Assessment of the Human-Machine Association on a Smart Wheelchair

F. Leishman, V. Monfort, O. Horn and G. Bourhis [a]
[a] *Laboratoire d'Automatique humaine et de Sciences Comportementales (L.A.S.C)*
bourhis@univ-metz.fr

Abstract. In this communication, we present a method to assess a mobility assistance developed on a smart wheelchair. This assistance provides to the users a functionality of wall following, as well as a functionality of automatic passing through narrow passages, usable via a deictic interface. The aim here is to compare a semi autonomous driving and the typical manual driving with a joystick. We would like that this assessment focuses on human. To do this, we have implemented a test protocol using a dual task method which allows to measure the attentional load of subjects for each type of driving. We also carry out a finer analysis of attentional load of subjects to identify the types of actions in which it is the highest during the driving with and without assistance.

Keywords. Smart Wheelchair, Deictic control, Cognitive assessment.

Introduction

In order to give back autonomous mobility to many people that can't drive powered wheelchairs, a lot of researches on the development of smart wheelchair have emerged [1]. They provide many functionalities of mobility assistance to assist users to drive wheelchairs in hard situations at different levels of autonomy. The assessment methods of these aids are diverse. We can quantitatively assess the performance of assistance proposed by measuring the course time, the number of collisions, the distance travelled, or the errors in relation to an optimal trajectory for different driving modes (with joystick, with the autonomous or semi-autonomous driving assistance) [2], [3], [4], [5], [6]. It's also possible to measure the driver's physical or mental workload using questionnaires (TLX method [5], battery of psychological tests [4]) or perform a secondary task in parallel of the driving (solve mathematical operations while driving [2]). Finally, the cooperation between the wheelchair and its driver can be assessed, for example, by measuring the frequency of interactions with the command interface or the joystick [2], [6].

The assessment that we propose here is focused on the attentional load of the driver by using the double task method. This allows to assess his attentional alert level during driving, and therefore, assessing the effectiveness of the cooperation between user and wheelchair from the analysis of the user’s actions.

1. A driving assistance with a deictic interface

Our driving assistance is developed on a smart wheelchair prototype, the VAHM. It's a Storm3™ classical wheelchair equipped with scanning laser range finders, a camera, a laptop, and a control card (figure 1). Two functionalities are proposed, the automatic wall following and the automatic passing through narrow passages usable via a deictic interface [7]. The principle is to allow to the user to indicate its target on an interface showing an overview of the environment. The wheelchair moves then automatically until this target is reached. To do this, we use a video image from the camera to achieve the interface and the scanning lasers to locate and move the wheelchair in the environment.

The interface, composed of the overview of the environment, shows to the user highlighted elements which correspond to the actions that can achieve the wheelchair automatically. In addition, a color code is used to differentiate actions. Thus, the automatic wall following will be highlighted by two green rectangles displayed on the left and right sides of the interface (corresponding respectively to a wall on the left and on the right). The narrow passages are highlighted by blue rectangles taking their shapes on the interface. The user only has to point its target to launch the corresponding action. This allows to perform a command "I want to cross this door" with a single indication on the interface (by pointing the blue rectangle highlighting this door). Figure 2 illustrates our interface.

To specify a target, the person uses the joystick button to switch from the manual control of the wheelchair to the mode in which he controls the mouse cursor on the interface. Then, he points its target by moving the joystick and, finally, he validates by pressing again on the button. As highlighted elements on the interface are quite large, the pointing tasks with a joystick are easy to achieve. We choose this type of human-machine interface in order to control the driving assistance and the manual mode with the same organ of control, limiting thus the movements that the users must perform.

To stop the automatic functionalities, the user has two solutions. Either, he expects that it ends, or he takes back control with one action on the joystick or on the button, causing immediately the return to the manual control mode. Thus, the switching from manual to automatic mode, or vice versa, is very easy. For example, a user can start with a wall following and then when a door appears on the interface, he passes through it automatically by pressing the button and pointing it, and finally, he can continue in manual mode actuating the joystick.

Figure 1. Vahm prototype.

Figure 2. Deictic interface.

2. Experimentation

The tests previously performed have showed that our driving assistance allows generally to reduce the workload, and particularly, the physical workload of the user while driving [1]. We would like now to assess and compare the attentional load of the user for these two driving modes. To do this, we use the dual task method which consists in performing a secondary task, firstly alone and then in parallel with the driving task in the two modes. The perturbations of the user can be observed by comparison of the secondary task achieved during a driving course and carried out alone.

