

The Role of Ergonomic Handrails in Inclusive Public Transport: User Aspects, Accident Risks and Design Guidelines [†]

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Abstract

Inclusive design is not a design framework provided by legislation, but a design strategy that takes into account the diversity of abilities of users. Ensuring the mobility of people with disabilities is central to their social inclusion, which is why accessibility standards have been developed. Some elements of this are costly (e.g., low-floor vehicles), but simple and cost-effective solutions can make a significant difference in inclusive public transport. This paper uses qualitative methods—interviews, case studies and literature review—to illustrate one of the problem areas, the difficulties of grabs, and one of the potential areas for improvement: grab rails. In non-crash accidents, properly designed handholds play a key role in preserving the integrity of passengers and in creating a sense of physical/psychological safety, contributing to intuitive and independent use and to the social sustainability of public transport.

Keywords: inclusive design; ergonomics; grab handle; public transport; non-collision accident; accessibility; user experience; universal design



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1. Introduction

Inclusive design of public transport is one of the most pressing societal challenges of our time, aiming to ensure that all users, regardless of their abilities, can travel safely and comfortably. One of the most important components of physical accessibility for wheelchair users is the use of threshold-free passageways, ramps and lifts, but equally important should be the design of handholds on vehicles, be they bar-like elements, handles or support surfaces. Inadequate handholds are not only an inconvenience but also a serious risk of accidents, especially for elderly passengers, people with reduced mobility, handicaps or temporary handicaps.

The aim of this study is to identify who and how they are hindered in using their hands, to highlight the need for inclusive design of handholds in public transport, to review the current regulatory environment, to present user experiences and to make recommendations for further improvements.

2. Inclusive Design, Universal Design and the Role of Handles

The concept of “Universal Design” was introduced by Ronald Mace, the idea being that every object and service should be usable by as many people as possible, regardless of their physical abilities, cultural background or intellectual capacity. Inclusive design [1] is

particularly important in public transport, where travel is not optional but a fundamental human right, enshrined in the UN CPDR Convention [2].

The CPRD states that “A person with a disability is any person who has a long-standing physical, mental, intellectual or sensory impairment which, together with a number of other barriers, may limit his or her full, effective and equal participation in society”. In Hungarian legislation, this is provided for in Act LXII of 2013 amending Act XXVI of 1998 on the rights of persons with disabilities and ensuring their equal opportunities. Unfortunately, anyone can become disabled as a result of an accident or illness [3].

According to the Central Statistical Office (2023), 273,558 people with disabilities were registered in the 2022 census and 639 000 people declared that their health condition severely limits their ability to carry out daily activities [4]. This therefore includes people with ‘normal’ health problems in old age that limit their activities of daily living (joint problems, mobility problems, dementia, etc.). The number of people aged 75 and over was 807,191 according to the 2022 census. The same number was 485 837 in 1980, 576,472 in 1990, 618,606 in 2001 and 730,305 in 2011, showing a strong upward trend. Although, according to the same statistics, the number of people with disabilities seems to have halved since 2001, the data collection and categorisation has also changed.

Article 9 of the agreement, signed by 147 countries, sets out the obligation to take appropriate measures to ensure access to transport for people with disabilities, both for new facilities and vehicles and to remedy deficiencies in existing infrastructure. However, it is not only our legal obligation, but also our social responsibility as intellectuals that drives us to contribute with our proposals to a more inclusive world [5].

During our research, we conducted several semi-structured interviews with people living with disabilities. We selected subjects of different ages and genders who had disabilities and health problems that were relevant to our research (female, 30 years old, syndactyly; female, 71 years old, rheumatoid arthritis; female, 32 years old, carpal tunnel syndrome; male, 51 years old, hand injury with a long recovery period; male, 41 years old, wheelchair user, lower limb paralysis).

We have explored the focus areas where we see potential for improvement in public transport with an inclusive design approach, given that it affects the majority of passengers and falls into a very modest category in terms of cost: grab rails and handholds. The ergonomic design of handholds reduces the risk of accidents and increases the comfort of the journey, which can promote independence, while at the same time improving the social support for public transport [1].

