Collective Dynamics

Older Adult Stair and Walking Speeds from Controlled Trials as Inputs into Simulations of Retirement Home Evacuation

Bronwyn Forrest[1] · **Karen Van Ooteghem**[2] · **Bryn Jones**[3] · **John Gales** [4] · **Elizabeth Weckman** [5]

[1] University of Waterloo, Department of Mechanical and Mechanical Engineering, Ontario, Canada,
E-mail: be2forre@uwaterloo.ca
[2] University of Waterloo, Department of Kinesiology and Health Sciences, Ontario, Canada,
E-mail: kvanooteghem@uwaterloo.ca
[3] Conestoga College, Department of Building Sciences, Ontario, Canada,
E-mail: bj2jones@uwaterloo.ca
[4] York University, Department of Civil Engineering, Ontario, Canada,
E-mail: jgales@yorku.ca
[5] University of Waterloo, Department of Mechanical and Mechanical Engineering, Ontario, Canada,
E-mail: beth.weckman@uwaterloo.ca

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Abstract This work aims to add to the current database of human movement data, specifically, 3-step descent speeds from controlled trials of typically aging older adults (n=212, aged 60-99) with and without mobility impairments. To explore the impacts of model input parameters, stair and walking speeds obtained from controlled trials are used to simulate demonstrative Canadian retirement home egress scenarios with Pathfinder. Analysis of descending step speeds reveal interesting trends and key inter-population variations. Moreover, when the step and horizontal walking speeds determined from these controlled trials are used as inputs into the illustrative egress simulations, a difference in predicted egress outcomes are seen compared to when model defaults are used. Together, the findings indicate important egress considerations for a vulnerable population.

Keywords Stair speeds · older adults · retirement home simulation

1 Background and Motivation

Population demographics are shifting towards a more advanced age in many countries around the world, and simultaneously, efforts are moving towards creating a more accessible built environment for all. As such, it is imperative that databases utilized for design and modelling of human movement are revisited to determine if the values are appropriate and representative of the current population trends. Specific to the context of fire safety, advanced age has been identified as an important factor when determining the risk of being involved in a fatal dwelling fire [1, 2]; however, aging brings upon a natural decline in cognition and physicality, which can also be accompanied and/or exacerbated by comorbidity such as disease, illness and injury which may add complexity to the task of evacuation in a variety of scenarios. With respect to movement, research has shown that gait becomes less automatic with age, and thus requires more cognitive resources [3, 4], which can add demands to everyday walking [5]. Older adults form a vulnerable part of the population that requires additional consideration. Despite this, it has been found in a recent study that there is a gap between the movement data provided in design curves and the data collected from evacuations in retirement facilities, highlighting that design curves do not adequately account for older adults with mobility impairments [6]. It was identified that there was little existing data available on movement speeds of people with disabilities and older adults. As such, studies have focused on the horizontal and stair speeds of older adults and people with mobility impairment [6–12]. Mean and ranges of descending stair speeds reported in the literature for older adults (age>50) and people with a mobility impairment (aged 20-85) demonstrate a high degree of variability within these populations. Detailed compilations of stair movement speeds reported in the literature can be found in [6, 10, 13]. This work builds upon existing efforts and parses out several human factors[1] that impact descending speeds on stairs. Illustrative modelling scenarios utilizing assigned movement speeds from this database are compared to the SFPE default movement speeds embedded in Pathfinder [14]. The hope is that these descending step speeds taken together with the assessment and analysis of the horizontal movement speeds given in [15], form a strong data set which will add to the robustness of the current movement speed databases that are utilized by researchers and practitioners alike in design and modelling applications of older adults.

2 Methods

Participants The cohort used in this secondary analysis consisted of 212 typically aging older adults (aged 60-99; n=68 males and n=144 females) residing in Ontario, Canada. The data were collected as part of a larger assessment of functional fitness which included controlled 7.62 m walking trials, ascending and descending steps. The participants lived in a continuum of care setting designed to accommodate those living independently in a condominum, through to retirement and long-term care; wherein level of care-taking, nursing and housekeeping services are provided to varying degrees based on the health

[1] Other factors such as effects of the environment on movement speeds are not examined in this work.

and functionality of the resident. Most of the participants included in this analysis were living in retirement care. Some participants used a mobility aid for walking in daily life (i.e. a cane or walker). With respect to the analysis presented, a participant was deemed an 'aid user' if they used their aid during the 7.62 m walking trials [15]. The study was approved by the University of Waterloo Research Ethics Board and all participants provided informed consent for use of their data prior to participation in the study. Tab. 1 summarizes the pertinent demographics of the participants; F and M denote females and males respectively.

