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The role of trust in automation reliance

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Abstract

A recent and dramatic increase in the use of automation has not yielded comparable improvements in performance. Researchers have found human operators often underutilize (disuse) and overly rely on (misuse) automated aids (Parasuraman and Riley, 1997). Three studies were performed with Cameron University students to explore the relationship among automation reliability, trust, and reliance. With the assistance of an automated decision aid, participants viewed slides of Fort Sill terrain and indicated the presence or absence of a camouflaged soldier. Results from the three studies indicate that trust is an important factor in understanding automation reliance decisions. Participants initially considered the automated decision aid trustworthy and reliable. After observing the automated aid make errors, participants distrusted even reliable aids, unless an explanation was provided regarding why the aid might err. Knowing why the aid might err increased trust in the decision aid and increased automation reliance, even when the trust was unwarranted. Our studies suggest a need for future research focused on understanding automation use, examining individual differences in automation reliance, and developing valid and reliable self-report measures of trust in automation.

Keywords: Automation trust; Automation reliance; Misuse; Disuse

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In December 1995, the crew of an American Airlines Boeing 757 descending through a mountain valley toward Cali, Columbia, attempted to route the aircraft toward their destination by entering into the flight management system (FMS) a substring of the code for a Cali navigational beacon. The computer's stored database of navigational beacons contained two very similar codes. One code denoted the beacon near Cali, which was several dozen miles ahead of the airplane. The other code corresponded to a beacon at the Bogota airport, several dozen miles behind the airplane. Presented by the FMS with a list of nearby beacons matching the inputted substring, the crew initiated an overlearned behavior, and selected the computer's first presented alternative—unfortunately, the FMS had presented the Bogota beacon first. The flight management computer dutifully began to turn the aircraft toward Bogota. Shortly after this, the aircraft crashed into the side of a mountain, killing all on board (Federal Aviation Administration [FAA], 1996).

1. Introduction

The underlying assumption in providing an automated aid to pilots and other human operators is that the human-computer "team" will be more productive than either the human or the automated aid would be working alone. Some researchers have found support for this underlying assumption (Corcoran et al., 1972; Dalal and Kasper, 1994; Parasuraman, 1987; Thackray and Touchstone, 1989a). However, as the above vignette illustrates, human–computer teams do not always function optimally.

One strategy used to optimize human–computer performance has been to call on system designers to create automated aids that are increasingly more reliable. Increasing the automated aid's reliability is assumed to lead to increased human–computer "team" performance. As with human teams, however, increasing the reliability of one team member's performance will not necessarily affect the team's performance. Sorkin and Woods' (1985) signal detection analysis revealed that optimizing an automated aid's performance would not always optimize the human-computer team's performance. Specifically, they found that using a response criterion that yielded the best performance for the automated aid (i.e., highest detection rates and fewest false alarms) did not yield the best performance for the human-automated team. Although "synergy" can be found in human-computer teams (e.g., Dalal and Kasper, 1994), it is not likely to be gained by optimizing human-alone or computer-alone performances. The interaction between the automated aid and human operator must be considered.

By understanding the processes that human operators use when deciding to rely on an automated aid's decisions or on their own decisions, one may be able to better design systems and train decision makers on the appropriate use of automated decision aids. One process that is hypothesized to be important in the human-automation reliance decision is trust (Cohen et al., 1998; Lee and Moray, 1992, 1994;

Moray et al., 2000; Mosier and Skitka, 1996; Muir, 1987, 1994; Singh et al., 1993; Tan and Lewandowsky, 1996; Wickens and Hoolands, 2000).

When human operators trust an automated aid that is more reliable than manual operation, they are likely to rely on the automated aid. Similarly, when human operators distrust an automated aid that is less reliable than manual operation, they are likely to choose self-reliance. In both cases, appropriate reliance should occur. However, when human operators trust an automated aid that is less reliable than manual operation or distrust an aid that is more reliable than manual operation, inappropriate automation reliance is likely to result. Parasuraman and Riley (1997) have identified disuse and misuse as two types of inappropriate automation reliance.

Distrusting an automated aid that is more reliable than manual operation may lead to disuse. Disuse is defined as "underutilization of automation" (Parasuraman and Riley, 1997, p. 233). Anecdotal evidence supports disuse; Parasuraman and Riley (1997) described many real-world incidents in which disastrous results occurred due to people ignoring automated warning signals they saw as untrustworthy. Further, laboratory experiments have found disuse in paradigms in which the aid's decisions are provided only after the human operators have indicated their decision (Dzindolet et al., 2002; Moes et al., 1999). In addition, Riley (1996, Study 1) found students favored manual operation over automated control, even when doing so was clearly not an optimal strategy.

Trusting an automated aid that is less reliable than manual operation may lead to misuse. According to Mosier and Skitka's (1996) authority hypothesis, people rely on the automated system's decision because they believe it to be more reliable, and thus place greater trust in it. Misuse is defined as "overreliance on automation" (Parasuraman and Riley, 1997, p. 233). Parasuraman et al. (1993) and Singh et al. (1997) found misuse among operators performing monitoring functions. They labeled this behavior complacency, "a psychological state characterized by a low index of suspicion" (Wiener, 1981, p. 117). Misuse has also been found with automated decision aids (Dzindolet et al., 2001a, b; Layton et al., 1994; Mosier and Skitka, 1996).

Thus, overly trusting an automated aid may lead human operators to misuse; lack of trust in a superior aid may lead to disuse. The purpose of this paper is to explore the relationship between trust and automation use in an effort to improve appropriate reliance on automated decision aids.

Trust in an automated aid, like trust in a person, is thought to be dynamic (Cohen et al., 1998; Lee and Moray, 1994; Wickens and Hoolands, 2000). Muir (1987, 1994), extending the interpersonal trust literature to understand human operators' trust of automation, predicted that after failure events, trust would decline rapidly and slowly increase again as the system performed without making errors.

