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The Impact of Individual Differences in Fine Motor Abilities on Wheelchair Control Behavior and Especially on Safety-Critical Collisions with Objects in the Surroundings

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Abstract. In order to significantly reduce the number of safety-critical collisions of wheelchair users with objects spread in their environment, a study has been conducted which relates wheelchair user's fine motor abilities with the collisions while driving through a standardized course in a realistic office environment. The conducted inferential statistics demonstrate that especially the participants' aiming capacity can significantly predict the collisions occurring while driving through the course. A graphical and qualitative analysis of these effects demonstrates in addition that specific maneuvering tasks influence this relationship and that especially driving next to an object without colliding requires a high level of aiming capacity. The results demonstrate the need to develop a wheelchair system which adapts its assistive functionality to the aiming capacity and the difficulty of the maneuvering task in order to provide as much help as necessary without risking the degradation of the wheelchair user's skills.

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

1 Motivation and State of the Art

The major goal of assistive technologies is to significantly ease the lives of those with sincere disabilities or serious impairments when executing activities of daily living. An example for such an assistive technology is an electrically powered wheelchair, which enables a mobility-impaired user to move freely and to a large degree independently. As a number of evaluations (see e.g., [1]; [2]; [3]; [4]; [5]) has demonstrated, this ambitious goal of easing the lives of those in need has not yet fully been achieved: While qualitative evaluations ([1]; [2]; [3]; [4]) demonstrated that long, tedious, and sometimes even unsuccessful training periods are required in order to use such an assistive device efficiently and effectively in everyday life; quantitative evaluations ([5]) showed that these (negative) effects can be traced back 1. to the number of input commands which are required in order to execute a given behavior, 2. to the space necessary for realizing special maneuvering tasks, and 3. to the time it takes to actually reach the desired goal position. These statistics are even more sincere considering the number of accidents of wheelchair users occurring, e.g. when driving backwards without noticing a staircase behind them going down.

A number of wheelchair assistance systems have been developed in the past, which aim at improving today’s technology for example by providing intention estimation behaviors and implementing methods developed in the field of robotics in order to automate as much as possible of the steering task (see e.g., [6]; [7]; [8]). This approach of easing the lives of those in need by taking over a great amount of the physical and cognitive work to actually control the assistive device is, however, criticized by physicians and nurses. The latter promote the concept that the assistance should only de-burden the persons with disabilities from those tasks, which cannot be achieved in their current condition, as otherwise the remaining skills and abilities deteriorate. Hence, as much support as necessary should be provided, not as much support as possible. In order to realize this vision, the development of an adaptive wheelchair system has been promoted (see e.g., [9]), which actually recognizes the current ability level of its user, derives an appropriate assistance level and actually uses this assistance level to support the user with disabilities as much as necessary such that on the one hand the remaining skills do not deteriorate and on the other hand the lives of those in need are eased and enhanced.

2 Problem Statement

In order to be able to actually realize such an adaptive wheelchair system, the current state of the art lacks a linkage between the ability profile of a wheelchair user and the occurrence of safety-critical situations.

3 Solution Approach

In order to fill this gap, a study was conducted, which is thoroughly described in the following sections.

3.1 Description of the Study

In order to relate the ability profile of a wheelchair user with the occurrence of safety-critical situations, 23 wheelchair users were asked to drive through a standardized course in a realistic office environment (for a floor plan, see Fig. 1). Within this office environment, five goal positions were identified and the participants were asked to drive from one of these five goal positions to the next. With repetitions, 14 goals had to be reached (for a detailed description of the course, see [10]). These course sections were defined such that reaching them required the participants to execute for wheelchair users difficult but also typical behaviors (such as e.g., turning on the spot, see [11]).