Age Group	Mean Age	Sex	Aid Use
60-79	76 ± 3	F, n=13; M, n=8	F, aid n=3; F, no aid n=10 M, aid n= 4; M no aid n=4
80-89	85 ± 3	F, n=95; M, n=37	F aid n=43; F, no aid n=52 M, aid n=13; M, no aid n=24
90+	92 ± 2	F, n=36; M, n=23	F, aid n=23; F, no aid n=13 M, aid n=12; M, no aid n=11

Table 1 Summary Demographics of Participants in Stair Trials

Controlled Trials Participants were asked to ascend and descend 3 steps in their preferred fashion. Their strategies for ascent and descent, along with the time it took to complete the 3 steps were recorded. Strategy in this case refers to the use of the handrail, handrail and their cane, or no assistance. Due to the evacuation scenario chosen, only descending step speeds were utilized in the model simulation and presented here. Step descent speeds were calculated based on the time taken to descend and the horizontal distance travelled (taken as 0.9m, based on Ontario Building Code stair requirements and measured distance of 3 residential steps in Ontario). Open source statistical computing software, R, Version 4.2.1 [16] was used to complete the statistical analysis. Homogeneity of variance and normality was assessed with the Levene and Shapiro-Wilks tests respectively ($P<0.05$). Independent t-tests and a two-way between groups ANOVA were used to assess statistical differences, and as all groups were non-normally distributed, the non-parametric Mann-Whitney U and Kruskal-Wallis tests were conducted respectively. Statistical significance was set at $P<0.05$[2].

Simulated Occupants In order to represent a Canadian retirement home facility, distribution of occupants based on age, sex and living arrangement used in these simulations were taken from data provided by Statistics Canada [17, 18] [3]. To assign a representative number of people who are aid users, the relative proportion of aid use was taken from the entire database from the aforementioned study [15], as 53% aid users and 47% non-aid users. Therefore, the number of residents in the scenario was set as 35, with 25 female, 10

[2]Results of the independent statistical t-tests are reported as t(df)=W-statistic, p-value.

[3]In 2016, 1/3 of seniors living in residences were 85+ [17]; in 2011, of seniors living in residences, 72% were female and 28% male, and 84% of people 85+ lived alone [18].

male; 19 occupants used an aid and 16 did not. In order to account for the heterogeneity within the older adult population, residents were put into a series of groups, each with their own horizontal walking speed and stair reduction factor. Horizontal walking speeds were taken as mean dual-task walking speeds[4] for each respective group as summarized in [15], stair reduction factors were determined as the ratio of descending 3-step speed measured in the controlled trials and 2 steps/s [7] as is default in PathFinder. In each scenario, the residents, staff and visitors were randomly distributed throughout the structure. Visitors and a portion of staff were set to the SFPE default walking range and default stair speed, another portion of the staff (n=13) were set to assist residents, as such, their movement speed was set to match an occupant type. Occupant type and parameters (number of occupant type, walking speed and stair reduction factor) used in the simulations are tabulated below.

	Age: 60-79	Age: 80-89	Age: 90+
F (aid-user)	n=1, 0.63m/s, 0.29	n=7, 0.51m/s, 0.42	n=4, 0.45m/s, 0.37
F (non-aid user)	n=1, 0.72m/s, 0.67	n=9, 0.63m/s, 0.67	n=3, 0.59m/s, 0.67
M (aid-user)	N/A	n=4, 0.59m/s, 0.5	n=3, 0.54m/s, 0.54
M (non-aid user)	n=1, 0.74m/s, 0.84	n=1, 0.81m/s, 0.75	n=1, 0.65m/s, 0.64