Thus, as interaction with automation takes place, levels of trust are expected to ebb and flow. At the beginning of a relationship, how much is a decision aid, human or automated, trusted? The social psychological literature has found that in the absence of other information, we believe people are good (positivity bias, Bruner and Tagiuri, 1954; Cacioppo and Berntson, 1994; Peeters and Czapinski, 1990). Unfamiliar people and things (e.g., insects; Cacioppo et al., 1997) are assigned positive rather than neutral evaluations. Does the positivity bias extend to automated decision aids?

2. Study 1

The purpose of Study 1 was to explore human operators' level of trust in an automated decision aid prior to interaction with the aid. A very simple soldier detection task in a laboratory, rather than a complex simulation or an actual system in a field study, was used in order to control extraneous variables and isolate the influence of trust.

3. Method

3.1. Participants

Fifteen Cameron University students volunteered to participate in the study. Although demographic information was not collected, the research pool consisted of predominately (about 2/3) non-traditional students; the average age of the participant pool ranged from 27 to 31 years with women and upperclassmen being over-represented. Guidelines set forth in the American Psychological Association Guidelines for Ethical Conduct were strictly followed.

3.2. Materials and procedure

Participants were told they would view 200 slides displaying pictures of Fort Sill terrain on a computer screen. In about half of the slides, a soldier, in varying degrees of camouflage would be present (Fig. 1 presents a sample slide). After each slide, they would be asked to indicate whether or not they believed the soldier was in the slide and the confidence they had in their decision on a five-point Likert scale. Next, they would view the absent-present decision reached by a pseudo-computer program called a, "Contrast Detector." Participants were told that the contrast detector was designed to use shading contrasts to determine the likelihood of a soldier's presence.

All participants were told that their automated decision aid was not perfect. Participants performed four very easy practice trials for which the aid supplied the correct decisions. Participants were then given an opportunity to ask questions. After performing only the four practice trials, participants were asked to estimate their and their automated aid's expected performance on 200 trials. Pairs of survey items asked participants to rate how well they and their aid would perform on the upcoming trials, to indicate how much they could trust their and their aid's decisions, and to estimate the number of errors they and their aid would make. In addition, two items assessed participants' expected relative performance. For most items a nine point Likert format scale was provided (see Table 1).

Fig. 1. Sample slide of camouflaged soldier.

Table 1
Means and standard deviations for responses to survey items in Study 1

Item	Mean	S.D.
How well do you think the contrast detector will perform during the 200 trials? (Not very well–Very well)	7.27	1.22
How well do you think you will perform during the 200 trials? (Not very well–Very well)	6.53	1.19
Who do you think will make more errors during the 200 trials? I will make (Many more errors–Far fewer errors)	4.60	2.26
How many errors do you think you will make during the 200 trials? I will make about _______ errors.	45.13	37.50
How many errors do you think the contrast detector will make during the 200 trials? The contrast detector will make about ________ errors.	16.40	13.59
To what extent do you believe you can trust the decisions the contrast detector will make? (Very little–A great amount)	6.60	1.64
To what extent do you believe you can trust the decisions you will make? (Very little–A great amount)	6.47	1.46
How would you rate the expected performance of the contrast detector relative to your expected performance? The contrast detector will perform (better than I will perform-much worse than I will perform)	4.27	2.02

Unless a blank line was provided, a nine-point Likert-type scale was used.

4. Results

To examine trust in the automated aid's decisions, a *t*-test compared the mean response to the survey item, "To what extent do you believe you can trust the decisions the contrast detector will make?'' with 5, the midpoint of the nine point Likert format scale anchored with 1, ''very little,'' and 9, ''a great amount.'' Results revealed participants' positivity bias toward the automated decision aid, $t(14) = 3.78$, $p < 0.01$, $M = 6.60$, S.D. $= 1.64$. A dependent t-test performed to compare the participants' level of trust in their own decisions with the level of trust in the automated aid's decisions failed to find significant differences. However, students estimated that the automated aids would make nearly 30 fewer errors than they, $M_D = 28.73$, $t(14) = 2.76$, $p < 0.02$, M-aid $= 16.4$, S.D. $= 13.59$, M-self $= 45.13$, S.D. $= 37.50$, over the 200 trials.

In addition, a t-test that compared the mean response to the survey item, ''How well do you think the contrast detector will perform during the 200 trials?'' with 5, the midpoint of the nine point Likert format scale anchored with 1, ''not very well,'' and 9, ''very well,'' indicated participants expected the aid to perform better than the average of the scale, $t(14) = 7.18$, $p < 0.01$, $M = 7.27$, S.D. $= 1.22$. The means and standard deviations for each item are presented in Table 1.

Correlational analyses revealed that the more participants felt they could trust the aid's decisions, the better they expected the aid to perform, $r(14) = 0.81$, $p < 0.01$, and the fewer errors they expected the aid to make, $r(14) = -0.50$, $p < 0.06$. Trust in the automated aid was not related to trust in one's own decisions, $r(14) = -0.16$, $p > 0.05$.

5. Discussion

Consistent with the positivity bias, students with little information about the reliability of their automated decision aid believed the aid would perform well and better than they would perform. Knowing little about the automated aid, participants deemed the aid trustworthy.

These findings are consistent with the results of Dzindolet et al. (2002; Study 1), in which a similar paradigm was used. In the Dzindolet et al. study, however, half the participants were told they would be provided with the decisions reached by the prior participant rather than the automated aid. When asked to estimate the number of errors the automated aid would make in the upcoming 200 trials, participants predicted, on average, the automated aid would make only 14.19 errors whereas the human aids were predicted to make, on average, 46.17 errors. People expected automated aids to outperform human partners. Other researchers have also found a bias toward automation. For example, Dijkstra et al. (1998) found students judged advice from an automated expert system to be more rational and objective than the same advise from a human advisor. However, Lerch et al. (1997) found greater trust in automated systems than human advisors only when the automation was an expert system and the human advisor was a novice. They did not find participants were more likely to trust an automated expert system than a human expert advisor.

