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Small-scale Studies on Evacuation Characteristics of Pedestrians with physical, mental or age-related Disabilities

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Small-scale Studies on Evacuation Characteristics of Pedestrians with physical, mental or age-related Disabilities

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ABSTRACT

Evaluation of evacuation process is common separated by two phases: pre-movement and movement-phase. Individual capabilities of pedestrians have an impact on both and therefore on the time required for safe escape. In view of evaluating the evacuation process, characteristics of realistic movements of pedestrians involved are needed, but so far such data are mainly available for individuals with unrestricted evacuation capabilities only.

Due to the lack of available data, parameter studies in an assisted living for people with disabilities were performed to explore the movement during evacuation. Preparation times for assistance (n=10), unimpeded walking speeds (n=34) depending on the assistance devices in the plane as well as walking speeds on stairs (n=11) were focussed.

Time to prepare an assistance device for utilisation depends significantly on the kind of device type. Further on, practical experience in handling the devices for assistance has an impact on the preparation time. In contrast to the results of the preparation times, any relation on assistance devices were investigated for the unimpeded walking speed in the plane. A remarkable decrease of walking speed on stairs was observed which is independent from the utilised assistance device.

The presented data improve and extend the insufficient engineering data base and raised up questions regarding the complexity of considering pedestrians movement with impairments in evacuation planning.

KEYWORDS

evacuation; human behaviour; egress; disabilities; pre-movement phase; movement phase; preparation time; unimpeded walking speed; walking on stairs; need for assistance

NOMENCLATURE LISTING

10MWT	10 metre walking test
ASET	Available safe egress time
$dist_{landing}$	Resulting walking distance on landing /m
gap_{width}	Gap between two stairs /m
r	Radius semicircle /m
RSET	Required safe egress time
SiME	Safety for people with disabilities
$stairtread_{width}$	Width of a stair tread /m
$v_{landing}$	Velocity on landing /ms^{-1}

INTRODUCTION

Reliable data of pedestrians' movement in infrastructures are required for a proper evaluation of egress in case of emergency. Due to the complexity of infrastructures, performance-based building regulations become relevant to predict the available safe egress time for providing an appropriate level of safety [1, 2]. Significant research has been carried out into investigating pedestrians' movement and human behaviour of evacuating occupants (see [3] for a comprehensive overview). Due to the challenges in organisation and regarding to financial limitations, most of the studies analyse the movement of young and unimpaired participants. Thus, the studies do not represent the real society with a wide variety of individual disabilities. This fact will further increase as the World Health Organisation estimates that 15 % of the world's population is on ageing [4] and live with some form of disability. This amount will increase in the future due to ageing and global increase in chronic health conditions. Currently there is a lack of comprehensive data for pedestrians with physical, mental or age-related disabilities [5]. For this purpose, comprehensive parameter studies on the individual behaviour in an appropriate home for people with disabilities were conducted. The objective of the study on small-scale is to observe the individual evacuation capabilities involving the needs of assistance and to analyse the individual movement behaviours of people with physical, mental or age-related disabilities through controlled video studies. The preparation time for assistance, individual unimpeded walking speeds and walking speed on stairs were performed.

METHODS

In the following we provide an overview of the conducted experimental research on evacuation behaviour involving individuals with disabilities, including the participant recruitment for the studies.

Participants recruitment

Due to the limited number of varying multiple disabled participants, a configuration of participants based on suitable single disabilities was improper. Gear the challenging individual characteristics towards the real life, we focused on voluntary participants and did not take any classification into account. All participants are characterised by multiple disabilities regarding mentally, mobility and aged disabilities with essential need for assistance in daily life (see Tab 1).

Tab 1: Description of the individual characteristics of the participants. Letters help to distinguish individuals.

