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Experimental Study of Persons with Disability, Wheelchairs, and Car Interaction

Eksperymentalne badanie interakcji osób niepełnosprawnych, wózków inwalidzkich i samochodu

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Abstract. Driving a car independently significantly enhances the quality of life, particularly for individuals with mobility disabilities. Wheelchair users face several challenges when loading and unloading their wheelchairs into and from vehicles, hindering their personal transportation independently. The influence of wheelchair design on the wheelchair and car compatibility for self-loading and unloading hasn't been

fully explored in the scientific literature; therefore, this study investigates the impact of various design features found in modern wheelchairs on their suitability for disabled drivers. Four types of wheelchairs were compared in this study; two participants with paraplegia, one male and one female, participated in the tests. Video recordings captured the procedures for getting in and out of the vehicle. Subsequent results analysis involved breaking down these procedures into steps and comparing them. The study demonstrated that times of independent entry into a car and loading of a wheelchair ranged from 48 to 74 seconds, while exiting the vehicle and unloading a wheelchair phase took between 56 and 86 seconds. A key takeaway from this research is that dividing the wheelchair frame, the largest and heaviest component, into two parts facilitates loading and unloading processes. However, this may slightly increase the duration of these activities. Detaching the seat aids more individuals with limited upper body strength.
Keywords: Independent Living, Wheelchair, Loading a Wheelchair, Unloading a Wheelchair, Ergonomics

Abstrakt. Zdolność do samodzielnego prowadzenia samochodu znacząco poprawia jakość życia, zwłaszcza osób z niepełnosprawnością ruchową. Niepełnosprawny kierowca korzystający z wózka inwalidzkiego napotyka jednak na problemy związane z załadunkiem i rozładunkiem wózka inwalidzkiego do i z pojazdu. Wpływ konstrukcji wózka inwalidzkiego na jego podatność do samodzielnego załadunku i rozładunku nie został w pełni opisany w literaturze naukowej; dlatego też w niniejszym badaniu przeanalizowano wpływ różnych konstrukcji nowoczesnych wózków inwalidzkich na ich przydatność dla niepełnosprawnych kierowców. W badaniu porównano cztery warianty wózków inwalidzkich. Do badań zaangażowano dwóch uczestników z paraplegią, kobietę i mężczyznę. Procedury wsiadania i samodzielnego załadunku wózka inwalidzkiego a następnie wysiadania z wyładunkiem tego wózka zostały nagrane na wideo. Rezultaty badań przeanalizowano i porównano. Samodzielne wsiadanie do samochodu i załadunek wózka inwalidzkiego w trakcie eksperymentu trwały od 48 do 74 sekund, natomiast wysiadanie z pojazdu z wyładunkiem wózka inwalidzkiego – od 56 do 86 sekund. Najważniejszy wniosek jest taki, że podzielenie ramy wózka inwalidzkiego, największego i najcięższego elementu, na dwie części ułatwia jego samodzielny załadunek i rozładunek, choć może wydłużyć czas trwania tych czynności. Możliwość odłączenia siedziska od ramy jest szczególnie korzystna dla osób o ograniczonej sile górnej części ciała.
Słowa kluczowe: niezależne życie, wózek inwalidzki, załadunek wózka inwalidzkiego, wyładunek wózka inwalidzkiego, ergonomia

Introduction

Independent driving plays a pivotal role in the lives of active wheelchair users, offering many benefits. Most notably, it gives them a profound sense of autonomy, liberating them from dependence on caregivers and granting them the freedom to shape their daily activities and choose their destinations (Darcy and Burke 2018). Driving a vehicle enables individuals with disabilities to navigate through their daily routines independently, free from the constant presence of caregivers or aides, thereby bolstering their overall well-being. This independence yields positive emotional outcomes by reducing feelings of isolation and lessening dependence. Becoming an independent driver is a vital personal accomplishment. It demands determination to acquire new skills, resulting in personal growth and heightened self-confidence (Claypool *et al.* 2017).

Moreover, independent driving facilitates social engagement. It empowers individuals to partake in social gatherings, visit loved ones, and pursue hobbies and recreational interests – enriching their social lives and overall well-being. Crucially, independent driving opens up new vistas of employment opportunities. Commuting to work independently enables disabled individuals to pursue careers and attain economic self-sufficiency (Van Roosmalen *et al.* 2010).

While extensive research has explored various aspects of disabled drivers using manual wheelchairs, a gap exists in understanding specific design features impacting the wheelchair's autonomous loading and unloading out-of-vehicle capabilities. Addressing this gap is justified as advancements in wheelchair design have the potential to improve the independence and daily lives of wheelchair users significantly. By analyzing the influence of specific wheelchair design features on self-loading and unloading times, this research aims to inform future innovations and propel advancements in wheelchair technology.

A brief literature review about vehicle adaptations for disabled drivers and entering and exiting vehicles with a wheelchair

Regarding disabled drivers using private passenger cars, three primary categories of challenges emerge: driving the vehicle, entering and exiting it, and loading the wheelchair into the car. Each aspect has been a focal point of scientific investigation (Koźma *et al.* 2016).

Significant advancements are underway in vehicle adaptations for drivers with disabilities (Stasiak-Cieślak 2022)Modifying standard vehicles to accommodate drivers with disabilities is facilitated by recent technological advances. Contemporary cars often have cameras and sensors that offer various driver-assist functions. These may include rearview cameras for parking, proximity sensors for obstacle detection, or lane-keeping sensors to assist with steering. When preparing a vehicle for a disabled driver, these advanced features are vital in improving their safety and overall driving experience (Stasiak-Cieślak *et al.* 2023).

Despite the automation of car control, disabled drivers rely on specialized adaptive devices to operate the vehicle comfortably and safely. These devices encompass hand controls for acceleration and braking, steering aids, and modified gearshifts. Specific supplementary elements or expert modifications may be necessary to ensure the harmonious functioning of these adaptive tools with the vehicle. Integrating these additional features and ensuring compatibility with standard vehicle systems makes the adapted vehicle accessible to non-disabled and disabled drivers, offering the necessary ergonomics and safety features for a well-rounded driving experience (Suliano *et al.* 2020).

Safety remains a paramount concern, but it can be effectively managed through vehicle modifications and specialized training. Notably, it is recommended that individuals who rely on wheelchairs transfer into a vehicle seat designed by the original manufacturer and utilize the vehicle's occupant restraint system, which has undergone rigorous crash testing (Buning *et al.* 2012). The advantages of independent driving far outweigh the potential risks. Studies indicate that drivers with paraplegia using hand controls have similar brake response times compared to drivers without paraplegia using foot pedals, strengthening the case for their safe and capable participation on the road (Santos *et al.* 2021).

Software tools are harnessed to match car adaptations with the driver's disability. In their work, Stasiak-Cieślak and Grabarek (2022) demonstrated the effective utilization of comprehensive databases, incorporating scientific literature, company assessments, evaluations of adaptive devices, and insights from mobility and disability professionals. This extensive knowledge pool streamlines the categorization of adaptive devices and the classification of driver disabilities, serving as the bedrock for crafting car adaptation guidelines.