Taken together, it appears that people generally have positive expectations of unfamiliar automated decision aids. They deem their decision aids trustworthy and even expect automated aids to outperform human aids. How does the trust in the automated decision aid evolve with interaction?

In Dzindolet et al.'s (2002, Studies 2 and 3) studies, participants actually viewed the 200 terrain slides and indicated whether or not a camouflaged soldier was present in each slide. After indicating their present–absent decision and their confidence in their decision, participants were able to view the decision reached by the contrast detector. When they completed all 200 slides, some participants were told the number of errors they and their aid had made. Finally, students were told they could earn $0.50 in coupons to be used at the cafeteria in the Student Union for every correct decision made on ten randomly chosen trials. Participants had to *choose* whether the performance would be based on *their decisions* or on *the decisions of their aid*. After making their choice, students were asked to justify their choice in writing.

Rather than misusing the contrast detector, participants in these studies disused the automated aid. Even among participants provided with feedback that their aid's performance was far superior to their own, the majority (81%) chose to rely on their own decisions rather than on the decisions of the automated aid! Analyses of the justifications of the task allocation decisions provided by participants indicated nearly one-quarter (23%) of the participants justified their disuse by stating they did not trust the automated aid as much as they trusted themselves, for example, "The computer did not earn my complete trust because I swear I saw someone when the computer said there was no one there." Others detailed instances in which the automated aid made an error to justify their disuse. Even among participants told that they made twice as many errors as their automated aid, 57% of the justifications of self-reliance included descriptions of the automated aid's errors. For example, one participant wrote, "I feel that I saw a soldier in a couple of the slides, but the computer said the soldier was not present." Another wrote, "I know for a fact the contrast detector was incorrect at least with four slides."

The results of these studies suggests that something happens during the experience with the automated decision aid that moves participants from an unjustified high level of trust in automation to an undeserving low level of trust and rampant disuse. What occurs during the interaction with automation to change trust levels and automation reliance? Further, what techniques can be used to induce appropriate reliance on automated systems? To answer these questions, a clarification of the definition of trust is needed. Although a consistent conception of trust in automation has not emerged in the literature, some overlap exists. For example, most conceptions of trust are multidimensional and include reliability as one of trust's factors. For example, Rempel et al. (1985) extended trust in human–human relationships to human-automation systems and proposed that predictability (based on reliability) is important. Using an empirically based, bottom-up approach, Jian et al. (2000) concluded that human-automation trust involves eight factors including reliability. Similarly, Sheridan (1988) and Dzindolet et al. (2001a, b) hypothesized reliability was important to trust in automation. Finally, Lee and Moray (1992) suggest performance is a basis of trust; performance is based on automation reliability. Therefore, reliable automated aids are likely to be deemed trustworthy.

However, automation reliability is not the only component of trust. Another factor of trust hypothesized by Lee and Moray (1992) is process. The more accurate the human operator's understanding of how the automated aid operates, the more the human operator will trust the automated aid. Without a correct understanding of the process a decision aid uses to attain its decision, human operators may deem an automated aid as untrustworthy.

Ironically, the expectations held by the human operator prior to interaction with automated aids may lead to distrust and disuse of the automated aid. Based on Study 1 and Dzindolet et al. (2002; Study 1), prior to interaction with an automated system people expect the aid to be reliable. The automated aid is expected to perform better than average and better than other human aids; it is deemed trustworthy.

When a participant views an easy slide, quickly spots the target, and makes his or her decision with a high degree of confidence, he or she assumes the automated aid will be in concurrence. When the automated aid indicates the target is absent, the participant is likely to notice the obvious error just committed by the aid. Without an understanding of why this error was made, this obvious error violates the trust the operator has in the aid's decisions. Trust may diminish slowly or may immediately drop to a low level. As long as participants are able to view the decisions made by their automated decision aids, obvious errors can be detected setting in motion the violation of trust.

In addition to reducing trust, errors made by the aid may affect the operator's perceived reliability of the decision aid. Researchers in cognitive psychology have found that information inconsistent with expectations (e.g., schemas) is likely to be well remembered and play an unduly large role in information processing (Ashcraft, 1994; Ruble and Stangor, 1986; Smith and Graesser, 1981). Because errors made by the automated aid are inconsistent with the human operator's expectation that the automated aid is reliable and accurate, the error made by the aid is more likely to be remembered than correct decisions made by the aid, distorting the operator's estimate of the aid's reliability. As the task progresses it may be hard for the participant to retain an accurate picture of the aid's reliability. This may lead participants to underestimate the performance of the automated aid. Cumulative feedback, the one-time piece of information given at the end of the 200 trials may not be enough to override the contradicted expectations and resulting bias against automation that has been allowed to grow over 200 trials of experience.

In summary, errors made by the aid violate the assumption that the aid is trustworthy and, because these errors are better remembered than correct decisions made by the aid, the errors may lead to distorted views of the aid's reliability. The purpose of the next study was to explore the effect of an aid's errors on trust and automation reliance.

6. Study 2

To eliminate the detection of obvious errors, some participants were unable to view the decisions by the automated aid (Decisions Absent). Others were able to view the aid's decisions (Decisions Present).

