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The Effect of Time Delay on Emotion, Arousal, and Satisfaction in Human-Robot Interaction

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This study investigates the influence of time delay on user emotion, arousal, and satisfaction in human-robot interaction (HRI). Time delay is a gap between an input from a user and the corresponding feedback response from the system, and its negative consequence on performance has been documented in various areas including psychology and HRI. On the contrary, the effects of time delay on user emotion and satisfaction have been difficult to establish due to the fluctuations in the emotional aspect of the physiological state of the user. In this study, the hypothesis of whether time delay during robot vehicle operation increases user arousal and negative emotions while lowering user satisfaction was tested. Participants were asked to remote-control a robot vehicle to navigate different mazes in a remote location. Time delay was manipulated by introducing lags into system feedback. Subjective and objective measures included emotion tracking through face recognition, and electrodermal activity (EDA). User frustration, anger, and arousal increased while user satisfaction decreased. A better understanding of how time delay influences user's emotion and how change in emotion is expressed in physiological signals would be of crucial importance to designing an affect-aware robotic systems that have the ability to appropriately respond to user emotional state.

INTRODUCTION

Remote-controlled robot finds many practical applications in areas such as military bomb disposal (Drascic, Milgram, & Grodski, 1989), radioactive environments maintenance (Draper, 1993), surgery (Casals, 1998), mine detection (Nonami, Shimoi, Huang, Komizo, & Uchida, 2000), and subsea manipulation (Ridao, Carreras, Hernandez, & Palomeras, 2007). Despite technological advancements made in the responsiveness of robotic system, time delay continues to be an issue. Time delays arise during the transmission of information between a robot and a user (Prewett, Johnson, Saboe, Elliott, & Covert, 2010; Owen-Hill, Suárez-Ruiz, Ferre, & Aracil, 2014), and is a relatively common problem that arises when interacting across far distances (Corde Lane et al., 2002).

Time delay has been studied in domains ranging from the business settings to internet browsing. Delayed responses from a human being or a computer can increase user stress, aversive behavior, anxiety, impatience, and irritation (Barber & Lucas, 1983; Guynes, 1988; Kuhmann, Boucsein, Schaefer, & Alexander, 1987; Schleifer & Amick, 1989; Szameitat, Rummel, Szameitat, & Sterr, 2009). While time delay is commonly seen as a shortcoming that could be lessened by the use of improved technology, it is also regarded as an unavoidable, inherent component of teleoperation technology and HRI (Adelstein, Lee, & Ellis, 2003; Lum, Rosen, Lendvay, Sinanan, & Hannaford, 2009).

Many studies have focused on the negative consequences of system delay on HRI. However, more empirical studies of system delay on user's emotions and satisfaction are needed in order to build concrete understanding of user's emotional and arousal reactions when interacting with robots. Such an understanding would be invaluable as it would enable creating a system that could effectively assess and respond to user's emotions to ultimately yield improved human-robot joint

performance. Moreover, detecting user's conditions such as emotional state, body activation, and satisfaction are key to building affect-aware systems to mitigate user's negative states and improve interaction contentment in HRI.

Navigation of a robot vehicle in remotely located mazes was conducted to investigate the emotional, physiological, and usability effects of time delay. Time delay was manipulated by introducing lags into system feedback. The next section discusses related work in time delay issues in HRI and the ways to detect human emotion. The experiment method and results are described. The paper ends with a discussion on the effects of time delay in HRI.

RELATED WORK

Time Delay in Human-Robot Interaction

System lags have been shown to exert negative consequences on diverse aspects of human user's performance. System lags have been shown to decrease the accuracy of task completion in teleoperation of a robot arm performing a welding task (Owen-Hill et al, 2014). Control performance and accuracy in a positioning task also degraded due to system latency (Corde Lane et al., 2002). System feedback lags have led to reduced perceptual sensitivity of users in virtual environments (Ellis, Mania, Adelstein, & Hill, 2004), increased task error rate (Szameitat, Rummel, Szameitat, & Sterr, 2009), and higher user workload (Sheik-Nainar, Kaber, & Chow, 2005). Task efficiency improved when lags were eliminated (Luck, McDermott, Allender, & Russell, 2006). For example, observation sensitivity of user was poorer with system lags. It showed that time delay from interaction processing led to lower human user's ability to observe environment by using teleoperation of an unmanned ground vehicle on multiple screens (Luck, McDermott, Allender, & Russell, 2006).

