Pump Status” area. Under “Pump Status,” two columns of numbers are present. In the first column, numbers 1 through 8, correspond directly to the pumps in the diagram. The second column indicates the flow rate in units per minute for each pump when it is on.

In the figure below, the numbers underneath tanks A and B and to the right on tanks C and D represent the amount of fuel for each of those tanks. Those numbers will be increasing and decreasing as the fuel levels change. The capacity for the main tanks, A and B, is 4000 units each. The supply tanks, C and D, contain a maximum of 2000 units each. Tanks E and F are supply tanks that have an unlimited capacity – they never run out. The areas shaded in light blue on the side of tanks A and B indicate the critical levels of fuel for those tanks. You must transfer fuel to tanks A and B to meet these criteria because the fuel tanks A and B are always being consumed.

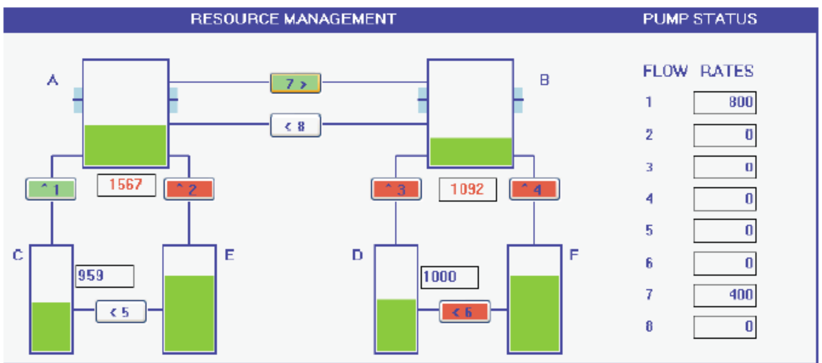


When the resource management task begins, the fuel level for Tanks A and B is at 2500 units. You are to keep the level of fuel from dropping below or above this level as indicated by the marker on either side of these pumps. As time passes, tanks A and B lose fuel. These tanks would eventually become empty without the transfer of additional fuel. Tanks C and D only lose fuel if they are transferring fuel to another tank.

Let’s consider the process of transferring fuel. Each pump can only transfer fuel in the direction indicated by the ^ arrow in its label. Pressing the number key corresponding to the pump activates the pumps. A pump is actively transferring fuel when it turns green.

So far, you've seen two conditions for the pumps: ON and OFF. If you press the pump number on the keyboard just once, you will turn the pump ON  ; pressing the key again turns that pump OFF  , and so on. If a tank fills up to its capacity, all incoming pump lines will be turned off automatically. This is because a full tank cannot receive any more fuel. You will have to turn those pumps back on at a later time, if the fuel level of the tank goes below the critical level. Furthermore, if a tank becomes empty, all outgoing pumps will automatically be turned off. This is because an empty tank can no longer transfer fuel. In that case, the proper action is to supply fuel to an empty tank before turning a pump that transfers fuel out of it.

At some point during the execution of the resource management task, one or more of the pumps may fail. When a pump fails, its label turns red. Depending on the level of fuel in the tank affected, you might need to transfer fuel from one main tank to another main tank to compensate for the loss of fuel. You can cross feed fuel from one main tank to the other by activating either pump 7 or 8 (see the figure below)



Once again, the overall goal is to maintain the fuel level in tanks A and B as close to 2500 units each for as long as you possibly can. There may be more than one way to achieve this goal; you may use the method that works best for you. If the fuel level in these tanks should deviate from this level, please return the fuel level back this this point as soon as possible.

Tank-spotting Task

Finally, you will be asked to search aerial images of a combat zone for the presence of enemy tanks. If you think a tank is present you simply click the button labeled "Tank Found!" at the bottom of the image. If you don't think there is a tank in the image you simply click the button labeled "No Tank." The picture below shows you what this task will look like.

The picture below shows you what the five potential tanks will look like that will occasionally be imbedded within the aerial images.

The picture below shows you what an imbedded tank looks like in the aerial image. The tank has been circled to show you where it is.

