Handrails for the elderly: A survey of the need for handrails and experiments to determine the optimal size of staircase handrails

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K. Ishihara, M. Nagamachi, K. Komatsu, S. Ishihara, M. Ichitsubo, F. Mikami, Y. Osuga, K. Imamura, H. Osaki, Handrails for the elderly: A survey of the need for handrails and experiments to determine the optimal size of staircase handrails, Gerontechnology 2002; 1(3): 175-189. Handrails inside and outside of the home are considered useful in assisting elderly people who live independently. We investigated the need for staircase handrails and the optimal dimensions of handrails used by elderly people to ensure their safety and comfort. We distributed a questionnaire to over 2,800 people, aged 60 years or older, living at home. Logistic regression analysis was used to reveal associations between the necessity of handrails for walking up and down stairs and the age and gender of the subjects, as well as the degree of difficulty with which they performed visual activities. We then conducted experiments to determine the optimal size of a staircase handrail. 41 subjects, 63-86 years old, reported how frequently they used handrails inside and outside their homes, and suggested the optimal thickness and height of a handrail, as well as the optimal length of horizontal extensions. Based on our findings, we recommend optimal handrails in Japan to be 33-35 mm in diameter and 670-780 mm high, with horizontal extensions approximately 400 mm long. We also propose a regression model for choosing the optimal height for an individual: $y = 0.294x_1 + 0.188x_2 + 18.63$, where y is the handrail height (cm), x_1 is the body height (cm) and x_2 is the body weight (kg) of the user.

Keywords: handrails, Japan, elderly, stairs

The population of elderly people in Japan is growing. In the year 2000, 17.2% of the population (about 22 million people) were 65 years or older; by 2020, the National Institute of Population and Social Security Research predicts an increase to 26.9% (33 million people)[1]. As the numbers of elderly increase, so will the number of accidents that they have at home. Domestic accidents most frequently occur on staircases. Between August 1992 and March 2000, 10,669 in-home accidents involving housing components were reported to the National Consumer Affairs Center of Japan. Of these accidents, 3,738 (30.5%, the highest fraction) occurred on staircases. Of 322 in-home accidents that resulted in severe injuries, 50 cases (15.5%) took place on staircases; most of these accidents were the result of falling down (72.4%) or overturning (22.6%)[2]. Investigations by the Ministry of Health and Welfare in 1993 showed that 63.8% of all fatal accidents due to falls from stairs or steps concerned people over 65[3].

Handrails are considered a necessity for elderly people to walk up and down stairs safely. Using a force plate, piezoelectric sensors, and a CCD camera, Ohtaki and colleagues analyzed the gaits of elderly subjects walking up and down stairs. The hip joints of subjects angled less when a handrail was used than when it was not, and subjects came to depend on handrails[4]. Thus, handrails continue to be endorsed as useful tools for promoting safety. Five different systems provide the building blocks of the control function for posture and gait: vestibulary system, visual system, somato-sensory system, motor system, and information processing[5]. The effects of aging on the first three systems have been relatively well studied[6,7], whereas its effects on the latter two systems have not been well studied to date.

Vision, which absorbs most outside information, changes with age. Many researchers have reported that visual function declines during aging[8-9]. Because the lens thickens and yellows with age, its flexibility and its ability to transmit light decrease, and light becomes scattered within the eye. Scattered light on the retina reduces contrast, which affects the recognition of objects and faces and the rate at which people adapt to dim lighting. Elderly people's vision is affected by glare that goes unnoticed by younger people; dynamic acuity is diminished by the deterioration of static acuity and eye movement. Hakkinen surveyed the relationship between vision and daily visual tasks, such as reading a newspaper or doing needlework, and discussed the importance of adjusted vision[10]. These studies suggest that visual decline has serious effects on daily life, but few of the relations have been assessed.

The objective of our study was to ergonomically assist older people who endure age-related difficulties in daily living. Comfortable handrails can assist elderly people in balancing and preventing falls. Based on biomechanical tests on staircase handrails, the optimum handrail was suggested as cylindrical with a diameter of 1.5 in. (38 mm)[11]. The optimal handrail height for a North American

Table 1. Number of subjects in age and gender groups.

Gender	Age (years)					
	60-64	65-69	70-74	75-79	80+	Sum
Male	294	345	278	155	161	1233
Female	328	368	304	246	267	1513
Sum	622	713	582	401	428	2746

population was recommended to be 36 in. (91.5 cm)[12]. However, because the body measures of Japanese differs from that of Western people, we determined the optimum handrail dimensions for elderly people in Japan.