The methods employed by wheelchair users when **entering and exiting vehicles** exhibit significant commonalities. Schaupp et al. (2016) analyzed twenty-five videos of wheelchair users transferring into and out of the driver's seat. In a follow-up study conducted in 2018, the authors presented a complementary observational investigation (Schaupp *et al.* 2018). In this study, the researchers recorded videos of five male wheelchair users as they performed transfers from their wheelchairs into two research vehicles, namely a small sedan and a mid-size sedan. The study aimed to discern the specific motions involved in getting in and out of the cars and identify key 'touch points' during these actions in a controlled environment. The participants' ingress and egress transfers were meticulously documented from various camera angles. The study's findings revealed that drivers predominantly employ one of two primary techniques: the 'trunk-first' or 'foot-first' method. Notably, clusters of touch points were consistently identified, primarily on the driver's seat and the steering wheel. Notably, the touch point locations for both ingress and egress were remarkably similar across all study participants. However, an interesting observation was that fewer drivers used the steering wheel as a touch point during exit than when entering a vehicle.

There are several different methods for **self-loading a wheelchair** into a car by the wheelchair user: (1) driving the wheelchair into the car, (2) using the automatic loading system, or (3) loading the wheelchair yourself (Sydor and Zabłocki, 2006).

The first method requires individual Wheelchair Accessible Vehicles, specially designed or modified to accommodate wheelchairs. They may have lifts or ramps, modified (widened) entrances, and wheelchair docking systems that allow the wheelchair to be secured within the vehicle. Such solutions force the car to be driven from a wheelchair, although it may be possible to transfer from a wheelchair to a car seat if these systems are used with swivel seats for ease of transfer (Hunter-Zaworski *et al.* 2015)

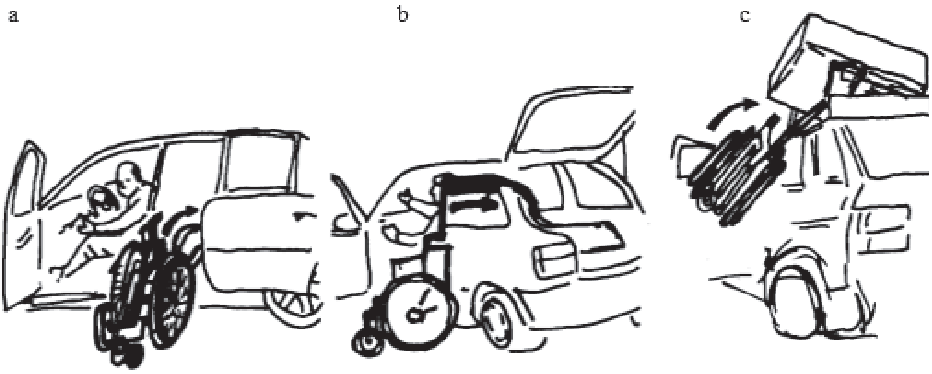

Fig. 1. Various configurations of automatic wheelchair loading systems: a – rear seat loading hoist, b – trunk loading hoist, c – roof rack loading crane

Source: Based on (Sydor and Zabłocki 2006)

The automatic loading systems employ mechanical and electronic devices to assist with lifting and stowing the wheelchair (Madej *et al.* 2023)These devices, such as hoists or lifts, are typically installed in the vehicle's rear left door (Fig. 1a), trunk (Fig. 1b), or roof (Fig. 1a). The user attaches the wheelchair to the lifting device, then lifts and secures it automatically into the car.

Before loading a wheelchair into a vehicle, the user manually transfers from their wheelchair to the car seat. This method suits individuals with good mobility and upper body strength. Subsequently, the user independently folds or disassembles the wheelchair and manually loads it into the vehicle. Self-loading the wheelchair does not preclude using assistive devices like swivel seats, transfer boards, etc. (Sydor and Zabłocki 2006).

Unloading a typical active wheelchair from a car involves three distinct phases, as illustrated in Figure 2: unloading the wheelchair frame (Fig. 2a-b), unloading the wheels (Fig. 2c-g), and placing the cushion on the wheelchair seat (Fig. 2h-i).

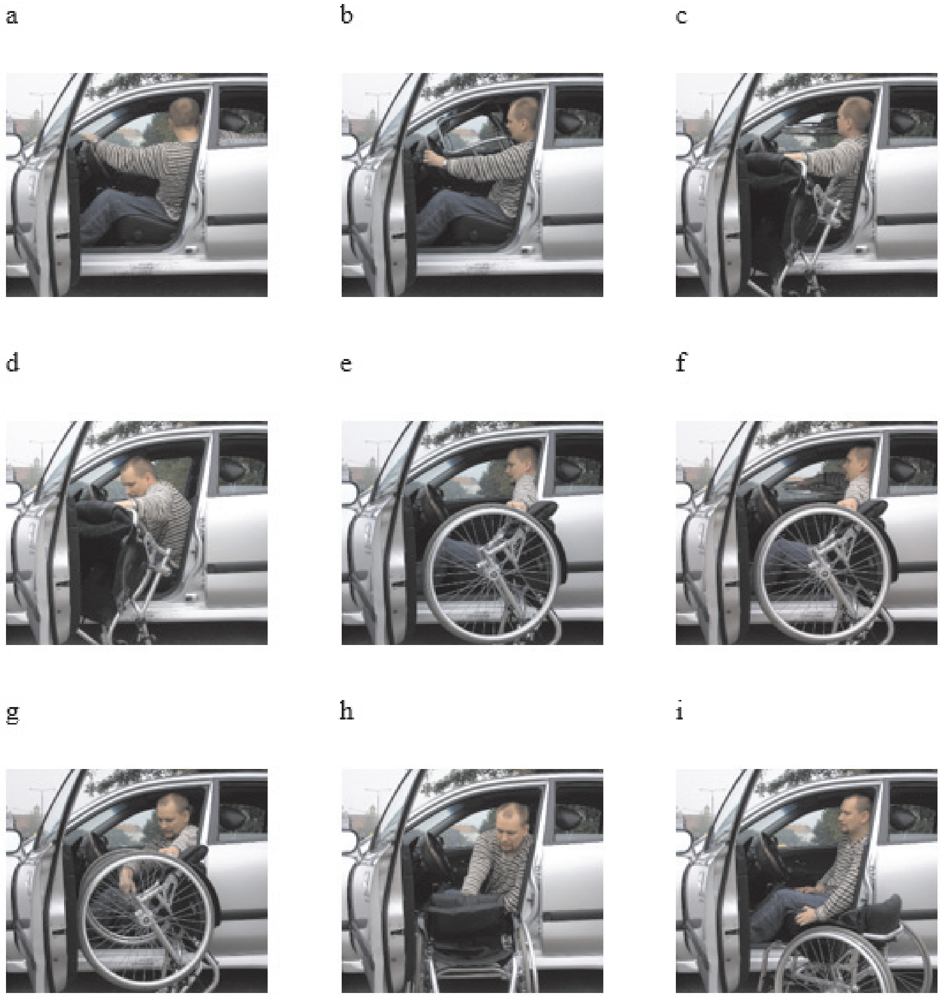

Fig. 2. Self-unloading of a typical active wheelchair from the car
Source: Own study, photo by M. Zabłocki

Methodology

Experimental setup

Two individuals took part in the study: a male and a female, both experiencing the paralysis of their lower limbs (paraplegia). The woman's body dimensions were close to the 5th percentile of the population in Poland (stature 150 cm), and the man's body dimensions were typical of the 95th percentile of this population (stature 186 cm). This selection of study participants covered a wide range of anthropometric measurements.

