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The effects of errors on system trust, self-confidence, and the allocation of control in route planning

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Abstract

The concept of trust is believed by some to compensate for feelings of uncertainty. Therefore, trust is considered to be crucial in people's decision to rely on a complex automated system to perform tasks for them. This experiment aimed to study the effects of errors on control allocation, and the mediating role of trust and self-confidence in the domain of route planning. Using a computer-based route planner, participants completed 10 route-planning trials in manual mode, and 10 in automatic mode, allowing participants to become equally experienced in operating both modes. During these so-called fixed trials, the numbers of errors in automatic as well as manual mode were systematically varied. Subsequently, participants completed six free trials, during which they were free to choose between modes. Our results showed that high automation error rates (AERs) decreased levels of system trust compared to low AERs. Conversely, high manual error rates (MERs) resulted in lower levels of self-confidence compared to low MERs, although to a lesser extent. Moreover, the difference between measures of trust and self-confidence proved to be highly predictive of the number of times automatic mode was selected during the six free trials. Additionally, results suggest a fundamental bias to trust one's own abilities over those of the system. Finally, evidence indicating a relationship between trust and self-confidence is discussed.

Keywords: System trust; Self confidence; Control allocation; Route planning

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1. Introduction

When computers and computer software are discussed, the issue of distrust is often raised. Apparently, people feel ill at ease using software, especially when it is intended to make decisions for them. Often, the cause seems to be a lack of knowledge about the application that causes users to feel uncertain about the outcome of the task at hand, especially when an element of risk is involved. For instance, for someone thinking about making a financial transaction on the Internet, the possibilities as to what might happen once the credit card number is entered may seem insurmountable. Third parties may get a hold of the credit card number and use it to their own advantage, money may get lost "underway", the company may have ceased to exist and, hence, may not be able to provide the required service and return the money, etc. It is not unlikely that such feelings of uncertainty may cause someone to decide not to make the transaction on the Internet.

1.1. Notions on trust

Trust is considered to be a mechanism to reduce feelings of uncertainty (Luhmann, 1979). Without trust, a person interacting with someone else would have to consider every possible positive and negative consequence of this interaction as realistic. The mechanism of trust effectively limits this number of possible consequences, allowing for a more careful investigation of a few remaining expectations, and, thus, a reduction of the user's uncertainty and perception of risk. Indeed, trust in the safety precautions provided by the e-commerce company may eliminate the perceived risk of using credit card numbers on the Internet; likewise, trust in Internet-connections may reduce uncertainty about money digitally changing hand. As a result, the user may decide to purchase an item by Internet after all.

In addition, Luhmann (1979) argued that trust constitutes a continuous feedback loop. Specifically, the "trustor" may closely watch the trusted person's behaviour to see if the trust vested in the trustee is justified. If the trustee performs according to the trustor's expectations trust may be maintained or increased; not living up to expectations will lower trust. (see also Altman and Taylor, 1973; Kohring and Kastenholz, 2000; Rubin, 1973; cf. Strickland, 1958).

According to Coleman (1990), placing trust involves putting resources in the hands of another, who in turn will use them to his own advantage, the trustor's advantage, or both. For instance, a bank may place trust in a person getting into business and lend him or her the necessary money. The bank will expect the trustee to put that money to his advantage and make profit in business. This will allow him to pay back the loan plus interest, which constitutes the bank's benefit. In other words, if the trustee is trustworthy, then the trustor is better off. Contrarily, if the trustee is not trustworthy, the trustor is worse off by placing trust.

Furthermore, Kohring and Kastenholz (2000) argued that trust is only relevant in situations that can be characterized by a certain degree of free will in placing oneself in a situation of risk (cf. Coleman, 1990). According to them, going for a certain behavioural option in a specific situation cannot be considered an act of trust if no other options are available. For example, withdrawing money from an ATM because one needs money immediately while all banks are closed, is an act of necessity rather than an act based on trust in cash dispensers.

1.2. System trust, self-confidence and automation use

Several researchers have recognized the role of trust on automation use (Lee and Moray, 1992; Lewandowsky et al., 2000; Moray et al., 2000; Muir, 1988; Sheridan and Hennessy, 1984, among others). A user's decision to either take manual control or let a process be governed by automation depends on the amount of trust he or she has in the automated system; when trust is low, users are more likely to perform a task manually compared to when trust in automation is high. Consequently, as Muir (1987) argued, trust may be a critical factor in the design of such systems. After all, overly trusting automation (mistrust) may cause people to use it inappropriately, allowing it to perform functions that would be performed better manually. On the other hand, not trusting a system (distrust), no matter how intelligent it may be, may lead to rejection of that system, and thus its potential benefits concerning system performance will be lost (Muir, 1987; cf. Parasuraman and Riley, 1997).