In this paper, we focus on the necessity for, and improvement of, handrails to ensure the safety of elderly people in Japan. First, we conducted an extensive questionnaire-based survey to investigate what types of people require staircase handrails. Second, we conducted experiments using a variety of banisters to determine the optimal size of stair railings for the elderly. On the basis of these data, we propose optimal specifications for handrail thickness and height, and for the length of horizontal handrail extensions.

NECESSITY OF HANDRAILS

Methods

Subjects

Subjects were men and women over 60 living in Onomichi City, Hiroshima. At the time of the study, all subjects were living in their homes and were in good health; none were bedridden or institutionalized. We sampled eight different regions of Onomichi City, including an old, densely built-up district, a suburban district, a rather remote area, and an island fishing community. Subjects were recruited by public health workers who visited all healthy older people in the sampled areas[13-15]. The genders and ages of the subjects are shown in Table 1.

For each subject, we collected profile information (e.g., gender and age category),

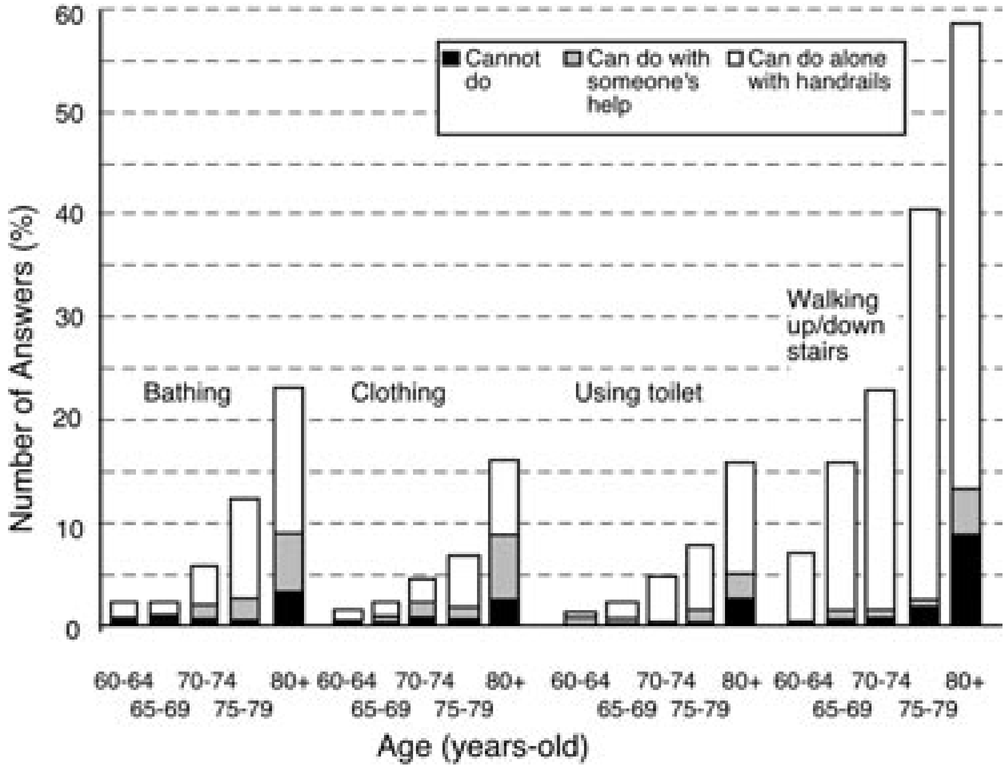

Figure 1. Percentage reporting difficulties with ADLs, by age categories. The necessity of handrails increased with age for all activities. Many subjects remained independent by using handrails, especially for walking up and down stairs.

and recorded responses to the following questions.

Ability to carry out ADL activities

We prepared questions to measure ADLs (the ability to carry out activities required in daily life) independently. We adapted three questions from a study on performing ADL activities alone, with some help, or not at all[16] and assessed the ability of subjects to bathe, dress, and use the toilet. In addition, we asked questions about walking up and down stairs and whether handrails were required. The subjects were asked to respond to each question with one of four answers: can do without handrails, can do with handrails, can do with someone's help, or cannot do.