In order to help human participants retain an accurate picture of the aid's reliability, the operator must be continuously aware of his and his aid's performance

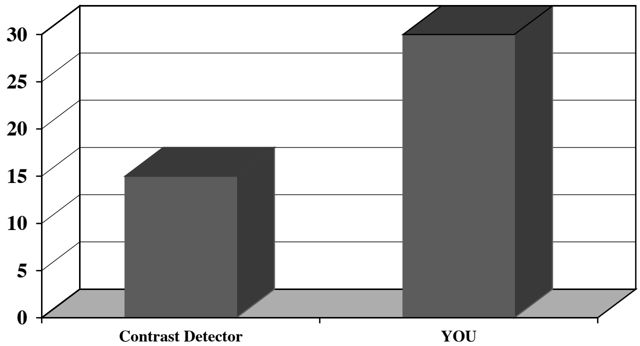

Fig. 2. Feedback display.

levels. Some of the participants in Study 2 were provided with a bar graph that displayed the number of errors made by the human operator and the automated aid *during the entire task* (Continuous Feedback; see Fig. 2). This graph was updated every five trials in order to prevent participants from gaining information of the aid's decision on any individual trial. Others were provided with a similar bar graph only *at the completion of the task* (Cumulative Feedback). Still others were not provided with any type of feedback (No Feedback).

In order to examine both misuse and disuse some participants were paired with an automated aid that made twice as many errors as the participant (Inferior); others were paired with an automated aid that made half as many errors as the participant (Superior). For the first 20 trials, the automated decision aid made either twice (Inferior) or half (Superior) as many errors as an average student in prior studies (i.e., 4 errors). At the end of the 20th trial, the experimental program determined the number of errors the participant had made on the previous 20 trials and instructed the contrast detector to make either twice (Inferior) or half (Superior) as many errors on the next 20 trials. This occurred every 20 trials, thus ensuring that at the end of the 200 trials, the aid would have made twice (Inferior) or half (Superior) as many errors as the participant.

This 2 (Aid's Performance Level: Superior or Inferior) $\times$ 2 (Provision of Aid's Decision: Present or Absent) $\times$ 3 (Type of Feedback: No Feedback, Cumulative Feedback, or Continuous Feedback) between subjects design allowed for an examination of the effects of obvious errors and distorted views of the aid's ability on automation usage decisions both individually and cumulatively.

7. Method

7.1. Participants

One hundred eighty Cameron University students volunteered to participate in this study. Some received extra credit in a course offered in the Psychology and

Human Ecology Department for their participation. Those enrolled in General Psychology fulfilled a research requirement for that course. Guidelines set forth in the American Psychological Association Guidelines for Ethical Conduct were strictly followed.

7.2. Materials

Two workstations contained a Hewlett Packard Vectra PC, 133 MHz CPU with 32 Mb of RAM, including an S3, Inc. Trio 64 Plug-n-Play PCI video card. The 17-in Hewlett-Packard Ultra VGA monitors were set at High Color (16 bit) resolution, 800×600 pixels. The operating system used was Windows 95, version 4.00.950. Slides of Fort Sill terrain were presented for about 3/4 of a second. The reliability of the automated decision aid was manipulated such that the aid was either superior, making half as many errors, or inferior, making twice as many errors, as the participant.

7.3. Procedure

Students were randomly assigned to one of the 2 (Aid's Performance Level: Superior or Inferior) $\times$ 2 (Provision of Aid's Decision: Decisions Present or Decisions Absent) $\times$ 3 (Type of Feedback: No Feedback, Cumulative Feedback, or Continuous Feedback) conditions. The appropriate instruction page was provided to each treatment group. The experimenter read the instruction page aloud while the student followed along. After the experimenter answered questions, students performed four practice trials. For each trial, the student viewed a slide of Fort Sill terrain for about 3/4 of a second. About half of the slides contained one soldier in various levels of camouflage; the remaining 50% of the slides were of terrain only. After viewing the slide, the participants were asked to indicate whether or not they believed the soldier was present in the slide and indicate their level of confidence in their absent/present decision on a five-point Likert-type scale.

In order to determine the effect of viewing obvious errors committed by an automated aid, some participants viewed the decision reached by the automated aid after indicating their decision (Decisions Present); others were not provided with that information (Decisions Absent). To improve the accuracy of the operators' reliability estimates of the automated aids, about one third of the participants were presented with a continuous feedback display that remained on the screen throughout the 200 trials and was updated every 5 trials (Continuous Feedback). Another third of the participants received a cumulative feedback display presented at the end of the 200 trials (Cumulative Feedback). Both the cumulative and continuous forms of feedback were graphically represented, indicating the number of errors the participant made and the number of errors their automated aid made (Fig. 2). Depending on the aid's performance level (Superior or Inferior), the feedback indicated that the aid made half as many errors or twice as many errors as the participant. The remaining third of the participants did not receive any feedback (No Feedback).

After completing the 200 trials, students were told that 10 trials would be randomly selected from the prior 200. Coupons would be earned for each correct decision made for these 10 selected trials. Participants were asked to decide whether they would like to rely on the decisions made by their automated aid or whether they would like to rely on the decisions they made. After indicating their preference, students were asked to explain why they chose to rely on themselves or the automated aid. The participants were then asked to complete a brief survey, which differed depending on condition. Finally, the appropriate monetary award was distributed.

