

Swadapt1: Assessment of an Electric Wheelchair-driving Robotic Module in Standardized Circuits: A Prospective, Controlled, and Randomized Pilot Study

Emilie Leblong

Pôle Saint Hélier

Bastien Fraudet (✉ bastien.fraudet@pole-sthelier.com)

Pole Saint Hélier

Louise Devigne

INSA Rennes: Institut National des Sciences Appliquees de Rennes

Marie Babel

INSA Rennes: Institut National des Sciences Appliquees de Rennes

François Pasteau

INSA Rennes: Institut National des Sciences Appliquees de Rennes

Benoit Nicolas

Pôle Saint Hélier

Philippe Gallien

Pôle Saint Hélier

Research

Keywords: smart wheelchair, rehabilitation, neurological diseases

Posted Date: December 11th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-125028/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Objectives

The objective of this study is to highlight the effect of a robotic driver assistance module of Powered Wheelchair (PWC), using infrared sensors and accessorizing a commercial wheelchair) on the reduction of the number of collisions in standardized circuit in a population with neurological disorders by comparing driving performance with and without assistance.

Methods

This is a prospective, single-center, controlled, randomized, single-blind pilot study including patients with neurological disabilities who are usual drivers of electric wheelchairs. The main criterion for evaluating the device is the number of collisions with and without the assistance of a prototype anti-collision system on 3 circuits of increasing complexity. Travel times, cognitive load, driving performance, and user satisfaction are also analyzed.

Results

23 patients completed the study. There was a statistically significant reduction in the number of collisions on the most complex circuit.

Conclusion

This study concludes that the PWC driving assistance module is efficient in terms of safety without reducing the speed of movement in a population of people with disabilities who are habitual wheelchair drivers. The prospects are therefore to conduct tests on a target population with driving failure or difficulty who could benefit from this device so as to allow them to travel independently and safely.

1. Introduction

Most people with disabilities need help getting around and often use technical mobility aids. These aids can have an assistance role, such as canes or walkers or, as in the case of the use of a wheelchair, a role of supplementing the action of the lower limbs when moving. For people with significant motor limitations, an electric wheelchair may be the only solution for long and safe journeys, providing them mobility and independence. Research has documented various benefits of using a wheelchair and has highlighted particularly improved mobility, better social participation, reduced caregiver burden, and reduced likelihood of orientation in the workplace (Kirby 2016).

The prevalence of people using a wheelchair tends to increase in developed countries, with an estimated range of 60 to 200 per 10,000 inhabitants (Vignier 2008). However, while only 10% of wheelchair users use electric models (Kaye 2002; Vignier 2008), 25% of accidents are linked to their use (Kirby 1995). In addition, 100,000 accidents involving wheelchair users were recorded in the United States in 2006, double

the number of accidents recorded in 1991 (Xiang 2006). The use of motorized devices for mobility assistance is not without risks and accidents can occur. In a more recent study on the prevalence of wheelchair accidents involving 95 participants, 54.7% of the subjects reported having had at least 1 accident in the past 3 years (Chen 2011).

Sometimes, due to cognitive disorders, behavioral disorders, or excessively disabling motor deficits (uncontrolled movements, non-functional spasticity, etc.), some of these people are not eligible to conduct a PWC due to the risk of putting themselves in a difficult situation or representing a danger to neighboring people. Indeed, if the risk of collisions with the environment is considered too high, it is prohibitive to benefit from a recommendation of PWC.

These difficulties then lead to the impossibility of driving a PWC safely and therefore a limitation of mobility by extension of the daily autonomy of these people (Cooper 2002, Fehr 2000, Rushton 2014). This lack of technical assistance generates activity limitations and restrictions on life in society and on social participation, which can impact the person's life plan if the handicap cannot be compensated (Law of February 11, 2005, Article L.114). A study carried out by the Breizh Cerebral Palsy Network has shown the negative impact of reduced mobility on the quality of life of people with Cerebral Palsy in a situation of motor disability (Gallien 2015).

The importance of improving the quality of life, user autonomy, and social inclusion through the development of dedicated smart technologies for driving assistance has been underlined by (Helal 2008) and (Edwards 2010). PWC would improve people's autonomy and help improve self-esteem (Del Carmen Malbrán 2011) while having a positive impact on social participation. Indeed, (Mortenson 2012) showed the correlation between the daily distance traveled and participation in other activities for 246 dependent elderly people. In this context, a PWC driving assistance system could benefit people who are currently not eligible for the use of a PWC by improving safety when driving and thereby reducing wheelchair accident rates.

As part of the European ADAPT project (<http://adapt-project.com/index-en.php>), a driver assistance module has been developed to provide a solution allowing PWC users to travel safely.

The objective of this study is to highlight the effects of this robotic driving assistance module for PWC on the reduction of the number of collisions in standardized circuits in a population suffering from neurological disorders and moving in an electric wheelchair by comparing performance with and without assistance.

2. Materials And Methods

2.1. Participants

2.1.1. Inclusion criteria

The inclusion criteria were:

- Being over 18 years of age,
- Suffering from neurological disorders such as acquired brain injury or neurodegenerative disease,
- Having benefited from a prescription for an electric wheelchair and traveling with one for more than 3 months,
- Having the electric wheelchair as one's main mode of travel,
- Having compatible physical measurements (weight, height) with the chosen chair (Quickie SALSA M2) as part of the development of the robotic assistance module,
- Having freely consented to participate in the study.