2.1. Hand Strength and Grasping

Older people, people with hand problems or people with reduced mobility may find it challenging to clamber on public transport, increasing the risk of accidents and injuries. Without being exhaustive, the following health problems may be included:

- Rheumatoid arthritis—an autoimmune disease that can deform the fingers and wrists and severely limit the ability to grasp objects (about 30,000 people in Hungary)
- Multiple sclerosis (MS)—an autoimmune disease that can lead to muscle weakness, limb tremors and coordination problems (10–12,000 people)
- Other autoimmune hand deformities
- Degenerative diseases of the rotator cuff (prevalence in the population over 40 years ranges from 6.8% to 22.4% and increases with age)
- Post-stroke condition, which causes loss of grip strength, hemiplegia and coordination problems (in Hungary there are about 35–40,000 new cases of stroke every year, and the mortality rate due to stroke is 10–12,000)

- Peripheral nerve damage—muscle weakness, numbness, often caused by diabetes, alcoholism, infections (e.g., Lyme disease)—numbers are difficult to estimate
- Raynaud’s syndrome—blood vessel network problems due to cold (clinically significant cases estimated at 1% of the adult Hungarian population)
- Carpal tunnel syndrome (CTS)—tingling, weakness due to compression of the median nerve (usually between 1-5% of the adult population)
- Parkinson’s disease—tremor, muscle stiffness, slow movement and deterioration of fine motor skills (18–20,000 people in Hungary)
- Sarcopenia—loss of muscle mass in old age, one of the main causes of loss of grip strength in old age (increases significantly with age: prevalence reaches 30% in people over 65 and up to 50% in people over 80)
- Limb and shoulder injuries (161,099 cases of upper limb injuries referred to a GP in 2018) [6]
- Other relatively rare diseases and disorders associated with the hand:
- Syndactyly—a congenital adhesion of the fingers of the foot and hand (about 5–7000 people in Hungary)
- Radioulnar synostosis—congenital adhesions of the forearm bones (rare, with a few cases per year in Hungary)
- Facioscapulohumeral muscular dystrophy—FSHD, which can also affect the shoulder (incidence 12/100,000 people)
- Inclusion body myositis—inflammatory muscle disease (prevalence 5–6/100,000 persons)
- Multifocal motor neuropathy (MMN) (a rare, immune-mediated peripheral neuropathy with a prevalence of about 0.6/100,000 people)

In medical practice, the Jamar[®] dynamometer is used to measure the grip force of the hand, the so-called strong grip, and is an accepted reference instrument in biomechanical studies (e.g., Mathiowetz et al., 1985) [7]. During measurement, the thumb is placed opposite the other fingers—this ranges from 392–588 N in healthy men and 196–343 N in women. The dynamometer cannot measure the force of the so-called monkey grip. Hand grip strength is also used as an indicator of mobility, and low grip strength has been associated with cardiovascular disease, diabetes, cognitive decline and increased risk of death.

Difficulty in getting around affects the above-mentioned members of the population and the elderly, not to mention those who are hindered by luggage or other reasons. And a study on passenger behaviour using image analysis highlights the increased passenger-mobile device interactions and the consequent reduction in the use of handholds. Designers could anticipate this change by developing body support devices on board vehicles that can be used not only by hand, but also by elbow or body, to help passengers with hand problems [8].

2.2. Behavioural Psychology Factors

An Australian study in behavioural psychology and ergonomics investigated patterns of grab rail use and people’s choices in public transport, and found that grab rails have a significant impact on passengers’ experience and tolerance of crowding. In particular, safe, hygienic and evenly distributed grab rails were preferred [9].

Handrails provide not only physical support but also psychological security. Especially for older people or people with reduced mobility, the presence of handholds increases self-confidence and reduces anxiety during the journey. Some people automatically look for a handhold the moment they board the vehicle, while others only hold on when they perceive a real emergency (e.g., sudden braking). It could be investigated whether anxious

or stress-sensitive passengers choose a handhold differently from those with a higher risk tolerance.

