RUPRECHT-KARLS-
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HEIDELBERG

International Workshop on the
Design of Dependable Critical Systems

ECOMODIS

Proceedings

of the
International Workshop on the
Design of Dependable Critical Systems
“Hardware, Software, and Human Factors
in Dependable System Design”

DDCS 2009

September 15, 2009
Hamburg, Germany

In the framework of
The 28th International Conference on
Computer Safety, Reliability and Security
SAFECOMP 2009

Edited by

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International Workshop on
the Design of Dependable Critical Systems
September 15, 2009, Hamburg, Germany

The Role of Task and Situational Characteristics on the Dependability of Human-Technology Interaction

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Abstract. While the impact of "human error" on failures of complex human-technology systems has widely been demonstrated and accepted, the relevance of situational and task-related characteristics on human performance has not yet been considered sufficiently. For this purpose and on the example of electrically powered wheelchair control this paper analyzes the effects of situational characteristics (e.g., turns to the left/right in the backward/forward driving mode) on the impact of fine motor abilities on human performance. A study with 23 participants is described in the paper, during which relevant data such as the subjects' precision and aiming capacity, the number of collisions caused while driving as an indicator for human performance, and the situational characteristics were measured. The data analyses demonstrate an influence of especially the number of turns driven to the right in the backward mode on the impact of the precision ability on the number of safety-critical collisions. The results highlight the necessity not only to develop a wheelchair system which is adaptable to the user's fine motor abilities, but also to the situational characteristics in order to increase the dependability of the human-technology system at hand.

Keywords: human-technology interaction, powered wheelchair control, fine motor abilities, adaptive automation systems, situational characteristics

1 Motivation and State of the Art

Statistics and analyses of failures of human-technology systems demonstrate the impact and most importantly the exponential rise of the so-called *human error*, classically categorized as either an error of commission or an error of omission. According to Hollnagel [1], the human operator contributed to about 20% of system errors in 1960. In 1990, this same percentage has risen up to 90% (cf. [2]). A number of reasons are discussed in the literature – covering the increasing complexity of the technical systems and the resulting incapability of the human operator to maintain a high level of situation/mode awareness, incorrect mental models of the technical system at hand, a loss of manual skills, etc. (cf. [3], [4], [5]).

In order to improve these statistics, the field of human reliability analyses has emerged, which first generation methods (e.g., Technique for Human Error Rate Prediction, THERP, [6]) aimed (1) at functionally decomposing human tasks, (2) at identifying performance shaping factors (e.g., cognitive abilities, fatigue, illness, experience/qualification, weather conditions, automation design), which are expected to impact the implementation of these (human) tasks, and (3) at mathematically combining this information to yield a probability number reflecting the likelihood of a human error in advance. The second generation methods criticized these first generation methods due to their roots in the field of probabilistic risk assessment, which ignored the cognitive characteristics of the human operator (cf. [7]). An example for a second generation method is the Cognitive Reliability Error Analysis Method (CREAM) ([7]), which is based on a cognitive model of human performance. Due to this theoretical foundation, the method can either be used post hoc for accident analyses, but also for a priori performance predictions, which allow developing reasoning algorithms impeding the human error by replacing the human function with appropriate automation.

2 Problem Formulation

While already the term *human error* implies that the human being itself plays a major role, it is often not considered sufficiently that human behavior is a function of the person **and** his/her environment. This is reflected in the, in the meantime, well-established behavior equation of Kurt Lewin [8]. While the "person-component" and its impact has been tested in the field of human-technology interaction (cf. [9]), the relevance especially of task and situational characteristics on the relationship between human characteristics and performance will be analyzed in this paper on the example of a safety-critical system, i.e., an electrically powered wheelchair for people with severe disabilities.

3 Solution Approach

In order to provide evidence for the impact of task and situational characteristics on the influence of human abilities on their performance, a study has been conducted, which is in the following thoroughly described and discussed.

3.1 Description of the Course of the Study

In order to collect data on the occurrence of safety-critical collisions, the study's participants were first asked to drive through a standardized course with 14 sections in a realistic office environment. Therefore, an electrically powered wheelchair was used, which is commercially available from the company Otto Bock Healthcare GmbH (type B600). This wheelchair has been equipped with additional hard- and software in order to be able to record the required data, but also to provide additional assistive functionality such as collision avoidance, which has, however, for this study been switched off. The wheelchair, as it was applied here, has thoroughly been described in [10]. While driving data such as the route or the time required for reaching a defined goal position as well as the number of caused collisions, were recorded.