2.1.2. Exclusion criteria

Comprehension disorders that make it impossible to consent to the use of clinical results for research purposes were an exclusion criterion, as were motor disorders of the upper limb that require additional technical driving assistance. Likewise, patients who expressed difficulties impacting their indoor and/or outdoor driving safety and vulnerable people were excluded.

2.2. Procedure (Table 1)

This is a prospective, single-center, controlled, randomized, single-blind pilot study carried out at Pôle MPR St Hélier, Rennes, France in June 2019, having received the agreement of the CPP Nord Ouest I on May 27th, 2019.

During medical consultations, the investigating doctor presented the objectives and procedures for participating in the protocol in verbal and written forms. For patients who volunteered after a 10-day cooling-off period, the consent form was signed.

Circuits (J1 ± 1 - J8 ± 1 - J15 ± 1)

As part of this investigation, the patients were followed for 15 days, at a rate of 3 visits to the Pôle Saint-Hélier :

- Circuit 1 (J1), figure 1,
- Circuit 2 (J8), figures 2 and 3,
- Circuit 3 (J15), figure 4.

The ADAPT project teams have defined three circuits intended to evaluate this first robotic assistance module. The circuits have been developed in collaboration with professionals in the training and

evaluation of electric wheelchairs, drawing on data from the literature concerning the circuits and recommendations for evaluation.

The purpose of these circuits is to assess the benefits of the various assistance modules designed as part of the ADAPT project.

These circuits are of increasing difficulty, allowing assistance to be tested through a sequence of tasks (table 2), in a situation of reproducibility that a circuit can offer.

These three circuits have been validated to meet specific electric wheelchair driving scenarios, corresponding to low to moderate sedan driving requirements.

The circuit is made up of flexible, mobile, and removable plastic walls that promote safe circulation: collision causes the structure to move.

The slopes use rails specifically dedicated to PWC traffic, secured by guardrails and lined with wheel guards.

The first circuit (fig. 1) makes it possible to test elementary driving tasks; the second circuit (fig. 2 and 3) adds tasks of moderate complexity; the third circuit (fig. 4) includes tasks of more marked difficulty. The different tasks are described in Table 1. The tasks included were chosen based on the one hand on a survey of 350 professionals competent in PWC driving training, carried out as part of the ADAPT project, and on the other hand on data from the literature. The different measurements were carried out by 2 independent trained occupational therapists.

To be able to assess the benefit of the assistance module on a PWC, the different circuits are carried out under the 2 following distinct conditions in a randomized order, known only to the engineer who programmed the assistance module and who was blinded to the evaluators and the patients.

- PWC with activated assistance module,
- PWC with deactivated assistance module.

Each patient therefore performed 6 trails per circuit spread over 3 days (see Table 1).

2.3. Device

As part of this investigation, a standard QUICKIE Salsa M² PWC from Sunrise Medical (Figure 5 – CE marked Class I medical device) was made available to patients for the various courses.

The sensors are integrated into the structure of the standard PWC and they do not modify the structure and the overall shape of the PWC in any way. These are Time-of-Flight infrared sensors distributed to the front right, front left, rear right, and rear left of the wheelchair (Devigne 2016, Devigne 2018).

The developed robotic assistance module is a semi-autonomous PWC driving assistance system, i.e. a control system shared with the user.

Intended to accessorize series, this system is made up of measurement modules (made up of ultrasonic sensors) and an on-board calculation unit connected to the sensors and to the wheelchair power module. The module's sensors are placed in different places on the PWC:

- under the PWC footrests,
- behind the seat of the PWC,
- on the lateral sides of the PWC.

Thus, the module is not in direct contact with the user (see Figure).

Constraints on the speed of the PWC are calculated from the distances measured around the chair. Deduced from the environment, these constraints are subsequently merged with the user's command (data from the control unit) to recalculate the speed to be applied to the wheelchair to gradually modify its trajectory and to avoid collisions with the environment, while respecting the user's intention as much as possible (Figure 2).

With the module activated, the PWC will stop on a frontal arrival in front of a positive physical obstacle (protruding from the ground, unlike a negative obstacle such as a hole or a curb ledge) at about fifteen centimeters. In the event of an angled arrival, the PWC will autonomously circumvent the obstacle by skirting it. At any time, the user can interrupt the assisted maneuver by releasing the control, as with the traditional PWC.

The chair control module is based on the use of a license from chair electronics manufacturer Penny & Giles, obtained by INSA Rennes. The system fully reuses the safeguards provided by Penny & Giles. Thus, when the assistance is activated, the safety installed on conventional PWC consisting of stopping the wheelchair when the joystick is released is maintained. The PWC therefore stops as soon as the joystick is released.

2.4. Objectives

The main objective is to highlight the effect of a robotic driving assistance module for PWC on the reduction of the number of collisions in standardized circuits in a population suffering from neurological disorders and moving in an electric wheelchair by comparing performance with and without assistance.

The secondary objectives were:

- To highlight the benefit of a robotic driving assistance module on driving speed,
- To highlight the value of a robotic driving assistance module on driving performance while carrying out defined tasks,
- To measure the impact of the module on cognitive load,

- To assess user satisfaction.

2.5. Efficacy endpoints

The main endpoint is the number of collisions on different standardized circuits with and without activation of the robotic assistance module as evaluated by 2 independent occupational therapist evaluators. The average value over 3 passages for each circuit and each patient is considered.

