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Experimental Investigation of Relationship between Complacency and Tendency to Use Automation System

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Abstract

In this study, we experimentally investigated the relationship between complacency, defined as missing automation malfunctions, anomalous conditions, or outright failures, and the human tendency to prefer either automation or manual operation. We experimented using two different tasks with human participants to evaluate their individual tendencies to lapse into complacency and to use automation. The result indicated that the participants who prefer manual operation also tend to lapse into complacency. We assume that participant vigilance against automation stability might link these two phenomena.

Keywords: Human-automation system interaction; Complacency; Automation usage; Vigilance

Introduction

Progress in technology has provided many opportunities for people to use automation systems, including on airplanes, ships, and in automobiles (Parasuraman, Molloy, & Singh, 1993; MacFadden, Giesbrecht, & Gula, 1998; Rajaonah, Tricot, Anceaux, & Millot, 2008). Parasuraman and Riley (1997) defined automation as technology that performs actions for humans. Human workload can be reduced by automation; however, the automation performance is often degraded by sudden environmental changes and automation malfunctions. Therefore, using automation is not always efficient. In using such automation, complacency is one major problem encountered by people. Complacency is defined as missing automation malfunctions, anomalous conditions, or outright failures caused by inadequate monitoring (Parasuraman & Manzey, 2010). Complacency causes fatal accidents since users do not detect or are slow to detect automation failures (Parasuraman et al., 1993).

Parasuraman and Manzey (2010) described why complacency happens. They stated that in multi-task situations where users allocate one task to automation and perform the other tasks by themselves, they need to manually conduct their tasks while monitoring the allocated automated task performance. In such situations, the manual tasks compete with the automated task for the user attention, and users tend to concentrate on their manual tasks instead of the automated task. Therefore, the frequency of monitoring automation is lowered, and users often fail or become slow to detect automation failures. Moreover, Parasuraman and Manzey (2010) showed that there are two types of complacency: fixation and attention failures. Fixation failure occurs when the automation failure is out of the users' sight. Attention failure occurs when the automation failure is within the users' sight, but out of their attention.

Many studies about complacency have experimentally investigated fixation failure with multi-task situations where the automated and manual tasks were displayed separately. The participants conducted their own manual tasks while simultaneously monitoring the automated task. Automation breakdown occurred during the experiments. When automation failure was detected, the participants had to push a particular button on their computer keyboards. Such task situations showed the following strong complacency effects: (1) when the automation capability is stable rather than variable (Parasuraman et al., 1993), (2) when the workload is high rather than low (Metzger & Parasuraman, 2005), and (3) when the arousal level is low rather than high (Singh, Molloy, & Parasuraman, 1993).

On the other hand, a few studies about complacency have experimentally investigated attention failure. Duley, Westerman, Molloy, and Parasuraman (1997) set up the same multi-task situation as in the previous studies about fixation failure, but they superimposed the automated task on the manual task on a single display. Automation breakdown also occurred during the task. In their experiment, complacency occurred on the superimposed display. They showed that even when the automated task is in the users' sight, complacency occurs because they do not focus on the automated task.

The previous studies of human-automation system interaction, which experimentally investigated the human preference to use automation or to conduct manual operation, indicated individual differences in the selection. Lee and Moray (1992, 1994) showed that users who have a tendency to use automation, i.e., automation-oriented users, tend to trust automation. Rajaonah et al. (2008) showed that manual-oriented users tend to perceive higher workload and greatly decrease their vigilance while monitoring automation more than automation-oriented users. Additionally, Maehigashi, Miwa, Terai, Kojima, and Morita (2011) showed that automation-oriented users tend to select whether to use automation or manual operation by reacting more sensitively to the changes of automation capabilities than manual-oriented users.

As indicated above, many studies have experimentally investigated the nature of human complacency in automation usage and its orientation. However, no experimental investigations have focused on the relationship between these two phenomena. In this study, we experimentally investigated the relationship between complacency and a preference of automation usage. We drew the following hypotheses:

- Hypothesis 1: A relationship exists between complacency and a preference for automation usage.