In general, passengers prefer handrails placed at eye level or above, as they require less effort to use and allow a more natural posture. Horizontal handrails placed on their sides are often more comfortable and feel safer, especially when making sudden movements or stops.

Congestion, vehicle movement and the behaviour of other passengers influence which handholds individuals choose. For example, if a handrail is already occupied or difficult to reach, passengers will seek alternative solutions, even if they are less comfortable or safe, or prefer not to grab on to avoid touching others. This is particularly true for handholds placed around the head, where the hand hangs into the other person's personal space.

3. Design Requirements for Handholds in Public Transport

The design of handrails is governed by a number of international standards (Table 1), including the Americans with Disabilities Act (ADA) Accessibility Specifications for Transportation Vehicles), the European TSI and UNECE R107 [10].

Table 1. Comparison of international standards.

Standard	ADA	TSI PRM	UNECE R107
Section of the handrail	not only circle	circle	not only circle
Size of the section	31.75–38.1 mm	30–40 mm	no dimension of the section shall be smaller than 20 mm or greater than 45 mm
Knuckle clearance from the nearest adjacent surface	38.1 mm	45 mm	40 mm
Other requirements	Eased edges with corner radii of not less than 3175 mm	Handrails and other objects must not have sharp edges. All handholds must be of a color that contrasts with the background.	The surface of every handrail, handhold or stanchion shall contrast visually with their immediate surroundings and be slip-resistant.

1. Cross section profile, dimensions for optimum grip and adhesion
2. Spatial position—who is reaching, what body and hand position is being grasped?
3. Grip length—how much space is there for the fingers of the hand?
4. Use of materials to optimise grip (microstructure)
5. Surface structure to optimise grip (macrostructure)
6. Cleanability (disinfection, as in COVID)
7. Manufacturability
8. Mountability
9. Resistant to high forces in case of impact and vandal-proof
10. Rounded, rounded shapes, which cause less damage in the event of impact
11. Selection of colours
12. Direction/amount of adjustment, etc., for flexible handholds
13. Items 1, 2, 3, 9, 10, 11 of the above list are covered in more detail or tangentially by regulations (e.g., TSI).

4. Accessibility Examples from the Field of Transport Infrastructure

4.1. Accessibility Costs for the Reconstruction of the M3 Metro Line in Budapest

According to an official press release from BKK, the renovation of the M3 metro line, to be completed in 2023, will cost HUF 225 billion. Although the original plan was that only 12 stations would have been accessible, all 20 stations of the entire metro

line were made fully accessible, and the related pedestrian underpasses and the relevant transport intersections were also made accessible. For five underground stations, the cost was 3,549,000 MSEK, which, incidentally, involved a very clever technical solution, the installation of a slant lift in place of an escalator, which could be installed at a quarter to a fifth of the cost of conventional lifts, and which had proven European references [11].

The average cost of accessibility for stations below the surface is cca. 500,000 MFt, while for the underground stations it was around 750,000 MFt, i.e., for the whole project a total of cca. 11,400,000 MFt, which is 5% of the total cost. It should be noted here that accessibility includes not only lifts but also standardised handrails next to the stairs, tactile guide rails on the walking surface and other devices, of which the retrofitting of lifts was clearly the most expensive [12].

In addition, predictions and experience from professional organisations show that lifts are regularly used not only by wheelchair users and people using walking frames, but also by pregnant women, people with prams, small children, medium and large dogs (e.g., guide dogs), people with large luggage, people with temporary mobility limitations due to accidents (e.g., with walking shoes, crutches) and older people. The accessibility of the M3 metro is therefore an example of inclusive design.

4.2. Elevators at the Tatabánya Railway Station

In the framework of MÁV's accessibility project, three new lifts were built at Tatabánya railway station in 2024–2025, two of which provide access to the platforms and one to the P+R car park. The tower structure of the lifts was erected in one piece above the tracks, and the construction took just over a year. The lifts are of vandal-proof and fail-safe design, and the walls and doors are also partly glazed. Thanks to their spacious design, they will also be suitable for transporting bicycles or prams, and their installation will increase travel comfort at the station, according to MÁV's communication material. In addition, the renovation included the replacement of the glass cladding of three staircases, corrosion protection, tactile guide rails and the replacement of the platform cladding. The investment was financed from MÁV's own resources of HUF 1 billion [13].