8. Results

A chi-square test of independence was used to determine whether participants' conditions (described by the 2 (Aid's Performance Level: Superior or Inferior) $\times$ 2 (Provision of Aid's Decision: Decisions Present or Decisions Absent) $\times$ 3 (Type of Feedback: No Feedback, Cumulative Feedback, or Continuous Feedback) between subjects design) were independent of their decisions to choose to rely on their or their aid's decisions. Results indicated that condition and automation reliance were related, $\chi^2(11) = 34.45$, $p < 0.01$. Table 2 presents the frequencies and percentages of those in each condition who chose to rely on their decisions rather than those of their automated aid. Because participants in the No-Decision-No-Feedback-Superior condition were essentially treated the same as those in the No-Decision-No-Feedback-Inferior condition, another chi square analysis, in which these two conditions were collapsed, was performed. The 11 (Condition) $\times$ 2 (Reliance Decision) chi-square test also revealed that condition and automation reliance were related, $\chi^2(9) = 34.20$, $p < 0.01$. Consistent with prior data (Dzindolet et al., 2002, Study 1; Moes et al., 1999), a bias toward self-reliance was found. The bias toward

Table 2
Number and percentage of participants who chose to rely on self by condition in Study 2

Condition	Superior aid		Inferior aid	
	Percentage	Number	Percentage	Number
No feedback				
Decision	73.33	11	80.00	12
No decision	80.00	12	86.67	13
Cumulative feedback				
Decision	73.33	11	86.67	13
No decision	60.00	9	73.33	11
Continuous feedback				
Decision	73.33	11	73.33	11
No decision	13.33	2	93.33	14

self-reliance was attenuated only among participants who were continuously provided with feedback indicating the superior performance of their aid and who were unable to view their aid's decisions.

After indicating their self-reliance or automation-reliance decision, participants were asked to justify their decision. Content analysis was performed with the participants' responses to the prompt: "We would like to know what led you to your decision to base your performance on either your decisions or on the decisions of the aid. Please tell us everything you thought of in coming to this decision. Do not worry about spelling or grammatical errors. Use the back side of this paper if necessary." Each justification was typed into an Access Database with the participant's number and condition. Two raters categorized each justification into separate categories. The 180 participants generated 189 justifications. Eight of the justifications were in lone categories and were not included in the final analysis.

The remaining 181 justifications fell into 14 different categories. However, 85% of the justifications fell into seven categories representing four general constructs: (1) trust in computers ("I don't trust computers that much. I know a lot about their tendency for errors"), (2) detection of obvious errors (e.g., "There were a few times that I'm pretty sure I saw the soldier, but the program said he was absent"), (3) confidence in self (e.g., "I was not confident in what I saw"; "I chose to use 'my decisions' because I trust my observations, and I never second guess my self"), and (4) relative performance (e.g., "I had less errors than the computer", "The contrast detector made less errors", "The computer made more mistakes compared to mine."). Only 15% of the justifications fell into the remaining seven categories.

A 2 (Aid's Performance Level: Superior or Inferior) $\times$ 3 (Type of Feedback: No Feedback, Cumulative Feedback, or Continuous Feedback) ANOVA was performed with responses to three questions asked only to participants in the Decision Present conditions. The first item explicitly asked participants to assess the trustworthiness of their automated aid: "How much did you trust the decisions make by the contrast detector?" Participants were provided with a nine-point Likert-format scale anchored with "very little" (1) and "a great amount" (9). The only significant finding was a main effect for the aid's performance level. Participants paired with superior aids reported they trusted their aid's decisions more than those paired with inferior aids, $F(1,84) = 5.06$, $p<0.03$, M-superior = 4.96, s.d. = 2.04, M-inferior = 4.02, s.d. = 1.88. Responses to a second item asked only to participants who were able to view the decisions made by the automated aid, "How often did you notice an error made by the contrast detector?" with anchors "not at all" (1) and "many times" (9), revealed the same pattern of findings, $F(1,84) = 7.63$, $p<0.01$, M-superior = 6.00, s.d. = 2.13, M-inferior = 7.13, s.d. = 1.70. Those paired with superior aids indicated they noticed fewer aid errors than those paired with inferior aids. No significant differences among conditions were found in response to the question, "To what extent did you lose trust in the contrast detector when you noticed it made an error?" with anchors "very little" (1) and "a great amount" (9).

T-tests comparing the mean response to the scale midpoint indicated that participants believed they lost trust in the automated aid when it made an error,

$t(89) = -4.42$, $p<0.01$, $M = 6.12$, and that they did not deem the automated decision aid as trustworthy, $t(89) = 2.42$, $p<0.02$, $M = 4.49$. Note that these items were only asked of participants who were able to view the decisions reached by the automated aid.

Analyses of variances were performed to compare survey responses to the above three items between participants who chose self-reliance and those who chose automation reliance. Compared with those who chose self-reliance, those who chose to rely on the automated decision aid trusted the aid more, $F(1, 88) = 7.84$, $p<0.01$, M-aid = 5.52, S.D. = 1.81, M-self = 4.17, S.D. = 1.97, noticed the aid made fewer errors, $F(1, 88) = 5.85$, $p<0.01$, M-aid = 5.67, S.D. = 2.08, M-self = 6.84, S.D. = 1.91, and indicated that they lost less trust in the aid when they noticed an error the aid made, $F(1, 88) = 5.22$, $p<0.03$, M-aid = 5.10, S.D. = 2.39, M-self = 6.43, S.D. = 2.34.

9. Discussion

Two techniques were developed to reduce the impact of the aid's errors on trust and reliance: (1) Preventing participants from viewing the decisions reached by the automated aid removed the possibility of participants noticing an obvious error committed by the automated aid. (2) The continuous feedback display served as a constant reminder of the relative performance of the aid, reducing the possibility that participants could distort the relative ability of the automated aid. The results of the reliance decisions indicated that only when both of these methods were employed was disuse eliminated. Participants who were prevented from viewing decisions but received continuous feedback regarding the aid's performance seemed much more willing to trust a superior aid than those in other conditions. Justifications for reliance on the aid by participants in this condition frequently included acknowledgement of the aid's superior performance. Although these participants could not be asked about the impact of individual aid decisions on trust, additional measures of trust were collected from those who could view the aid's decisions.

Among participants who could view their aid's decisions, obvious errors committed by the aid were often used as justification for self-reliance. They indicated the aid's trustworthiness was below average and that they had lost trust in the automated aid when it made an error. Participants who chose to rely on the automated aid indicated they trusted the decisions made by the automated aid more, noticed fewer errors that the aid made, and lost less trust in the aid when it did err than those who chose to rely on their own decisions.