If Hypothesis 1 is supported, two detailed hypotheses are raised. Lee and Moray (1992, 1994) showed that users who tend to use automation also tend to trust it. Parasuraman and Manzey (2010) argued that overtrust in automation may lower the frequency of monitoring it, causing complacency. Therefore, it is predicted that automation-oriented users will detect automation failures more slowly than manual-oriented users. Therefore, Hypothesis 2a is as follows:

- Hypothesis 2a: Users who prefer to use automation tend to lapse into complacency.

On the other hand, Rajaonah et al. (2008) showed that users who tend to conduct manual operation tend to greatly decrease vigilance while monitoring automation more than automation-oriented users. Vigilance is the ability to sustain attention, and a lack causes complacency (Molloy & Parasuraman, 1996). Therefore, it is predicted that users who tend to conduct manual operation will tend to detect automation failures slower than automation-oriented users. Therefore, Hypothesis 2b is as follows:

- Hypothesis 2b: Users who prefer manual operation tend to become complacent.

Experimental task

We used two different experimental tasks. The first was the auto-manual selection task used by Maehigashi et al. (2011). We evaluated participant preferences to use automation based on their performances in this task, where they tracked a line that scrolls downward past a circle vehicle. When the circle vehicle veers off the line, the performance score is reduced as operational error. The participants were allowed to switch to either auto mode (operation completely performed by the program) or manual mode (operation performed by participants using left and right arrow keys) by pressing a selector on the keyboard. We manipulated the auto and manual capabilities with five levels, and the auto and manual capabilities changed independently. The participants had to compare the auto and manual capabilities to select the mode that shows higher task performance (see Maehigashi et al. (2011) for details). It is preferable to select the auto mode when the auto capability is higher and the manual mode when the manual capability is higher. However, deviation from the normative behavior is caused by the participant tendencies to use automation. We evaluated their preferences to use automation based on the percentage of using the auto mode in the auto-manual selection task.

The second was a supervisory control task (Figure 1). We evaluated participant tendencies to lapse into complacency based on their performances on a dual task shown on a single display. One was a search task in which the participants looked for target stimuli (L) among distracter stimuli (T) that scroll downward. When the target was found on the screen, the participants pressed a selector on the keyboard while the target is inside the double line (detection area) at the display's bottom. If the target is successfully detected, the color of the target letter changes to red. When the participants missed the target or gave a false alarm, the performance score was reduced as operational error. We manipulated the number of target and distracter stimuli for high and low workload conditions in the experiment.

The other supervisory control task was a monitoring one. The participants monitored an auto that operates a circle vehicle to track a line. The line scrolls downward past the circle vehicle. When the circle vehicle veers off the line, the performance score is reduced as operational error. Basically, the auto perfectly performs the line tracking. However, in specific timing, auto failures occur and the circle vehicle stops tracking the line during the task. When the participants detect the auto failures, they need to manually operate the circle vehicle by pressing the left and right arrow keys. In the supervisory control task, the participants simultaneously conducted these two search and monitoring tasks. We evaluated their tendency to become complacent based on their reactions to the auto failures.

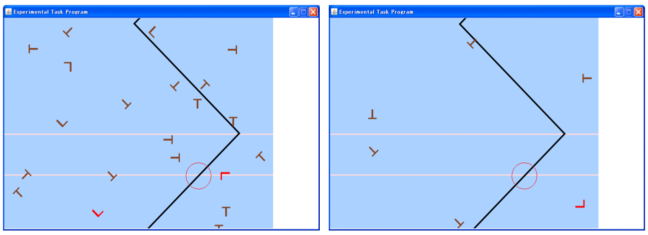

Figure 1: Supervisory control task: high (left) and low (right) workload conditions.

Experiment

Method

Participants Thirty-five university students participated in our experiment.

Factorial design In the supervisory control task, the experiment had a two-factor within participants design: (1) workload (high and low) and (2) type of failure (sudden and gradual). For the workload factor, 100 target and 400 distracter stimuli in the high workload condition and 25 target and 100 distracter stimuli in the low workload condition emerged during the task. For the type of failure factor, in the sudden failure condition, the auto that has perfectly operated the circle vehicle suddenly stops because its capability suddenly becomes 0. The breakdown continues for 10 seconds. The circle vehicle that tracks the line suddenly stops moving and immediately veers off the line. In the gradual failure condition, the auto gradually stops operating because its capability gradually decreases to 0 for 40 seconds. The breakdown continues for 10 seconds. The circle vehicle that tracks the line gradually slows down and finally veers off the line.