It should be stressed that both of the above investments involved major railway infrastructure built 40–50 years ago, with major structural interventions. While the accessibility of a new-build passenger transport project is much better, there are also situations, such as monuments, where accessibility is not feasible at all, as the protection of the built heritage does not allow it.

4.3. Additional Costs of Low-Floor Vehicles

The low-floor design of the vehicles is primarily for accessibility, but also for faster and safer passenger exchange, which improves operational efficiency. The production costs of these vehicles are higher than for conventional vehicles, in particular for running gear and propulsion. Low-floor trams are prone to increased wheel wear, which also results in faster wear of the track [14].

MAN built the world's first 100 percent low-floor tram in 1990. Initial teething troubles were overcome with various technical solutions (e.g., serpentine motion with double articulation, narrow internal cross-section with brain motors), and by the mid-1990s more and more European cities were opting for low-floor trams. The turnaround came with the entry into force of the TSI PRM (Technical Specifications for Interoperability—Persons with Disabilities and with Reduced Mobility) in 2008, which made accessibility mandatory in the EU for railway systems. "In 1980, the price of a six-axle articulated trolley was around one million Deutschmarks, while a GT6N (AEG's low-floor tram) with a similar

capacity cost four million Deutschmarks in 1995. And even then, the business was not always profitable and transport companies had to dig deep into their pockets.” [15].

Although low-floor vehicles and some infrastructure elements require a significant financial investment, as they are the alpha of accessibility, without them the vast majority of transport services would be unusable for people with disabilities, or would be so only with significant limitations.

4.4. Cost Analysis of “Universal Design” from the Perspective of a Norwegian Study

A Norwegian publication from 2011 analyses the costs of 13 different bus transport measures specifically related to inclusive design: seating and lighting in covered bus shelters, regular snow clearing at bus stops, raised kerbs next to the bus, and the role of different types of information, etc., on a cost/benefit basis. These are included in the analysis because they affect as many passengers as possible, including those with physical disabilities, cognitive difficulties, fear or uncertainty, etc.; i.e., they do not focus on specific solutions (wheelchair ramps, braille).

The study found that passengers were more positive about these solutions than previously assumed, meaning that they should be given priority in the future. For example, a bus stop with seating already generates a positive net value for 5000 passengers per year (14 passengers per day), whereas previously the lower limit was set at 25,000. The conclusion of the article is that inclusive design measures are likely to be socially profitable even in urban environments where public transport use is minimal. It points out that the calculation of the cost/benefit ratio must also take into account indirect social benefits and that certain solutions (e.g., lighting at stops) make public transport more attractive in general.

5. Non-Collision Accidents on Public Transport

Several summarising studies have been carried out on this type of accident over decades (1985–2015) and point out that it is difficult to draw clear conclusions due to the different circumstances/evaluations. For example, the articles do not discuss whether the accident occurred on low or high floor vehicles, which understandably distorts the statistics on take-offs and landings [16].

However, in terms of injury mechanism, it is strongly reported that acceleration, but mostly deceleration, led to injury on public transport (average risk of falling in a moving vehicle 0.3–0.5 per million UAH), and in the vast majority of cases, the injured were travelling standing. A significant proportion of injured passengers had luggage in one or both hands at the time of injury. This is also supported by the vehicle dynamics of public transport, with a typical acceleration for a bus of around $1.2\text{--}1.5\text{ m/s}^2$, a more severe service braking of $2.0\text{--}2.5\text{ m/s}^2$, but in the case of emergency braking this can be as high as $4\text{--}5\text{ m/s}^2$, which is a challenge for a young man of small stature and prepared at the moment of braking. And accidents involving take-off and landing are less frequent, especially since the advent of low-floor vehicles [17].