To help you accomplish this task, you can use the *tank spotting aid* that will notify you when it thinks there is a tank present. If the tank spotting aid thinks a tank is present it will circle one of the four quadrants and sound an alarm. In the image below, the tank spotting aid has correctly sounded the alarm for a tank.

In the image below, the tank spotting aid has correctly remained silent because there is no tank in the picture.

You will be working with three different tank spotting aids today. Importantly, some of these aids will be unreliable and may make some errors. I will give you a general idea about the reliability of each aid before you use it. You will be asked to interact with these aids in the most efficient strategy you deem possible.

To help you track your performance, there is a point bank at the bottom of the screen. You will start out with 20 points. You should try to accumulate as many points as possible.

Every time you click "Tank Found!" when there is a tank in the picture, you will receive 1 point. Every time you click "No Tank" when there is no tank in the picture, you will receive 1 point.

Every time you click "Tank Found!" when there is NO tank in the picture, you will loose 1 point. Every time you click "No Tank" when there is a tank in the picture, you will loose 1 point.

For researcher only:

Experimental session:

Now that you have had a chance to practice these tasks do you have any questions?

Before we begin, I have a questionnaire for you to fill out (give perceived risk questionnaire).

Ok, now you will start the first of three experimental sessions. Halfway through each session I will pause the simulation and ask you to fill out a questionnaire. After each session you will have a chance to take a break if you wish.

100%:
If you are ready to begin the first experimental session we will start now (start session).

90%:
For this experimental session, we know from past performance history that the tank spotting aid tends to be pretty reliable, so it probably will not make a lot of mistakes. You should use this information to help you complete the tank finding task. Do you have any questions about the experiment so far? (start session)
60%:
For this experimental session, we know from past performance history that the tank spotting aid tends to be pretty tends to be pretty unreliable, so it probably will make a lot of mistakes. You should use this information to help you complete the tank finding task. Do you have any questions about the experiment so far? (start session)

APPENDIX F

DEMOGRAPHIC FORM

Participant #_____ Date:__________ Time:__________

The purpose of this questionnaire is to collect background information for participants in this experiment. This information will be used strictly for this experiment and for research purposes only. Please complete or circle each item to the best of your knowledge.