Procedure Prior to the supervisory control task, we conducted an auto-manual selection task whose procedure was basically the same as in Maehigashi et al. (2011). First, the participants practiced conducting the task in two training trials. Next we conducted an experimental task that consisted of 25, 40-second trials. The auto and manual capabilities randomly changed among five levels during the task. When one trial ended and another began, the display showed "capabilities changed" at the center of the screen. Throughout the experiment, the values of the auto and manual capabilities were not displayed on the screen. The participants were required to achieve as high a score as possible. They were given a five-minute break after the auto-manual selection task was completed.

After the break, we conducted the supervisory control task. In the training trials, the participants first separately practiced conducting the search and monitoring tasks and then experienced both simultaneously. Each training trial lasted one minute. After the training trials, we conducted the experimental task that consisted of two blocks of nine trials each. One block was conducted in the high workload condition and the other in the low workload condition. The order of the workload conditions was counterbalanced among the participants. The auto failures occurred three times in each block. Sudden failure occurred 40 seconds after the second trial began. Gradual failures occurred from the beginning of the fifth (or sixth) and the ninth trials. The participants were required to operate the circle vehicle manually when auto failure occurred. However, participants were not informed about either types, the frequency, or the timing of the auto failure. When the auto capability recovered after the auto failures, the display showed "capability recovered" at the center of the screen. The participants were instructed to delegate the operation back to the auto after the recovery. Throughout the experiment, the manual capability was stable and sufficient to manually track the line.

Result

Manipulation check In the auto-manual selection task, for all participants, the mean percentage of using the auto mode was 44.20%, and the mean task performance (the percentage the circle vehicle was on the line) was 75.02%. In the search task of the supervisory control task, the mean number of missed targets was 0.28 in the high workload condition and 0 in the low workload condition. The mean number of false alarms was 0.67 in the high workload condition and 0.31 in the low workload condition. Since the numbers of missed targets and false alarms were quite low, the participants conducted the search task almost perfectly. We conducted t-tests on the numbers of missed targets and false alarms in the high and low workload conditions. The number of missed targets was significantly higher in the high workload condition ($t(34) = 2.53, p < .05$), and the number of false alarms was marginally higher in the high workload condition ($t(34) = 1.77, p = .09$). These results confirmed that the workload was higher in the high workload condition than in the low workload condition.

Evaluation index We evaluated the participant preferences to use automation based on the percentage of using the auto mode in the auto-manual selection task. We evaluated the participant tendencies to lapse into complacency in the supervisory control task based on three evaluation indices: reaction time, distance, and accumulated distance. The reaction time was the time (msecs) from when the auto failure began to when the manual operation was first conducted. We utilized the time from when the auto breakdown occurred for the sudden failure and the time from when the auto capability started to decrease for the gradual failure. The distance (pixels) was measured between the circle vehicle and the line when the manual operation was first conducted during the auto failure. A distance over 30 pixels means that the circle vehicle is out of the line. The accumulated distance (pixels) is the distance accumulated from when the auto failure began through when the manual operation was first conducted. Table 1 shows the mean reaction time, the distance, and the accumulated distance for all participants in each condition of the supervisory control task.

Consistency of tendency to lapse into complacency Prior to verification of the hypotheses, we investigated the consistency of the participant tendencies to lapse into complacency. We conducted correlation analyses on the individual

Table 1: Mean reaction time, distance, and accumulated distance for all participants in each condition of supervisory control task. Values in parentheses show standard deviations.

	High workload		Low workload	
	Sudden failure	Gradual failure	Sudden failure	Gradual failure
Reaction time (msecs)	1051.74(425.16)	23350.63(9795.37)	1137.46(450.49)	24674.71(10222.56)
Distance (pixels)	19.83(7.44)	9.09(9.27)	20.96(7.75)	9.94(8.75)
Accumulated distance (pixels)	655.77(517.82)	1926.23(2165.69)	738.93(549.87)	1910.13(2025.02)

reaction times, distances, and accumulated distances across the four conditions in the supervisory control task (Table 2). The results showed similar correlations in each index. First, there were correlations between the high and low workload situations both in the sudden and gradual failure conditions. The results suggest that the participants who reacted faster to the auto failure in the high workload condition also reacted faster in the low workload condition. This consistency was observed only within the same type of auto failure. Moreover, there was a correlation between the sudden and gradual failure situations in the high workload condition, suggesting that the participants who reacted faster to the sudden failure also reacted faster to the gradual failure but only in the high workload condition.