Table 1. Tested wheelchairs

Wheelchair No. 1 (mod. U3 Light, Panthera AB, Spånga, Sweden)		Overall mass	6.10 kg
		Frame mass	3.25 kg
		Mass of the rear wheels	2.35 kg
		Weight of the cushion	0.50 kg
		Width × length × height (with wheels removed)	48 × 70 × 64 cm
Wheelchair No. 2 (mod. Küschall K-series, Invacare, Elyria, OH, USA)		Overall mass	11.36
		Frame mass	6.44
		Mass of the rear wheels	3.61
		Weight of the cushion	1.30
		Width × length × height (with wheels removed)	48 × 70 × 75 cm
Wheelchair No. 3 (mod. CarboLite, Cosmotech, Bytom, Poland)		Overall mass	9.68 kg
		Frame mass	5.73 kg
		Mass of the rear wheels	3.18 kg
		Weight of the cushion	0.77 kg
		Width × length × height (with wheels removed)	48 × 60 × 65 cm
Wheelchair No. 4 (mod. Freeasy, Cosmotech, Bytom, Poland)		Overall mass	8.05 kg
		Frame mass	2.91 kg
		Mass of the rear wheels	2.30 kg
		Weight of the cushion	2.84 kg
		Width × length × height (with wheels removed)	48 × 50 × 50 cm
		Width × length × height of the shell seat	45 × 52 × 27 cm

Source: Own study

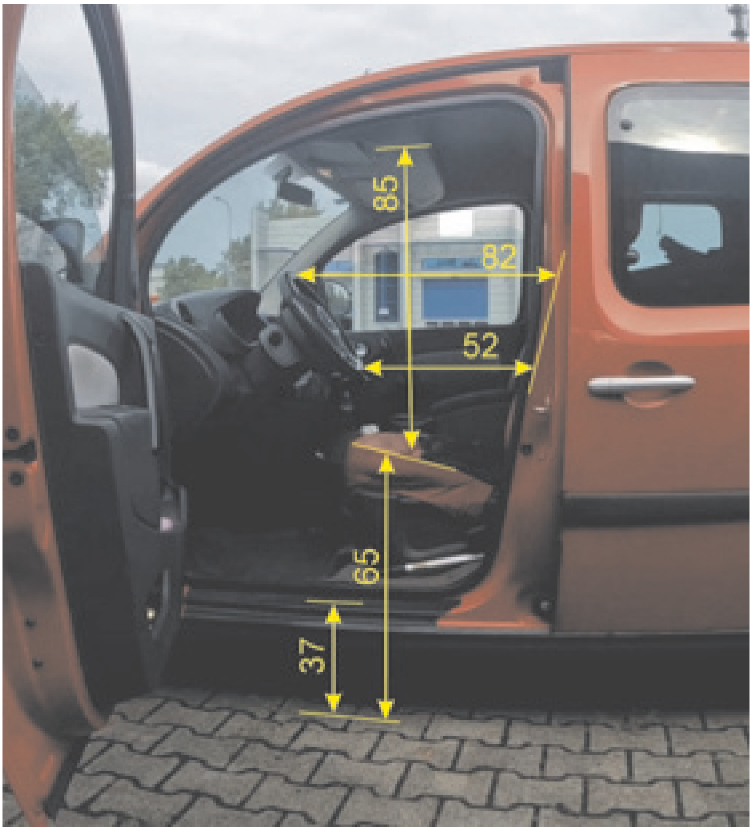

Fig. 3. Key dimensions in centimeters of the vehicle access space
Source: Own study

The technical specifications of the wheelchairs used in the study are summarized in Table 1. Wheelchairs numbered 1 and 2 are utilized as daily mobility aids by the study participants. Wheelchairs 3 and 4 introduced innovative designs, both featuring carbon fiber frames. Additionally, wheelchair number 4 stands out by incorporating an innovative separable shell seat, which equates the mass distribution of its components compared to wheelchairs 1, 2, and 3. Wheelchairs 1, 2, and 3 can be dismantled into separable components: a cushion, left wheel, right wheel, and frame. In contrast, wheelchair no. 4 uniquely folds into a unified structure, combining a shell seat with a cushion, left wheel, right wheel, and frame.

The study employed a Renault Kangoo II car, as shown in Figure 3. The chosen car model featured wide door openings, ample space between the seat backrest and overhead, and a raised driver's seat position.

Research methodology

Each study participant was introduced to the innovative, new for them wheelchairs No. 3 and 4. It's worth noting that timing was not a factor during these introductions. Study participants learned about the new wheelchairs at their own pace and could ask as many questions as they wanted. During this phase, the study participants collaborated with the research team to determine the optimal arrangement and placement of individual wheelchair components within the test car. This process aimed to familiarize the participants with the specific features of wheelchairs No. 3 and 4. Study participants performed trial entry and exit from the vehicle with all wheelchairs used in the study.

The core part of the experiment encompassed independently entering and exiting the car and loading and unloading the wheelchairs. A woman used wheelchairs No. 1 and 4 to enter and exit a vehicle, while a man used No. 2, 3, and 4. The woman did not load and unload wheelchair No. 3 due to the frame's excessive mass.

Video recordings of the test procedures were captured, employing a standardized coding system: "W" for female participants, "M" for male participants, and wheelchair numbering from 1 to 4 (as per Table 1). The symbols "in" and "out" were used to differentiate between entry and exit actions from the vehicle. A total of ten test cases were conducted:

- W1in. The female research participant (W) independently entered the car and loaded her wheelchair, No. 1, into the back seat.
- W4in. The female research participant (W) independently entered the car and loaded an innovative wheelchair, No. 4, into the back seat.
- W1out. The female research participant (W) unloaded her wheelchair No. 1 and independently exited the car.
- W4out. The female research participant (W) unloaded her wheelchair, No. 4, and independently exited the car.
- M2in. The male research participant (M) independently entered the car and loaded his wheelchair No. 2 into the back seat.
- M3in. The male research participant (M) independently entered the car and loaded an innovative wheelchair, No. 3, into the back seat.
- M4in. The male research participant (M) independently entered the car and loaded an innovative wheelchair, No. 4, into the back seat.

- M2out. The male research participant (M) unloaded his wheelchair, No. 2, and independently exited the car.
- M3out. The male research participant (M) unloaded an innovative wheelchair, No. 3, and independently exited the car.
- M4out. The male research participant (M) unloaded an innovative wheelchair, No. 4, and independently exited the car.

The study participants entered and exited the car in slightly different ways. The male participant went directly from the wheelchair to the driver's seat, while the female participant first sat on the door sill before transferring to the driver's seat. An analogic difference was observed when they exited the vehicle. Figure 4 illustrates this variation.

Every test was recorded using a GoPro camera (model: Hero12, GoPro Inc., San Mateo, CA, USA) at 30 frames per second, ensuring precise measurement of each phase's duration with an accuracy of 0.1 seconds.