The secondary endpoints are:

- the speed measured by the time to complete the course with and without the activation of the assistance system on various circuits in seconds,
- driving performance measured by the Wheelchair Skill Test items corresponding to the different routes, with and without the activation of the assistance system (WST, Kirby, 2016),
- the cognitive load of the tests under the 2 conditions as measured by the NASA-Task Load Index (NASA TLX, Hart & Staveland, 2006),
- satisfaction with the use of PWC under the conditions as assessed by the Ease of Use Questionnaire (USE, Lund, 2001).

2.6. Statistical analyses

Statistical data were analyzed using the Rstudio software on paired data n=23. Quantitative descriptive data consisted of mean and standard deviation, median, and quartiles.

The changes in the different scores are compared based on the non-parametric Wilcoxon test with a 0.05 significance threshold. No extreme data was replaced. There was no missing data.

3. Results

3.1. Population

This study included 25 patients, 23 of whom completed the study. 2 patients left the study for personal reasons (a car breakdown and a broken leg following a fall at home independent of the study). The final sample consisted of 11 women and 12 men, with a mean age of 48 years (SD 11 years). Neurological pathologies were varied: 7 spinal cord injuries, 5 MS, 5 cerebral palsies, 3 peripheral neuropathies, 2 strokes, and 1 neuromuscular disease. Only 2 patients presented associated visual disturbances (restriction of the visual field and neglect).

3.2. Number of collisions

Circuit 1: there were 13 collisions in those without assistance and 5 collisions in those with assistance.

Circuit 2: there was 1 collision in those without assistance and 1 collision in those with assistance.

Circuit 3: there were 43 collisions in those without assistance and 13 collisions in those with assistance.

There was therefore a statistically significant difference ($p=0.038$) between the conditions with and without assistance on circuit 3, the most complex circuit, with an average effect size ($ES=0.72$).

We can therefore conclude that the assistance had a significant effect on the score by reducing the number of collisions.

3.3. Time to completion (table 3)

The mean time score on course 1 was higher in the “with assistance” condition than in the “without assistance” condition. This difference was significant ($p=0.029$), with a small effect size ($ES=0.48$).

The mean time score on circuit 3 was significantly higher in the “with assistance” condition than in the “without assistance” condition ($p=0.047$), with a small effect size ($ES=0.36$).

We can therefore conclude that the assistance had a significant effect on the time to completion. The course time increased when the assistance was activated.

3.4. Driving performance (WST)

There was no significant difference between the conditions in terms of the overall driving ability scores for either circuit ($p=1$, $p=0.35$, and $p=0.10$, respectively).

3.5. Cognitive load (NASA-TLX)

There was no significant difference between the conditions in terms of the overall cognitive load scores for either circuit ($p=0.25$, $p=0.67$, and $p=0.31$, respectively).

3.6. User satisfaction (USE)

There was no significant difference between the conditions in terms of the U.S.E scores or sub-scores for either circuit.

4. Discussion

Our study reports statistically significant results on the number of collisions, leading to the conclusion that the electric wheelchair driver assistance module is effective in enhancing user safety, despite a difference in travel time. As this is a pilot study on a prototype power wheelchair add-on, several factors for SWADAPT1 could not be calculated. Nevertheless, the results relate to a population of 23 participants, which is relatively high in view of the data existing in the literature.

As part of the European ADAPT project, the driver assistance module makes it possible to navigate in safety as shown by the significant reduction in the number of collisions thanks to a system adaptable to any model of electric wheelchair based on inexpensive ultrasound technology.

4.1. Semi-autonomous solutions including existing anti-collision assistance

In the context of accidentology, sometimes leading to a refusal of allocation of PWC to people who are then restricted in their movement, the issues around the development of a navigation aid system in PWC and its technological transfer for use by end-users are important. The problems of assistance to navigation in PWC have for several years been at the heart of the research themes of many research laboratories and have been addressed during several collaborative projects such as the NavChair (Levine 1999), Radhar (Demeester 2012) Project Sysiass (Kokosy 2013), and Coalas (Ragot 2014). The semi-autonomous and autonomous PWC navigation assistance solutions developed within the framework of these projects use fragile and expensive sensors and are conventionally based on algorithms requiring computing power, reducing the battery and therefore the autonomy of the PWC. In addition, these solutions use bulky and fragile multi-sensor systems, resulting in a modification of the physical configuration of the PWC on which they are equipped. Finally, these solutions are not generic and cannot be adapted to all the different PWC models.

The main drawback of these systems remains the final cost of the solution and the lack of clinical trials leading to technology transfer for use by end-users (Simpson 2005, Boucher 2013).

In all the studies evaluating this type of system, safety is one of the main judgment criteria. Evaluation can be made directly by counting the number of collisions with the environment or indirectly through the measurement of success in different driving tasks, defined specifically for the needs of studies or through standardized driving scores such as WST or PIDA.

McGarry et al. tested an anti-collision system coupled with a ground line tracking solution with 4 children suffering from cerebral palsy. The children used the system for 16 training sessions. At the end of the 16 sessions, the children improved their driving skills as measured by the Power Mobility Program Assessment. This underlines the potential use of an assistance system for learning to drive, but only on 4 participants. The disadvantage of such a system lies in the adaptation of the structure itself (drawing lines on the ground), reducing the field of exploration for patients.

Sharma et al. evaluated an anti-collision assistance system for PWC in 19 healthy people blinded by a blindfold on a standardized circuit. The test included a comparison between driving with a cane and driving with assistance system plus the cane. The use of the assistance system has significantly reduced the number of collisions and mental load (NASA-TLX), especially when the assistance solution was coupled with the cane.