2.1. The choice of the secondary task

The selected task is a task of reaction time in the auditory modality. The stimuli are sent in a headphone (a beep) at random time intervals (1.5 to 3 seconds), and the subject must respond by pressing as quickly as possible on a button held in his left hand (he uses his right hand to drive the wheelchair).

We chose an auditory stimulus to not interfere with the visual environmental exploration of subjects during the driving task. However, this task of reaction time measures the level of tonic alertness of a subject, namely, his responsiveness and his willingness to process information and respond to external stimuli performed in competition with the driving task. It is supposed to interfere with the attentional mechanisms that may also be used by the driving.

2.2. The Protocol

The experimentation takes place with twelve subjects without disability (eight men and four women), according to a well-defined protocol. First, each person makes a learning of driving in both modes and familiarizes oneself with the task of reaction time during driving. To do this, he performs several times the course with and without a driving assistance until the transit times are stabilized. Then, he achieves the courses with the task of reaction time to get acquainted with it.

The subjects are divided into two groups to avoid effects of order (four men and two women per group). The first group achieves the following protocol. Firstly, the subject performs the task of reaction time alone (Tr) so as to have a control condition. The duration of this task depends on the average course time that he has achieved during learning. Each subject carries out five times this task. Next, he performs the reaction task in parallel of driving with assistance (Tauto), five times also. Finally, he drives five times in manual mode with the reaction task in parallel (Tmanu). The subject must then take pause for 5 to 10 minutes. Then, he restarts all in reverse order, first, five times the task in manual modes, then, five times with the driving assistance and finally, five reaction tasks alone. The subjects of Group 2 perform the same tasks in reverse order. They carry out the task of reaction time alone, then, with the manual mode, and finally, with the driving assistance. Table 1 shows the Protocol.

Table 1. Experimental protocol for each group.

Group 1		Group 2	
Learning	(10 to 20 min)	Learning	(10 to 20 min)
Tr		Tr	
Tauto	(20 to 30 min)	Tmanu	(20 to 30 min)
Tmanu		Tauto	
Pause	(10 min)	Pause	(10 min)
Tmanu		Tauto	
Tauto	(20 to 30 min)	Tmanu	(20 to 30 min)
Tr		Tr	

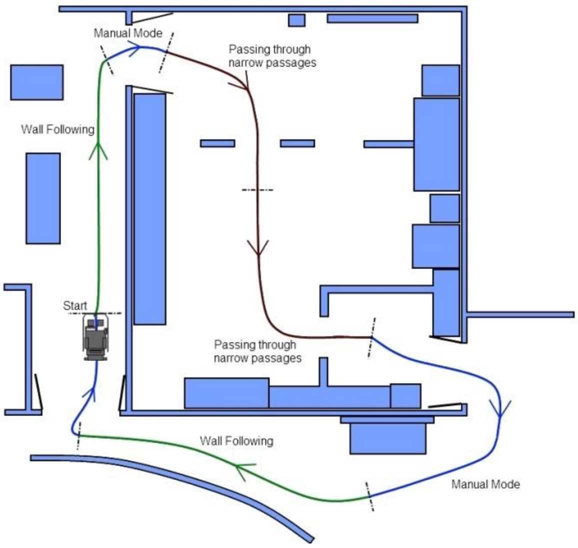

Figure 3. Course with driving assistance.

2.3. The course

The course is chosen to use every functionality in balanced manner. The phases of passing through narrow passages, wall following, manual mode, or stop, must last long enough to have sufficiently stimuli in each condition. Figure 3 shows the course.

3. Results

3.1. Effect of order and fatigue

First, we check the effect of order between the two groups to determine whether the fact of performing the manual driving before the driving with assistance has an influence, and vice versa. To do this, we use a Mann-Whitney test for these two conditions. We compare averages obtained with assistance for group 1 and group 2, and similarly for the manual driving. For each of the conditions, there is no significant difference. The effect of order has therefore insufficient influence (learning done previously contributes dramatically to reduce this effect).

Then, as the tests are relatively long for subjects (between an hour and an hour and a half), we also check if there is no effect of fatigue between the beginning and the end of testing. We perform a Wilcoxon test between the averages of reaction times obtained at the beginning and at the end. There is also no difference. These two effects have not enough influence to differentiate the two groups, so we bring together all the data.