6. “Hand-Made” Innovation—Development Objectives

Accident statistics, research in behavioural psychology and changing social circumstances are all prompting us to call for further improvements in grip devices. At present, the PRM TSI, for example, sets out certain parameters (diameter, spatial positioning, etc.), but already states in its introduction (point 10) that “In order to keep pace with technical progress and encourage modernisation, innovative solutions should be encouraged and their introduction should be made possible under certain conditions” [18]. Although there are a number of standards for buses (e.g., UNECE R107), experience in the country shows

that there are some advanced, some average and some particularly poor solutions, even for new vehicles, although they all meet the standards [19].

Our aim is to develop ergonomically optimised grip prototype(s) for use on public transport, with a particular focus on the needs of users with grip strength loss, hand problems or cognitive impairments and the use of mobile devices during travel, which has become common in recent years. The development of the prototypes will be based on the background research presented in this article, further interviews, and analysis of national and international examples.

The design of handholds can be analysed (e.g., in terms of surface quality, cross-section, shape, etc.) and categorised in an exact way. Based on this analysis, we would like to propose several design proposals for both vertical and horizontal handholds, as well as for handholds with non-fixed positions, and evaluate the different versions by comparative analysis. The retention strength of the handholds can be measured and tested, but anthropometric characteristics, health status, and other factors (e.g., sweating or fatigue of the hands during the tests) should be taken into account when evaluating the results.

The trials are planned to involve ten participants, who will be a heterogeneous group in terms of age, physical abilities and functional capacity: young and old, disabled and people with hand problems. In a first step, the grip strength of the participants will be measured with a Jamar[®] dynamometer, and then tests will be performed with static and dynamic forces of different intensity/direction with prototypes of left and right hands, which differ in their parameters and design.

We could also use integrated pressure sensors to measure the strength and location of the grip (ergonomic grip pressure mapping). In addition, sensors could be used to obtain information on the most frequent grip areas on vehicles, the duration of contact, the surface area and the periods of most intense traffic. And using a sensor/video analytics hybrid, the data obtained can be used to optimise handrail placement, allowing designs to be adapted to passenger needs. Moreover, this data can also play an important role in improving the efficiency of sanitation protocols. Following the test, participants complete a standardised questionnaire that asks questions on comfort, form-fit and psychological safety on a 5-point Likert scale. In addition to laboratory tests, we also aim to conduct real-world tests, with in-vehicle sensor and camera data collection, to explore the actual usage patterns and environmental context of handrails. Similarly, Tešić et al. [20] demonstrated through the FUCOM–FUZZY MAIRCA model that structured, data-driven evaluation frameworks can enhance transparency and decision quality in human-centered systems, aligning with the integration of sensor-based feedback and digital analytics proposed in this study.

The aim of the study is to explore the shape and surface of handholds that provide adequate grip and safety for passengers with different abilities. The results could help to develop grab rail systems that will provide greater accessibility and usability in future public transport [7,21].

There are many analogies to the design of handles in other areas, such as tools, sports equipment, gun handles, and there are situations where a single parameter or innovative solution can be crucial to the outcome. For example, the thickness of the grip on tennis rackets, which varies on an 8-degree scale according to the size of the hand, not to mention the material of the grip bandage. Analogy analysis can also provide a number of lessons—such as the shape of the rib, cross-section, etc.

7. Conclusions

In summarizing, the adoption of the UN CRPD Convention and the subsequent introduction of accessibility standards for public transport vehicles and infrastructure in recent decades has changed the accessibility of public transport for people with disabilities

in the European Union. The most important step in this direction is wheelchair accessibility, which makes life easier for a much wider range of users, but also involves significant investment in national economic terms, as the examples show.

There are several factors that justify the fact that passenger handling and/or body support on public transport requires further development and innovative solutions with an inclusive design approach, at almost negligible cost. Qualitative methods—interviews, case studies, literature analysis—were used to formulate recommendations for user-centred improvements. The research highlights the physical and psychological safety-enhancing effects of handholds and emphasises the importance of alternative forms of restraint and sensor-based enhancements. The proposed solutions contribute to the social sustainability of public transport.

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