Sharma et al. then tested this solution under the same test conditions with 7 people with visual disturbances and obtained comparable results concerning the benefit of the anti-collision system. However, this solution has not been tested by people with motor impairments.

Simpson et al. demonstrated the benefit of a voice-controlled collision avoidance solution. Compared to the absence of assistance, the test carried out on 6 healthy people on 3 different tasks showed a

difference: no collision occurred with the active system, with a more accentuated and statistically significant difference on the door passage task.

The same team evaluated this solution in the context of visual disturbances, including 4 healthy people blinded by a blindfold and 1 person with visual disturbances. Carried out on an obstacle course, the tests carried out with the system activated were less exposed to collisions: the authors notably identified 4 collisions out of all the tests without assistance for the disabled person, and no collision when the system was activated.

However, Wang et al. evaluated a smart wheelchair PWC driver assistance system in elderly patients with moderate cognitive impairment under 3 driving conditions, two of which were in a dedicated circuit. For only 2 participants, the use of assistance reduced the number of collisions and decreased mental load as measured by the NASA-TLX. The chair had several assistance modes (visual, haptic, sound feedback) including an anti-collision system for 5 elderly people with moderate cognitive impairment. The progress at the end of the 2 days of testing was assessed by the PIDA (Power Indoor Driving Assessment) concerning driving performance and safety, cognitive load through the NASA-TLX, and psychological impact through the PIADS (Psychosocial Impact of Assistive Devices Scale). Using the system, they achieved PIDA scores ranging from 66% to 91%, moderate impacts on mental load, and good acceptance with PIADS sub-scores (>0) for all people assessed.

Boucher et al. (Boucher 2013) compared the driving performance of 17 participants (8 healthy participants, 9 users) with and without the activation of a driving assistance system that performed complex tasks autonomously (e.g. parking) to the PWC using a voice command. The driving performance of the participants was assessed using a version of the standardized Wheelchair Skills Test (WST) adapted for robotic PWC. This study showed a reduction of more than 60% in the number of collisions when the navigation assistance module was activated.

4.2. Tests on circuits

One criticism that can be made is related to the evaluation of driving on a standardized course during this first phase and not in a daily life situation. However, the on-road test of a PWC allows a precise assessment of the technical performance and/or driving capabilities of the PWC. Indeed, the use of a course for evaluating the use of a PWC has the advantage of reproducing strictly identical situations and thus of working on the precision of the trajectory, particularly on the avoidance of obstacles, on a persistent difficulty such as going through a door or on learning by repeating a course. This exercise also makes it possible to compare the capacities of users (Kirby 2015) or, in the same way, to evaluate a PWC and/or a device adjoining this wheelchair (LoPresti 2011, Kokosy 2013). In addition, by offering the user the opportunity to get into specific situations in complete safety (avoidance of cardboard obstacles, delicate maneuver in a secure environment, etc.), the course is of definite interest concerning the learning and validation of basic driving skills of a PWC.

Among the studies regarding a tool for learning and/or evaluating the capacities for using PWCs, the method and the quality of performance of each task is observed. The travel strategy (Sorrento 2011, Yousefi 2012, Boucher 2013), the completion time (Sharma 2010, How 2013, Pearlman 2009), and the number of collisions (How 2013) are notably evaluated.

Among the studies that evaluate an “intelligent” PWC driving assistance device, priority is given to the evaluation of the system, i.e. of the attitude of the wheelchair equipped with the system in the face of an obstacle, particularly on the ability to move around and maneuver (Yousefi 2012, Boucher 2013) by comparing the number of collisions and the time to complete the course with and without assistance (Sharma 2010, How 2013). The practical evaluation of an on-course PWC is regularly accompanied by an evaluation questionnaire such as the QUEST (Demers 2002), the WST-Q (Mountain 2004), and the NASA-TLX (Hart 2006).

Due to a lack of precise information in studies including course evaluations, it is difficult to reproduce the courses and scenarios presented in the literature, which has the consequence of slowing down the possibility of cross-referencing the results of studies using similar routes. Among these studies, several tools have nevertheless proved their validity and reliability: the WST-P (Kirby 2016), the PMCDA (Letts 2007), and the PIDA (Dawson 2006).

5. Conclusion

This article presents a study to evaluate the use of an electric wheelchair driver assistance system. The objective of the solution developed within the framework of the ADAPT project is to improve safety conditions when driving a PWC, to make it possible to reduce the rate of wheelchair accidents, and to facilitate access to PWC for people who are not currently eligible. The study assessed the efficiency of such a PWC driver assistance system on the driving performance of regular drivers with disabilities to ensure safety. The reduction in the number of collisions confirms the interest of such a module among its target population. This does not modify the cognitive load of driving and meets the objectives of patient satisfaction. The next step is of course the conduct of a similar study to evaluate such an assistance module in prospective users who are currently not eligible, either due to driving difficulties or to not having access to such devices for safety reasons.

The authors report no conflicts of interest regarding the methods or the interpretation of the results.

6. Declarations

- **ethical approval and consent to participate**

This study received the ethical approval n°2019-A00476-51 from Comité de Protection des Personnes Nord Ouest I. The trial has been retrospectively registered the 28/08/2019 on ClinicalTrials.gov in ID: NCT04072536 -

Only patients who consent to participate have been included in this trial.