In the first laboratory-based study in this field, Muir (1989) had participants operate a milk pasteurization plant, parts of which could run in both automatic and manual mode. She managed to demonstrate a strong correspondence between automation accuracy, changes in users' trust in automation and their decisions concerning the allocation of control: when automation turned faulty, both system trust and automation use diminished.

However, others have argued that the relation between trust and the willingness to rely on automation is influenced by an additional variable, namely the trust people have in their abilities to perform the task at hand themselves, labelled self-confidence (Kantowitz et al., 1997; Lee and Moray, 1992; Lee and Moray, 1994; Riley, 1996). Kantowitz et al. (1997), for example, studied the acceptance of advice from an Advanced Traveller Information System (ATIS) in route selecting tasks on the Battelle Route Guidance Simulator. While trying to find the fastest routes and avoid heavy traffic, participants could purchase ATIS information. Failure to avoid heavy traffic resulted in a reduction of the bonus that participants received each trial. In the first study reported, Kantowitz et al. (1997) found that harmful unreliable information (ATIS reported light traffic ahead, when actually heavy) decreased trust, causing self-confidence to exceed trust, but not harmless unreliable information (reported traffic was heavy, when actually light). Subsequently, they compared information reliability levels of 100%, 71%, and 43% in familiar versus unfamiliar environments. They found that driver trust in the ATIS was decreased by unreliable information, especially by 43% reliable information, but that it recovered when reliable information was received. For drivers in a familiar environment, who received information that was only 43% accurate, self-confidence was shown to exceed trust. Kantowitz et al. (1997) suggested that in situation where self-confidence exceeds trust, drivers would prefer their own solutions and ignore advice provided by the ATIS, especially when the environment is familiar.

Using a pasteurization plant similar to Muir's (1989), Lee and Moray's (1994) experiments provided evidence that the occurrence of errors changes self-confidence and trust, which subsequently influences operators' control-allocating decisions. Lee and Moray (1994) concluded that people use automatic control when trust exceeds self-confidence. Contrarily, when trust in one's own abilities exceeds trust in automation, users are more likely to abstain from using automatic mode. In addition, it became evident that operators preferred either complete manual or automatic control, and displayed a reluctance to change allocation strategy, even when trust and self-confidence changed. Finally, a general predisposition for manual control became evident, indicating a possible user bias to distrust unfamiliar automation (see also Sheridan and Hennessy, 1984).

1.3. Imbalance of experiences

Although Lee and Moray's (1994) participants apparently based at least their initial control-allocating decision on which mode they trusted most, participants also displayed a reluctance to change modes, regardless of changes in trust and self-confidence levels.

A possible explanation for this phenomenon may lie in an imbalance of experiences. For instance, high system trust may have influenced participants to select automatic mode repeatedly. The experience with automatic mode thus gained may allow system trust to be built up. At the same time, however, no experience with manual mode is gained to build trust in one's own abilities on. Thus, the difference between self-confidence and system trust may increase, causing participants to become more reluctant to switch to manual mode in the trials to come. Lee and Moray (1994) did incorporate practice trials in their experiments, allowing participants to get acquainted with manual and automatic mode on 10 alternate trials in the first hour of the experiment; afterwards, however, the free trials ran for five more hours, thus outweighing the practice trials. In other words, the design of these experiments did not exclude a possible imbalance of experiences. As such, participants may have received sufficient information to allow for a sound judgement regarding one mode, but, consequently, virtually no information about the other, which may explain why participants were reluctant to change control modes.

1.4. The present study

This experiment was designed to study trust in the domain of route planning.

In this study, we consider trust to be a mental state. Specifically, based on the different notions on trust described in Section 1.2, we consider trust to be the expectation of a user about the system, that the system will perform a certain task for him or her, while the outcome of that task is uncertain, in that it can have both positive and negative consequences. In other words, an element of risk should be present.

Extending Lee and Moray's (1994) experiment, we strived to maintain a higher degree of experimental control, in order to shed more light on the previously mentioned preference of manual control over automatic control. First, participants had to complete a total of 26 route-planning trials using a computer-based program. In the first 20 trials participants familiarized themselves with both the manual and the automatic mode. During these so-called fixed trials, they encountered systematically varied numbers of errors in automatic as well as in manual mode. During the final six trials participants were free to choose modes; the number of times automatic mode was selected in these six trials constituted the main dependent variable.

One fundamental difference with previously discussed experiments is that the number of practice trials far exceeded the number of free trials. The practice trials required participants to complete 10 trials manually, and 10 automatically, ensuring that they would become equally experienced in both manual and automatic mode before they started completing the free trials. Thus, we hoped to prevent an imbalance of experiences. Additionally, automation performance was pitted against manual performance. We expected that if a fundamental preference for manual mode would manifest itself, this would become overt in the conditions where performance in manual mode matched automatic mode.