Table 2 Occupant Parameters in Egress Simulations

Simulated Scenarios A schematic of a retirement home facility supplied to the authors from colleagues in the UK was used for this illustrative modelling exercise. The ground floor had 9 rooms, the second floor had 12 rooms and the third floor had 9 rooms, for a total of 30 rooms. Three scenarios were modelled: a 'day-time' scenario, a 'night-time' scenario, and a 'night-time + pre-evac.' scenario with pre-evacuation times randomly assigned to each occupant. The pre-evacuation times ranged from 46-186 seconds, which included a range of time to wake to alarm [13]. For each scenario, two iterations on resident movement speeds were run, one with the default movement speeds (2steps/s on stairs, SFPE range for horizontal movement speeds) and one with the assigned parameters for a given occupant type (Tab. 2). In the 'day-time' scenario, the total number of simulated occupants was 88, with 35 residents, 35 visitors and 18 staff, randomly distributed throughout the structure. During the two 'night-time' scenarios, the total number of occupants was 44, with 35 residents and 9 staff. Residents were set to be in their rooms, and staff were randomly placed in gathering spaces throughout the structure. All staff had default movement speeds assigned. It should be noted that movement speeds were kept constant for both sets of simulations and thus changes to speeds over the course of the evacuation due to factors like fatigue and/or exhaustion are not accounted for.

[4] Dual-task is defined as performing a motor and cognitive task simultaneously, for example walking while reading a map. This results in a division of attention and cognitive resources across multiple brain regions, and negatively impacts the performance of both tasks [19].

3 Results and Discussion

Descending Stair Speeds Summary statistics (Tab. 3) and Fig. 1 demonstrate that there is a decrease in mean 3-step descent speed in the 90+ age group, with minimal change to the median between age groups. Independent t-tests reveal that overall the female participants descended steps significantly slower compared to the male participants t(210)=3877, p=0.02. Individuals who do not walk with an aid in daily life are able to descend steps significantly faster than aid users t(206)=8484, p=5.4x10^{-12}. Results of the Kruskal-Wallis test probing effects of sex and aid use, and the interaction between these factors, revealed that within the aid user and non aid user groups, sex did not have an effect. For both sexes, aid use did have an effect ($p<0.05$) and this is mirrored in the means presented in Tab. 4. Participants who use a walker in daily life descend steps slower (0.25 ± 0.14 m/s) compared to those who use a cane (0.28 ± 0.18 m/s). This suggests a key factor: people who use a walker may require extra stability granted by their aid, so when completing a task such as descending stairs that does not facilitate the use of the aid, stability is compromised and thus people take longer to descend. Further, female aid users appear to form a vulnerable sub-group, reflected in the lowest mean (0.24 m/s) and the lowest measured descending step speed (0.02 m/s). Individuals who are able to descend steps unassisted (this would include both aid and non aid users) are significantly faster than individuals who need assistance from the handrail, or handrail and their cane t(207)=3930, 2.2x10^{-4}. Additionally, people who used their cane and the handrail descended much slower (0.23 ± 0.13 m/s) compared to people who just used the handrail (0.34 ± 0.17 m/s), most likely because there are increased coordination requirements for someone manoeuvring their cane, a handrail and the stairs. Interestingly, the majority of older adults used the handrail as seen in the sample sizes in Tab. 5.

	60-79	80-89	90+	Males	Females
Sample size	n=21	n=132	n=59	n=68	n=144
Mean±SD	0.35 ± 0.22	0.36 ± 0.18	0.32 ± 0.18	0.38 ± 0.17	0.33 ± 0.19
Range	0.09 - 0.76	0.02 - 0.91	0.05 - 0.98	0.08 - 0.98	0.02 - 0.91

Table 3 Summary Statistics of Descending Step Speeds, Age and Sex, given in m/s

	M aid user	M non aid user	F aid user	F non aid user
Sample size	n=28	n=40	n=66	n=75
Mean±SD	0.29 ± 0.18	0.44 ± 0.14	0.24 ± 0.14	0.41 ± 0.19
Range	0.08 - 0.98	0.09 - 0.83	0.02 - 0.76	0.06 - 0.91

Table 4 Summary Statistics of Descending Step Speeds, Sex and Aid Use, given in m/s

Fig. 1 demonstrates the heterogeneity and inter-population differences within the older adult cohort, as seen in the large range of descending step speeds, from 0.02-0.98m/s across the entire cohort. Overall, ascending and descending stairs requires more coordination, strength and confidence [20] compared to horizontal walking. Navigating stairs during an evacuation scenario may be a stressful endeavour, especially for someone who has the added complexity of moving with their aid. Stair speeds would most likely decrease further as a result. The mean speeds presented here overlap with speeds reported previously [9–12]. Similar to other studies, this data shows a wide range of movement speeds on steps, which would be expected for individuals with mobility limitations and/or advanced age.