- **Consent for publication**

All authors consent to this publication

- **Availability of data and materials**

The dataset uses and analysed during the current study are available from the corresponding author on reasonable request.

- **Competing interests**

The authors declare that they have no competing interests.

- **Fundings**

This study is funded by INTERREG publics funds, in the context of the ADAPT project (adapt-project.com)

- **Authors' contributions**

The authors cited have all contribute to this trial.

MB FP LD have participated to technical the development of smart powered wheelchair. They all participate to the technical support during the trial.

BN PG and EL participate to the enrolment of the patients. PG and EL participate to the protocol writing.

BF participate to the protocol elaboration and coordinate the trial.

EL PG and BF participate to the analyze of the results.

- **Acknowledgements**

Not applicable

References

AZIZ F, AROF H, MOKHTAR N, MUBIN M, HMM based automated wheelchair navigation using EOG traces in EEG. In : J Neural Eng. 2014 Oct;11(5):056018. doi: 10.1088/1741-2560/11/5/056018. Epub 2014 Sep 4.

BOUCHER, P, ATRASH A, KELOUWANI S, et al. Design and validation of an intelligent wheelchair towards a clinically-functional outcome. *Journal of neuroengineering and rehabilitation*, 2013, vol. 10, no 1, p. 58.

CERES R, PONS JL, CALDERON L, JIMENEZ AR, AZEVEDO L. A robotic vehicle for disabled children. Providing assisted mobility with the PALMA project. *IEEE Eng Med Biol Mag*. 2005 Nov-Dec;24(6):55-63.

CHEN WY, JANG Y, WANG JD, et al. Wheelchair-related accidents: relationship with wheelchair-using behavior in active community wheelchair users. *Archives of physical medicine and rehabilitation*, 2011, vol. 92, no 6, p. 892-898.

COOPER, Rory A., THORMAN, Tricia, COOPER, Rosemarie, et al. Driving characteristics of electric-powered wheelchair users: how far, fast, and often do people drive?. *Archives of physical medicine and rehabilitation*, 2002, vol. 83, no 2, p. 250-255.

DAWSON, Deirdre R., KAISERMAN-GOLDENSTEIN, Ethel, CHAN, R., et al. Power-mobility indoor driving assessment manual (PIDA). Toronto (Canada): Department of Occupational Therapy, Sunnybrook and Women's College Health Sciences Centre, 2006.

DEL CARMEN MALBRÁN, María. World report on disability. *Journal of Policy and Practice in Intellectual Disabilities*, 2011, vol. 8, no 4, p. 290-290.

DEMEESTER, Eric, VANDER POORTEN, Emmanuel, HÜNTEMANN, Alexander, et al. Wheelchair navigation assistance in the fp7 project radhar: Objectives and current state. 2012.

DEMERS, Louise, WEISS-LAMBROU, Rhoda, et SKA, Bernadette. The Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0): an overview and recent progress. *Technology and Disability*, 2002, vol. 14, no 3, p. 101-105.

DEVIGNE, Louise, NARAYANAN, Vishnu K., PASTEAU, François, et al. Low complex sensor-based shared control for power wheelchair navigation. In : *Intelligent Robots and Systems (IROS)*, 2016 IEEE/RSJ International Conference on. IEEE, 2016. p. 5434-5439.

DEVIGNE L, PASTEAU F, LE BORGNE N, BABEL M, CARLSON T, GALLIEN P. Assisting power wheelchair driving on a sidewalk: A proof of concept. *Modelling, Measurement and Control C*, 79(4):185-189, Décembre 2018.

EDWARDS, Kara et MCCLUSKEY, Annie. A survey of adult power wheelchair and scooter users. *Disability and Rehabilitation: Assistive Technology*, 2010, vol. 5, no 6, p. 411-419.

FEHR, Linda, LANGBEIN, W. Edwin, et SKAAR, Steven B. Adequacy of power wheelchair control interfaces for persons with severe disabilities: A clinical survey. *Journal of rehabilitation research and development*, 2000, vol. 37, no 3, p. 353.