The wheelchair which was used for data collection is a powered wheelchair from Otto Bock Healthcare GmbH (type B600), which is thoroughly described in [12]. This wheelchair was equipped

- with a control PC, which was mounted underneath the seat of the wheelchair and used to record data (e.g. on the route taken during the course),
- a touchscreen for human-machine communication, which was, however, switched off in this study,
- a set of ultrasonic sensors, which can be used for realizing a collision avoidance behavior (see [12]) and which were also switched off,
- and a head-mounted eye- and headtracking system, which can be used to realize a gaze-based intention estimation behavior [12].

While driving, it was recorded for each of the 14 sections of the course and the complete course, whether and how often the participants hit objects such as tables spread in the environment. In addition, the participants' fine motor abilities were administered with the Motor Performance Test [13]. More specifically, data on the participants' tremor, their aiming ability, their wrist-finger speed, and their arm-hand velocity was collected on a number of standardized fine motor tasks. In addition, the participants filled in a biographical questionnaire to control additional variance of the dependent measures. This data covered e.g. the participants' gender, age, profession, experience in driving, etc.

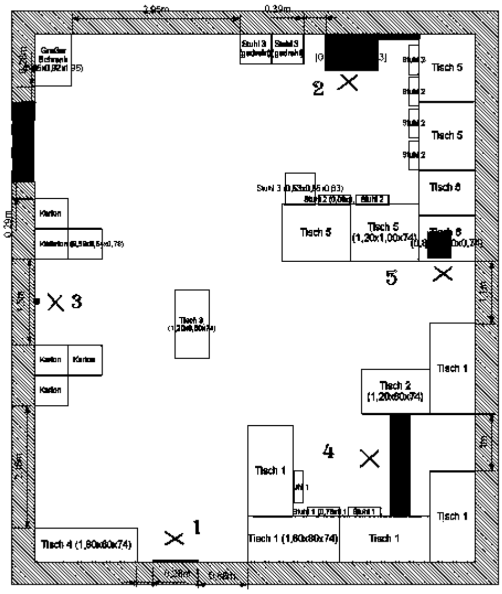

Fig. 1. Floor plan of the room in which the study took place – the crosses and the numbers inserted in the floor plan refer to the goal positions, which had to be reached by the participants.

Before the participants drove through the course, they were given unlimited time to practice with the wheelchair in the same environment in which the course was set up. This procedure was taken in order to ensure that no skill acquisition effects influenced the data, as the participants were healthy individuals and have never been sitting in a wheelchair before in their lives. It was decided to work with healthy individuals due to practical considerations.

The sample consisted of 23 students of the Universities of Mannheim and Heidelberg (Germany). Most of them (n = 20) were Bachelor students of psychology; the minority were Master's students (n = 3) of computer engineering. The sample's average age was 23.1 years. 48% of the sample was male; 52% were female.

3.2 Data Analyses

After analyzing the descriptive statistics, inferential statistics were applied in order to relate the participants' fine motor abilities with the number of collisions when driving through the 14 sections of the course.

In a first step, univariate analyses of variance were conducted with the total number of collisions during the complete course as a dependent variable, the fine motor abilities of the participants as independent variables and variables such as the participants' gender as control variables. The analyses testing the relationship between (1) the tremor, the precision, the arm-hand velocity and the hand-finger speed and (2) the number of collisions were not significant. Significant results (see Tab. 1) were, however, found for the relationship between the results of the aiming capacity test and the number of collisions during the complete course:

- As Tab. 1 demonstrates, the time required to complete the aiming capacity task was a significant predictor ($F(1, 2) = 4.56$, $p < 0.05$, $f^2 = 0.19$) of the number of collisions caused while driving. As the reported statistics demonstrate, the effect is a large one according to the classification of Cohen [14]. As the positive correlation of $r = 0.26$ ($p < 0.05$) between the two variables demonstrates, the relationship is such that the greater the time required to complete the aiming capacity task, the more collisions occur.
- The other independent variables (i.e. the number of mistakes, the number of hits, and the duration of mistakes when completing the aiming capacity task) do not have a significant impact on the dependent variable ($p > .05$).