Additionally, all 26 trials required participants to stake bets on the outcome of the trial (i.e. a route turned out either faster or slower than a certain criterion); the credits accumulated over 26 trials supposedly determined the amount of money participants received in return for their participation. Not only did this introduce the necessary element of risk into the experiment, the number of credits they staked was also used as a measure of trust, either in the automated route planner or in their own route-planning abilities. No information about why a route was fast or slow was given, to ensure that participants formed expectations in the absence of sufficient information.

We expected that automation reliability during the first 20 trials would influence automation use in the final six trials. More specifically, when automation has a high failure rate, i.e. automation error rate (AER) is high compared to manual error rate (MER), people will use it to a lesser extent. Likewise, we expected that a MER that exceeds AER would increase peoples' preference of automatic mode over manual. What would happen when MER and AER are equally high, or low, was not entirely clear. As discussed in previous sections, earlier findings have indicated that participants are biased towards the use of manual mode (Lee and Moray, 1994). However, the decision to use automation in completing a route-planning task may also be influenced by the fact that using automation saves effort. In other words, because the automatic mode allows participants to come up with a route with just one click of a button, they may abstain from using the more laborious manual mode.

Furthermore, we expected the relation between error rates and control allocation to be mediated by trust: higher AER will cause a decrease in system trust, which, in turn, will influence participants to select automatic mode less often. Likewise, higher MER presumably cause a decrease in trust participants have in their own route-planning abilities, which, in turn, will cause participants to select automatic mode more often. Finally, we expect that variations in the differential variable Trust−Self-Confidence (or T−SC), obtained by subtracting trust in one's own abilities (or Self-Confidence, SC) from trust in automation (Trust, T), will correspond strongly with changes in control allocation. Specifically, when T−SC is positive, i.e. when trust exceeds self-confidence, people will choose automatic mode more often than manual mode. Contrarily, when T−SC is negative, i.e. when self-confidence exceeds trust, participants will choose manual mode more often than automatic mode.

2. Method

2.1. Participants and design

Ninety-six undergraduate students at Eindhoven University of Technology took part in this experiment in return for a payment of Dfl. 7.50 (approximately US$3). They were randomly assigned to the cells of a 2 (AER: low versus high) $\times$ 2 (MER: low versus high) between participants design.

2.2. Procedure

On arrival at the laboratory, participants were seated in separate cubicles, where the experiment was run at computers. First, all participants were instructed to carefully read the instruction before starting the route planning program. From the instruction they learned that they would participate in research concerning the way people deal with complex systems. Specifically, they would have to interact with a route planner capable of determining an optimal route by estimating the effects of a vast number of factors, ranging from simple ones, like obstructions and one-way roads, to more complex ones, such as (rush-hour) traffic patterns. Furthermore, they were told that the computer had a database at its disposal, containing route information based on the reported long-time city traffic experiences of ambulance personnel and policemen from that city. These experiences supposedly constituted a reliable set of optimal routes, against which both manually and automatically planned routes could be compared and subsequently scored. Thus, the route planning capability of both human and machine could be validated.

During the experiment, a city map was shown on the screen. Twenty-six times participants were requested to come up with the quickest possible route from a square positioned on the map, indicating a starting point, to a circle elsewhere on the map, indicating a destination. In principle, the program comprised both a manual and an automatic planning mode. The manual mode required participants to indicate the route they thought was quickest by clicking each encountered crossing between start and finish, while the automatic mode could be used to generate a route by just one push of a button (Fig. 1).

In order to allow participants to gain an equal amount of experience with both control modes, the first 20 trials were fixed. Ten of these trials (in blocks of five) had to be done manually, the other 10 were to be executed automatically. The order in which both modes were to be used was counterbalanced.

At this stage of the experiment errors were introduced. After comparison with the reported routes database mentioned earlier, manually or automatically planned