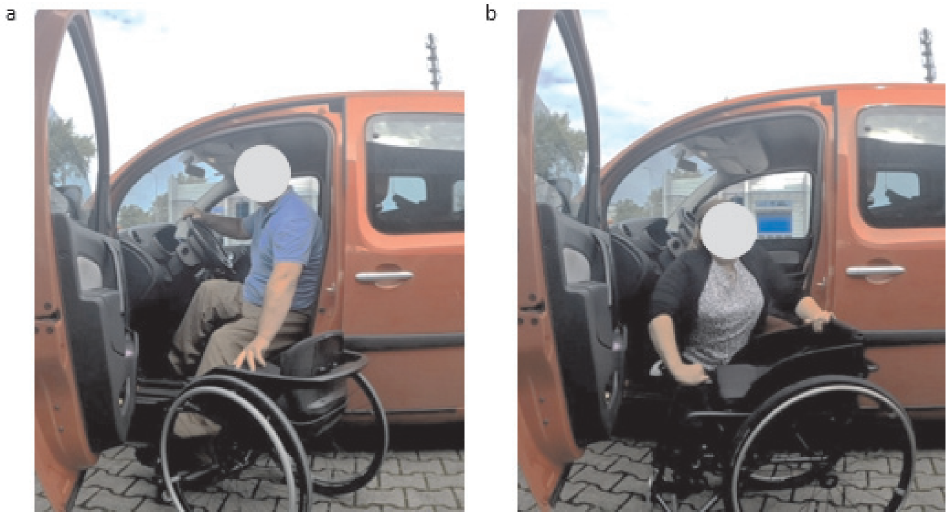

Fig. 4. Difference in the way of getting in and out of the car: a – the man manipulates the wheelchair sitting on the driver's seat, b – the woman folds and unfolds the wheelchair while sitting on the sill of the vehicle

Source: Own study

Results

The total times of entering and exiting the vehicle with loading and unloading the wheelchair are summarized in Table 2, and the decomposition of these processes on steps and the durations of these steps is shown in Figures 10-19 in the Appendix.

Table 2. Total entry and exit times, including loading and unloading the wheelchair

Variant	W1in	W4in	W1o-ut	W4o-ut	M2in	M3in	M4in	M2o-ut	M3o-ut	M4out
Time (s)	73.3	73.7	76.1	83.2	68.9	48.3	52.7	56.2	62.7	77.1
W – female research participant M – male research participant 1, 2, 3, 4 – numbering of the tested wheelchairs, as in Table 1 in – entering the vehicle out – exiting the vehicle										

Source: Own study

The process of entering the vehicle while the female research participant autonomously loads a wheelchair (test variants W1in and W4in) yielded the following observations:

1. The type of wheelchair did not affect the time required to complete the task (73.2 s for wheelchair No. 1 and 73.8 s for wheelchair No. 4). Differences were observed in the location where the wheels were stored. In the case of wheelchair no. 1, the wheels were placed on the rear seat of the vehicle, while for wheelchair No. 4, the wheels were relocated to the right front passenger seat. This reduced the total wheel manipulation time, decreasing from 23.9 s for wheelchair No. 1 to 19.5 s for wheelchair No. 4.
2. The wheelchair frame manipulation times were different. Here, the beneficial effect of the divided structure of wheelchair No. 4 was very clearly visible, for which the time was 12.3 s. In the case of wheelchair No. 1, with a heavier frame, it was 19.7 s. This difference was influenced by a significant beneficial shortening of the time of the carrying phase (lifting the frame) from 18.5 s to 9.2 s (Fig. 5).
3. The time reduction obtained in this way was „used" to carry out the additional precise operation of attaching the seat console to the frame.

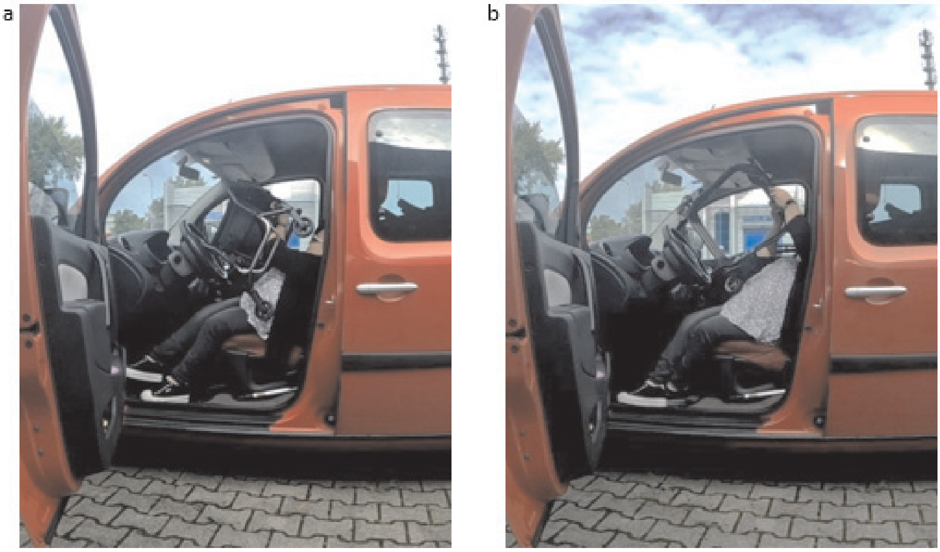

Fig. 5. Comparison of the interior space occupied by the wheelchair frame when the female research participant gets into the vehicle: a – wheelchair No. 1 (W1in), b – wheelchair No. 4 (W4in)
Source: Own study

When analyzing the process of a female research participant exiting the vehicle while self-loading the wheelchair in test variants W1out and W4out, several observations have been made:

1. Wheelchair No. 4, compared to Wheelchair No. 1, necessitated an increased number of steps. This included positioning the body twice in the car seat and attaching the shell wheelchair seat.
2. The manipulation time for the wheelchair frame was significantly reduced, decreasing from 13.5 seconds to just 5.0 seconds.
3. The time required for manipulating the wheels to place them outside the vehicle was 21.7 seconds for wheelchair No. 1 (8.0 seconds for positioning and 13.7 seconds for attaching) and 19.5 seconds for wheelchair No. 4 (9.5 seconds for positioning and 10 seconds for attaching). This implies that repositioning the wheels to a more accessible location on the front seat equalized the time needed to handle each wheel and reduced the overall unloading time for wheelchair No. 4.
4. The increase in the total exiting time when switching from wheelchair No. 1 to wheelchair No. 4 was 7.1 seconds (as shown in Table 2). This increase was due to additional activities related to moving and attaching wheelchair No. 4 seat, which took 14.5 seconds. This increase was not offset by the reduction in time for attaching the wheels and positioning the wheelchair

frame (a gain of 3 seconds) or the shortened time for moving the frame (as previously indicated, an improvement of 8.5 seconds) (as depicted in Fig. 6).

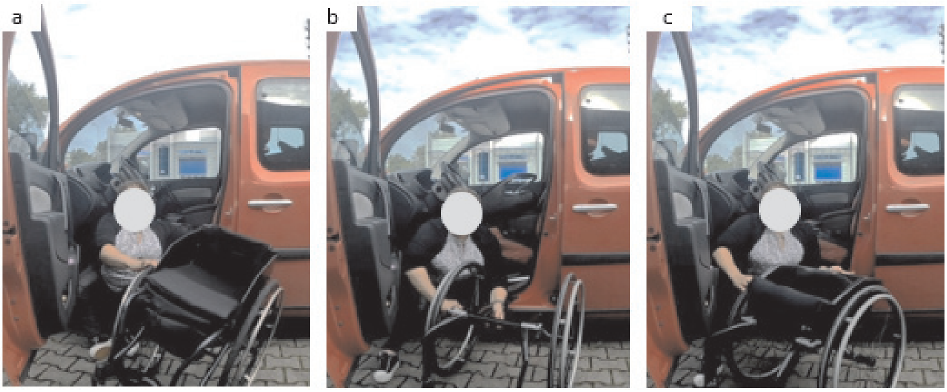

Fig. 6. The attaching the wheels while the female research participant is getting out of the vehicle: a – wheelchair No. 1 (W1out), b and c – wheelchair No. 4 (W4out) with visible seat attaching

Source: Own study

Changing the type of wheelchair in tests W1out and W4out increased the time needed to transfer from the car to the seat from 5.2 to 7.3 s. This may be related to the reported problem of less reliable support of the hands on the elements of wheelchair No. 4, which is crucial when getting out of a vehicle.