Visual activities in daily life

To estimate visual ability, we asked subjects how often they had difficulty completing visual activities in daily life. We posed nine questions to investigate several visual functions. Two questions (8 and 9) were based on the results of a simulation that we had devised previously to inquire about yellowed vision[17]. The other seven questions (1 through 7) were adapted from questions that were significantly associated with the measurement of visual function[18]. The questions were: Q1: Do you have trouble reading small print? Q2: Do you have trouble seeing things because they appear hazy? Q3: Does it take time to adjust to bright lights? Q4: Does it take time to adjust to dim lighting? Q5: Are you blinded if light shines into your eyes from the side? Q6: Do you have trouble reading signs or identifying faces while walking? Q7: Do you bump into people or things to your side? Q8: Do you have difficulty telling whether the flame of a gas cooker is on or off? Q9: Do you fail to notice a pedestrian traffic signal until it starts blinking? According to an earlier cluster analysis[18], Q1

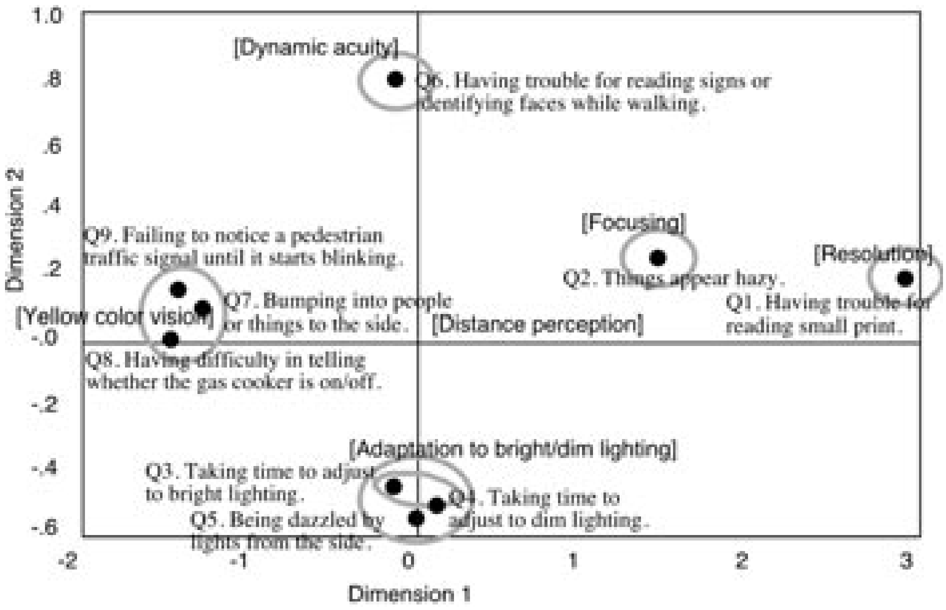

Figure 2. Categorization of visual abilities. The questions were mapped by MDS according to similarities in the answering patterns and classified into six categories (enclosed in gray circles) using a hierarchical cluster analysis.

and Q6 were classified into "resolution" questions together with questions on trouble reading in dim light and trouble reading signs in clutter; Q2-4 were classified into "adaptation" questions; Q7 was a "distance" question together with trouble judging distance of curb, distance of objects, and distance from foot; and Q5 was not classified into any of these categories. The subjects were asked to respond to each question with one of four answers: never, sometimes, often, or always.

Public health workers distributed a questionnaire to each subject at home. If the subject was unable to complete the questionnaire alone, the health worker asked the questions and filled in the answers according to the subject's replies. Responses were collected from 2,826 subjects (1,233 male; 1,513 female; with 80 unfilled).

Results

ADL and age

Percentages of respondents who reported difficulty with each activity according to age are shown in Figure 1. The necessity of handrails increased with age for all activities. Many subjects remained independent by using handrails, especially for walking up and down stairs. Handrail use on staircases dramatically increased for subjects over 75; 38.0% of subjects aged 75-79 years and 45.3% of subjects over 80 could only walk up and down stairs by themselves using handrails.

Visual ability and handrail use

We analyzed the survey data to determine which visual abilities affected daily activities. The questions were classified into six categories according to similarities in the answer-

Table 2. Factors associated with the necessity for handrails in walking up and down stairs (n=2064).