3.2. Measures

During each course, we measure multiple elements, the reaction time of the response to a stimulus, the moment where it appears on the course, as well as the chronology of the actions made by each subject. These elements allow to link the different actions made by each subject with the appearance of stimuli. For each of them, we obtain a chronology of the variation of reaction times during each course. Figures 4 and 5 present respectively an example of a course made with the driving assistance, and, in manual driving. Table 2 presents the legend of the chronologies.

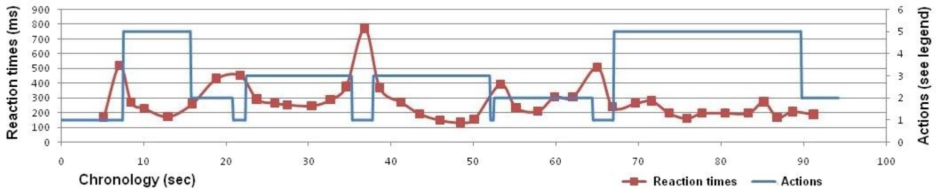

Figure 4. Chronology of the driving with assistance.

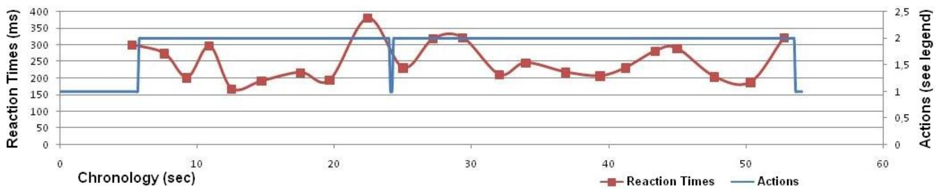

Figure 5. Chronology of the manual driving.

Table 2. Legend of the actions of the chronologies.

Identifiant	Description of actions
0	Debug Mode
1	Stop
2	Manual Driving with Joystick
3	Passing Through a Narrow Passage
4	-Reserve-
5	Wall following

We also measure the mistakes that the subjects can do (omissions, a response when there isn't stimulus…), in order to deduce a percentage of error for each course based on the number of stimuli heard. The averages of response times and the percentage of errors for each type of driving, and for the task of reaction time performed alone, are shown on figure 6. In total, each subject performs ten times the course in each mode. We obtain an average of 120 averages of 25 stimuli (approximately) for each type of driving (similarly for errors).

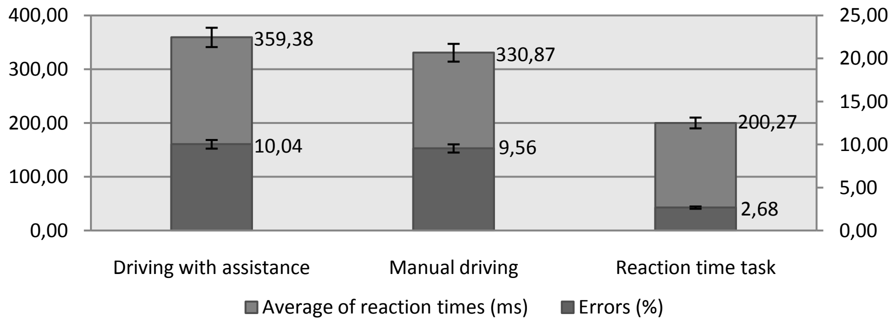

Figure 6. Averages of reaction time and percentages of errors done for all subjects for different driving modes.

In order to differentiate the two driving modes with the reaction time task, we first test the normality of our samples with the Shapiro-Wilk test. Our samples don't follow a normal distribution, so we used the non-parametric Kruskal-Wallis test with multiple comparisons.

This test is done, on one hand, with the averages of reaction times, and on the other hand, with the number of errors. Table 3 presents the confidence intervals of differences between groups at threshold $\alpha = 0.05$. If an interval between two groups contains the value zero, this means that we can't differentiate them.

Table 3. Kruskal-Wallis test (difference between driving modes for average reaction times).