When a male research participant (in M2in, M3in, and M4in test variants) enters the vehicle while self-loading the wheelchair, distinct variations in boarding and independently loading the wheelchair become apparent. Figure 7 illustrates disparities in wheel placement and the wheel detachment phase.

Changing the type of wheelchair in tests M2in, M3in, and M4in reduced the total time needed to load the wheelchair into the vehicle and the number of activities performed. This mainly concerns the time spent manipulating the rear wheels. In total, wheel manipulation took almost 15 s in the case of M2in, while in the case of M3in, it was 8.8 s, and in M4in, only 6.8 s.

It was beneficial to reduce the frame manipulation time; these times were M2in 8.1 s (including the frame lifting time 4.7 s), M3in 8.2 s (7.5 s), and M4in 7.2 s (5.1 s). In the case of wheelchair No. 3, the extended frame lifting time is the inconvenient location of the handle, located at the top of the wheelchair on its foldable backrest. This makes it challenging to maneuver the frame and causes greater demand for space inside the vehicle (Fig. 8).

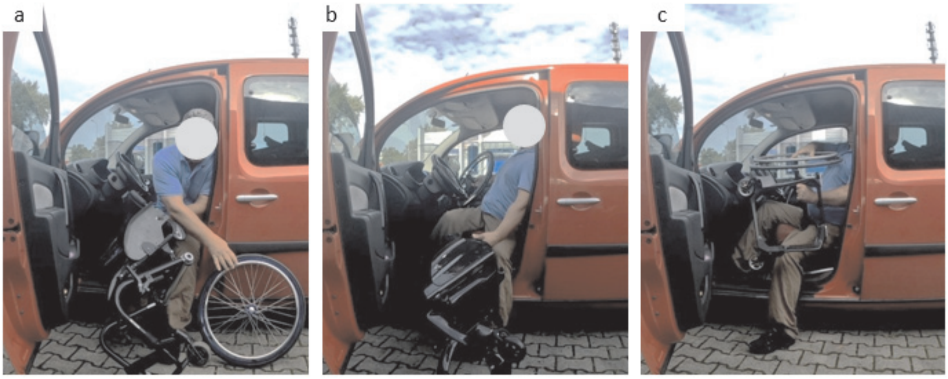

Fig. 7. Differences when entering the vehicle in the way the wheels are arranged when detaching them: a – wheels placed on the side of the vehicle (M2in), b – wheels placed on the front right seat (M3in), c – wheel detached inside the vehicle (M4in)

Source: Own study

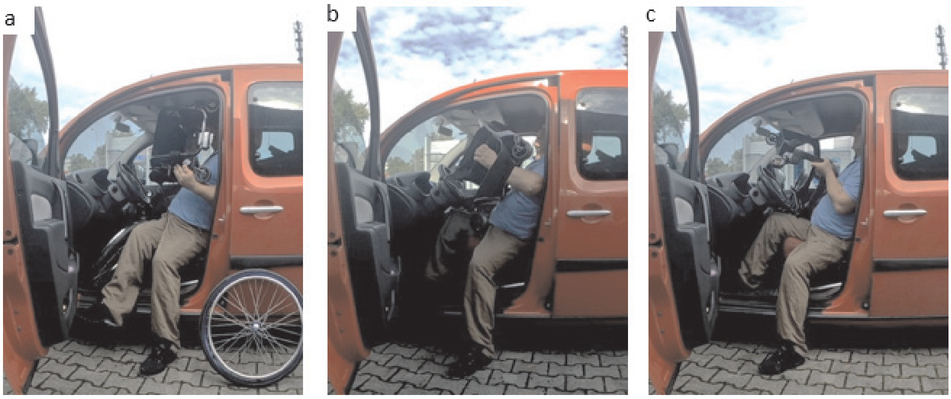

Fig. 8. Occupation of the interior space by the wheelchair frame when the male research participant enters the vehicle: a – wheelchair No. 2 (M2in), b – wheelchair No. 3 (M3in), c – wheelchair No. 4 (M4in)

Source: Own study

The observed increase in the time of moving the frame of wheelchair No. 4 by 0.4 s compared to the operation with wheelchair No. 3 will not increase the burden on the person loading the wheelchair into the vehicle because the mass of this element in wheelchair No. 4 is almost 60% lower.

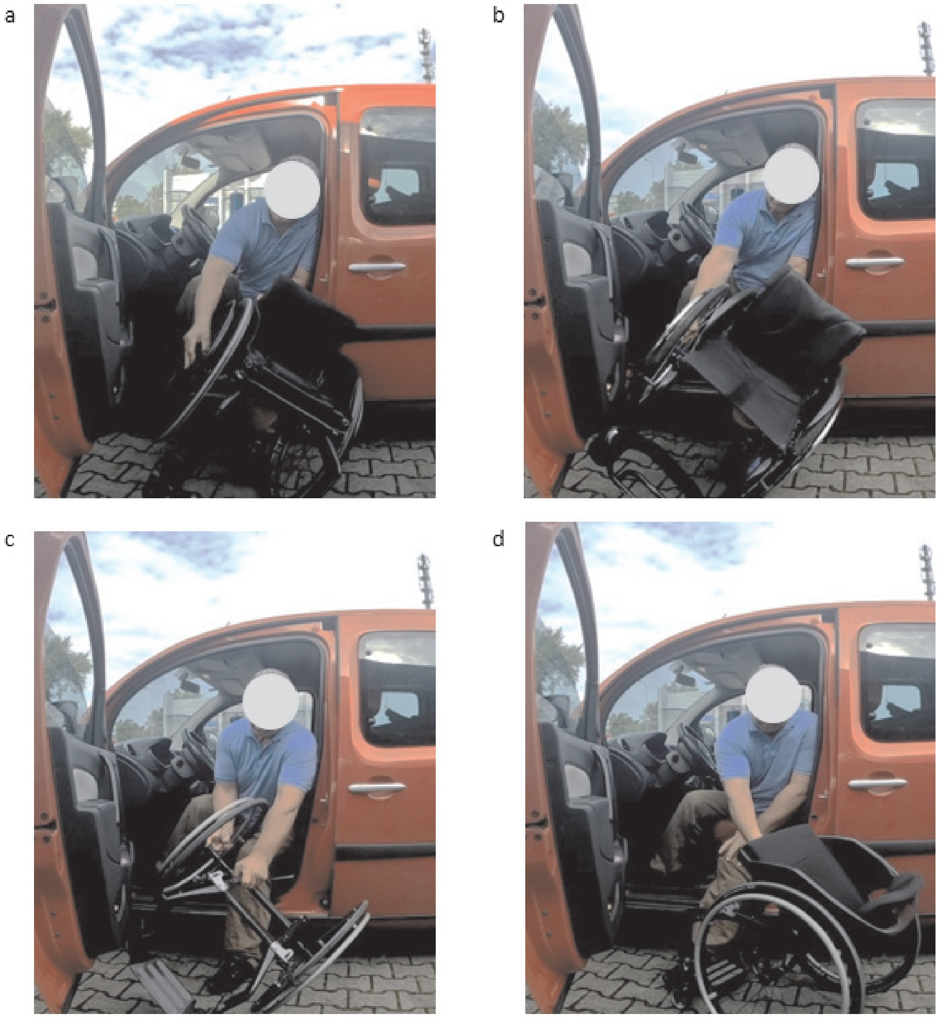

Fig. 9. Attaching the wheels when the male research participant gets off the vehicle: a – wheelchair no. 2 (M2out), b – wheelchair No. 3 (M3out), c, d – wheelchair No. 4 (M4out)

Source: Own study

When analyzing the procedure of the male research participant exiting the vehicle while independently loading the wheelchair, particularly in the test variants M2out, M3out, and M4out, several significant observations come to light:

1.Changing the type of wheelchair did not alter the task completion time. The total time of getting out of the vehicle is the shortest for wheelchair No. 2 because it is the participant's wheelchair.