Decrease in user satisfaction due to time delays can cause dissatisfied users to seek an alternative system (Hoxmeier & DiCesare 2000). Moreover, system lags cause lower satisfaction of users (Kuhnmann, 1989; Shneiderman, 1992; Hoxmeier & DiCesare 2000; Davis & Hantula, 2001).

Manipulating Emotions

Lags in system feedback have been used to induce frustration in a computer game (Klein, Moon, & Picard, 2002; Hone, 2006). Delays in acting on mouse clicks also induced frustration (Powers, Rauh, Henning, Buck, & West, 2011).

Detecting Human Emotion

Various sensors have been used to assess emotional state, including: electrodermal activity (EDA), event-related brain potentials, electroencephalography, skin conductivity (GSR), palmar sweat, heart rate, pupil diameter, muscle tension, electromyography (EMG), cortisol levels, galvanic skin response (GSR), respiration, and blood volume pulse (BVP), and video (facial expressions and gestures), (Kiesler, Zubrow, Moses, & Geller, 1985; Kramer, 1991; Wiethoff, Arnold, & Houwing, 1991; Scheirer, Fernandez, Klein, & Picard, 2002; Octavia, Raymaekers, & Coninx, 2011).

Human emotions can be characterized by arousal and valence. Arousal refers to emotional excitedness or activation, and ranges from calming or soothing to exciting or agitating. Valence refers to whether the emotional state of user is positive or negative, and ranges from highly positive to highly negative (Schlosberg, 1954; Russell, 1980; Frijda, 1986; Lang, Greenwald, Bradley, & Hamm, 1993; Kensinger, 2004). These two aspects of human emotion that can be measured (Lang, Greenwald, Bradley, & Hamm, 1993; Kim, Bang, & Kim, 2004; Nasoz, Alvarez, Lisetti, & Finkelstein, 2004; Li, & Chen, 2006). FaceReader automatically analyzes facial expressions to calculate arousal and valence. It detects 'happy' has mid-arousal and positive valence, while 'angry' has high arousal and negative valence (Loijens et al., 2012).

Facial expressions accompany muscle movements beneath the skin of the face. Since patterns of muscle activation can represent emotional states (Ekman, 1970), recording and analyzing an individual's facial expression has been widely used to assess user emotional state such as anger, happiness, sadness, surprise, dislike, fear (De Silva, Miyasato, & Nakatsu, 1997; De Silva & Ng, 2000), and disgust (Bença et al., 2009). For instance, facial electromyography (EMG) employs a sensor placed at the corrugator of the face to assess facial expression (Hazlett, 2003).

Skin conductance has been the basis of many sensor techniques, including galvanic skin response, electrodermal response, psychogalvanic reflex, skin conductance response, or skin conductance level (Conesa, 1995). For example, sweat gland activity raises skin conductance as a result of the sympathetic branch of the autonomic nervous system becoming highly aroused. Thus, GSR could be used for measuring emotional responses (Carlson, 2013).

Electrodermal activity (EDA) is defined as changes in the skin's electricity. An EDA sensor can detect autonomic changes in the electrical properties of the skin. Fluctuations

and reduction in EDA signals were observed when the subjects were reminded of negative memories (Barrowcliff, Gray, Freeman, & MacCulloch, 2004). In contrast, higher EDA signals were detected when participants were shown evocative photos (Radin, 2004). The EDA sensor may be employed to investigate implicit emotional states, which may raise conscious awareness or intention of behavior (Braithwaite, Watson, Jones, & Rowe, 2013).

Delayed response and its impact in HRI are the focus of the study described in the next section.

METHOD

Objective and Hypothesis

The objective of this study was to establish the effects of time delay on human emotion, physiological signals, and user satisfaction. Time delay of system is expected to result in increased negative emotions, increased arousal, and decreased user satisfaction for tasks of both low and high difficulty.