		Coef.	df	$\chi2$	*p*
Age		0.131	1	217.894	<.0001
Sex	Female	0.771	1	38.469	<.0001
Resolution	Sometimes	-0.21	3	4.2	0.2407
	Often	-0.23			
	Always	0.123			
Focusing	Sometimes	0.096	3	1.003	0.8005
	Often	0.217			
	Always	0.031			
Adaptation to bright/dim lighting	Sometimes	0.495	3	13.891	0.0031
	Often	0.647			
	Always	0.468			
Dynamic acuity	Sometimes	0.274	3	6.605	0.0856
	Often	0.282			
	Always	0.699			
Distance perception	Sometimes	0.447	3	5.224	0.1561
	Often	0.23			
	Always	0.952			
Yellowish vision	Sometimes	0.422	3	5.846	0.1193
	Often	0.903			
	Always	0.16			
Pearson			835	830.039	0.5419
Deviance			835	898.651	0.0623
Likelihood ratio			20	430.92	<.0001

ing patterns, using a hierarchical cluster analysis (unweighted pair-grouping by arithmetic means) and multidimensional scaling (ALSCAL). MDS mapping of questions and results of cluster analysis (gray circles) are shown in Figure 2. Our classification results were generally consistent with the earlier data[18]. We assigned Q2 as a focusing, Q6 as dynamic visual acuity, and included Q5 into adaptation. Q8 and Q9 were related each other, as assumed.

We used logistic regression analysis to determine which visual abilities were significantly associated with handrail use. The analysis focused on whether independent subjects (those who were able to walk up and down stairs without help) required handrails. We assigned "0" to responses from independent subjects who answered "can do without handrails" for walking up and down stairs, and we assigned "1" to "can do with handrails". Gender, age, and responses to the questions about visual ability were used as explanatory variables. Ages were pooled into five-year categories and the median value of each category was used as the data point (e.g., 62, 67). Male subjects were coded as 0, female subjects as 1. For questions about visual difficulty, the four possible answers were expressed as three variables; the three responses other than "no" were assigned coefficients indicative of their relationship to the "no" response. The highest value per group of one to three vision questions (see the previous section) was used in the analysis. We also ran a logistic regression using all vision questions as explanatory variables, because the groups did not contain equal numbers of questions.

Factors associated with needing handrails

As shown in Table 2, older subjects, females (both $p < 0.0001$), and subjects who had trouble adapting to bright or dim lighting ($p < 0.01$), tended to use handrails for walking up and down stairs. Dynamic acuity was also related to handrail use ($p < 0.1$). The necessity of staircase handrails was thus related to age, gender and vision, although we could not conclude that the relationship was causal. Subjects who had difficulty adapting to bright or dim light or had an impaired dynamic acuity required handrails on staircases, regardless of whether other factors were involved. Obviously, it is essential to illuminate staircases to eliminate dim areas.

We examined the goodness-of-fit of the logistic regression models described above using the Pearson chi-square statistic, standard deviation, and likelihood ratio. The model fitted the data well: Pearson and deviance indices showed no difference from the saturated model, which was a theoretically induced 100%-fit model containing as many parameters as there were data points[19]. Additionally, the "model" likelihood ratio test showed that the obtained model was meaningful because it differed significantly from one in which all regression parameters were zero[20].

Table 3. Number of subjects in age and gender groups.

Gender	Age (years)					
	60-64	65-69	70-74	75-79	80+	Sum
Male	0	0	3	5	3	11
Female	2	2	9	11	6	30
Sum	2	2	12	16	9	41

FREQUENCY OF USE

Methods

Subjects

We asked all 85 attendees of Yasuura College for the Elderly to cooperate in our research. Forty-one of them aged 63-86 years participated and were paid as subjects. The town of Yasuura, Hiroshima, is a small agricultural village with a population of 13,000. Most healthy elderly people look forward to attending Elderly College, which opens once a month. The most active attendees participate in social dancing; two attendees crawled up and down the staircases because they had bad legs. In other words, most of the healthy older people hope to be a part of society. Ages and genders of these subjects are shown in Table 3.

Questions

We selected the following situations for the questionnaire: walking up the stairs at home, walking down the stairs at home, walking up the stairs in the community hall, waking down the stairs in the community hall, walking up the stairs of a pedestrian bridge or underground passage, walking down the stairs of a pedestrian bridge or underground passage, walking along the hallway at home, walking along the hallway in the community hall. Subjects reported how often they used handrails in each situation by selecting one of five responses: frequently, comparatively frequently, seldom, comparatively rarely, and rarely.