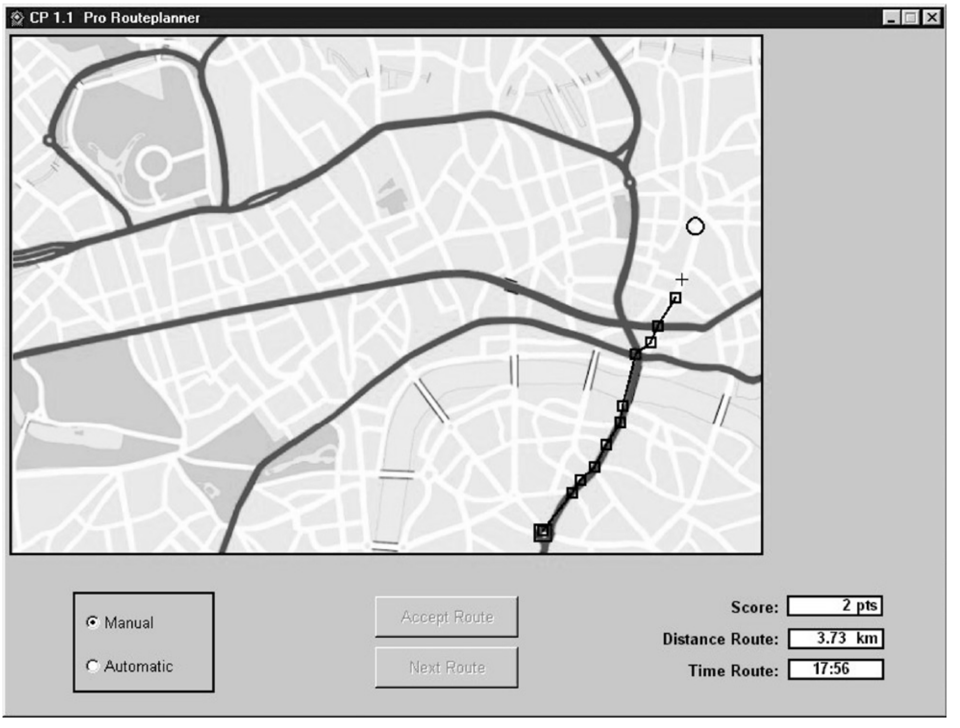

Fig. 1. Screen capture of the route planner program used in this study. Labels are translated from Dutch to English.

routes supposedly turned out as either "fast" or "slow". While in automatic mode participants in the low AER condition experienced errors (i.e. "slow" routes) at a rate of one in five trials. In the high AER condition this amounted to three errors in five trials. Likewise, participants in the low MER condition experienced one error in five manually completed trials, and three out of five in the high MER condition. Feedback regarding the quality of the routes was given after each route planning trial. In the final six trials participants could choose whether they wanted to plan routes manually or automatically. In order to create the possibility of detecting a possible recovery of participants' trust in their own or the system's route planning capability, these trials were devoid of errors, regardless of the selected control mode.

Two countermeasures were taken to discourage participants from selecting automatic mode out of mere convenience. First, care was taken to ensure that automatic routes were generated at approximately the same speed as manual routes. Thus, on average, the time needed to obtain an automatically generated route did not differ from the time it took to plan a route manually. This, we assumed, would eliminate the duration factor as an incentive to choose automatic mode. Secondly, we designed the experiment so that a certain risk was associated with control allocation. Per route planning trial, participants received 10 credits, which, either entirely or partially, could be put at stake in a bet. Directly after a route was indicated on the map and a control mode was chosen, a dialogue box would appear on the screen, asking participants to enter any number of the allotted 10 credits as stakes. When an either manually or automatically generated route, after comparison with the database with reported routes, was judged slower, participants lost the indicated number of credits; a quicker route resulted in a doubling of the indicated credits. The number of credits participants accumulated was updated after each trial, and was visible on the screen throughout the experiment. Thus, participants could accumulate credits over all 26 trials; they were told that the actual amount of money they would receive in return for participating would depend on this sum of revenues. Moreover, we assumed that the number of staked credits would prove to be an accurate measure of trust. After all, high stakes indicate equally high levels of trust that the system would not betray participants' expectations regarding its performance. Consequently, the average number of credits staked in manual trials could be considered as the trust participants have in their own route-planning abilities (SC), whereas the average number of credits staked in automatic trials could be interpreted as trust in automated route-planning (Trust, T).

After completion of all 26 route-planning trials, participants were required to rate the extent to which they trusted both the system and their own abilities (7-point scales, ranging from "very little" (1.) to "very much" (7.)). Thus, we obtained self-reports of trust and self-confidence, in addition to our behavioural measures.

Finally, participants were debriefed, thanked and paid. However, as the program gave only bogus feedback, the accumulated credits depended largely on the condition participants were assigned to. Therefore, all participants were rewarded equally with Dfl. 7.50 (approximately US$3).

3. Results

Due to counterbalancing, participants could start the 20 practice trials either with a set of five manual trials or with five automatic trials. In some of the following analyses, this variable, labelled "Order", produced significant effects on the dependent variables. Therefore, the reported results will all be corrected for order effects. The variable Order is dichotomous, as the first five trials could either be automatic (i.e. Order equals 1) or manual (Order equals 2).

3.1. Effects of manipulations on the allocation of control

The number of times automatic mode was selected during the six free trials was averaged and subjected to an analysis of variance (ANOVA). Table 1 shows these average levels of control.

