Delegation of a task to a partner in cooperation with a human partner and with a system partner

Akihiro Maehigashi (ak-maehigashi@kddi-research.jp)
Interaction Design Laboratory, KDDI Research, Inc., Japan

Kazuhisa Miwa (miwa@is.nagoya-u.ac.jp)
Graduate School of Informatics, Nagoya University, Japan

Kazuaki Kojima (kojima@lt-lab.teikyo-u.ac.jp)
Learning Technology Laboratory, Teikyo University, Japan

Abstract

This study investigated the delegation of tasks to a partner in cooperation with a human partner and with an automation system as a system partner. In the experiment, a line-tracing task was used, in which the performance in the task of the participants and their partners was dynamically altered at multiple levels. The participants were informed that their task partners were human (human condition) or automation system (system condition). However, in reality, all participants performed their task with an automation system. The results showed that a relationship between subjective trust in the partner and the percentage of the task delegated to the partner was found only in the system condition but not in the human condition. Moreover, sensitivity to change in the task performance of the participants and their partners was higher, and the suitability of task delegation was greater in the system condition than in the human condition. These results were discussed based on the previous studies.

Keywords: Automation system; Task delegation; Trust; Misuse; Disuse

Introduction

Cooperation with automation system

In recent years, automation systems are entering all aspects of life, technologies such as AI development. An automation system is a technology that autonomously conducts a task on behalf of human beings (Parasuraman & Riley, 1997). Currently, automation systems such as cleaning robots and automated driving systems become prevalent. In the future, many human activities are expected to be automated. Automation systems are artifacts that equip decision-making mechanisms and have autonomy. They can behave like agents that have autonomy, adaptability, sociability, and learnability (Sarter & Woods, 1997). Having progressed to this point, automation systems are different from tools that strengthen physical or cognitive functions. Human activities that are undertaken with automation systems are considered to be done in cooperation with a partner rather than with a tool (e.g., Paris, Salas, & Cannon-Bowers, 2000; Klein, Woods, Bradshaw, Hoffman, & Feltovich, 2004).

When working with an automation system, the human operator has a role of supervisory control (e.g., Lee & Moray, 1992; Lee & See, 2004; Muir, 1994; Muir & Moray, 1996). It is a matter of the greatest importance in supervisory control to monitor the task performance of a system and decide whether or not to delegate a task to it, based on which is superior in the task, the human operator or the system. Normatively, a human operator should delegate a task to the system when the system has a better performance than the operator does; however, a human operator should not delegate a task to the system and should conduct the task by him- or herself when the system has poorer performance than the operator. However, task delegation is not always decided according to superiority of performance.

Unsuitable task delegation to an automation system is called misuse or disuse (Parasuraman & Riley, 1997). Misuse is when a human operator delegates a task to a system when the system shows worse performance than the operator. By contrast, disuse occurs when a human operator does not delegate a task to a system when the system has a better performance than the operator does. For example, an automated driving system might not sense oncoming traffic or road conditions in extremely bad weather. Misuse would occur when the driver delegates driving to the automated driving in a situation where manual driving is superior. Therefore, misuse can cause fatal accidents. Contrarily, disuse happens when the driver does not delegate the driving to the automated driving system, even though the system is able to handle the situation better than the driver. Disuse could cause human excessive workload, which could lead to accidents.

As noted above, automation systems are different from classical tools that strengthen human physical functions, such as knives and hammers, and from cognitive artifacts that strengthen human cognitive functions, such as computers. In some aspects, automation systems could be considered a third generation of artifacts and new partners for human beings. Current reality dictates that it is important to know the features of cooperation with automation systems as partners and understand the difference between working with one and cooperating with a human partner.

Determinative factors for task delegation to an automation system

Because an automation system has a complex internal information process and autonomy, the operator can hardly understand how the system internally processes environmental influences and the operations of the operator (Rasmussen, 1986). The internal processes of a highly advanced automation system are all the more a black box. Therefore, it is difficult for the operator to perceive possibilities of system performance or predict system behavior.