2.Differences were observed in activities related to frame manipulation (grabbing the frame, carrying it outside, and first positioning to attach the wheel), respectively wheelchair no. 2 – 8.7 s, wheelchair No. 3 – 10.8 s and wheelchair No. 4 – 12.5 s.

3.Smaller differences in times were observed for moving, positioning, and attaching the wheels (Fig. 9), which amounted to wheelchair No. 2 – 14.6 s (6.7 + 7.9 s) for wheelchair no. 3 – 18.0 s (8.0 + 10.0 s) and for wheelchair No. 4 – 24.6 s (9.2+15.4 s). In the latter case, a noticeable problem was the frame's low mass, and the force applied too high when positioning the frame and attaching the wheels.

Discussion

Many factors affect the process of self-loading a wheelchair, such as the design of the car's entrance door (Petzäll 1995), the height of the car's seat relative to the wheelchair's seat (Koźma *et al.* 2016), and the cabin's interior size (Sydor and Zabłocki 2006). The self-loading and unloading of a wheelchair when entering and exiting a vehicle is primarily influenced by the physical characteristics of the disabled person rather than the wheelchair type. Comparing the manipulation times of new wheelchairs with participants' existing ones reveals that the new wheelchair design requires the development of new motor habits, including element arrangement, activity sequence, and muscle force application.

The observations suggest that the presence or absence of suitable handles on wheelchair components significantly impacts unfolding, folding, and manipulation efficiency. This was particularly notable in wheelchairs No. 3 and 4. Wheelchair no. 4's ability to separate the seat resulted in a more balanced distribution of the wheelchair frame's mass, reducing transfer time to and from the car and requiring less physical effort from participants. This statement is confirmed in the literature. Zabłocki and Sydor (2006) analyzed the processes of self-loading and unloading the wheelchair and found that the most challenging component to place in the car is the wheelchair's frame due to its relatively large weight (4-6 kg) and dimensions.

The innovative, unusual design of wheelchair No. 4 makes it difficult for male participants to load or unload from the vehicle. There was considerable variability in the times of particular process phases for male participant. In contrast, female participant showed less variability in times. The most critical factor is the design of the wheelchair, the possibility of its disassembly, and the weight and overall dimensions of individual components. The new design of wheelchair No. 4, compensates for this challenge in self-loading with a more even distribution of mass among its components.

Conclusions

Independent driving is indispensable in fostering mobility, autonomy, social engagement, employment prospects, and well-being for active disabled individuals who utilize wheelchairs. It represents a powerful force for positive change in their lives. The literature review discusses advancements in vehicle adaptations for disabled drivers, highlighting the integration of advanced technology solutions to enhance safety and the overall driving experience. It also explores the methods wheelchair users employ when entering and exiting vehicles, identifying two standard techniques. During the experiment, getting into a car and loading a wheelchair independently, took from 48 to 74 s; getting out of the vehicle – from 56 to 86 s.

The primary focus of the experimental research presented in the article is to assess how the design of modern active wheelchairs influences their susceptibility to self-loading into a car. This addresses a gap in existing studies. The experimental study conducted yielded the following observations and conclusions:

1. The method of entering and exiting a vehicle while independently loading and unloading a wheelchair is significantly more dependent on the physical characteristics of the disabled individual than on the type of wheelchair utilized.
2. A comparison of the manipulation times for the components of new wheelchairs with the results obtained for the study participants' existing wheelchairs demonstrates that the novel wheelchair design necessitates the development of new motor patterns (arrangement of elements, sequence of actions, and muscle force utilized).
3. The placement or absence of appropriate handles on wheelchair components is crucial for the efficiency of unfolding, folding, and maneuvering the wheelchair (as observed during testing with wheelchairs No. 3 and 4).
4. The ability to detach the seat from wheelchair No. 4 resulted in a favorable distribution of the wheelchair frame components' weight (a mere 130-gram difference between the frame and the seat). This positively impacted the minimization of physical effort for those conducting the test.
5. The considerable variation in time durations observed during the activities performed by the male study participant was primarily attributed to differences in the design of the tested wheelchairs. This participant exhibited exceptional physical strength. In contrast, the female participant's performance exhibited less significant variability. The enhanced design of wheelchair No. 4, while increasing the time required for loading into the vehicle for the male participant, was positively compensated for by a more uniform distribution of mass among its components, which benefited the female participant.

In light of this experimental study's findings, it is feasible to propose practical design guidelines for active wheelchair manufacturers and enterprises specializing in adapting passenger cars for wheelchair users:

1. Evaluate the merits of detaching the seat from the frame to facilitate effortless transfer and manipulation, particularly for individuals with limited upper body strength.
2. Propose user-friendly manipulation means, such as intuitive and ergonomic handles and mechanisms for unfolding, folding, and maneuvering the wheelchair components, specifically designed for loading into the vehicle.
3. Design a spacious area between the steering wheel and the driver's body to enable unobstructed transfer of wheelchair components.
4. Provide secure storage compartments within the vehicle for folded or detached wheelchair elements, such as tie-down points and blocking areas for disassembled wheelchair components.

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Appendix

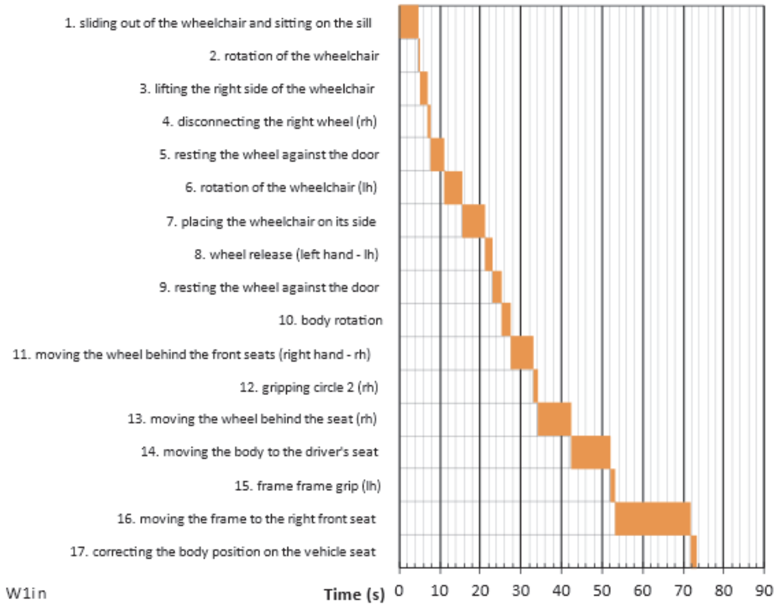

Fig. 10. Independent entrance of a woman with wheelchair no. 1 into a vehicle (W1in)