The course, which the participants had to drive through, was designed such that a number of supposedly critical behaviors (e.g., turning on the spot; driving around corners) were evoked in order to be able to relate such task/situational characteristics with human abilities and their performance.

In a second step, the participants' fine motor abilities were diagnosed with the "Motor Performance Test" of Neuwirth and Benesch [11], which is necessary in order to answer the stated research question.

Last, the participants were asked to fill in a biographical questionnaire assessing data for example on the age of the participants, their gender, field of study, etc.

3.2 Description of the Sample

Out of practical considerations, the convenience sample consisted of 23 students of the Universities of Heidelberg and Mannheim (Germany). The students were not disabled. In order to be able to control e.g. skill acquisition effects, the participants had unlimited time available to practice maneuvering with the wheelchair in the environment, in which the actual data recording took place.

The majority of the participants were Bachelor students enrolled in psychology (n = 20), while n = 3 were Master students in computer engineering. In addition, 12 participants were female, 11 were male.

3.3 Data Analyses

In order to relate the characteristics of each course section with the number of collisions and the participants' fine motor abilities, we first of all identified the critical situational characteristics of the course by counting especially the number of turns which needed to be driven in the forward mode to the right and to the left, the number of times, a participant had to drive straight backward, the number of times, the participant had to drive a turn to the right/left in the backward mode and the number of times the participant had to turn on the sport to the right and to the left. In order to demonstrate that there were no sincere dependencies between these variables, their correlations were calculated (see Tab. 1).

As Tab. 1 shows, these correlations vary between $r = 0.339$ ($p > 0.05$) and $r = -0.552$ ($p < 0.05$). The latter correlation is the only one, which has reached an acceptable level of significance and reflects the fact that, if a course section contained turns to the right (to be driven in the forward mode), less turns to the left (also to be driven in the forward mode) had to be made in order to achieve the current goal position. Hence, despite this correlation, there were no significant relationships between the different task characteristics in the course.

In a second step, inferential statistics were applied in order to test whether these situational characteristics have an influence on the relationship between the impact of the fine motor abilities on the number of collisions caused while driving.

For these purpose, we calculated univariate analyses of variance with the described situational characteristics as independent variables. As dependent variable, we used the impact of (1) the precision ability and (2) the aiming capacity on the number of collisions (see also [12], [13]). This impact can statistically be described as an effect size [14]. The results of the univariate analyses of variance regarding the precision ability are summarized in Tab. 2.

Table 1. Correlations between the task and situational characteristics of the course

	Number of turns to the right, forward mode	Number of turns to the left, forward mode	Backward, straight ahead	Number of turns to the right, backward mode	Number of turns to the left, backward mode	Turning on the spot to the right	Turning on the spot to the left
Number of turns to the right, forward mode	-						
Number of turns to the left, forward mode	-0.552*	-					
Backward, straight ahead	0.077	-0.439	-				
Number of turns to the right, backward mode	-0.372	0.025	0.240	-			
Number of turns to the left, backward mode	-0.025	-0.322	0.240	-0.077	-		
Turning on the spot to the right	0.057	0.339	-0.228	-0.439	-0.439	-	
Turning on the spot to the left	-0.025	0.025	0.240	-0.077	-0.077	-0.439	-

* $p < 0.05$

As Tab. 2 demonstrates, there is a highly significant effect ($F(1, 12) = 103{,}14$, $p = 0.00$, $f^2 = 0.90$) of the number of turns to the right driven in the backward mode on the impact of the precision ability on the number of collisions caused while driving. To visualize this effect, a line plot is displayed in Fig. 1, which shows that the greater the number of turns driven to the right in the backward mode, the greater the relationship between the number of caused collisions and the precision ability.