Participants

Power analysis was conducted by using the results of preliminary experiment in order to figure out proper number of participants for the main study. The results of power analysis suggested 20.93 as enough n size under .05 significance level with 90% power. A total of 21 university students (14 males, 7 females), with an average age of 28.3 (range: 22 – 43) participated. All subjects were experienced computer users who had been using computers on average 3.8 hours in a day. Also, all participants had normal or corrected-to-normal vision in order to exclude the possibility of diminished attention due to vision problems.

Task

Participants navigated a robot in a simple and complicated (see Figure 1). Participants were spatially separated from the maze and could only see the video from the robot's camera.

Figure 1. Silpe (left) and complicated (right) maze.

Independent Variables

The two independent variables were *Time Delay* (no time delay, time delay) and *Task Difficulty* (low, high). Time delay was manipulated via lags in the system feedback. Based on findings from a pilot study, the duration of each feedback delay varied randomly at either 2 or 3 seconds. Task difficulty was manipulated via maze complexity (see Figure 1).

Dependent Variables

The principal dependent variables were emotional state, physiological arousal, and user satisfaction. Emotional state

had both a subjective component, reported via self-assessed emotion questionnaire, and an objective component, which utilized FaceReader software that provides a distribution of 7 emotions – happy, sad, surprised, scared, disgusted, and neutral – that together equal 1. The subjective questionnaire of user emotion asked participants to rate, on a five-point Likert scale, 7 different emotions as same as FaceReader category except frustrated instead of neutral. To detect user arousal, an EDA sensor was used for detecting variation of physiological signals during the experiment. Finally, user satisfaction was measured with subjective questionnaires. Table 1 shows the measurements of dependent variables.

Table 1. Dependent variables and associated metrics.

DV	Metric	Measurement	Frequency
Emotion	Questionnaire	Likert Scale 1 – 5	After each trial
	FaceReader	Continuous Scale 0 – 1	During each trial
Arousal	EDA	Microsiemens	During each trial
Satisfaction	Questionnaire	Likert Scale 1 – 5	After each trial

Experiment Design

This was a 2 (time delay: none vs. time delay) x 2 (task difficulty: low vs. high) within-subject design. Each condition was tested twice (eight trials). Trials were counterbalanced.

Procedure

The experiment began with consent, short briefing, demographic survey, and the attachment of physiological sensors. Participants were asked to read for 15 minutes in order to collect baseline EDA data for each participant. Participants were trained on robot operation. After every trial, participants completed a questionnaire on emotion and satisfaction. A post-experiment survey gathered participant opinions and strategies.

Testing Apparatus

Figure 2 shows the robot developed by Zhong (2013). The mazes measured 8.9 feet by 8.9 feet and were made of foam board. The EDA was placed around the wrist of the non-dominant hand of users. The EDA sensor used was an Affectiva Q-sensor connected to a Dell Precision T1700 desktop PC. The robot measured 6 inch by 4 inch by 5.5 inch.

Figure 2. Robot's side and front view.

RESULTS

Shapiro-Wilk tests were used for normality; Bartlett's tests were used for homogeneity of variance. ANOVA results are reported as significant for $\alpha < .05$. Continuous measures of EDA signals were normalized by using each participant's baseline data.

Emotional State

Subjective Rating. Of the five emotions measured, only frustration and anger showed significant results. The participants' subjective rating of frustration showed that feedback delay in both simple ($M=2.98$, $SD=1.25$) and complicated maze ($M=3.19$, $SD=1.29$) was significantly ($F_{(1,19)}=30.37$, $p<.0001$) higher than no feedback delay of both simple ($M=1.95$, $SD=0.89$) and complicated maze ($M=2.50$, $SD=1.06$) (see Figure 3). The main effect of task difficulty on user frustration was also significant in time delay condition ($F_{(1,20)}=6.33$, $p<.03$). However, interaction between time delay and task difficulty was not significant.

Figure 3. Frustration (left) and anger (right) ratings on a five-point Likert Scale.

Anger showed a significant difference ($F_{(1,19)}=29.179$, $p<.0001$) with time delay, in both low ($M=2.15$, $SD=1.22$) and high task difficulty ($M=2.33$, $SD=1.26$) causing higher anger than the no time delay condition with both low ($M=1.27$, $SD=0.55$) and high task difficulty ($M=1.69$, $SD=1.05$) (see Figure 3). However, task difficulty and interaction between time delay and task difficulty were not significant.