Previous studies have shown that in cooperation with such an automation system, the operator forms trust in the system, and based on this trust, the operator decides whether or not to delegate a task to the system. Lee and See (2004) stated that trust could be defined as the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability, and the agent could be either human or automation system.

Lee and Moray (1992) investigated the relationship between trust in an automation system and task delegation to a system using a juice plant task. In this task, a juice plant was simulated on a computer. The participants were required to pasteurize the juice, deciding whether to delegate the task operation to the automation system or perform the task by themselves. During the task, the system was set up to cause a system error and not to operate normally. The participants rated their trust in the system at certain intervals during the task. The trust rating was found to decrease after the system error occurred, and the amount of delegation of the task to the system also decreased. Additionally, trust ratings gradually increased after the system restarted normal operation; with this, the percentage of the delegation of the task to the system also increased. The experimental results of this study have been confirmed elsewhere (e.g., Muir, 1994; Muir & Moray, 1996).

As shown above, the operator's trust in the system is the determinative factor for task delegation to an automation system. Therefore, when an operator overestimates system performance and overtrusts the system, misuse can occur; moreover, when the operator underestimates system performance and undertrusts the system, disuse can occur (Parasuraman & Riley, 1997).

Focus and features of this study

This study examines the features of task delegation to an automation system as a system partner compared with task delegation to a human partner. In this study, we set up a situation of cooperation with a human partner as a control condition, comparatively investigating the features of cooperation with a system partner. Previous studies that have comparatively investigated cooperation with human and system partners focused on limited activities: the reactions to the errors of the operators or their partners (Dzindolet, Pierce, Beck, & Dawe, 2002; Lewandowsky, Mundy, & Tan, 2000). By contrast, in this study, in order to understand the features of task delegation to a system partner directly, we set up a situation where the superiority relationship of the task performance of the operators and their partners was dynamically changed.

Hypothesis

In relation to the determinative factor of task delegation to a system partner, trust in the partner has been found to influence decision making for task delegation (e.g., Lee & Moray, 1992; Muir, 1994; Muir & Moray, 1996). Studies have shown that the greater the trust in a system partner is, the more likely that the task is delegated to the partner. On the other hand, in cooperation with a human partner, a person's behavior does not always correspond to trust in the human partner (Mayer, Davis, & Schoorman, 1995). People show agonistic and cooperative behaviors with respect to their human partners in spite of their degree of trust. Based on these findings, it is assumed that a relationship between trust in the partner and task delegation to that partner will appear only with system partners and not with human partners. Hypothesis 1 (H1) is as follows.

H1: A relationship between trust in a partner and task delegation to that partner appears only with system partners, not with human partners.

Moreover, studies that have investigated cooperation with a human partner and with a system partner comparatively indicate that participants' sensitivity to task execution errors of the participants and their partners was higher in with system partners than with human partners (Dzindolet et al., 2002; Lewandowsky et al., 2000). This means that participants tended to show the normative delegation to system partners; on the other hand, in cooperation with human partners, participants tended to delegate tasks to their human partners in spite of their errors; further, participants tended to perform tasks themselves even in the fact of their own errors.

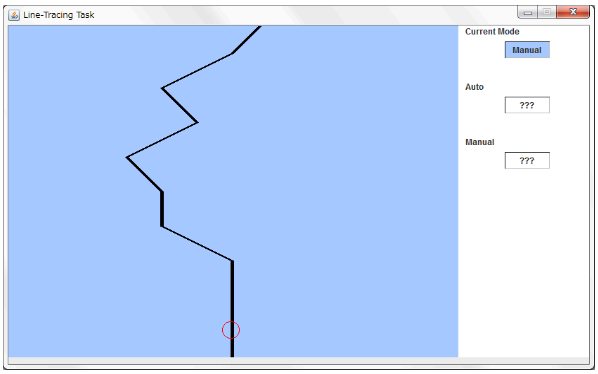
In this study, corresponding phenomena is expected to be observed even cases where a relationship of superiority in the task performance of the operators and their partners changed dynamically. In particular, the operators' sensitivity to changes in performance were higher in cooperation with system partners than with human partners; that is, the operators would have a tendency to change their decision whether or not to delegate a task to their partners according to changes in the performance of the operators and their partners in cooperation with system partners more than with human partners. Additionally, owing to high sensitivity, suitable task delegation is assumed to be higher in cooperation with system partners than with human partners. Hypothesis 2 (H2) is as follows.