Table 1. Results of the univariate analyses of variance

Independent Variable	Value of the test statistic F	Probability p	Effect size f^2
aiming – number of mistakes	$F(1, 20) = 0.04$	0.71	0.01
aiming – number of hits	$F(1, 18) = 2.41$	0.14	0.12
aiming – duration of mistakes	$F(1, 21) = 0.06$	0.80	0.00
aiming – total duration	$F(1, 20) = 4.56$	0.04^{*}	0.19

* p < .05

In a second step, general linear model analyses with repeated measurements were calculated using the number of collisions in each section as dependent variables, the fine motor abilities as independent, and variables describing additional information about the participants as control variables. In parallel to the results reported for the univariate analyses of variance, significant relationships were found mainly for the variables measured during the aiming capacity task. These significant effects are twoway interaction effects between the repeated measurement factor (i.e., the number of collisions per course section) and the aiming capacity measure (i.e., number of mistakes, number of hits, duration of mistakes, total duration). More specifically, the following significant effects ($p < .05$) have been found (see also Tab. 2):

- The interaction between the repeated measurement effect and the number of hits explains a significant proportion of the dependent variable's variance with $F(13, 260) = 3.20$ ($p < .01$). Following Cohen's [14] convention, this effect size is large with $f^2 = 0.14$.
- The interaction effect between the repeated measurement effect and the duration of mistakes is significant with $F(13, 247) = 2.08$ ($p < .05$). In contrast to the previous effect, this effect can be considered medium-sized [14].
- Last, the interaction effect between repeated measurement effect and the total duration of the task is significant with $F(13, 247) = 2.63$ ($p < .01$). This effect is also a large effect ($f^2 = 0.12$).

Table 2. Results of the general linear model analyses

Independent Variable	Value of the test statistic F	Probability p	Effect size f^2
Aiming – number of mistakes	$F(13, 247) = 1.67$	0.07	0.08
Aiming – number of hits	$F(13, 260) = 3.20$	0.00^{**}	0.14
Aiming – duration of mistakes	$F(13, 247) = 2.08$	0.02^{*}	0.10
Aiming – total duration	$F(13, 247) = 2.63$	0.00^{**}	0.12

* p < .05; ** p < .01.

In order to further analyze these effects, line plots were generated which are displayed in Figure 2.

These line plots first of all illustrate that the significant effects are mainly due to four sections of the course, which are Sections 2, 4, 7, and 14. These sections cover driving from Goal Position 4 to Goal Position 2; from Goal Position 5 to Goal Position 2; from Goal Position 3 to Goal Position 1 and from Goal Position 4 to Goal Position 1 (see Fig. 1). There is one criteria, which all of these course sections have in common, i.e., the goal position can only be reached if the participants drive next to an object: For Goal Position 2, the participants were asked to drive next to a cupboard such that they could withdraw a paper from it; for Goal Position 1 the participants were asked to drive next to a table. Hence, at least from this qualitative analysis of these course sections, it can be assumed that driving next to an object requires aiming capacity.

Second, the relationship between the performance in the aiming capacity tasks and the collisions was analyzed on the basis of these line plots. As the line plots demonstrate, the persons with worse aiming capacity performance collided more often in a course section, if they collided, when compared to those with better aiming capacity performance. In addition, the participants with greater aiming capacity performance measures collided less often within one course section; however, their probability of colliding overall sections was increased.