Objective Results. Of the seven emotions classified by FaceReader, only anger was significantly ($F_{(1,20)}=5.13$, $p<.05$) affected by time delay (see Figure 4). The average intensity value of anger in time delay condition with both low ($M=0.53$, $SD=0.24$) and high task difficulty ($M=0.57$, $SD=0.29$) was higher than no time delay with both low ($M=0.41$, $SD=0.25$) and high task difficulty ($M=0.46$, $SD=0.24$). However, the task difficulty and interaction between time delay and the task difficulty were not significant.

Figure 4. Anger (left) on FaceReader and user satisfaction (right) ratings on a five-point Likert Scale.

User Satisfaction

Time delay in both simple ($M=2.39$, $SD=0.97$) and complicated maze ($M=2.09$, $SD=0.82$) was significantly ($F_{(1,19)}=98.37$, $p<.0001$) lower than no feedback delay of both

simple ($M=3.68$, $SD=0.72$) and complicated maze ($M=3.24$, $SD=0.88$) (Figure 4). The main effect of task difficulty on user satisfaction was also significant ($F_{(1,20)}=12.37$, $p<.003$) in both time delay and no time delay conditions. However, interaction between time delay and task difficulty was not significant.

Physiological signals: Electrodermal Activity

Only 16 of the 21 participants' sensor data was used due to a loss of five participants' data that were caused by a poor fixation of the sensor to the wrist which resulted in a loose connection when the participants were moving. EDA signal data were normalized to the participant's baseline data and averaged to create profiles of signals in different conditions. Figure 5 illustrates the time course of the (averaged) normalized EDA for the four conditions. The EDA signal collected showed a marked increase in the time delay over the no time delay condition, across both task difficulty conditions.

Figure 5. Average normalized change of electrodermal activity.

DISCUSSION

The results of the study show that time delay significantly influences emotional state (specifically frustration and anger), physiological arousal, and user satisfaction in robotic control task. These results held true for both low and high task difficulties. In the post-experiment questionnaires, participants reported that they felt higher frustration, anger with the time delay than no delay condition.

Among the seven emotions, only frustration and anger show significant relation to time delay. Frustration and anger have been shown to be related. Frustration is highly related to aggression (Dollard, Miller, Doob, Mowrer, & Sears, 1939; Miller, 1941; Morlan, 1949) and anger is regarded to contain higher emotional activation than frustration (Barrett, 2006; Lindquist, & Barrett, 2008). Comments from the participants included: "It is annoying," "I don't understand why it is not moving properly," "I'm almost angry."

Averaged results of normalized EDA showed different levels of arousal for four different combinations of time delay and task difficulty levels. In spite of steady occurrence of the feedback delay events throughout the trials, the EDA signals gradually decreased in low task difficulty condition after the middle of the trials. It is possible that the participants acclimatized to time delay during the trials. If this were the case, this has implication for the ability of EDA to detect arousal during long term exposure. This is an area where further work might establish relation between EDA and

emotional excitedness or activation over long periods of time. Since EDA was evaluated by looking at the entire recorded value over time in this study, future analysis will evaluate the specific EDA effects of event onset and response measures.

Successful systems support users to help maximize productivity and minimize overheads. According to DeLone and McLean (2002), one of the key measurements of system success in human-computer interaction is user satisfaction level. Likewise, user satisfaction would be a key factor to design more desirable HRI. This study shows that users were more dissatisfied with lags of system than without lags when they navigated mazes. Task difficulty was also influential factor to decrease user satisfaction.

These findings illustrate how time delay leads to negative emotions and lower user satisfaction. In the future work, combining different time delays with incremental complexity in mazes will be considered to examine the effects of time delay in various conditions. A deeper understanding of the relationship between system delays and the emotional repose can be used to inform the design affect-aware systems that adapt based on the user's emotional state. Together with the ability to detect user emotion, adaptive systems (Scherbo, Freeman, Mikulka, 2003; Feigh, Dorneich, & Hayes, 2012), could adjust its behavior to respond to negative emotions, may have the potential to enhance performance and productivity in the context of human-robot interaction.

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