H2: Sensitivity to change in the performance of operators and their partners is higher with a system partner than with a human partner. Additionally, because of high operator sensitivity to performance with regard to system partners, the suitability of task delegation is greater in cooperation with a system partner than with a human partner.

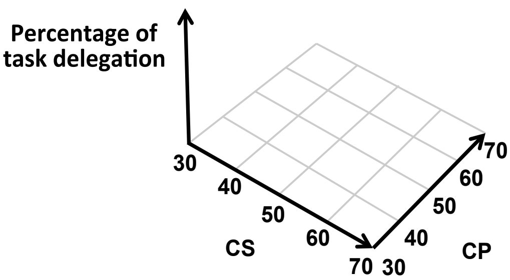
Experimental task

We used the line tracing task (Figure 1a) used in Maehigashi, Miwa, Terai, Kojima, and Morita (2011). In the task, using a circle on the screen, the participants were to trace a line that scrolls downward. When the circle veered off the line, the task score was reduced due to operational error. The participants could switch to either a partner-delegated mode (where the operation was entirely performed by the program) or self-operation mode (whether the operation was performed by participants using left and right arrow keys) by pressing a selector on the Microsoft Xbox360 controller.

In the task, to change the performance for each mode, we manipulated the capability of each mode. In particular, we set the capability of the partner operation (CP) and the capability of the self-operation (CS) at five levels each (30, 40, 50, 60, and 70). During the task, the values for the capability independently changed in each mode. The higher the values of CP and CS were, the easier the line tracing was. For example, if the values of CP and CS were 30, the straight lines could be traced, but the curve lines were traced appropriately only with difficulty. If the values were 50, gradually curving lines could be traced, but steeply curving lines could not be traced. Finally, for the values of 70, almost all lines could be traced appropriately, and almost perfect line-tracing performance could be obtained. In this task, the percentage of task delegation to a partner (the percentage of time that partner-delegated mode was used) were measured at each combination of CP and CS (Figure 1b). To maximize their task score, the participants were required to monitor the movements of the vehicle as they performed the task and when the partner did, choosing the mode that performed better.



(a) Line tracing task



(b) Combinations of CP and CS

Figure 1: (a) Line tracing task and (b) combinations of CP and CS

Experiment

Method

Participants In all, 41 university students participated in this experiment. They were randomly assigned to one of the two experimental conditions: 20 participants were assigned to the system condition, and the other 21 were assigned to the human condition.

Procedure Each experiment was conducted as a small-group experiment with a maximum of six participants. First, the participants were given instructions on the line tracing task and their task partners. In the system condition, the participants were told that their partners were automation systems. In the human condition, they were told that their partners were other participants in the room. However, in reality, all participants conducted the task with automation systems. The participants were asked to achieve as high a score as possible. After receiving an explanation of the task and the partner, the participants conducted the task with four trials as a practice. Each trial took 40 seconds. The values of CP and CS in each trial were 30 and 70, 70 and 30, 40 and 60, and 60 and 40.

After the practice, the participants performed the task in 25 trials. Each trial consisted of one of 25 combinations of 5 (CP: 30, 40, 50, 60, 70) $\times$ 5(CS: 30, 40, 50, 60, 70). The CP and CS values were given to the participants in randomized order. Each trial lasted for 40 seconds. In the experiment, the values of CP and CS were not displayed on the screen. Thus, the participants were unaware of the values. Also, when one trial ended and the next began, the display showed "Capabilities change" in the center of the screen. At the same time, the number of completed trials among the 25 trials was shown. During the task, the participants could freely switch the mode, i.e., whether the task was delegated or not.