Age	Frequency	Characterisation (Identifier)
$0 < a \leq 40$	2	Walking and cognitive disability, including spasm, evacuation incapable (Impaired B); unrestricted participant without disabilities (Unimpaired B)
$40 < a \leq 60$	4	Two participants with restricted physique and cognition, limited evacuation capabilities (Impaired D, Impaired F, Impaired G); participant without impairments (Unimpaired A)
$60 < a \leq 70$	2	Participant with restricted physique in a wheelchair and mental disability (Impaired A); participant with limited walking abilities with walking frame (Impaired H)
$a > 70$	2	Participants with age-related disabilities and walking frames (Impaired C, Impaired E)

In total, ten participants aged between 21 and 71 years including two unrestricted study participants without any disabilities have taken part in these studies investigating the egress time (Fig 1). The cooperating association Lebenshilfe Bergisches Land supports participation of people with disabilities in working life including accommodation and has chosen suitable participants with disabilities for the studies on evacuation behaviour. Participation was voluntary for everybody and a cancellation without any negative consequences at any time was possible. Three participants were limited in contractual capability. For those cases, participants and their legal representatives agreed the participation.

For participation all attendees have been paid 25 € per half day. Only anonymous data were used for the experiments. The ethics committee of the University of Wuppertal (Germany) has approved the conduction without any ethical concerns.

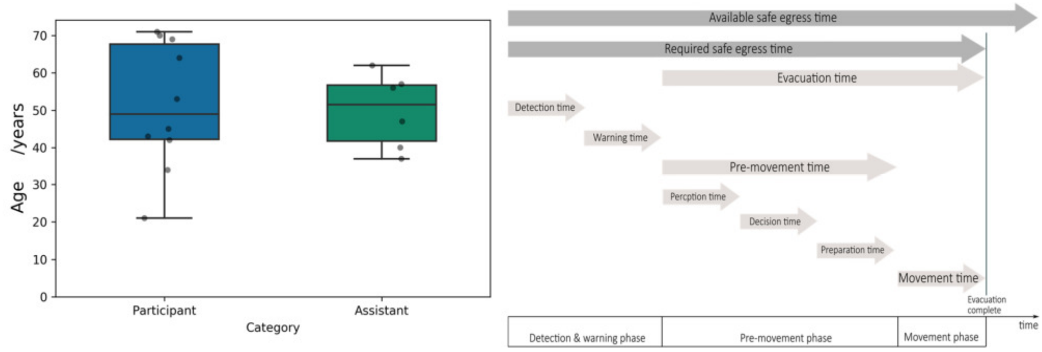

Fig 1. Ageing characteristics of participants and assistants (left) and engineering timeline (right).

Setting and data collection

We focussed the preparation time for assistance, the unimpeded walking speed and the (average) walking speed on a stair depending on assistance for investigation. Studies were captured by high definition cameras. The collected video data was synchronised by time and used to extract the preparation and movement times of the participants.
Firstly, the preparation time for repositioning from lying in bed to sitting in wheelchair was determined. In addition, changeovers from one wheelchair to wheelchair and evacuation chair were observed. Considering preparation as most important part of the pre-movement time (Fig 1, right) for people with disabilities, the objective was to measure time requirements for prepare an assisted or an autonomous evacuation. Start and end of preparation runs were defined by a reference point on the floor near the door (Fig 3 (b)). Two assistants were involved and changed after two conducted runs. Performed actions were spoken aloud by the assistants, recorded and documented.