Results

Frequency of handrail use

Figure 3 shows the total number of "frequently" or "comparatively frequently" responses for each situation. When walking up the stairs at home, 36.6% of the subjects reported using handrails "frequently", and 43.9% either "frequently" or "comparatively frequently". Subjects stated that handrails are more effective in going down than in

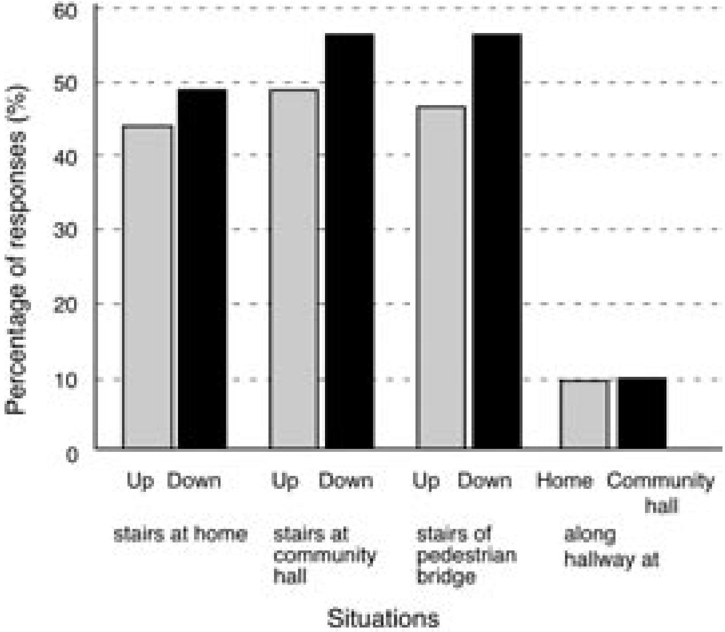

Figure 3. Frequency of handrail use in different situations. The bars show the total numbers of frequently or comparatively frequently responses for each situation.

going up stairs, because knee joints absorb the force of downward steps. While walking down the stairs at home, 41.5% of subjects reported using handrails “frequently”, while 48.8% used railings either “frequently” or “comparatively frequently”. Handrail use did not differ between walking up or down stairs; almost half of the subjects polled used handrails to assist them on stairs.

Falling

Subjects were asked whether they had fallen while walking. Five subjects (12%) aged 71-75 years had experienced falls in hallways or on roads. More subjects (34.2%) reported the experience of being saved from near falls by using the handrail.

PREFERRED DIMENSIONS FOR STAIRCASE HANDRAILS

Our results suggest that older people need handrails to remain independent in daily life. Thus, we conducted three experiments to investigate which handrail optimally assists elderly people in using stairs. Many researchers have studied staircase handrails in the past. Recording the performance of 37 elderly subjects on the stairs in a station forecourt, fifteen percent of female subjects aged 65-69 years complained that the handrail was too high; it was about 85 cm high and 40 mm in diameter[21]. Kose proposed that handrails should be 45 mm in diameter along corridors, 35 mm in diameter along staircases, and 80-90 cm high[22]. Later, they allowed 20 elderly subjects to rate various heights of handrail, and concluded that 800-850 mm was too high: subjects preferred a height that was approximately half of their body height in hallways and about 80 mm lower than that on staircases[23]. On the basis of experiments in which subjects stepped up or down a stair, an optimal diameter for handrails of 37.5 mm was found and a regression model of optimal handrail height for walking up stairs: $y = 1.249x - 82$, where y is rail height (cm) and x is body height (cm)[24] We feel that the obtained height from this regression model is comparatively high; the 12 subjects may have been particularly vigorous, because they were registered members of the Silver Human Resources Centers (job search agency), and they determined their optimal height for a single step to be around 27-30 cm, where they felt a heavy strain if not using a handrail.

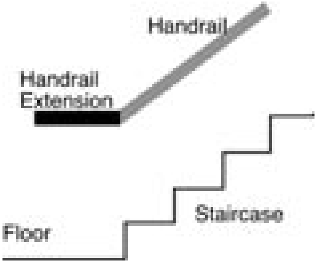

Figure 4. Handrail extension. It continues from a staircase handrail and are level with the floor at the top and bottom of a staircase.