When the partner-delegated mode was selected during the task, the display showed "Auto" in the system condition and "Follower" in the human condition. When the self-operation mode was selected, the display showed "Manual" in the system condition and "Leader" in the human condition.

After the task was performed, the participants rated their subjective trust of their partners during the task with a 7-point scale (1: Extremely untrustworthy, 2: Very untrustworthy, 3: Somewhat untrustworthy, 4: Neither trustworthy nor untrustworthy, 5: Somewhat trustworthy, 6: Very trustworthy, 7: Extremely trustworthy). Also, participants were required to give a free description of how they decided to switch modes.

Results

First, to confirm the analysis of the data, we searched for participant data in each trial 4SD above or below the mean in each condition for the percentage of task delegation (the percentage of time in partner-delegated mode), task scores, and the number of times the modes were switched. We eliminated data from one participant in the human condition, whose number of times switching modes was above 4SD from the mean. We conducted the following analyses using data from twenty participants in each condition.

To assess H1, we conducted a correlation analysis between the subjective trust ratings and the percentage of task delegation in each condition. In the system condition, there was a significant correlation ($r = .52, p < .05$). However, in the human condition, there was no significant correlation ($r = .14, p = .55$). This showed that a relationship between trust in the partner and task delegation to the partner appeared only in the cooperation with a system partner and not with a human partner. Therefore, H1 was confirmed.

Moreover, to investigate sensitivity to change in performance in H2, we fitted a logistic regression model to the average percentage of task delegation for the 25 data points for each participant in each condition (Figure 2). We used the Hosmer-Lemeshow test to assess the goodness of fit of the predicted curves to the observed data. The test was significant in neither the system ($x^2(8) = 0.27, p = 1.00$) nor the human ($x^2(8) = 1.74, p = .98$) conditions, indicating that the logistic curves described the data well. The calculated logistic regression formulas were as follows.

System condition

$$\textit{Percentage of task delegation} = 100 \times 1/(1+e^{-(0.059+0.038CP-0.046CS)}) \quad (1)$$

Human condition

$$\textit{Percentage of task delegation} = 100 \times 1/(1+e^{-(0.509+0.022CP-0.031CS)}) \quad (2)$$

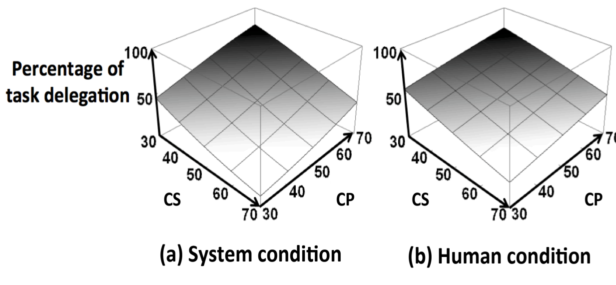


Figure 2: Predicted curve of the percentage of task delegation according to the logistic regression model in (a) the system condition and (b) the human condition.

We calculated the odds ratios for CP and CS from the logistic regression formula for each condition (Table 1). Each odds ratio represented the degree of change in the percentage of task delegation with change in CP or CS. As the odds ratio of CP or CS exceeded 1 and became larger, increase in the percentage of task delegation with increase in CP or CS was greater. Contrarily, as the odds ratio of CP or CS fell below 1 and became smaller, decrease in the percentage of task delegation with increase in CP or CS was greater.

As a result, the odds ratios for CP in the two conditions exceeded 1, and the ratio was larger in the system condition than in the human condition. This result indicated that increase in the percentage of task delegation with increase in CP was greater for the system condition than for the human condition. Moreover, the odds ratios for CS in the two conditions fell below 1, and the ratio was smaller in the system condition than in the human condition. This result showed that decrease in the percentage of task delegation with increase in CS was greater in the system condition than in the human condition.

Figure 3 displays changes in the percentage of task delegation with changes in CP and CS. It shows that changes in the percentage of task delegation were more sharply associated with both changes in CP and CS in the system condition than in the human condition. These results showed that sensitivity to change in the performance of the human operators and their partners was higher with cooperating with a system partner than with a human partner.