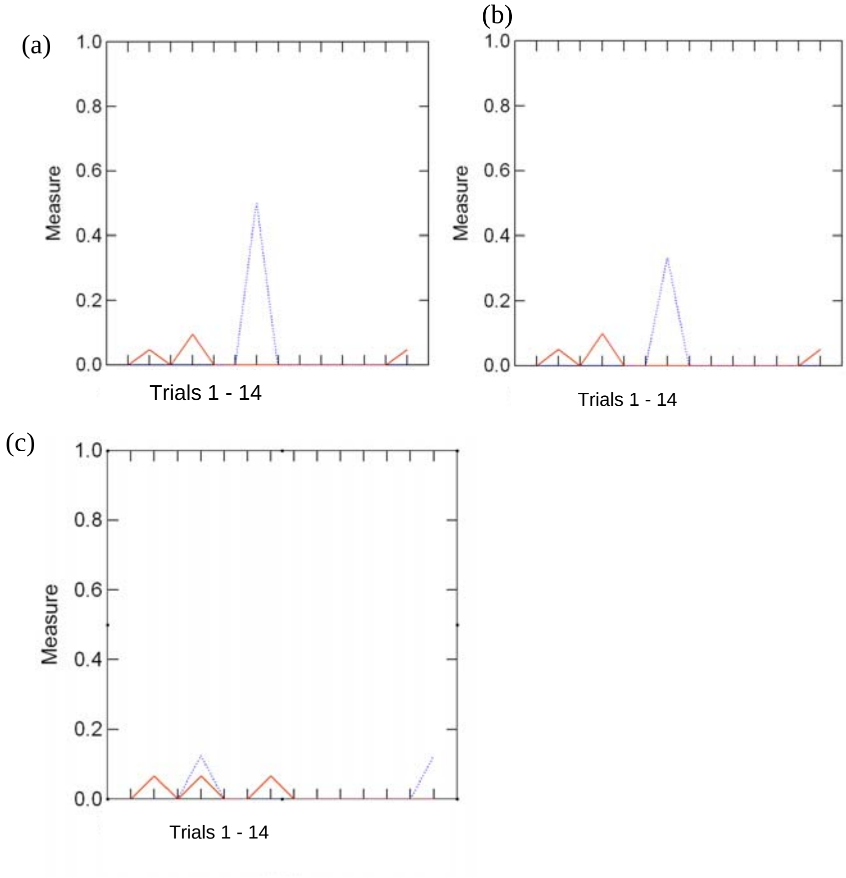

Fig. 1. (a) Line plot showing the number of collisions overall 14 course sections for those participants with an optimal number of hits (drawn-through line) and a worse number of hits (dotted line). (b) Line plot showing the number of collisions overall 14 course sections for the participants with greater durations of the mistakes (dotted line) and lower durations of the mistakes (drawn-through line). (c) Line plot showing the number of collisions during the 14 sections for those participants with a greater total duration of the aiming capacity task (drawn-through line) and smaller total durations (dotted line).

3 Discussion, Conclusions, and Future Work

It was the goal of this paper to demonstrate the relationship between the occurrence of safety-critical situations (i.e., collisions) and the fine motor abilities of wheelchair users. For this purpose, a study has been conducted, which is described in this paper, during which participants drove through a standardized course. Their collisions with objects in the environment were measured, as was their fine motor abilities.

The results of univariate analyses of variance and general linear model analyses demonstrate 1. a relationship especially between the aiming capacity performance measures of the participants and the number of collisions happening while driving through the complete course and 2. an interaction of this effect with the different sections of the course implying that there are maneuvering tasks, which require a higher level of aiming capacity than other maneuvering tasks. On the basis of graphical, qualitative analyses of line plots for participants with greater/lower aiming capacity performance measures and their collisions per course section, it was demonstrated that, on the one hand, participants with lower performance measures had an increased collision probability for some course sections requiring them especially to drive next to an object in their environment but a decreased collision probability for the complete course. On the other hand, the participants with greater aiming capacities collided less often during these risky sections, but had an increased risk of colliding during the complete course.

These results show that it is actually necessary to adapt the assistive functionality of a powered wheelchair system to the fine motor abilities (and especially the aiming capacity) of their users to successfully decrease the number of collisions with objects spread in the environment and to adapt the assistive functionality to the degree of difficulty of special maneuvering tasks in everyday behavior. As a next step, a cognitive model will be developed and implemented, which allows a wheelchair system to assess the aiming capacity level of its user and to adapt its assistive functionality accordingly (for a description of the methodology therefore, see for example [15].

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