1. Age _________

2. Male
   Female

3. Have you ever been diagnosed as color blind or color deficient? ________

   0 = No
   1 = Yes

4. Have you ever been diagnosed as having hearing loss?________

   0 = No
   1 = Yes

5. If yes, do you have correction with you (i.e. hearing aid)?_______

   0=No
   1=Yes

6. Have you ever been diagnosed as being nearsighted (myopic)? _______

   0=No
   1=Yes

7. Have you ever been diagnosed as being farsighted (hyperopic)?_______

   0=No
   1=Yes

8. If you answered yes to either #6 or #7, do you have correction with you (i.e. glasses, contact lenses, etc.)? _______

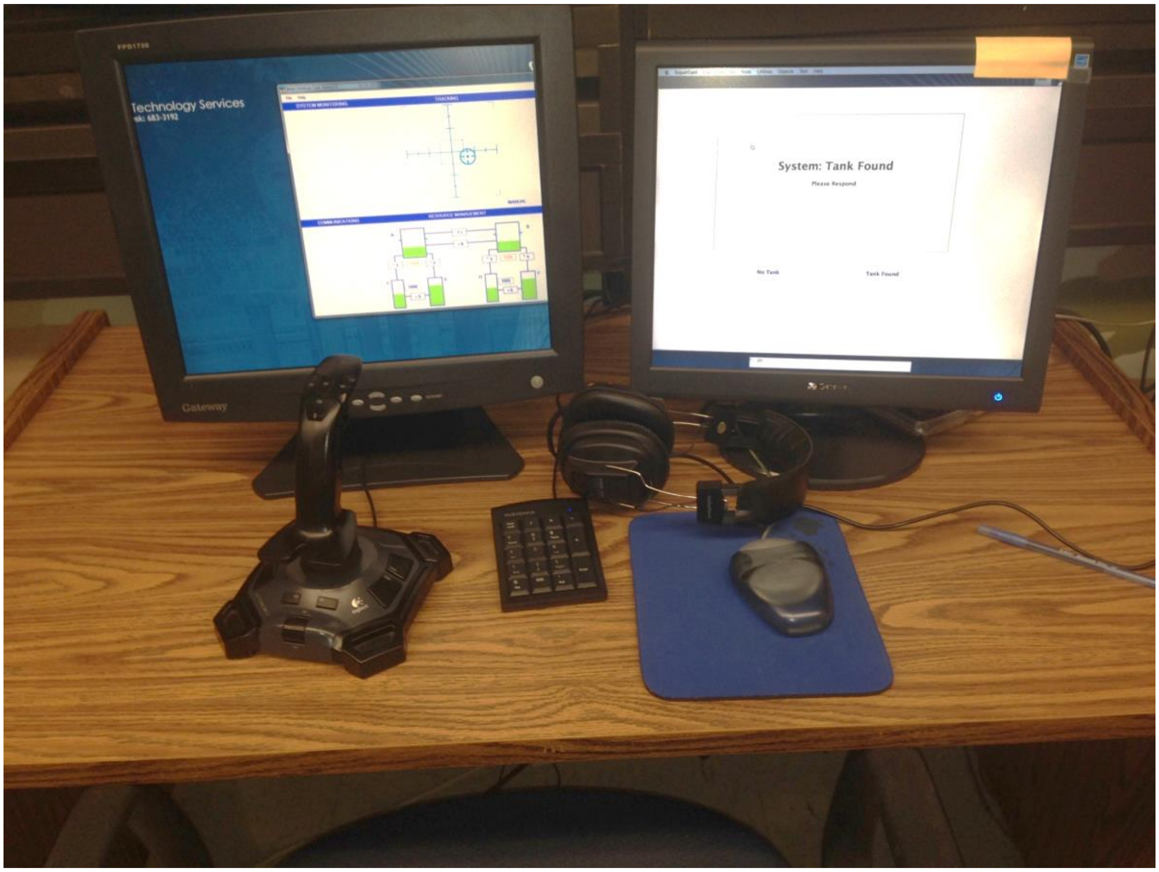
   0=No
   1=Yes

9. How many hours per week do you play video/simulation games? _______

10. How many hours per week do you use a computer (work and recreation combined)?______

APPENDIX G

PICTURE OF EXPERIMENTAL SETUP



APPENDIX H

DESCRIPTIVE STATISTICS

Reliance					
	Risk	**Error**	**Mean**	**Std. Deviation**	**N**
90% Reliability	**High Risk**	**False Alarm Prone**	0.9432	0.11323	22
		Miss Prone	0.8788	0.14511	22
		Total	0.911	0.13269	44
	Low Risk	**False Alarm Prone**	0.947	0.1137	22
		Miss Prone	0.8864	0.08482	22
		Total	0.9167	0.10376	44
	Total	**False Alarm Prone**	0.9451	0.11215	44
		Miss Prone	0.8826	0.11753	44
		Total	0.9138	0.11845	88
60% Reliability	**High Risk**	**False Alarm Prone**	0.863	0.2461	22
		Miss Prone	0.6919	0.08273	22
		Total	0.7775	0.20103	44
	Low Risk	**False Alarm Prone**	0.9085	0.1855	22
		Miss Prone	0.6566	0.12373	22
		Total	0.7825	0.20129	44
	Total	**False Alarm Prone**	0.8858	0.21659	44
		Miss Prone	0.6742	0.10554	44
		Total	0.78	0.20001	88

Compliance					
	Risk	**Error**	**Mean**	**Std. Deviation**	**N**
90% Reliability	**High Risk**	**False Alarm Prone**	0.846	0.0821	22
		Miss Prone	0.928	0.09724	22
		Total	0.887	0.09814	44
	Low Risk	**False Alarm Prone**	0.7955	0.08972	22
		Miss Prone	0.9432	0.06499	22
		Total	0.8693	0.1076	44
	Total	**False Alarm Prone**	0.8207	0.08875	44
		Miss Prone	0.9356	0.08209	44
		Total	0.8782	0.10277	88
60% Reliability	**High Risk**	**False Alarm Prone**	0.5253	0.06823	22
		Miss Prone	0.9242	0.14298	22
		Total	0.7247	0.23018	44
	Low Risk	**False Alarm Prone**	0.5253	0.11858	22
		Miss Prone	0.9394	0.16703	22
		Total	0.7323	0.25371	44
	Total	**False Alarm Prone**	0.5253	0.09561	44
		Miss Prone	0.9318	0.15384	44
		Total	0.7285	0.24086	88