- GALLIEN, P., NICOLAS, B., DURUFLE, A., et al. Quality of life of adults with cerebral palsy living in britanny. *Annals of Physical and Rehabilitation Medicine*, 2015, vol. 58, p. e131-e132.
- HART, Sandra G. NASA-task load index (NASA-TLX); 20 years later. In : *Proceedings of the human factors and ergonomics society annual meeting*. Sage CA: Los Angeles, CA : Sage Publications, 2006. p. 904-908.
- HELAL, Abdelsalam, MOKHTARI, Mounir, et ABDULRAZAK, Bessam. *The engineering handbook of smart technology for aging, disability and independence*. John Wiley & Sons, 2008.
- HOW, Tuck-Voon, WANG, Rosalie H., et MIHAILIDIS, Alex. Evaluation of an intelligent wheelchair system for older adults with cognitive impairments. *Journal of neuroengineering and rehabilitation*, 2013, vol. 10, no 1, p. 90.
- HOW TV, WANG RH, MIHAILIDIS A. Evaluation of an intelligent wheelchair system for older adults with cognitive impairments. *J Neuroeng Rehabil*. 2013 Aug 7;10:90. doi: 10.1186/1743-0003-10-90.
- KAYE, H. Stephen, KANG, Taewoon, et LAPLANTE, Mitchell P. Wheelchair use in the United States. In : *Disability Statistics Abstract*. 2002. p. 1-4.
- KIRBY, R. L., SMITH, C., PARKER, K., et al. *Wheelchair Skills Program (WSP) manual*. 2016.
- KIRBY, R. Lee, MILLER, William C., ROUTHIER, Francois, et al. Effectiveness of a wheelchair skills training program for powered wheelchair users: a randomized controlled trial. *Archives of physical medicine and rehabilitation*, 2015, vol. 96, no 11, p. 2017-2026. e3.
- KIRBY, R. Lee et ACKROYD-STOLARZ, Stacy A. Wheelchair safety--adverse reports to the United States Food and Drug Administration. *American journal of physical medicine & rehabilitation*, 1995, vol. 74, no 4, p. 308-312.
- KOKOSY, Annemarie, FLOQUET, Thierry, HOWELLS, Gareth, et al. *SYSIASS? an intelligent powered wheelchair*. 2013.
- LETTS, Lori, DAWSON, Deirdre, BRETHER, Irit, et al. Reliability and validity of the power-mobility community driving assessment. *Assistive Technology*, 2007, vol. 19, no 3, p. 154-163.
- LEVINE, Simon P., BELL, David A., JAROS, Lincoln A., et al. The NavChair assistive wheelchair navigation system. *IEEE transactions on rehabilitation engineering*, 1999, vol. 7, no 4, p. 443-451.
- LOPRESTI, Edmund F., SHARMA, Vinod, SIMPSON, Richard C., et al. Performance Testing of Collision-Avoidance System for Power Wheelchairs. *Journal of Rehabilitation Research & Development*, 2011, vol. 48, no 5, p. 529.
- LUND, A.M. (2001) Measuring Usability with the USE Questionnaire. *STC Usability SIG Newsletter*, 8:2

MCGARRY S, MOIR L, GIRDLER S. The Smart Wheelchair: is it an appropriate mobility training tool for children with physical disabilities? In : Disabil Rehabil Assist Technol. 2012 Sep;7(5):372-80. doi: 10.3109/17483107.2011.637283. Epub 2011 Nov 29.

MORTENSON, W. Ben, MILLER, William C., BACKMAN, Catherine L., et al. Association between mobility, participation, and wheelchair-related factors in long-term care residents who use wheelchairs as their primary means of mobility. Journal of the American Geriatrics Society, 2012, vol. 60, no 7, p. 1310-1315.

MOUNTAIN, Anita D., KIRBY, R. Lee, et SMITH, Cher. The wheelchair skills test, version 2.4: validity of an algorithm-based questionnaire version 1. Archives of physical medicine and rehabilitation, 2004, vol. 85, no 3, p. 416-423.

PEARLMAN, Jon, COOPER, Rory, CHHABRA, H. S., et al. Design, development and testing of a low-cost electric powered wheelchair for India. Disability and Rehabilitation: Assistive Technology, 2009, vol. 4, no 1, p. 42-57.

RAGOT, Nicolas, CARON, Guillaume, SAKEL, Mohamed, et al. Coalas: A eu multidisciplinary research project for assistive robotics neuro-rehabilitation. In : IEEE/RSJ IROS Workshop on Rehabilitation and Assistive Robotics: Bridging the Gap Between Clinicians and Roboticians, Chicago, USA. 2014.

RUSHTON, Paula W., KAIRY, Dahlia, ARCHAMBAULT, Philippe, et al. The potential impact of intelligent power wheelchair use on social participation: perspectives of users, caregivers and clinicians. Disability and Rehabilitation: Assistive Technology, 2014 vol. 10, no 3, p. 191-197.

SHARMA, V., SIMPSON, R., LOPRESTI, E., et al. Evaluation of semiautonomous navigation assistance system for power wheelchairs with blindfolded nondisabled individuals. Journal of rehabilitation research and development, 2010, vol. 47, no 9, p. 877-890.

SIMPSON, Richard C. Smart wheelchairs: A literature review. Journal of rehabilitation research and development, 2005, vol. 42, no 4, p. 423.

SIMPSON R, LOPRESTI E, HAYASHI S, GUO S, DING D, AMMER W, SHARMA V, COOPER R. A prototype power assist wheelchair that provides for obstacle detection and avoidance for those with visual impairments. J Neuroeng Rehabil. 2005 Oct 3;2:30.

SORRENTO, Gianluca U., ARCHAMBAULT, Philippe S., ROUTHIER, François, et al. Assessment of Joystick control during the performance of powered wheelchair driving tasks. Journal of neuroengineering and rehabilitation, 2011, vol. 8, no 1, p. 31.

VIGNIER, Nicolas, RAVAUD, Jean-François, WINANCE, Myriam, et al. Demographics of wheelchair users in France: results of national community-based handicaps-incapacities-dependance surveys. Journal of rehabilitation medicine, 2008, vol. 40, no 3, p. 231-239.

XIANG, Huiyun, CHANY, A. M., et SMITH, Gary A. Wheelchair related injuries treated in US emergency departments. *Injury prevention*, 2006, vol. 12, no 1, p. 8-11.

YOUSEFI, Behnaz, HUO, Xueliang, KIM, Jeonghee, et al. Quantitative and Comparative Assessment of Learning in a Tongue-Operated Computer Input Device--Part II: Navigation Tasks. *IEEE Transactions on Information Technology in Biomedicine*, 2012, vol. 16, no 4, p. 633-643.