In summary, eliminating operators' awareness of an automated decision aid's obvious errors (through blinding the participants to the decisions of the aid) was useful in promoting appropriate automation reliance if participants were continually reminded of their and their aid's performance. Unfortunately, applying these techniques outside the laboratory is problematic. It would not be reasonable to provide someone with an automated decision aid but not allow them to see the decisions the aid has made. In addition, in many instances, it would be unreasonable to provide a human–computer team with continuous feedback concerning the performance of each. Finally, automation reliance is rarely a one-time, dichotomous decision as it was in Study 2.

In the next study, variations to the paradigm were made in order to increase the external validity of the findings of the last study. One reason why obvious errors made by the aid may violate the operator's expectation of the trustworthiness of the aid is because the human operator does not understand why the automated decision aid made an error. Many automated aids we deal with daily operate with an all-or-none principle (e.g., calculators). They either work perfectly or not at all. Therefore, an error is a signal that the automated aid is malfunctioning and should no longer be trusted. Merely telling participants that the automated aid is not perfect was not effective in reversing the effect of obvious errors on automation reliance (although see Dzindolet et al., 2002, Study 3 to see how reducing expectations of performance can lead to more appropriate reliance). Perhaps explaining how the aid could err and still function properly would reduce the negative effect of the aid's errors on trust in automation and automation reliance.

The majority of the participants in Study 2 opted for self reliance rather than automation reliance. This is consistent with some prior research (e.g., Riley, 1996; Study 1) and is not surprising given the high level of manual performance (Wickens, 2002). To avoid a potential ceiling effect in the next study, we varied the paradigm slightly in an attempt to create a situation in which automation reliance might be more likely. Specifically, a second task was added. The second task had to be performed manually (as in Parasuraman et al., 1996). The intent was to increase the mental workload of participants, making automation reliance more attractive (although see Parasuraman and Riley, 1997).

10. Study 3

Because participants expected the aids to be error-free and do not understand *why* an automated aid might err, each error made by the aid was likely to represent a violation of trust and be remembered, leading to disuse. Providing participants with an explanation as to why the automated aid might err may lead participants to more accurately perceive their automated aid's performance, making appropriate automation use more likely. In Study 3, a 2 (aid's relative performance level: inferior or superior) $\times$ 2 (provision of a rationale for the aid's errors) $\times$ 4 (aid's decision) design was utilized in which the aid's relative performance level and the provision of a rationale for the aid's errors were between-subjects and the aid's decision was a within-subjects variable. Rather than using a one-time reliance decision as in Study 2, participants were able to rely on or ignore the aid's decision for 100 trials. One concern about the previous study was that the artificial nature of the task resulted in low external validity of the findings. Therefore, three measures were taken to engage participants in a somewhat more realistic decision-making task. First, rather than collecting a one-time reliance decision as in Study 2, participants were given the opportunity to rely on or ignore the aid's decision for 100 trials. During each of these trials, participants were first given the aid's decision and then required to report their own decision. Second, the continuous feedback condition was removed, as this type of feedback regarding the aid's decisions is not likely to be available outside the laboratory. Third, considering that real-world decision-making does not usually occur in isolation, a secondary task was added whereby participants were required to simultaneously attend to a taped recording of battlefield communications.

11. Method

11.1. Participants

Twenty-four Cameron University students participated in the study. Some received extra credit in a course offered in the Psychology and Human Ecology Department for their participation. Those enrolled in General Psychology fulfilled a research requirement for that course. Guidelines set forth in the American Psychological Association Guidelines for Ethical Conduct were strictly followed.

11.2. Materials and procedure

The first 200 trials of the experiment were patterned after Study 2. Participants were told to view slides of Fort Sill terrain in search of a camouflaged soldier. A "contrast detector" would view shadings of the slide to generate its absent–present decision. Regardless of condition, participants were told that their automated aid was not perfect. Participants in the Information condition were also told, "The contrast detector will indicate the soldier is present if it detects forms that humans often take. Since non-humans (e.g., shading from a tree) sometimes take human-like forms, mistakes can be made." Those in the control condition were not provided with the explanation as to why the automated aid might err.

Participants performed four practice trials, were provided an opportunity to ask questions, and then proceeded to view the 200 slides. When they completed the task, participants were provided with cumulative feedback that, based on condition, indicated that the aid had made half as many (Superior Aid) or twice as many (Inferior Aid) errors as they had made during the previous 200 trials.

After viewing the cumulative feedback, participants were told that they would now perform another 100 trials. However, for these trials, the decision reached by the automated aid would be provided *prior* to the participants reporting of their decisions. Specifically, they would view the slide and then view the aid's decision. Only after seeing the aid's decision, would they be asked to indicate their present/absent decision and their level of confidence.

While performing all 300 trials, participants were assigned an additional task. Specifically, they listened to a taped recording of battlefield communications and were to press the space bar each time they heard anyone say the word "Roger." Participants were instructed not to ignore the soldier identification task to better identify "Roger" and not to ignore the battlefield communication task to better detect the soldier in the Fort Sill terrain slide. They were told to perform as best they could at both tasks.

Upon completion of the 300 trials, participants were asked to complete a survey, which included an item to measure trust in the automated aid: "How much did you trust the decisions made by the contrast detector?" As in the prior study, participants were provided with a nine-point Likert-format scale anchored with "very little" (1) and "a great amount" (9).