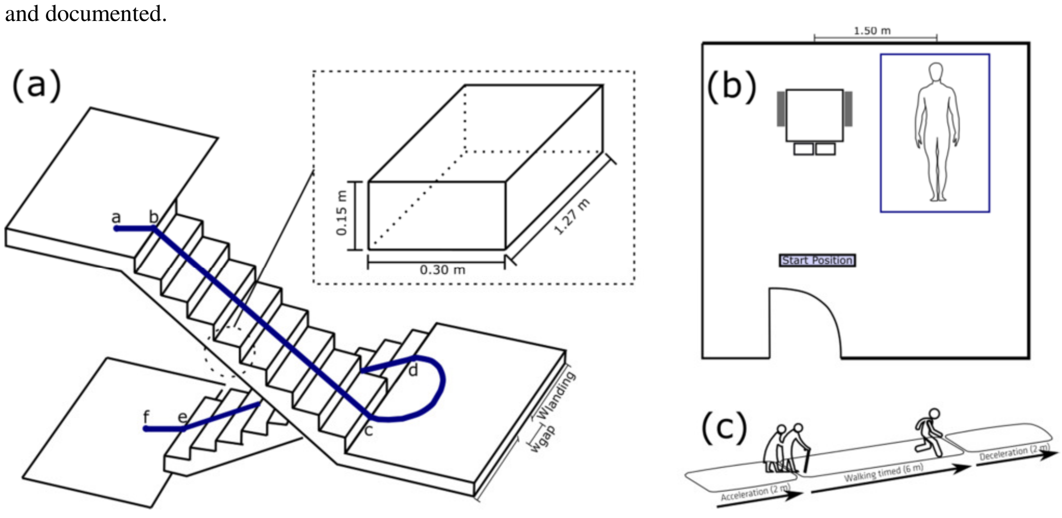

Fig 2. Sketches of the studies on movement on stairs (a), preparation time (b) and unimpeded walking speed (c). Note that the length of the measurement area in the 10MWT has been modified to 5.6 m.

Secondly, the unimpeded walking speeds (v_0) depending on the kind of assistance device (evacuation chair, wheelchair and escape mattress) were measured. A well-documented, clinical measurement method [6] for walking speed over a short time – called 10 metre walking test (10MWT) – was used. Participants were instructed to walk a distance of six meters while the time was measured. For acceleration and deceleration additional space was given, which was not included in the measurement (Fig 3 (c)). The distance covered is divided by the time it took the individual to walk that distance. Due to a technical camera shift, the length of the measurement area in the 10MWT has been modified to 5.6 m for analysis.

Thirdly, movement on stairs (Fig 3 (a)) was observed for using the evacuation chair and escape mattress. Both stair sections have nine steps respectively with a tread width of 0.30 m and a riser height of 0.15 m. The result in the diagonal yields 3.02 m width gradient angle of 26.6°, which is decisive for the sliding speed on steps. The width of the stair treads was 1.37 m, as measured between the handrails on either side. The path of the emergency staircase turns anticlockwise in descent. Four video cameras were used to record the movement on stairs. One camera was installed in front of the stairs on the upper floor, another above the landing area and two cameras on the lower floor from frontal and lateral perspective. To distinguish movement on stairs and movement on landings, both parts were considered separately.

For calculation of the velocity on stairs the walking distance between the points *b* - *c* and *d* - *e* was considered. Movement on the landing between the points *c* - *d* was estimated by the circumference of a semicircle. The resulting walking distance on landing ($dist_{landing}$) is calculated by Eq 1.

$$\mathrm{dist}_{\mathrm{landing}} = \pi r \qquad \text{(Eq 1)}$$

Two assistants were involved in every run and switched the positions after one run.

RESULTS AND DISCUSSUION

Resulting preparation times, (individual) unimpeded walking speeds in the plane and walking speeds on stairs are presented and discussed in the following.

Studies on preparation of assistance

The required preparation times are presented in Fig 4. Overall, we measured mean preparation time of 68.8 ± 66.0 s in a wide range from 15.1 s up to 253.4 s. Starting from lying needs less preparation time and has a less variance for preparation (33.3 ± 15.6 s) than starting from seating (83.4 ± 78.5 s). Repositioning of participants to the evacuation chair is more difficult. The temporal range for the participant Impaired A is 18.0 s. An improvement over time caused by training in the assistance can be detected. The participant is raised, then moved into a stable position by hugging one of the assistants, afterwards rotated and finally positioned on the evacuation chair. For this run, the movements are executed one after the other, which leads to shorter preparation times.