Dependence Rate					
	Risk	**Error**	**Mean**	**Std. Deviation**	**N**
90% Reliability	**High Risk**	**False Alarm Prone**	0.8848	0.06956	22
		Miss Prone	0.8985	0.10714	22
		Total	0.8917	0.08954	44
	Low Risk	**False Alarm Prone**	0.8561	0.07793	22
		Miss Prone	0.9091	0.05651	22
		Total	0.8826	0.07242	44
	Total	**False Alarm Prone**	0.8705	0.07444	44
		Miss Prone	0.9038	0.08482	44
		Total	0.8871	0.08109	88
60% Reliability	**High Risk**	**False Alarm Prone**	0.5576	0.0676	22
		Miss Prone	0.7152	0.07107	22
		Total	0.6364	0.10512	44
	Low Risk	**False Alarm Prone**	0.5621	0.12184	22
		Miss Prone	0.6848	0.11671	22
		Total	0.6235	0.13325	44
	Total	**False Alarm Prone**	0.5598	0.0974	44
		Miss Prone	0.7	0.09672	44
		Total	0.6299	0.1195	88

Trust					
	Risk	**Error**	**Mean**	**Std. Deviation**	**N**
90% Reliability	**High Risk**	**False Alarm Prone**	0.7745	0.12936	22
		Miss Prone	0.7008	0.17863	22
		Total	0.7376	0.15858	44
	Low Risk	**False Alarm Prone**	0.7043	0.1731	22
		Miss Prone	0.7157	0.13684	22
		Total	0.71	0.15431	44
	Total	**False Alarm Prone**	0.7394	0.15513	44
		Miss Prone	0.7082	0.15743	44
		Total	0.7238	0.15618	88
60% Reliability	**High Risk**	**False Alarm Prone**	0.5235	0.15545	22
		Miss Prone	0.4338	0.16697	22
		Total	0.4787	0.16575	44
	Low Risk	**False Alarm Prone**	0.478	0.20704	22
		Miss Prone	0.4237	0.15081	22
		Total	0.4509	0.18109	44
	Total	**False Alarm Prone**	0.5008	0.18238	44
		Miss Prone	0.4288	0.15731	44
		Total	0.4648	0.17315	88

Performance (Trust)					
	Risk	**Error**	**Mean**	**Std. Deviation**	**N**
90% Reliability	**High Risk**	**False Alarm Prone**	0.7598	0.14735	22
		Miss Prone	0.6629	0.22008	22
		Total	0.7114	0.19148	44
	Low Risk	**False Alarm Prone**	0.6727	0.20129	22
		Miss Prone	0.7038	0.1452	22
		Total	0.6883	0.17416	44
	Total	**False Alarm Prone**	0.7163	0.17981	44
		Miss Prone	0.6833	0.18542	44
		Total	0.6998	0.18234	88
60% Reliability	**High Risk**	**False Alarm Prone**	0.4523	0.19199	22
		Miss Prone	0.353	0.17785	22
		Total	0.4027	0.18965	44
	Low Risk	**False Alarm Prone**	0.4348	0.19986	22
		Miss Prone	0.3432	0.1718	22
		Total	0.389	0.18993	44
	Total	**False Alarm Prone**	0.4436	0.19387	44
		Miss Prone	0.3481	0.17288	44
		Total	0.3958	0.18882	88