Table 1: Odds ratios of CP and CS for each condition

	Odds ratio of CP	Odds ratio of CS
System condition	1.038	0.954
Human condition	1.022	0.968

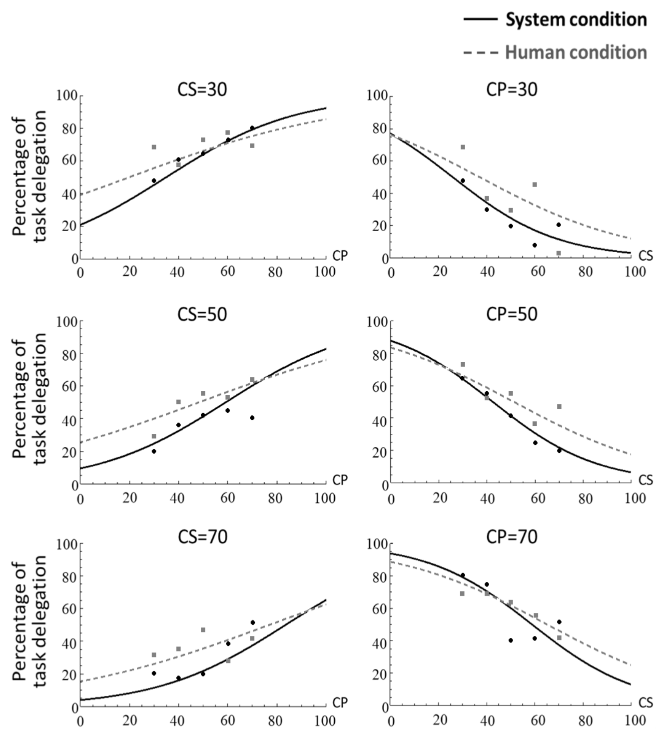


Figure 3: Cross-sectional figures of predicted curves and average percentages of task delegation for each condition. The curves represent the logistic regression curves for CS and CP (30, 50, and 70), and dots and squares represent the observed average percentages of task delegation in the system and human conditions respectively.

Finally, to investigate the suitability of the task delegation in H2, we divided the 25 data points, 5 (CP: 30, 40, 50, 60, 70) × 5(CS: 30, 40, 50, 60, 70), into 10 data points where the values of CP were greater than those of CS (partner superiority) and 10 data points where the values of CS were greater than those of CP (self-operating superiority). Suitable delegation in this task means a high percentage of task delegation for partner superiority and a low percentage of the task delegation for self-operating superiority. Task delegation to one's partner for the two different superiorities indicates different meanings. Therefore, we compared the average percentage of task delegation in the two conditions for each superiority (Figure 4).

For partner superiority, there was no significant difference in the average percentage of task delegation in the two conditions ($t(38) = 0.78, n.s.$). On the other hand, for self-operating superiority, the average percentage of task delegation was significantly lower in the system condition than in the human condition ($t(38) = 3.88, p < .001$). These results showed that the suitability of task delegation was greater in cooperation with a system partner than with a human partner.

Logistic regression analysis indicated that sensitivity to change in the performance of the participants and their partners was higher with a system partner than with a human partner. In addition, the results of an analysis of the superiority of partner-delegated and self-operating modes revealed that the suitability of the task delegation was greater with a system partner than with a human partner. Thus, H2 was confirmed.

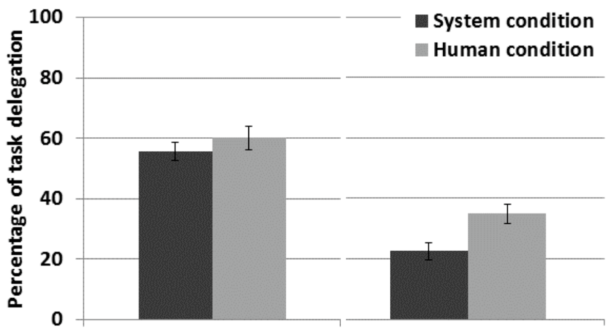


Figure 4: Percentage of task delegation in partner superiority and self-operating superiority

General discussion

In this study, to understand the features of task delegation to a system, in cooperation with a system partner, compared with task delegation to a human partner, we set up a situation where the superiority relationship of task performance between the participants and their partners was dynamically changed, investigating the task delegation to partners. As the development of automation systems progresses, it is important to compare cooperation with human partners and with automation systems as system partners.