Examining the kind of assistance, long preparation times using the escape mattress are striking (between 138.0 s and 254.0 s). While preparation using an evacuation chair or a wheelchair takes less time than approx. 60.0 s, utilisation of an escape mattress took more than 120.0 s for preparation (Fig 3, right), which applies for disabled and non-disabled participants. Analysing the captured videos it is emphasised that handling of this kind of assistance device is not intuitive for the staff and the usage was not known. It took a lot of time to prepare the escape mattress for usage. Assistants had difficulties fixing the participant on the mattress in the process. Furthermore, the proper method for turn the participants lying in an escape mattress was unknown by all associates. It has shown that it is useful to rotate the participant sideways on bed, so that the participant can be placed on the escape mattress in shorter time.

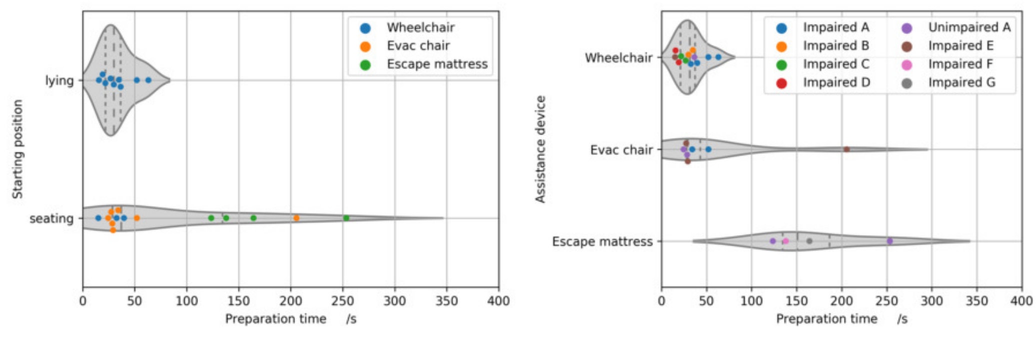

Fig 3. Preparation times depending on starting position (left) and type of assistance device (right).

Studies on movement in the plane

Unimpeded walking speeds of participants are presented in Fig 5. Overall a mean walking speed of 2.01 ± 0.49 m/s (0.76 up to 2.69 m/s) was measured. Unimpeded walking speed is high influenced by individual abilities and boundary conditions (like age, gender, health status, motivation, facility, familiarity, day time) [7, 5]. Recommendations in the order of 1.20 m/s are embedded in international design codes [8, 9]. Wide variations (0.3 m/s up to 2.5 m/s and higher) in the walking speed of non-disabled pedestrians are well documented [3, 5, 10]. Take pedestrians with disabilities into account leads to comparable ranges and variations of unimpeded walking speeds (0.23 m/s up to 1.95 m/s) [11].

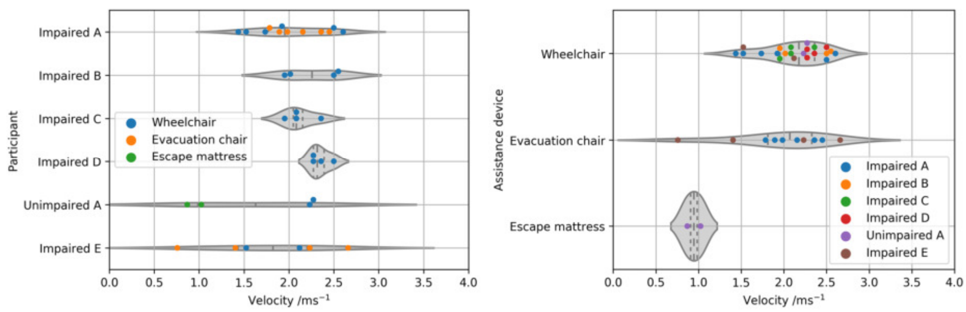

Fig 4. Unimpeded walking speed depending on participant (left) and assistance device (right).