We then conducted experiments to determine optimal dimensions using more subjects who lived in ordinary rural areas. We were interested in the thickness and height of staircase handrails, and also examined handrail extensions, which continue from a staircase handrail and are level with the floor at the top and bottom of a staircase (Figure 4). While walking down stairs, people have to slouch and draw themselves up again to step down onto the floor at the bottom. Because older people tend to remain stooped when they step down to the floor, they are in danger of falling unless there is a handrail extension. Even more dangerous, however, is that if the extension is too short; a person’s hand ends up behind their body because the hand is still gripping the rail. Therefore, we determined the optimal length of handrail extensions.

Methods

Subjects

The same 41 subjects described earlier participated in these experiments. They ranged in age from 63-86 years, with a mean age of 75.4. Men ranged from 151-174 cm tall (mean ± S.D. = 158.9 ± 6.28 cm); women from 130-159 cm tall (145.1 ± 5.63 cm). The Research Institute of Human Engineering for Quality Life (HQL) presented the most current measurement data from 34,000 people across Japan. Men between 63 and 79 years of age ranged from 143-176 cm tall (mean ± S.D. = 159.5 ± 5.69 cm), and women from the same age group were between 132 and 163 cm tall (147.7 ± 5.58 cm)[25]). Male subjects in our study and in the HQL study did not differ significantly in body height, but our female subjects were significantly shorter ($p < 0.05$) than those in the HQL study.

Settings

Experiments were carried out on the staircase of the community hall of the elderly college. We could not install our handrails there because this was a public area. Prior to the experiment, subjects were asked to establish a clear image of their movement by walking down the staircase (45° gradient) from the level of the classroom and then walking up once. After that, we presented the subjects with our handrail samples. Subjects were asked to respond by judging the sample railings as safe and comfortable while thinking about their situation as they walked up and down the stairs.

Handrail thickness

We acquired six banisters of different, commonly used diameters: 30 mm, 32.5 mm, 35 mm, 38 mm, 40 mm and 45 mm. Each banister was 600 mm long. Subjects gripped or held each banister with their dominant hand and described it using one of five categories, from "too thick" to "too thin", in terms of being able to grip it comfortably and safely (Figure 5). Each individual was subject to two sets of trials. Half (n = 20) of the subjects started to rate railings from the thinnest to the thickest first and then from the thickest to the thinnest. The remaining subjects were presented with railings in reverse order; they started from the thickest to the thinnest and then from the thinnest to the thickest.

Figure 5: Experimentally rating the optimal handrail thickness

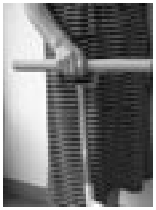

Figure 6: Adjusting the height of the sample handrail

Handrail height

We designed a rail height adjuster using a spring with enough resistance to support a banister 400 mm long and 35 mm in diameter. Each subject gripped only the center of the banister at the distance s/he could use the handrail comfortably and safely, and where the base of the adjuster was positioned firmly on the floor (Figure 6). We confirmed by observations that grip height changed little based on the angle of the banister to the floor, because all subjects settled the adjuster just in front and to the side of their bodies. Each subject repeated the set of trials twice; the subject adjusted the banister from the top down to the height they judged optimal, which was recorded by the researcher, and then adjusted it from the bottom up to the optimal height. We obtained the average of four responses from each subject.

Length of handrail extensions

Subjects walked slowly down the staircase in the community hall. When they stepped down to the floor, they imagined that the handrail was extended horizontally, and they shifted their dominant hand to where they would want the rail to extend in order to feel safe. The observer recorded the distance from the end of the stair rail to the subject's wrist.

Results

Handrail use on staircases

The subjects were observed walking down

and up the staircase prior to the experimental trials. All of them slid their hands along the handrail while gripping it just in front and to the side of their bodies, in preparation for a firm grip in the event of a fall. They placed some, but not all, of their weight on the handrail while walking up and down the stairs.

Optimal handrail thickness

The percentage of subjects that described each of the six handrails as being the "right size" are shown in Figure 7. Twenty-five of the subjects responded "right size" to two or more banisters. For example, 70.7% of subjects rated the 35-mm rail as being the "right size", 26.9% as "thin", and 2.4% as "thick". Most subjects rated the 30-mm and 45-mm banisters as being "thin" and "thick", respectively. Handrails should be thin enough for people who have small hands to be able to maintain a firm grip that can bear their body weight in the event of a fall. The banister diameter corresponding to the 50th percentile from the thickest of banisters rated as the "right size" was 36.0 mm; the diameter corresponding to the 90th and the 70th percentile from the thickest was 32.9 and 34.7 mm, respectively. Therefore, we recommend that staircase handrails for elderly people in Japan be between 33 and 35 mm in diameter.