As was expected, the analysis revealed a significant main effect of AER: participants who experienced a low error rate in automatic mode chose automatic mode more often than did participants in the high error rate condition, $M = 3.09$ versus $M = 1.55$, $F(1, 88) = 18.5$, $p < 0.01$. However, the main effect of MER was slighter and only marginally significant, $M = 2.00$ versus $M = 2.63$, $F(1, 88) = 3.0$,

Table 1
Number of times automation was selected (out of a total of six) as a function of error rates in manual and automatic mode

		Manual error rate					
		Low		High		Total	
		M	S.D.	*M*	S.D.	*M*	S.D.
Automation error rate	Low	2.88	1.83	3.29	2.05	3.09	1.93
	High	1.13	1.23	1.96	1.49	1.55	1.41
	Total	2.00	1.77	2.63	1.90	2.31	1.85

Table 2
Average number of credits staked in 10 automatic trials

		Manual error rate					
		Low		High		Total	
		M	S.D.	*M*	S.D.	*M*	S.D.
Automation error rate	Low	6.04	1.81	6.52	2.17	6.28	1.99
	High	4.84	1.82	5.89	1.97	5.37	1.95
	Total	5.44	1.89	6.21	2.07	5.82	2.01

$p<0.09$. The interaction between AER and MER remained non-significant, $F(1,88) = 0.37$, N.S. In addition, no significant effect of Order was found, $F(1,88) = 0.05$, N.S.

A planned comparison revealed that automatic mode was selected significantly more often in the Low AER-High MER condition than in the High AER-Low MER condition, $M = 3.29$ versus $M = 1.13$, $F(1,88) = 17.9$, $p<0.01$.

3.2. Effects of manipulations on trust and self-confidence (as indicated by staked credits)

Ten of the first 20 routes had to planned manually and another 10 automatically. During each of these trials, a variable number of credits could be staked. Averaging the number of credits staked in the automatic trials, and pitting them against the manipulations, yielded the pattern displayed in Table 2. Table 2 shows that a higher error rate in automatic route planning corresponds with a lower average number of credits staked, $M = 5.37$, versus $M = 6.28$ when AER was low. This difference proved to be significant, $F(1,88) = 5.47$, $p<0.02$. The main effect of MER was marginally significant, $F(1,88) = 3.79$, $p<0.06$. No significant main effect of Order was found, $F(1,88) = 0.01$, N.S.

A planned comparison revealed that the number of credits staked in automatic mode was significantly higher in the Low AER-High MER condition than in the High AER-Low MER condition, $M = 6.55$ versus $M = 4.84$, $F(1, 88) = 11.3$, $p < 0.01$.

Table 3 shows the pattern of results that emerged after averaging the number of credits staked in the manual trials, and pitting them against the manipulations.

As can be seen in Table 3, manipulations in MERs did not result in a difference in credits staked, $M = 6.53$ versus $M = 6.49$. Indeed, an ANOVA revealed the main effect of MER to be non-significant, $F(1, 88) = 0.003$, N.S. Not surprisingly, the main effect of AER did not reach significance either, $F(1, 88) = 0.20$, N.S. However, a marginally significant main effect of Order was found, $F(1, 88) = 2.87$, $p < 0.09$.

A planned comparison revealed that the number of credits staked in manual mode in the Low AER-High MER condition did not differ from that staked in the High AER-Low MER condition, $M = 6.18$ versus $M = 6.40$, $F(1, 88) = 0.1$, N.S.

3.3. Effects of manipulations on trust and self-confidence ratings

Table 4 shows the average ratings of system trust. As can be seen in Table 4, manipulations in MERs resulted in a slight difference in ratings of system trust. As expected, an ANOVA revealed this main effect of MER to be non-significant, $F(1, 88) = 1.29$, N.S. The main effect of AER, however, did reach significance, $F(1, 88) = 28.30$, $p < 0.01$, indicating that participants reported higher levels of trust when AER was low than when it was high. Furthermore, a significant interaction

Table 3
Average number of credits staked in 10 manual trials

		Manual error rate					
		Low		High		Total	
		M	S.D.	*M*	S.D.	*M*	S.D.
Automation error rate	Low	6.66	1.69	6.18	2.19	6.42	1.95
	High	6.40	1.49	6.81	1.59	6.61	1.54
	Total	6.53	1.58	6.49	1.92	6.51	1.75

Table 4
Average ratings of system trust scored on a seven-point scale (higher scores indicate higher levels of trust)

		Manual error rate					
		Low		High		Total	
		M	S.D.	*M*	S.D.	*M*	S.D.
Automation error rate	Low	5.00	1.56	4.58	1.35	4.79	1.46
	High	2.79	1.14	4.83	1.20	3.31	1.27
	Total	3.90	1.75	4.21	1.32	4.05	1.55

Table 5
Average ratings of self-confidence scored on a seven-point scale (higher scores indicate higher levels of self-confidence)

		Manual error rate					
		Low		High		Total	
		M	S.D.	M	S.D.	M	S.D.
Automation error rate	Low	5.37	1.06	4.46	1.72	4.92	1.49
	High	5.58	1.18	4.75	1.29	5.17	1.29
	Total	5.48	1.11	4.60	1.51	5.04	1.39

was found, $F(1,88) = 6.44$, $p < 0.02$, indicating that the effect of AER was most pronounced when MER was low. No effect of Order was found, $F(1,88) = 0.86$, N.S.