12. Results

The p(error) was calculated separately for each participant for the slides in which the automated aid made a false alarm, correct rejection, miss, and hit. Since it is inappropriate to perform an analysis of variance with probability data, the arcsine transformation was used (Howell, 1992). Specifically,

$$\text{Dependent Variable} = 2^{*}\,\text{arcsine}[p(\text{error})]^{1/2}.$$

A 2 (Aid's Relative Performance: Inferior Aid vs. Superior Aid) $\times$ 2 (Provision of a Rationale for Why Aid Might Err: Information vs. Control) $\times$ 4 (Aid's Decision: False Alarm, Correct Rejection, Miss, or Hit) analysis of variance was performed with the transformed p(error). A significant main effect for aid's decision was found, $F(3,60) = 16.11$, $p < 0.01$. Inspection of the means indicated that participants were more likely to make an error when the target was present (i.e., aid's decisions were hits or misses) than when the target was absent (i.e., aid's decisions were correct rejections or false alarms).

In addition, an interaction between provision of a rationale as to why the aid might err and the aid's decision was found, $F(3,60) = 2.26$, $p < 0.10$, though it did not reach standard levels of significance. Automation reliance was defined as the difference between the $p(\text{error} \mid \text{aid error})$ and $p(\text{error} \mid \text{aid correct})$. If no difference existed for these two probabilities, the participant did not rely on the automated aid. However, if $p(\text{error} \mid \text{aid error}) > \text{p}(\text{error} \mid \text{aid correct})$, then participants did rely on the automated aid. Inspection of the means indicated that participants were more likely to rely on automated aids (both inferior and superior ones) when they were provided with a reason why the aid might err than when this information was not provided to them (see Fig. 3).

A 2 (Aid's Relative Performance: Inferior Aid vs. Superior Aid) $\times$ 2 (Provision of a Rationale for Why Aid Might Err: Information vs. Control) ANOVA performed with the response to the item querying participants' level of trust in the automated decision aid revealed two main effects. Those provided with a rationale explaining why the aid might err indicated the aid was more trustworthy than those not provided with this information, $F(1,25) = 4.96$, $p < 0.04$, M-rationale = 5.43, S.D. = 0.94, M-no rationale = 4.13, S.D. = 2.10. In addition, superior aids were deemed more trustworthy than inferior aids, $F(1,25) = 3.95$, $p < 0.06$, M-superior = 5.38, S.D. = 1.61, M-inferior = 4.25, S.D. = 1.73.

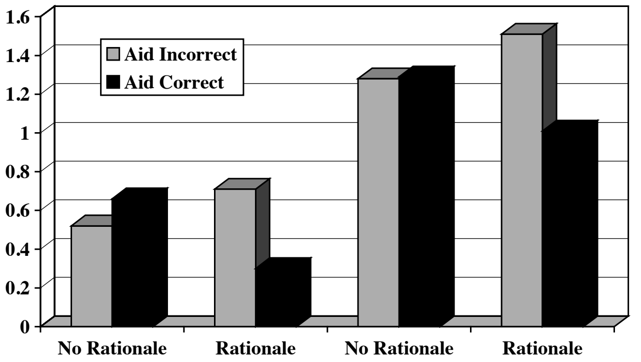

Fig. 3. Mean transformed probability of error for each condition.

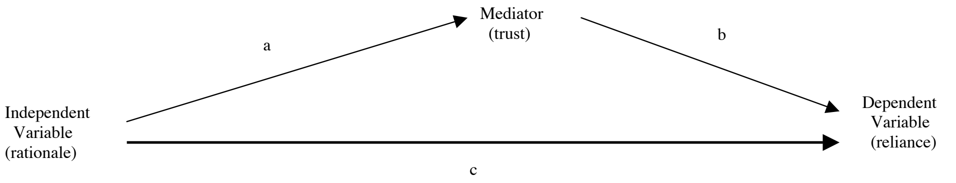

Fig. 4. Baron and Kenny's (1986) mediational analysis.

To determine if trust mediated the relationship between provision of a rationale as to why the aid might err and reliance, Baron and Kenny's (1986) analyses were employed. Fig. 4 expands Baron and Kenny's path diagram to clarify the meaning of mediation in this context.

According to Baron and Kenny, "a variable functions as a mediator when it meets the following conditions: (a) variations in levels of the independent variable significantly account for variations in the mediator (i.e., Path a), (b) variations in the mediator significantly account for variations in the dependent variable (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" (p. 1176).

Through simple and multiple regression analyses, it was determined that the three requirements necessary to demonstrate that one variable (trust) mediates the relationship between two others (rationale and reliance) were met. Specifically, the effect of providing a rationale as to why the aid might err on trust was found to be significant, $b1 = 1.30$, $t(1) = 2.12$, $p < 0.05$. In addition, though not reaching standard levels of significance, reliance could be predicted from trust, $b1 = 0.78$, $t(1) = 1.72$, $p < 0.10$. Finally, although the effect of providing a rationale as to why the aid might err on automation reliance was significant, $b1 = 0.55$, $t(1) = 2.39$, $p < 0.03$, when controlling for trust, the effect of providing the rationale on automation reliance was reduced, $b1 = 0.52$, $t(1) = 1.81$, $p > 0.05$. Therefore, trust mediated the effect that providing a rationale for why the aid might error increased reliance on the aid.

13. Discussion

Participants who were given a reason why the aid might err trusted the aid's decisions more and were more likely to rely on the aid than those not provided with this information. Although superior aids were deemed more trustworthy than inferior aids, the two were equally likely to be relied upon. Participants paired with an inferior aid were just as likely to rely on the aid as were those paired with a superior aid.

Interestingly, even though the information provided about why the aid might err focused on false alarms rather than misses, participants were equally likely to rely on the aid when it made both types of errors. Participants seemed to conclude that if there is a logical reason for making a false alarm, there is also a logical reason for the aid to miss a target.

Providing information regarding why the automated decision aid might err increased trust in automation, which increased automation reliance. For some participants (those paired with a superior aid), this reliance was appropriate. However, for other participants (those paired with an inferior aid), this reliance represents misuse.