Table 2. Results of the univariate analyses of variance with the relationship between the precision ability and the number of collisions as a dependent variable

Independent Variable	Value of the test statistic *F*	Probability *p*	Effect size f^2
Number of turns to the right, forward mode	$F(1, 12) = 0.95$	0.38	0.07
Number of turns to the left, forward mode	$F(1, 12) = 0.08$	0.79	0.01
Number of times driven backward, straight ahead	$F(1, 12) = 0.21$	0.66	0.02
Number of turns to the right, backward mode	$F(1, 12) = 103.14$	0.00^{**}	0.90
Number of turns to the left, backward mode	$F(1, 12) = 0.12$	0.74	0.01
Turning to the right on the spot	$F(1, 12) = 1.89$	0.19	0.14
Turning to the left on the spot	$F(1, 12) = 0.12$	0.74	0.01

** $p < 0.01$

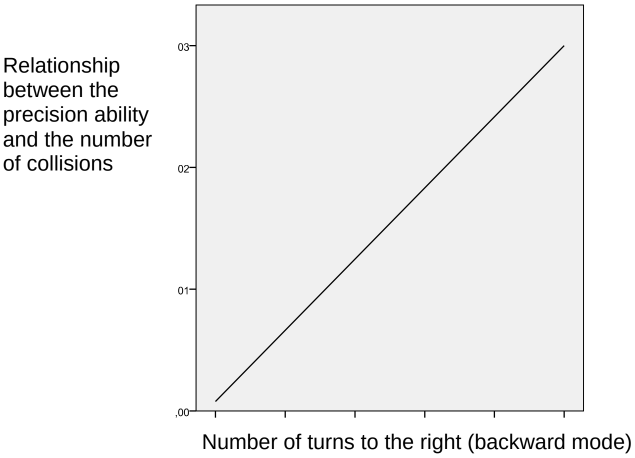

Fig. 1. Line plot of the relationship between the effect of the precision ability on the number of collisions while driving through the course and the number of turns to the right.

In a next step, we analyzed the impact of the situational characteristics of the course sections on the relationship of the aiming capacity and the number of collisions. Again, we calculated univariate analyses of variance with the situational characteristics as independent measures and the relationship (i.e., the effect sizes) between the aiming capacity and the caused collisions as a dependent variable. The results are given in Tab. 3.

As Tab. 3 demonstrates and in contrast to the results introduced before, no significant effects with $p < 0.05$ have been found. Hence, at least these results give the impression that the chosen situational characteristics do not influence the impact of the aiming capacity on the number of collisions. However, it is to be considered that the sample size was relatively small. As the effect sizes, which are also displayed in Tab. 3, demonstrate, there are effects, which partially have reached a medium-size according to Cohen [14]. Due to the low power of the study at hand, these effect sizes might not have reached an appropriate level of significance.

Table 3. Results of the univariate analyses of variance with the relationship between the aiming capacity and the number of collisions as a dependent variable

Independent Variable	Value of the test statistic F	Probability p	Effect size f^2
Number of turns to the right, forward mode	$F(1, 12) = 1.47$	0.25	0.11
Number of turns to the left, forward mode	$F(1, 12) = 1.31$	0.28	0.10
Number of times driven backward, straight ahead	$F(1, 12) = 0.92$	0.36	0.07
Number of turns to the right, backward mode	$F(1, 12) = 0.03$	0.87	0.00
Number of turns to the left, backward mode	$F(1, 12) = 0.11$	0.75	0.01
Turning to the right on the spot	$F(1, 12) = 0.44$	0.52	0.04
Turning to the left on the spot	$F(1, 12) = 0.11$	0.75	0.01

4 Discussion, Conclusions, and Future Work

Summarizing, this paper introduces the necessity to consider not only the characteristics of the human operator/user, but also task- and situation-related factors, which influence the relationship between the human operator and his/her performance. In order to demonstrate this relationship, a study has been conducted, during which participants drove through a course with an electrically powered wheelchair being one example of a safety-critical system. The course was defined such that a number of presumably critical situations occurred. The participants' collisions with objects in the environment were measured. In addition, the participants' fine motor skills were administered. In order to answer the stated research question, inferential statistics with the resulting data set were applied. More specifically, univariate analyses of variance demonstrated that the characteristics of the course sections impact the relationship between the precision ability and the number of collisions while driving: The turns which needed to be driven in a backward mode to the right side require a higher level of precision in order to avoid collisions when compared to turns which need to be driven to the left. Other effects have not reached an appropriate level of significance. This could be due to the low sample size, the inexistence of this effect or a high correlation between the situational characteristics. However, the latter reason can be rejected, as the analysis of the correlational patterns has shown that only minor relationships existed between the occurrences of situational characteristics.

In a next step, it will be aimed at collecting additional data in order to check whether the in this study insignificant medium-sized effects actually exist. In the long run, methods will be developed, which enable a complex computer system to judge on the complexity of a future action and change its level of autonomy accordingly, such that the dependability of safety-critical human-technology systems increases.

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