A planned comparison revealed that ratings of system trust were significantly higher in the Low AER-High MER condition than in the High AER-Low MER condition, $M = 4.58$ versus $M = 2.79$, $F(1,88) = 20.4$, $p < 0.01$.

Our two measures of system trust, i.e. the number of credits staked in automatic mode, and ratings of system trust correlated significantly, $r = 0.35$, $p < 0.01$.

Table 5 shows the ratings of self-confidence. Ratings of self-confidence were considerably higher than those of system trust ($M = 5.04$ for self-confidence, versus $M = 4.05$ for system trust), and, contrary to trust ratings, were only affected by manipulations of MERs. In the high MER condition, self-confidence ratings were lower than in the low MER condition, $F(1,88) = 9.37$, $p < 0.01$. No significant effects of AER, Order, nor an interaction between MER and AER were found, all F's < 1. A planned comparison revealed that ratings of self-confidence trust were significantly lower in the low AER–high MER condition than in the high AER–low MER condition, $M = 4.46$ versus $M = 5.58, F(1,88) = 7.56$, $p < 0.01$.

Our two measures of self-confidence, i.e. the number of credits staked in manual mode, and ratings of self-confidence correlated significantly, $r = 0.36$, $p < 0.01$.

3.4. Effects of manipulations on T−SC

The average levels of T−SC, calculated by subtracting the number of credits staked in the manual trials from those entered in the automatic trials, are shown in Table 6.

An ANOVA revealed a highly significant main effect of AER on T−SC, $F(1,88) = 15.93$, $p < 0.01$: trust in automation is higher than self-confidence when AER is low, and is lower than self-confidence when AER is high. Also, a significant main effect of MER emerged, indicating that self-confidence is highest when MER is low, $F(1,88) = 7.62$, $p < 0.01$. This time however, a significant effect of Order emerged, $F(1,88) = 5.45, p < 0.02$. T−SC was slightly lower when the first five routes had to be planned automatically, compared to when the first five trials were manual trials, $M = -1.1$ versus $M = -0.3$. Order did not interact significantly with AER or MER, $F(1,88) = 0.03$, N.S., and $F(1,88) = 0.07$, N.S., respectively.

Table 6
Average levels of T-SC across 20 fixed trials

		Manual error rate					
		Low		High		Total	
		M	S.D.	*M*	S.D.	*M*	S.D.
Automation error rate	Low	−0.62	1.13	0.34	1.71	−0.14	1.52
	High	−1.56	1.18	−0.93	1.39	−1.24	1.31
	Total	−1.09	1.24	−0.30	1.67	−0.70	1.52

Furthermore, a planned comparison revealed that T−SC was significantly higher in the Low AER-High MER condition than in the High AER-Low MER condition, $M = 0.34$ versus $M = -1.56$, $F(1,88) = 22.4$, $p < 0.01$.

3.5. Correspondence of T−SC and the allocation of control

The number of times automation was selected across six free trials was subjected to a linear regression, in which T−SC, and the order-variable were inserted as independent variables, and the level of control as dependent variable. Thus, for T−SC, the analysis yields regression coefficient $\beta = 0.41$, $t(95) = 4.12$, $p < 0.01$. For the effect of Order this amounts to $\beta = -0.06$, $t(95) = -0.65$, N.S.

3.6. The role of T−SC as mediating variable

To investigate whether the relation between error rates and control allocation is mediated by trust, or, more specifically, the differential variable T−SC, a number of regression analyses were performed, as recommended by Baron and Kenny (1986). First, regressing T−SC on AER, MER and Order yielded regression coefficients $\beta = -0.36$ for AER, $t(95) = -4.00$, $p < 0.01$, $\beta = 0.25$ for MER, $t(95) = 2.78$, $p = 0.07$, and $\beta = 0.22$ for Order, $t(95) = 2.43$, $p < 0.02$. Thus, variations in AER are shown to significantly account for variations in the presumed mediator T−SC; for MER this is only marginally significant.