The results of the correlation analyses in the supervisory control task showed the consistency of the participant tendencies to lapse into complacency. However, we only found consistency in the participant reactions to the different types of auto failures in the high workload condition. In the low workload condition, the number of search stimuli was low. The participants may have allocated enough attention to monitoring the auto operation to easily detect the auto failure. On the other hand, in the high workload condition, the participants probably had difficulty concentrating on the monitoring activities. Therefore, individual differences in complacency became salient only in the high workload condition.

Relationship between complacency and tendency to use auto mode To verify the hypotheses, we conducted a correlation analysis on the relationship between the individual reaction times, the distances, and the accumulated distances in the supervisory control task and the individual percentage of using the auto mode in the auto-manual selection task (Table 3). The results showed a correlation between each index in the sudden failure situation of the supervisory control task and the percentage of using the auto mode in the auto-manual selection but only in the high workload condition (Figure 2). The participants who had a tendency to conduct manual operation in the auto-manual selection task also tended to react slowly to the auto failure in the supervisory control task. The result supports Hypotheses 1 and 2b, but only in the sudden failure situations when the workload was high.

Discussion

As a result of our experiments, we found a relationship between complacency and the tendency to prefer automation or manual operation. The participants who tended to conduct manual operation in the auto-manual selection task also tended to react to the automation failure slowly: they tended to lapse into complacency. This result supported Hypotheses 1 and 2b, but only in the high workload and sudden failure condition.

For the tendency to use automation, Rajaonah et al. (2008)

Table 2: Correlation matrices that show correlations on individual reaction times, distances, and accumulated distances among four conditions. Values are correlation coefficients (r).

Reaction time

		High workload		Low workload	
		Sudden failure	Gradual failure	Sudden failure	Gradual failure
High workload	Sudden failure	1			
	Gradual failure	.54**	1		
Low workload	Sudden failure	.54**	.27	1	
	Gradual failure	-.16	.40*	.09	1

Distance

		High workload		Low workload	
		Sudden failure	Gradual failure	Sudden failure	Gradual failure
High workload	Sudden failure	1			
	Gradual failure	.48**	1		
Low workload	Sudden failure	.56**	.19	1	
	Gradual failure	-.02	.36*	.23	1

Accumulated distance

		High workload		Low workload	
		Sudden failure	Gradual failure	Sudden failure	Gradual failure
High workload	Sudden failure	1			
	Gradual failure	.50***	1		
Low workload	Sudden failure	.59**	.26	1	
	Gradual failure	.15	.55*	.29	1

$*p < .05, **p < .005, ***p < .001$

Table 3: Correlation matrices that show correlations among individual reaction times, distances, and accumulated distances in four conditions of supervisory control task and individual percentage of using auto mode in auto-manual selection task. Values are correlation coefficients (r).

		Supervisory control task High workload					
		Sudden failure			Gradual failure		
		Reaction time	Distance	Accumulated distance	Reaction time	Distance	Accumulated distance
Auto-manual selection task	Percentage of using auto mode	-.49$**$	-.50$**$	-.56$**$	-.21	-.12	-.09

		Supervisory control task Low workload					
		Sudden failure			Gradual failure		
		Reaction time	Distance	Accumulated distance	Reaction time	Distance	Accumulated distance
Auto-manual selection task	Percentage of using auto mode	-.28	-.26	-.30	.32	.26	.20