	Confidence interval for the reaction time averages	**Significant difference at $\alpha = 0.05$**	**Confidence interval for the errors number**	**Significant difference at $\alpha = 0.05$**
Tr - Tauto	-177,45 to -114,47	yes	-89,81 to -29,72	yes
Tr - Tmanu	-155,30 to -92,33	yes	-111,44 to -51,36	yes
Tmanu - Tauto	-9,35 to 53,60	no	-51,68 to 8,41	no

Then, we specifically detail the attentional load of subjects during the driving with assistance. To do this, we determine the average of reaction times for each action: the average of reaction times when the subject is stopped Moy_Tr_Arr (this corresponds to the moments when he established a command on the interface), the average when the subject follows automatically a wall, Moy_Tr_Sdm, or when he crosses automatically a narrow passage, Moy_Tr_Pdp, and finally, when he uses the manual driving mode, Moy_Tr_Manu. Figure 7 illustrates these averages. For each condition, we have a minimum of five stimuli per course, and so, approximately 600 responses to stimuli for each condition.

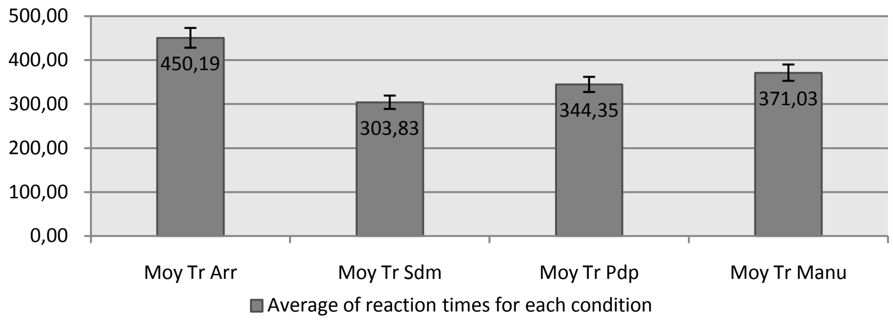

Figure 7. Averages of reaction times for all subjects with driving assistance for each condition.

We perform the same statistical tests than previously to differentiate different conditions of the driving with assistance. Table 4 presents the results of the Kruskal-Wallis test.

Table 4. Kruskal-Wallis test (difference between different conditions of driving with assistance).

	Confidence interval for the reaction time averages	**Significant difference at $\alpha = 0.05$**
Moy_Tr_Arr – Moy_Tr_Sdm	827,62 à 1205,72	yes
Moy_Tr_Arr – Moy_Tr_Pdp	508,45 à 896,26	yes
Moy_Tr_Arr – Moy_Tr_Manu	301,87 à 714,89	yes
Moy_Tr_Sdm – Moy_Tr_Pdp	-465,74 à -162,88	yes
Moy_Tr_Sdm – Moy_Tr_Manu	-675,56 à -341,02	yes
Moy_Tr_Pdp – Moy_Tr_Manu	-366,72 à -21,24	yes

4. Discussion and conclusion

This experimentation allows us to compare the attentional load required by the two driving modes and the reaction time task. Generally, both require a sustained attentional level. Each subject can accomplish both tasks without too much difficulty but must remain concentrated. Statistical tests show that attentional levels of both modes are very close and not differentiable. However, the attentional load is highly variable on chronologies for the two driving modes. For driving with assistance, there is a significant increase in reaction times when the subjects establish a command on the interface, whereas on the contrary, when a functionality is launched, the attentional load becomes very low. Descriptively, we can observe that the attention peaks measured are short and intense in this mode. For manual driving, the attentional load varies also during the course. Reaction times increases when the user must perform a maneuver (a narrow passage, or a delicate situation). The peaks of attention observed are a bit less intense that the driving with assistance but are much longer.

We notice the same observation with errors analysis. We can't differentiate the two driving modes statistically. However, we observe qualitatively that they don't occur in the same situations. The errors in manual driving happen when the user is in trouble. There are even successive errors on several stimuli which show that the user, in these moments, can't manage both tasks and focuses more on security (the driving task). This happens when subjects enter badly in a maneuver (a turn in a narrow passage begun too late for example). For driving with assistance, the attention required by the command may lead the user to make mistakes, especially when it occurs in a situation of hesitation, as for example, when he validates a command on the interface out of his target, or when he moves the joystick involuntarily after have finished to establish a command. In these cases, the wheelchair switches in the manual mode for security reasons and the user must retry the command. So he hesitates about what to do and commits a large number of errors.

These tests have therefore allowed to locate the situations and the actions in which the user is in trouble. This will allow us to evolve our driving assistance (on the human-machine interface, human-machine interaction and control modes aspects) to lighten the attentional load required by the driving.

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