Second, regressing control allocation on AER, MER and Order yielded regression coefficients $\beta = -0.42$ for AER, $t(95) = -4.49$, $p < 0.01$, $\beta = 0.17$ for MER, $t(95) = 1.81$, $p = 0.07$, and $\beta = 0.02$ for Order, $t(95) = -0.17$, N.S., establishing the effects of AER (significant) and MER (marginally significant) on control allocation.

Third, regressing control allocation on T−SC, AER, MER and Order yielded regression coefficients $\beta = -0.25$ for T−SC, $t(95) = 2.4$, $p < 0.02$, $\beta = -0.33$ for AER, $t(95) = -3.32$, $p < 0.01$, $\beta = 0.11$ for MER, $t(95) = 1.11$, N.S., and $\beta = -0.04$ for Order, $t(95) = -0.43$, N.S.

Inserting T−SC effectively lowered AER regression coefficients $\beta = -0.42$ to $\beta = -0.33$. For MER, regression coefficient were lowered from $\beta = 0.17$ to $\beta = 0.11$, while showing a significant regression coefficient of T−SC.

In sum, for AER, all conditions necessary to establish mediation of T−SC hold. However; for MER this is not the case, as a number of only marginally significant regression coefficients were found.

4. Discussion

This experiment successfully demonstrated the effects of error feedback on trust, self-confidence, and the allocation of control. First, participants who experienced a low error rate in automatic mode chose automatic mode more often than did participants in the high error rate condition. A similar effect of error rates in manual mode was observed: people displayed a tendency to abstain from use of manual mode when the MER in the fixed trials was high. Remarkably, this effect was far smaller than that of AER, and only marginally significant. Second, our results complement earlier findings by showing a strong preference for use of the manual mode; the number of times automatic mode was selected hardly ever exceeded three (out of six), even when the number of errors in automation was lower than the MER. Therefore, having eliminated the possibility of imbalanced experiences, we can conclude that our results conform to those of Lee and Moray (1994) by pointing towards a more fundamental bias to trust one's own abilities more than the abilities of a system. Apparently, this bias is strong enough to overcome participants' possible motivation to select the less laborious automatic mode.

Furthermore, we analysed the staked credits in the fixed manual and automatic trials. Manipulations of AERs did affect the number of credits that were staked in each of the fixed automatic trials: participants who had experienced a low error rate staked more credits than did those who experienced a high error rate. Rather surprisingly, manipulations in MER had a marginally significant effect on the height of the stakes in automatic mode. The stakes in the fixed manual trials, however, showed no significant influences of manual and AERs, an effect strikingly resembling the aforementioned failure to influence control allocation by means of MER manipulations. Furthermore, by subtracting our measure of trust from self-confidence, a variable was created that was hypothesized to be a good predictor for the allocation of control. Indeed, results of a regression analysis clearly indicated a rather strong correspondence between changes in this differential variable and control allocation. In addition, a strong influence of the manipulations of manual and automatic error rate on this differential variable became visible, both highly significant. Trust in automation proved to be higher than self-confidence when the AER was low, and was lower than self-confidence when the AER was high. Likewise, self-confidence was highest when the MER was low. Surprisingly, the variable trust minus self-confidence was slightly lower when the first five routes had to be planned automatically, compared to when the first five trials were manual trials. Possibly, the first five trials convinced participants that planning either manually or automatically was quite difficult. However, this first impression apparently had a stronger impact on system trust than on self-confidence.

Although our partly successful mediation analyses necessitate careful interpretation, there seems to be at least some support for our notion that the effects of our error rate manipulations at least in part follow an indirect route, i.e. via the concepts of trust and self-confidence. In other words, error feedback may influence cognitive representations, which in turn guide people's decision to either trust in the capacities of a system, or trust in one's own abilities.

Besides providing support for earlier findings under more controlled circumstances, our data also suggest these relationships to be of a more complex nature than previously believed. For instance, as mentioned before, it became clear that manipulations in MER somehow exerted an influence on trust in the automatic mode, contrary to our expectations. Being small, and only marginally significant, this effect could easily be dismissed as a random occurrence. However, an alternative explanation is available. Apparently, high MERs made participants aware that route planning in cities is indeed a precarious affair, which, in turn, may have had a negative effect on trust in the automatic mode. Our data show that participants tended to use manual mode more often than the automatic mode, suggesting higher levels of trust in themselves than in the system. Consequently, participants may have reasoned that if manually planning a route is difficult enough to result in numerous errors, it must be even less likely that the computer will come up with successful routes. Apparently, one's own performance constitutes a firm frame of reference whenever we need to assess the trustworthiness of a system.