Tables

Table 1: design of study SWADAPT1

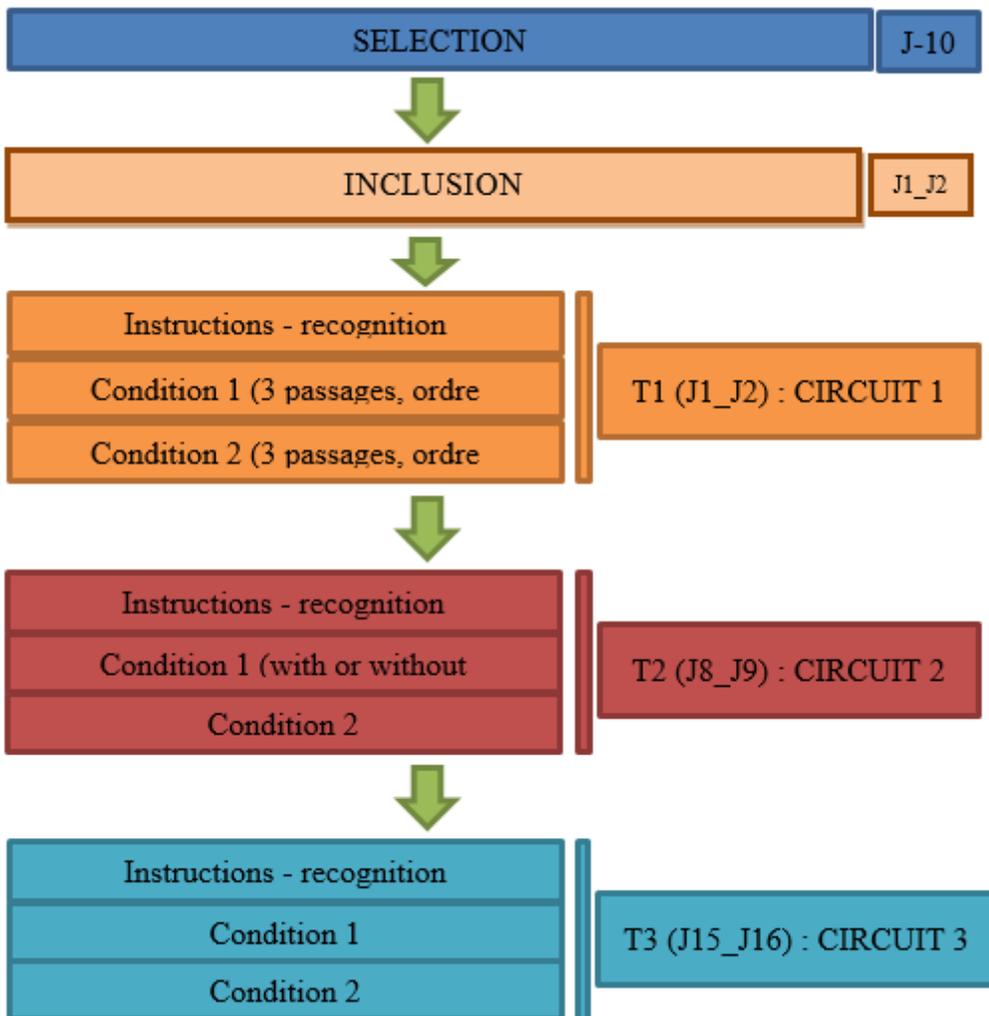
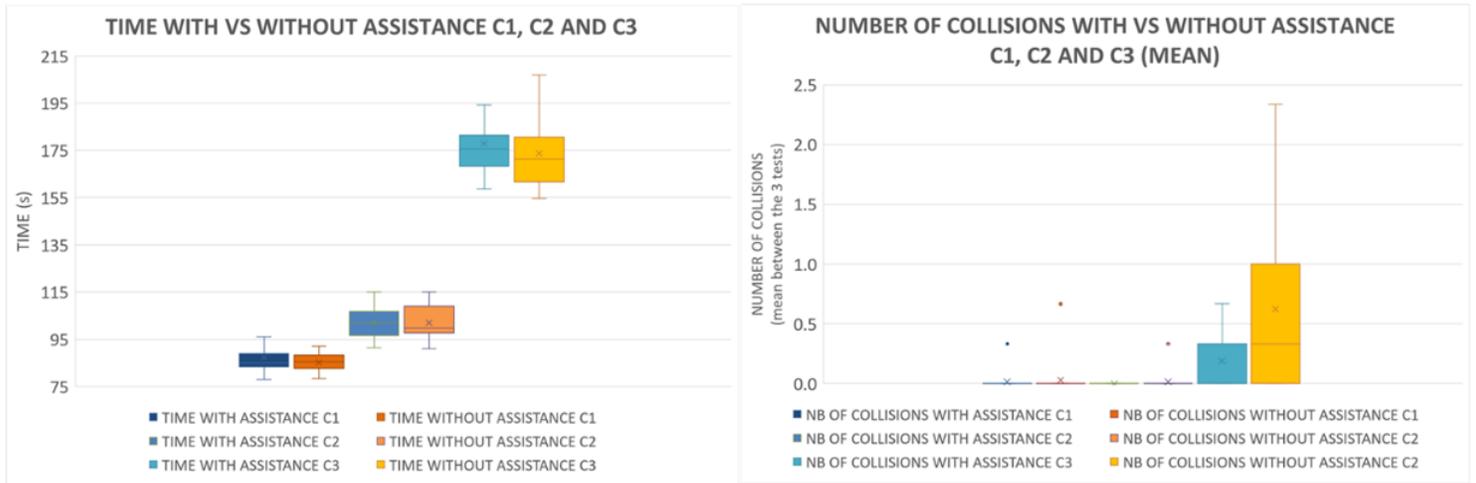