	Aid-user, A	Aid-user, UA	Non aid-user, A	Non aid-user, UA
Sample size	n=88	n=7	n=91	n=24
Mean±SD	0.25 ± 0.12	0.44 ± 0.33	0.40 ± 0.17	0.48 ± 0.17
Range	0.02 - 0.55	0.11 - 0.98	0.06 - 0.83	0.28 - 0.91

Table 5 Summary Statistics of Descending Step Speeds, Aid Use and Strategy, given in m/s. UA and A denote unassisted and assisted descent respectively.

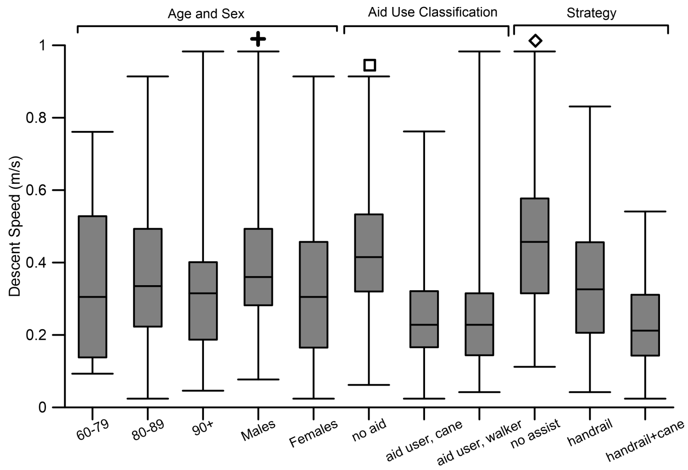

Figure 1 Descending step speeds for various groups within OA population with indicator of statistically different stair speeds between groups. Plus sign: males significantly faster than females; square: non-aid users significantly faster than aid users; diamond: unassisted descent significantly faster than assisted descent.

Predicted Egress Outcomes A convergence analysis and repeat simulations of each scenario were not performed. As such, the summary of the total time to egress from the simulations are given to demonstrate the differences seen and are as follows: 'day-time' assigned=108s, default=67s; 'night-time' assigned=89, default=48; 'night-time + pre-evac.' assigned=274s and default=234. The results of these preliminary simulations show that assigned speeds have a notable impact on the predicted time to egress. A more rigorous modelling exercise (many more iterations using the entire range of movement speeds for each occupant type) with convergence assessment should be carried out and statistical analysis run to provide clearer insights into the impacts of using population specific assigned speeds versus the default range of speeds currently employed.

4 Conclusions and Future Steps

The 3-step speeds presented here, taken with the horizontal walking speeds compiled in [15], indicate that an important determinant in movement speeds of older adults is aid use. This has important implications for crowd flow, particularly on stairs during an evacuation. Ensuring that model input parameters accurately represent these segments of the older adult population is critical in rendering more realistic predicted egress outcomes.

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Ethics Statement These data presented were abstracted from the Heart and Stroke Foundation Canadian Partnership for Stroke Recovery Rehabilitation Affiliates Longitudinal Database, which included individuals recovering from a stroke from multiple rehabilitation facilities in Ontario, Canada. All protocols were approved by the Research Ethics Boards of the participating institutions and all participants provided informed consent. Subsequent approval for use, analysis and distribution of the collected data shown in this work was also approved by the University of Waterloo Research Ethics Board (45472: Modelling fire egress scenarios using human behavior data).

Author Contributions Bronwyn Forrest: Conceptualization, Formal analysis, Writing – original draft / Bryn Jones: Methodology / Karen Van Ooteghem: Conceptualization, Investigation, Data curation, Supervision / John Gales & Elizabeth Weckman: Conceptualization, Supervision

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