$** p < .005$

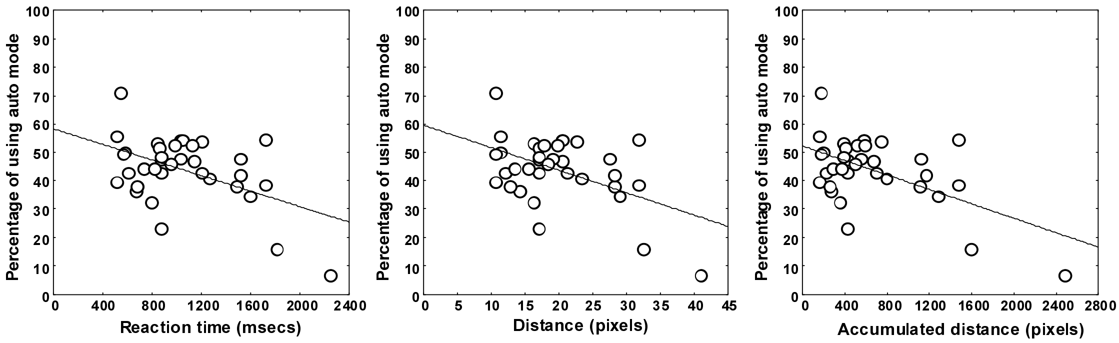

Figure 2: Correlation between individual reaction times, distances, and accumulated distances in high workload and sudden failure condition of supervisory control task (x-axis) and individual percentage of using auto mode in auto-manual selection task (y-axis).

showed that users who prefer manual operation tend to perceive higher workload and greatly decrease their vigilance while monitoring automation more than users who prefer to use automation. They discussed the possibility that manual-oriented users might try to avoid high workload and vigilance decrement without using automation. As a result, the manual-oriented participants in our study might tend not to use automation even when using it was efficient.

Next, for the effect of workload on complacency, the relation of the tendency to use automation in the auto-manual selection task and the reaction to the automation failure was detected only in the high workload condition of the supervisory control task. Molloy and Parasuraman (1996) showed that vigilance decrement is greater in the high workload condition than in the low workload condition. In our experiment's low workload condition, the number of search stimuli was relatively low so the participants could allocate enough attention to the auto operation. Therefore, the manual-oriented participants might be able to successfully manage vigilance and quickly detect automation failure. On the other hand, in the high workload condition, the vigilance decrement became greater for the manual-oriented participants, resulting in slower detection of automation failure. That is the reason that we could only detect a significant correlation in the high workload condition.

Moreover, for the effect of automation failure types on complacency, the consistency of the tendency to use automation in the auto-manual selection task and the reaction to automation failure was detected only in the sudden failure situation of the supervisory control task. Endsley (1995) stated that individual differences in situation awareness influence individual decision making and the performances of actions. Endsley (1996) also indicated a relationship between vigilance and situation awareness decrements. In our experiment, in the gradual failure situation, the circle vehicle gradually slowed down and finally veered off the line. Some participants quickly shifted to manual operation after they noticed the irregular movement of the circle vehicle. Others might continue to monitor the auto operation until just before the auto breakdown, anticipating that the circle vehicle would veer off the line after a certain amount of time. In such a situation, we assume that the participant reactions were influenced not only by individual differences in the awareness of the auto failure but also such factors as decision making strategy and action selections followed by awareness. By contrast, in the sudden failure situation, the circle vehicle suddenly stopped tracking the line and immediately veered off the line. In such a situation, the individual differences in the awareness of the auto failure directly influenced the participant reactions. As a result, there is only a relationship between the tendency to use automation and the reaction to the automation failure in the sudden failure condition.

Finally, Lee and Moray (1992, 1994) showed that users who tend to use automation tend to trust it. An overtrust in automation might lower the frequency of monitoring it and cause complacency (Parasuraman & Manzey, 2010). Therefore, we predicted that automation-oriented users would slowly detect automation failures. Contrary to our prediction, however, we found that manual-oriented users tended to slowly detect the automation failures, rejecting Hypothesis 2a. In our experiment, to evaluate the participant tendencies to lapse into complacency, we set up a situation where attention failure–not fixation failure–was induced using a superimposed display. Perhaps in such a situation, individual differences in vigilance rather than trust in automation link complacency and the tendency to use automation.

In this study, we investigated the relationship between complacency and the tendency to select whether to use automation or conduct manual operation. We evaluated complacency with a supervisory control task in which attention failure was induced. We evaluated the preference to use automation with an auto-manual selection task. Our experiment indicated that users who tend to conduct manual operation tend to lapse into complacency. However, such a relationship was found only in the high workload situation where sudden automation failure occurs. We assume that individual differences in vigilance link complacency and the tendency to use automation.

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