As shown for the preparation times, a slower movement is striking out, if the escape mattress is utilised (Fig 4, right). Pull the mattress over the ground is the principle of movement using this assistance device. In consequence the speed depends on friction and there is a high demand on physical strength to move on. The unimpeded walking speed depends on the person moving the wheelchair or evacuation chair. The type of impairments (participant) does not affect the unimpeded walking speeds.

Studies on movement in on stairs

Walking on stairs was investigated by a lot of researchers during the last decades with focus on quantitative (e.g. walking speed) and qualitative (e.g. merging, overtaking) aspects (see [3] for a comprehensive overview). Walking without any disabilities and without assistance devices downstairs leads to decreased walking speeds in a scale of 0.30 to 0.70 m/s (e.g. [12 - 15]) because of the increased complexity of movement, the impact of individual strength and stamina. Unimpeded walking speeds on stairs depending on the assistance device are presented in Fig 6. Overall a mean walking speed on stairs of 0.38 ± 0.07 m/s (0.24 up to 0.46 m/s) and a mean walking speed on the landing stairs of 0.17 ± 0.06 m/s (0.09 up to 0.29 m/s) was measured. For comparison, Hunt et al. [16] measured walking speeds in a (significantly longer) stairwell for an evacuation chair (0.83 ± 0.04 m/s) and rescue sheet (0.67 ± 0.15 m/s). Walking on the landing between the two stairs is more widely distributed. This is caused by manoeuvrings because of the untrained usage of the assistance devices.

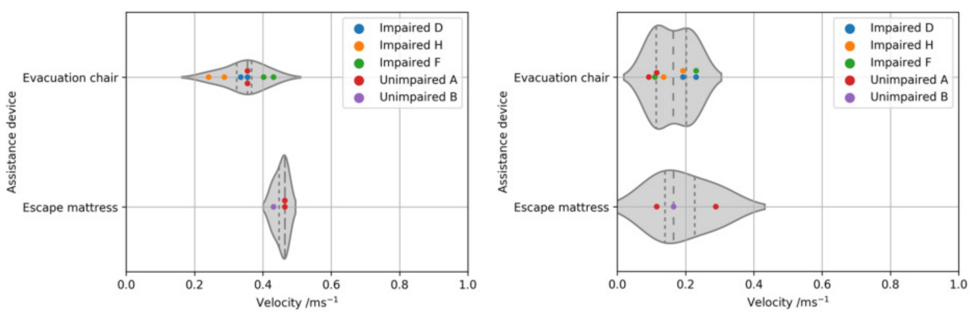

Fig 5. Walking speed on stair (left) and walking speed on landing depending on assistance device (right).

The evacuation chair is used for people who are not able to walk down the stairs. The sliding system of the evacuation chair provides a braking effect on the steps. This braking effect is achieved by the interaction of the weight of the evacuated person with the pressure, which is exerted by the assistance in the direction of steps. Downstairs one assistant is sufficient and overtaking is possible (but rarely observed [17]). Carry handles should be mounted behind the armrests for a better balance.

SUMMARY

Parameter studies under laboratory conditions on the pre-movement and movement phase in an assisted living for people with disabilities were performed. Preparation times, unimpeded walking speed in the plane and moving on stairs were focussed. The time to prepare an assistance device depends significantly on the kind of device. Small difference between starting position lying or seating was observed. Practical experiences in handling the devices for assistance have a positive impact on the preparation time. Our studies show the distribution of unimpeded walking speeds and the dependence of the assistants moving the wheelchair or evacuation chair. The movement does not depend on the assistant device but on the capability of the pusher. As expected, a significantly decreased walking speed on stairs was observed, which is independent from the utilised assistance device. Manoeuvrings caused by the large and unwieldy escape mattress leads to slow walking speeds on the landing. The large variety of impairments (of which we have investigated a small sample only) and the diversity of assistance devices make it difficult to obtain general movement characteristics. Even though the small sample size of participants, the studies improve the insufficient engineering data base leading to the conclusion that the training of the assisting person in proper usage of the assistance devices has a significant impact on pre-movement and movement-phase.

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