14. General discussion

Although realistic techniques to improve appropriate automation reliance have not been discovered in this series of studies, much has been learned about the relationship between trust, automation reliability, and automation reliance in a very simple laboratory task performed by university students. The results of the first study indicate that after very limited interaction with an automated decision aid, people believe the aid to be trustworthy ($M = 6.60$) and expect it to perform better than average. However, the results of Study 2 indicate that after interacting with the decision aid for 200 trials, even an aid that makes half as many errors as the operator, people lose trust in the aid, assigning it a less than average rating of trustworthiness ($M = 4.49$) and choose self-reliance over automation reliance. Among people who were not allowed to view the decisions reached by the aid and who received continuous feedback of their and their aid's performance, appropriate reliance on the automated decision aid was found. However, the role of trust in appropriate reliance decisions could not be completely explored because those who were not provided with the aid's decisions were not asked how much they trusted the aid's decisions. The results of Study 3 indicate that trust does indeed play a role in automation reliance decisions. Providing a reason why the automated aid might err increased trust, thereby increasing automation reliance. Unfortunately, this appeared to operate independently of the automated aid's relative ability. Even among participants who were told that the aid made twice as many errors as they had made in the previous 200 trials, provision of a rationale regarding why the aid might err increased trust and reliance in 100 future trials.

Clearly, trust is an important factor in understanding automation reliance decisions. Generalizing from these studies, observing an automated decision aid make errors leads to distrust of the automated decision aid, unless an explanation is provided explaining why the aid might err. Knowing why the aid might err increases trust in the decision aid and increases automation reliance, even when this trust is not warranted.

Based on these studies, what recommendations do we have for system designers and human operators? Realize that human operators may be positively biased toward the automated decision aid. This bias may be due to prior information about the aid or previous experiences with other aids. A high level of trust may be dangerous as it could lead the operator to overcompensate if he or she notices the aid make errors. Inflation of reliability estimates should be avoided. Operators' a priori trust in the aid should be probed, if possible, and used in the design of training programs.

Ideally, training should include instruction on how the aid operates and experience using the aid. Both can play a role in producing an appropriate level of trust in the aid. Without appropriate instruction, experience with the aid can quickly lead to distrust (and disuse) if the aid malfunctions in a way that the operator is unable to explain. Though it is unlikely these conditions could be met, this problem may be alleviated by providing operators with continuous feedback of their and their aid's performance and preventing them from noticing errors made by the aid.

More realistically, instruction may be used to moderate the effects of experience with the aid. Simply providing reasons why the aid might err, however, is not a foolproof solution. The danger is that trust and reliance may be increased to an inappropriate level, resulting in distrust (and misuse) of the aid. Comprehensive instruction on the algorithms used by the aid may be effective in explaining not only why the aid might err, but also how the aid arrives at correct decisions.

Several limitations of these studies suggest a need for future research to be conducted in this area. First, the task was very simple and artificial. Wickens (2002) has found that automation reliance is likely to be found in situations in which the automation is highly reliable and manual operation is effortful or difficult. The task used in this series of studies is simple; people performing the task without the automated decision aid were correct about 80% of the time. Reliance may be higher with a more complex task. Thus, the relationships among understanding why an automated aid might err, its reliability, trust, and automation reliance remain to be explored in more realistic environments with complex tasks. Consequences for failures were limited, whereas penalties for incorrect decisions outside the laboratory can be lethal. Future studies need to examine how trust and reliance relate under various levels of motivation.

We have focused on the human-automated dyad, yet oftentimes teams of humans are provided with one automated decision aid. The effect of one person's view of the automated aid's trustworthiness on other group members' reliance decisions needs to be explored.

In these studies, the difficulty of the slide was not related to the probability of the aid making an error. Are aids viewed as more trustworthy if their probability of error is related to the slide's difficulty? Or is trustworthiness related to the agreement of what is considered a difficult or easy slide? Because human and automated aids often process information differently, what might be considered an easy, unambiguous slide for a human decision-maker may be considered more ambiguous and difficult for the automated decision aid. The greater this difference, the less trustworthy the automated aid may be perceived to be.

Individual differences in trust in automation and automation reliance should be further explored. Lee and Moray (1992, 1994) found strong individual differences in automation use with a paradigm in which participants could allocate three tasks to manual operation or to an automated system and could change their allocations easily anytime they wanted. However, participants rarely changed their allocation strategy. Some participants were prone to use manual control; others were prone to use automation. Similarly, Riley (1996; Study 1) found students favored manual operation over automation control even when doing so was clearly not an optimal strategy. Moreover, Riley (1994) found consistent differences in reliance strategies between students and pilots with a task bearing no similarity to aviation. Singh et al. (1993) created a survey to measure a human operator's tendency toward compliance (or misuse). Although not designed to be used with decision aids, it may be able to identify people who are most likely to overly trust an automated decision aid.

Finally, various operational definitions of trust and automation reliance need to be examined. Taking Wickens and Hoolands, (2000) lead, we made a distinction between automation trust and automation reliance. Automation reliance was measured by examining self-reliance and automation-reliance decisions (in Study 2) and performance data (in Study 3); trust was measured with a single item self-report scale administered to participants *after* their automation reliance decisions had been made. In order to understand the relationship between automation reliability, trust in automation, and automation reliance, valid and reliable self-report measures of trust need to be developed (e.g., Jian et al., 2000).

In conclusion, optimizing the performance of the automated aid will not be successful in optimizing human–computer team performance. Understanding the processes that humans use to determine whether or not to depend on their automated aids will help to improve performance of the human-computer team. Our studies focused on the effect of trust on these automation reliance decisions. Clearly, additional research is needed to understand and improve these special teams.

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