The results revealed that a relationship between trust in a partner and task delegation to the partner appears only where there is cooperation with a system partner but not with a human partner. When working with a system partner, a human operator forms trust based on its performance and decides whether or not to delegate a task according to that trust (e.g., Lee & Moray, 1992; Muir, 1994; Muir & Moray, 1996). However, when working with a human partner, people can be cooperative without trusting each other (Mayer et al., 1995). For example, if one person is motivated to behave as his or her partner desires, the two can cooperate with each other. In cooperation with a system partner, trust in the partner is a determinative factor for the task delegation. However, in cooperation with human partners, other factors influence task delegation.

Previous studies (Dzindolet et al., 2002; Lewandowsky et al., 2000) that comparatively investigated cooperation with a human partner and with a system partner did not investigate whether there was direct relationship between trust in a partner and task delegation. This study investigated this direct relationship and indicated a difference in relationships of cooperation with a human and system partners.

Moreover, we confirmed that with a system partner, sensitivity to change in the performance of the operators and their partners was higher, and the suitability of the task delegation was greater than with a human partner; that is, in cooperation with a system partner, the participants were assumed to change their trust in the partners and decision of task delegation according to changes in the performance of the participants and their partners. On the other hand, in cooperation with a human partner, the concept of equity in effort, found in the field of social psychology, is considered a possible determinative factor for task delegation. As a result of the influence of equity in effort, sensitivity and the suitability might be lower in the human condition than in the system condition.

In cooperation with a system partner, a human operator perceives that he or she bears the ultimate responsibility of a task (e.g., Muir, 1987). However, in cooperation with a human partner, the responsibility of a task is distributed between the person and his or her partner (Darley & Latané, 1968). In cases where task responsibility is distributed, people tend to match their activities and efforts (Jackson & Harkins, 1985). An individual is sensitive to this equity in effort in human cooperation; in particular, he or she sensitively perceives whether others lower their own efforts depending on his or her efforts, in a phenomenon called the free-rider effect, and tried to avoid this type of situation (e.g., Schnake, 1991; Shepperd, 1993).

In this experiment, the participants in the human condition were considered to determine whether to delegate tasks, with the consideration of equity in effort. In other words, the participants tried to make their task execution time equal with that of their partners. In particular, they might have adjusted their task execution time within self-operating superiority; as a result, they reduced the overall sensitivity to change in the performance and the suitability of the task delegation especially in a situation where the participants performed better in cooperation with a human partner.

In fact, the average percentage of task delegation at all the 25 data points in the human condition ($M = 50.82, SD = 7.48$) settled around 50%. Additionally, after the task, the participants were required to explain in a free description how they decided to switch the modes. Three participants in the human condition clearly stated that they tried to make their task execution time equal to that of their partners. No participant wrote about such equality or equity in system condition. These additional results support the possibility that the participants in the human condition performed their tasks with due consideration of equity in effort.

Further, separately from the hypotheses in this study, there was a difference in the average percentage of task delegation among the 25 data points between the system and human conditions. The average percentage of task delegation was significantly lower in the system condition ($M = 42.48, SD = 16.03$) than in the human condition ($M = 50.82, SD = 7.48$) ($t(38) = 2.11, p < .05$). We discuss this difference below. Previous research (Dzindolet et al., 2002) that comparatively investigated cooperation with human and system partners has shown that people act with the formula that automation systems are always perfect, called the perfect-automation schema. Therefore, if an automation system causes errors, even if the errors are only slight, people greatly reduce their trust in the given system and tend not to delegate tasks to it.