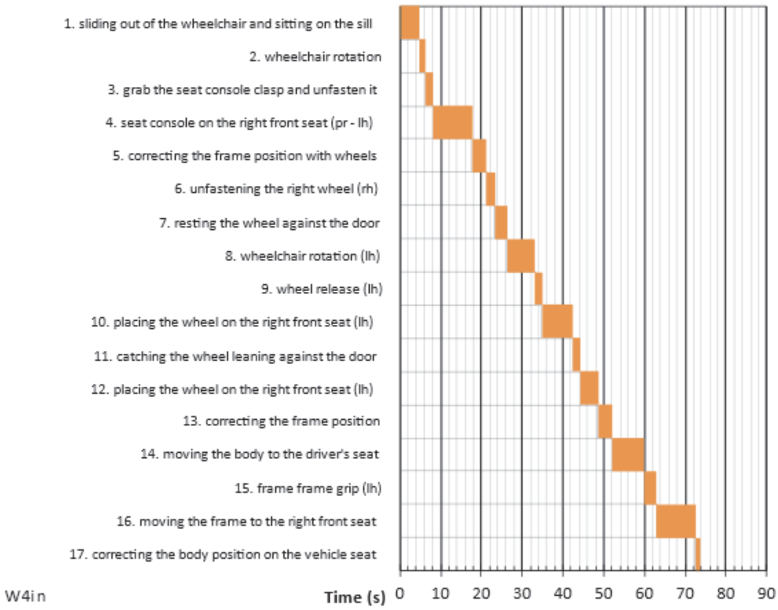

Fig. 11. Independent entrance of a woman with wheelchair no. 4 into a vehicle (W4in)

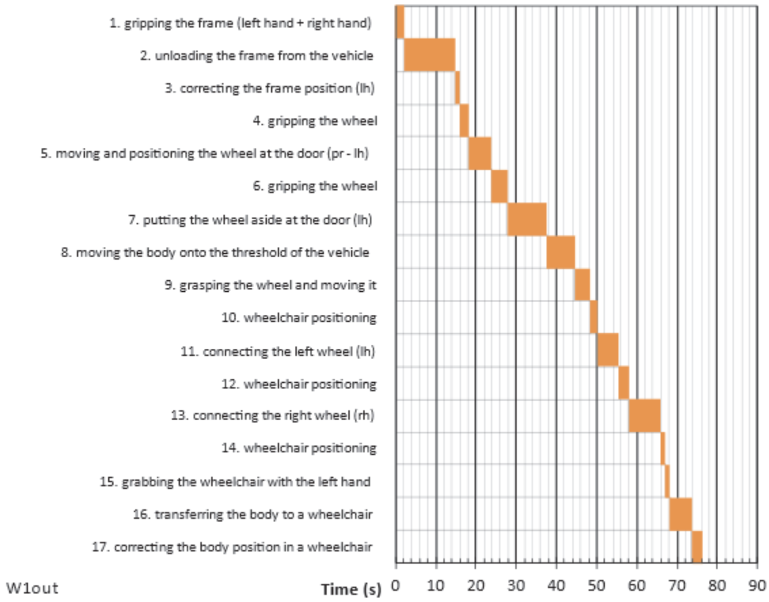

Fig. 12. Independent exit of a woman with wheelchair no. 1 out of a vehicle (W1out)

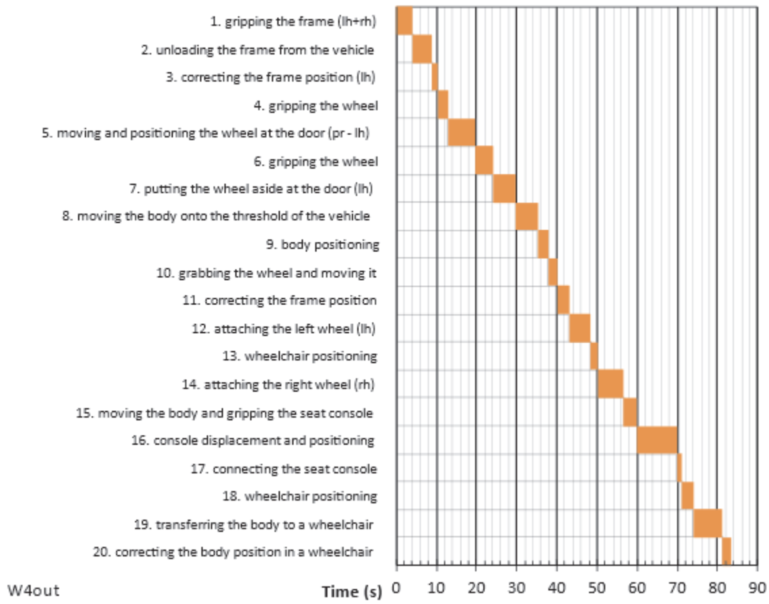

Fig. 13. Independent exit of a woman with wheelchair no. 4 out of a vehicle (W4out)

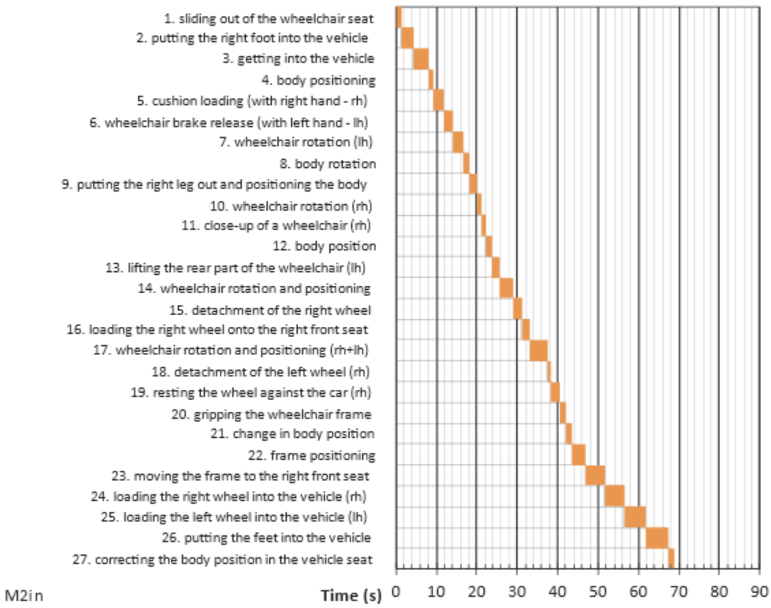

Fig. 14. Independent entrance of a man with wheelchair no. 2 into a vehicle (M2in)