Table 2: The different tasks included in each circuit

CIRCUIT	TASK DESCRIPTION
1	wide corridor (2,5m)
	forward
	wide turn
	U-turn on site
	reverse
2	fixed obstacle on the ground to be circumvented
	low slope (5 °) to go down and up
	wide corridor / wide doorway
	fixed obstacle on the ground to cross
	low and moderate slope (5 ° and 10 °) to go down and up
3	fixed obstacle in height
	emergency stop
	stop with precision
	walk along a wall
	narrow corridor (1.5m)
	Table: setting up
	double stain
	Elevator simulation: forward entry and reverse exit
	restricted space
	moving obstacle to bypass

Table 3: time to completion (in seconds): mean of 3 assessments for each participant



Figures

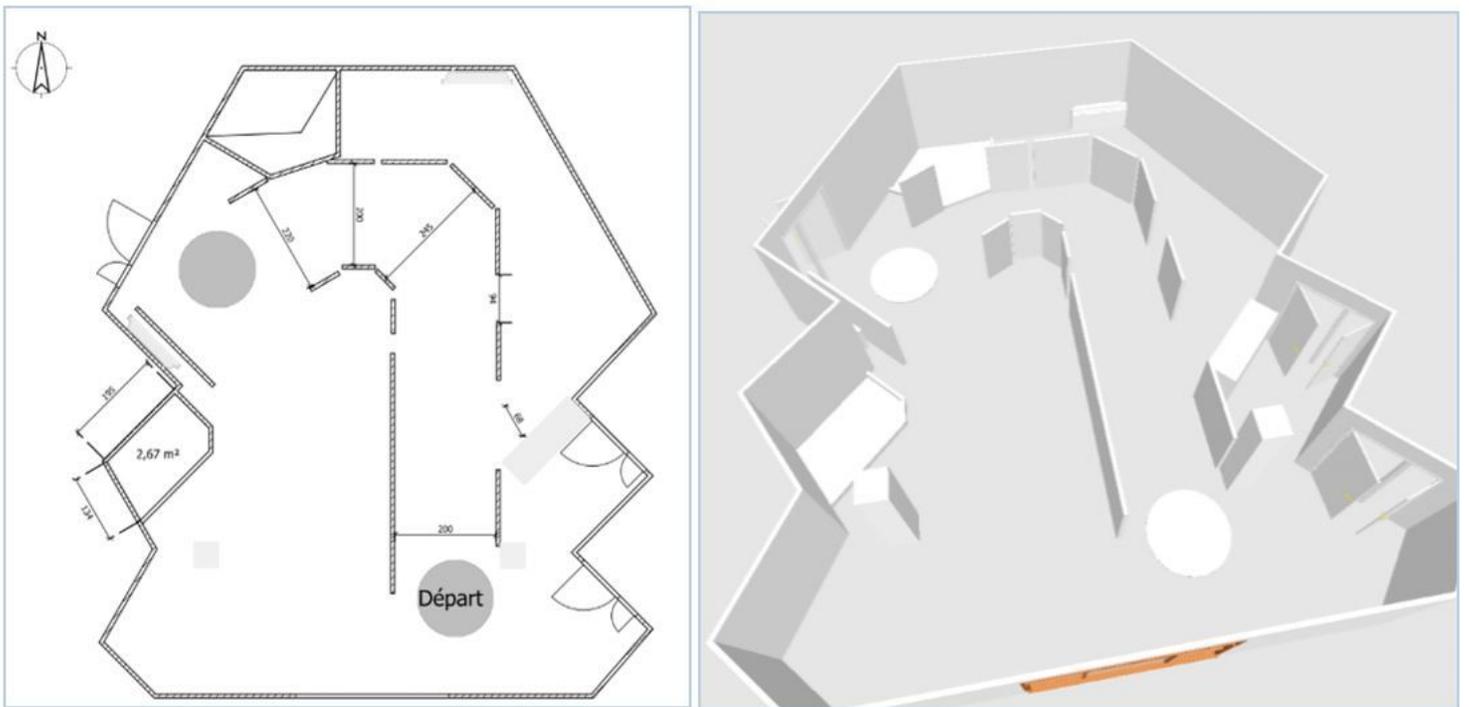


Figure 1

Plan and 3D model of circuit 1

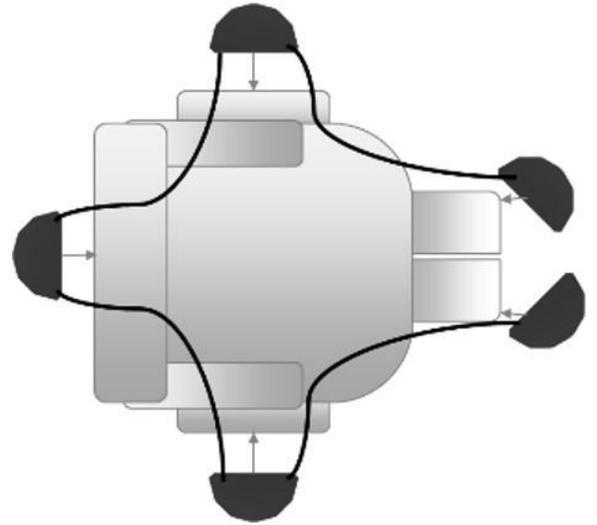


Figure 5

The smart wheelchair with US sensors