In this study, the capability of the partner operation was manipulated to alter at multiple levels. Consequently, in many situations, the system partner did not perform perfectly. As a result, the participants in the system condition might have lowered their trust in the system partner and tended not to delegate tasks to it, even when it performed better than the participants. The subjective trust rating after the completion of the task was significantly lower in the system condition ($M = 4.90, SD = 1.12$) than in the human condition ($M = 6.00, SD = 0.97$) ($t(38) = 3.32, p < .01$). This result supports the possibility that the participants lowered their trust in the automation system and their likelihood of delegating the task to it, because of the influence of the perfect automation schema.

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References

Darley, J., & Latané, B. (1968). Bystander intervention in emergencies: Diffusion of responsibility. *Journal of Personality and Social Psychology*, *8*, 377–383.

Dzindolet, M. T., Pierce, L. G., Beck, H. P., & Dawe, L. A. (2002). The perceived utility of human and automated aids in a visual detection task. *Human Factors*, *44*, 79–94.

Jackson, J. M., & Harkins, S. G. (1985). Equity in effort: An explanation of the social loafing effect. *Journal of Personality and Social Psychology*, *49*, 1199–1206.

Klein, G., Woods, D. D., Bradshaw, J. M., Hoffman, R. R., & Feltovich, P. J. (2004). Ten challenges for making automation a "team player" in joint human-agent activity. *IEEE Intelligent Systems*, *19*, 91–95.

Lee, J. D., & Moray, N. (1992). Trust, control strategies and allocation of function in human-machine systems. *Ergonomics*, *35*, 1243–1270.

Lee, J. D., & See, A. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors*, *46*, 50–80.

Lewandowsky, S., Mundy, M., & Tan, G. P. A. (2000). The dynamics of trust: Comparing humans to automation. *Journal of Experimental Psychology: Applied*, *6*, 104–123.

Maehigashi, A., Miwa, K., Terai, H., Kojima, K., & Morita, J. (2011). Selection strategy of effort control: allocation of function to manual operator or automation system. In L. Carlson, C. Hoelscher, & T. Shipley (Eds.), *Proceedings of the 33rd annual conference of the cognitive science society* (pp. 1977–1982). Austin, TX: Cognitive Science Society.

Mayer, C., Davis, J. H., & Schoorman, F. D. (1995). An integrative model of organizational trust. *The ACPdemy of Management Review*, *20*, 709–734.

Muir, B. M. (1987). Trust between humans and machines, and the design of decision aids. *International Journal of Man-Machine Studies*, *27*, 527–539.

Muir, B. M. (1994). Trust in automation: Part i. theoretical issues in the study of trust and human intervention in automated systems. *Ergonomics*, *37*, 1905–1922.

Muir, B. M., & Moray, N. (1996). Trust in automation: Part ii. experimental studies of trust and human intervention in a process control simulation. *Ergonomics*, *39*, 429–460.

Parasuraman, R., & Manzey, D. H. (2010). Complacency and bias in human use of automation: an attentional integration. *Human Factors*, *52*, 381–410.

Parasuraman, R., & Riley, V. (1997). Humans and automation: use, misuse, disuse, abuse. *Human Factors*, *39*, 230–253.

Paris, C. R., Salas, E., & Cannon-Bowers, J. A. (2000). Teamwork in multi-person systems: A review and analysis. *Ergonomics*, *43*, 1052–1075.

Rasmussen, J. (1986). *Information processing and human-machine interaction: An approach to cognitive engineering*. New York, NY: Elsevier Science Publishing.

Sarter, N. B., & Woods, D. D. (1997). Team play with a powerful and independent agent: Operational experiences and automation surprises on the airbus a-320. *Human Factors*, *39*, 553–569.

Schnake, M. E. (1991). Equity in effort: The "sucker effect" in co-acting groups. *Journal of Management*, *17*, 41–55.

Shepperd, J. A. (1993). Productivity loss in performance groups: A motivation analysis. *Psychological Bulletin*, *113*, 67–81.