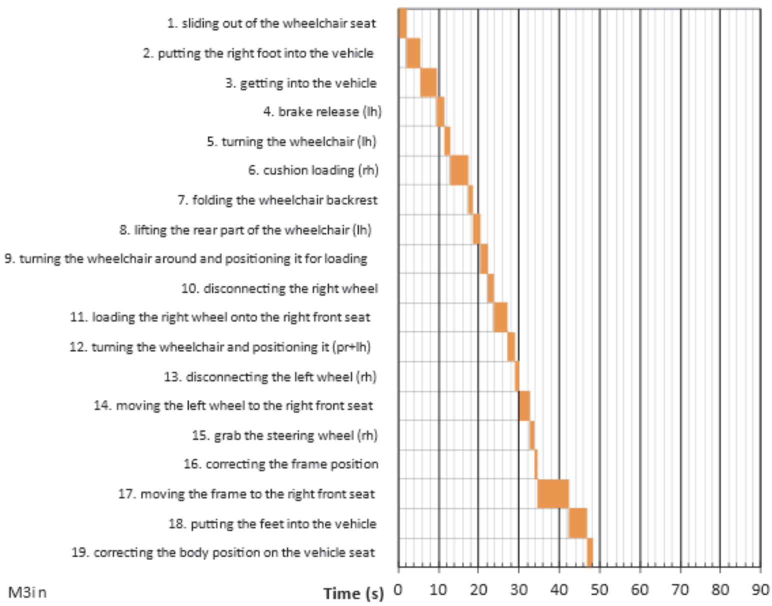

Fig. 15. Independent entrance of a man with wheelchair no. 3 into a vehicle (M3in)

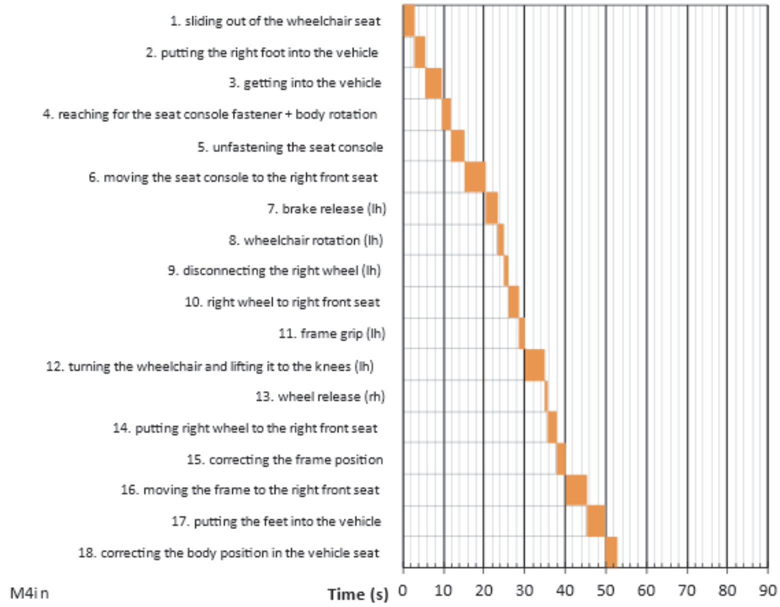

Fig. 16. Independent entrance of a man with wheelchair no. 4 into a vehicle (M4in)

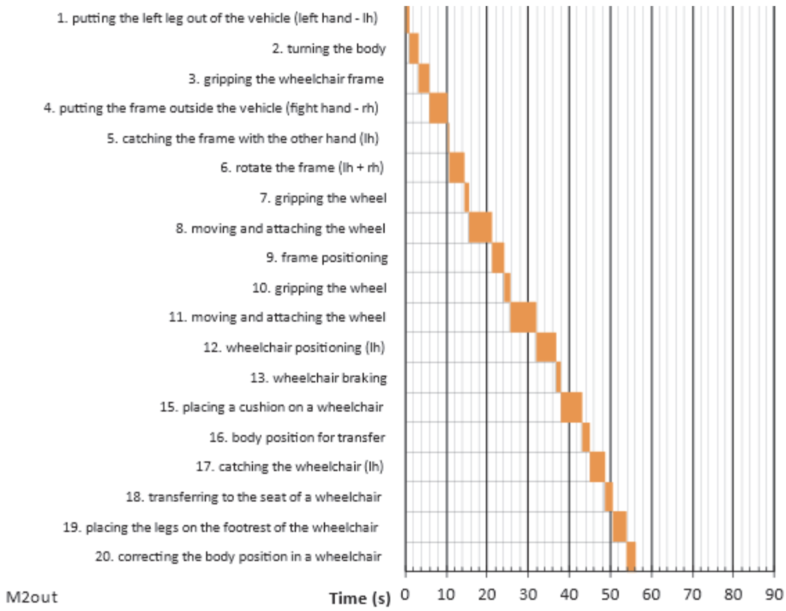

Fig. 17. Independent exit of a man with wheelchair no. 2 out of a vehicle (M2out)

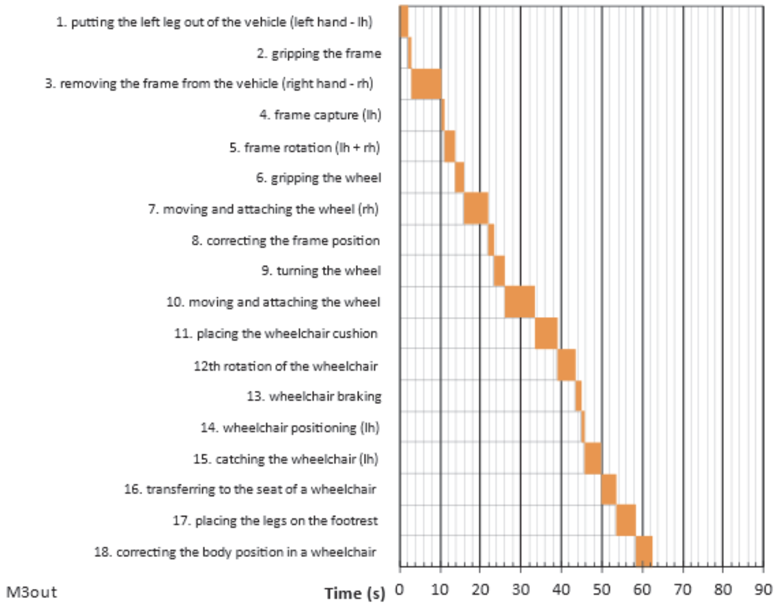

Fig. 18. Independent exit of a man with wheelchair no. 3 out of a vehicle (M3out)

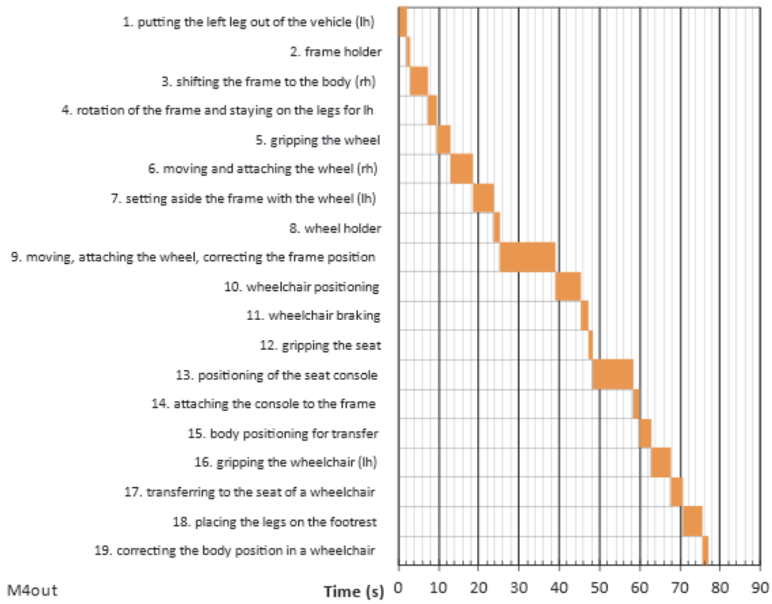

Fig. 19. Independent exit of a man with wheelchair no. 4 out of a vehicle (M4out)