Furthermore, manipulations of AERs did affect both control allocation as well as the number of credits that were staked in each of the fixed automatic trials. However, manipulations in MERs produced only a weak, and marginally significant effect on control allocation. In addition, the stakes in the fixed manual trials showed no significance influences of MERs whatsoever. Apparently, self-confidence is a rather robust phenomenon, in that it is less susceptible to the occurrences of errors than trust in a system. Presumably, trust in one's own route-planning abilities cannot be isolated that easily from a more overall trust in oneself. It does not seem altogether strange that trust in one's specific abilities does not simply take a nose dive whenever things go wrong, when there are multiple other activities we feel confident about performing ourselves. Consequently, strong feelings of trust in our abilities in general may patch up our damaged trust in specific abilities. Moreover, a route-planning task may call upon several different abilities that underlie the more generic concept of route-planning abilities. For instance, planning a route may invoke several basic abilities like mathematical insight, the ability to visualize and scrutinize abstract information, or even the ability to work with computers. Presumably, people invoke these basic abilities in numerous different situations, in principle allowing them to evaluate those abilities quite thoroughly. Hence, an experimenter's attempts to manipulate someone's perceived ability in any given setting may fail, simply because this perceived ability hinges on more than just their performance in that particular setting.

Another interesting explanation for the higher susceptibility of system trust to errors is suggested by Dzindolet et al. (2002). They found evidence to support their idea that a bias toward automation causes errors in automation to become more easily noted and remembered. Specifically, Dzindolet et al. (2002) suggested that users expect automated systems to be near perfect, i.e. they have a schema in which automation has an extremely low error rate. Automation errors that do occur, i.e. information contrary to the schema, are highly conspicuous, and therefore easily noticed and remembered.

We believe that the present study offers clues about the processing of information from one's own experiences that can be of interest to system designers and researchers alike. Forcing participants to use an equal number of manual and automatic trials in principle allowed them to get a good idea of system performance and manual performance. However, in real life people may not gain such balanced experiences. The bias for manual mode discussed earlier, may cause users to gain far more experience with manually planning a route, using a paper map, than with operating a route planner. As discussed in the introduction, this imbalance of experience may further reduce the chance that the user will switch from paper maps to computer-based route planning. This effect will be enhanced if the route planner has produced suboptimal results in the recent past (errors). In addition, users seem less susceptible to their own errors than for system errors. In other words, one's own suboptimal routes may easily be forgotten, whereas automatically generated routes are kept in mind for a far longer time. Thus, the system's capabilities may become highly underestimated, which will reduce a user's willingness to rely on its advice.

The opposite effect, too much trust leading to overreliance, however, has also been found (Parasuraman and Riley, 1997). Especially when automation errors are infrequent, users may initially grow to trust the system. If trust increases to excessive levels, this may cause users to rely uncritically on the system. Thus, users may become unaware of occurring errors. This effect, however, was only found in professional settings with high workload, such as airliner cockpits, and it remains to be seen whether users of everyday systems like route planners are also likely to become overreliant on automation.

In sum, system designers face a difficult task trying to facilitate appropriate automation use. However, Parasuraman and Riley (1997) may have provided them with a possible solution. They suggested that more and better knowledge of how the automation works may result in more appropriate use of automation. In other words, by allowing users to learn about the procedures used by the system, they may come to understand the system, and have more trust in its capabilities. Disuse of automation may therefore be prevented if designers of new technologies found ways to allow users a glimpse of the system's decision rules through process feedback. A certain degree of transparency could increase initial trust, causing existing and new technology to become more easily accepted and more appropriately used.

A theoretically interesting question that remains unanswered, however, is how users interact with a system with which they have had no previous experience. It is reasonable to assume that in such cases users will search for and use other sources of information. Indeed, some researchers have suggested that trust could also be based on the motives and intentions that are attributed to the designer of a system (Barber, 1983; cf. Lee and Moray, 1992; Zuboff, 1988). In addition, as Numan (1998) suggests, behaviours that may be interpreted as trusting behaviour may induce the observer to conclude that the system is trustworthy (see also Arion et al., 1994). Likewise, one could base trust upon "second-hand experiences", i.e. the experiences of others, in the form of recommendations, or reported interactions with a system. Exactly how such indirect information compares to one's own experiences in the formation of trust, or how it could be used to encourage appropriate use of automation, remains open to debate.

In conclusion, this experiment provided further support for the idea that the concepts of system trust and self-confidence are important for understanding automation use. Our results not only showed the difference between measures of trust and self-confidence to be highly predictive of control allocation, they also suggested a fundamental bias to trust one's own abilities over those of the system. Furthermore, several possible explanations concerning the observed robustness of self-confidence were discussed, as well as evidence indicating a relationship between trust and self-confidence. However, since these discussions are based on the results of a single experiment, future research is needed to corroborate and further explain these findings. Moreover, as the correct calibration of system trust is a necessity for optimizing both performance and user satisfaction, we believe that further research into other roads leading to trust, such as indirect information, is also essential.

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