Process (Trust)					
	Risk	**Error**	**Mean**	**Std. Deviation**	**N**
90% Reliability	**High Risk**	**False Alarm Prone**	0.8136	0.1197	22
		Miss Prone	0.7576	0.1668	22
		Total	0.7856	0.14625	44
	Low Risk	**False Alarm Prone**	0.7644	0.19088	22
		Miss Prone	0.7674	0.16064	22
		Total	0.7659	0.17436	44
	Total	**False Alarm Prone**	0.789	0.15941	44
		Miss Prone	0.7625	0.16191	44
		Total	0.7758	0.1603	88
60% Reliability	**High Risk**	**False Alarm Prone**	0.6553	0.16301	22
		Miss Prone	0.553	0.19359	22
		Total	0.6042	0.18427	44
	Low Risk	**False Alarm Prone**	0.5697	0.25936	22
		Miss Prone	0.5492	0.19186	22
		Total	0.5595	0.22569	44
	Total	**False Alarm Prone**	0.6125	0.21841	44
		Miss Prone	0.5511	0.19048	44
		Total	0.5818	0.20606	88

Purpose (Trust)					
	Risk	**Error**	**Mean**	**Std. Deviation**	**N**
90% Reliability	**High Risk**	**False Alarm Prone**	0.75	0.15171	22
		Miss Prone	0.6818	0.18637	22
		Total	0.7159	0.17144	44
	Low Risk	**False Alarm Prone**	0.6758	0.18226	22
		Miss Prone	0.6758	0.16181	22
		Total	0.6758	0.17033	44
	Total	**False Alarm Prone**	0.7129	0.16992	44
		Miss Prone	0.6788	0.17251	44
		Total	0.6958	0.1711	88
60% Reliability	**High Risk**	**False Alarm Prone**	0.4629	0.16973	22
		Miss Prone	0.3955	0.16944	22
		Total	0.4292	0.17103	44
	Low Risk	**False Alarm Prone**	0.4295	0.20548	22
		Miss Prone	0.3788	0.16684	22
		Total	0.4042	0.18674	44
	Total	**False Alarm Prone**	0.4462	0.18701	44
		Miss Prone	0.3871	0.16639	44
		Total	0.4167	0.17847	88

APPENDIX I

SUMMARY OF HYPOTHESES AND RESULTS

Hypotheses	*Results*
1.) Trust will mediate the relationship between signaling system reliability and compliance for FP systems.	*Partially Supported*: A significant conditional indirect effect indicated that the purpose factor of trust mediated the relationship between reliability and compliance for the FP system. *Supported*: Serial mediation analyses revealed that the indirect effect of performance, process, and then purpose, significantly indirectly affected compliance rate through all three of the bases of trust sequentially.
2.) Trust will mediate the relationship between reliability and dependence rate for the FP signaling systems.	*Not Supported*: Neither trust nor any of its individual bases mediated the relationship between false alarm rate and general dependence rate.
3.) Risk will moderate the mediating effect of trust in the tested relationships.	*Supported*: The purpose factor of trust mediated the FP-compliance relationship and the process factor mediated the FP-reliance relationship. Conditional indirect effects showed that those factors of trust only mediated those relationships for participants in the high risk group. *Not Supported*: The index of moderated mediation for both analyses were not significantly different from zero, indicating those conditional indirect effects were not significantly different from each other.
4.) Trust will not mediate the relationship between reliability and reliance for MP systems.	*Supported*: Neither trust nor any of its individual factors mediated the relationship between reliability and reliance for the MP systems.
5.) Trust will not mediate the relationship between reliability and dependence rate for the MP signaling systems.	*Supported*: Neither trust nor any of its individual factors mediated the relationship between reliability and dependence rate for the MP systems.
6.) Higher reliability will lead to higher subjective ratings of trust	*Supported:* A main effect indicated participants in the higher reliability group assigned higher ratings of trust.
7.) An interaction will occur, where the FP system will more directly impact compliance.	*Supported:* An interaction revealed that higher reliability led to a higher compliance rate, but only for the FP group.
8.) An interaction will occur, where the MP system will more directly impact reliance.	*Supported*: An interaction revealed that a higher reliability led to a higher reliance rate, but only in the MP group.
9.) Participants in the high-risk group will report higher perceived risk ratings than those in the low-risk group.	*Supported*: A main effect indicated that the high risk group assigned higher perceived risk ratings associated with poor task performance.

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