Optimal handrail height

Figure 8 shows the percentage of subjects that raised or lowered the adjustable handrail. Subjects chose handrail heights between 646 mm and 864 mm (mean = 722 mm) as optimal. Although subjects did not support their entire bodyweight with the handrail while walking up and down stairs, they were required to keep gripping the rail near their body in preparation for a potential fall. For

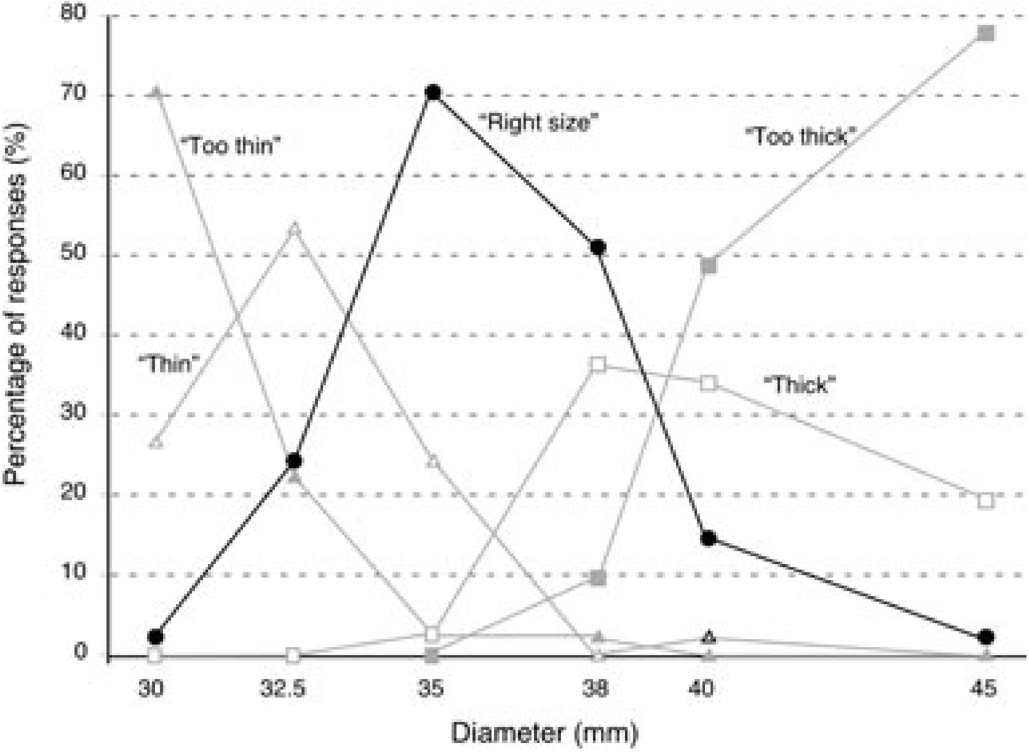

Figure 7. Percentage responses to each handrail thickness. The percentage of subjects that described each of the six handrails as being the right size, thick, too thick, thin and too thin.

this purpose, the optimal height must be based on the elbow height or body height, which are highly correlated. Generally, body heights of the subjects were normally distributed. Thus, we recommend handrails with mean heights (± 1 S.D.) of 666-778 mm as optimal. We assume that the optimal height is little affected by the slope, because the subjects kept their hands close to the body even while walking down the stairs.

Multiple regression analysis to determine optimal rail heights for individuals

Elderly people vary greatly in their individual optimal heights. Staircase handrails in private houses should be installed at the optimal height of the most frequent user. We designed a model to estimate this height according to the body measurements of an individual. Table 4 shows the multiple correlation coefficient (R^2) between the height to which a subject moved the adjustable handrail and his or her body measurements which could be easily obtained: finger thickness while gripping a handrail 35 mm in diameter, hand length, body height, body weight, and distance from the elbow to the floor. The preferred handrail height was significantly correlated with all body measurements, except finger thickness ($p < 0.01$). The height of the subject was highly correlated ($R^2 = 0.911$) to the height of his or her elbow. We designed a multiple regression model that included all the body measurement as independent variables, then we removed variables which contribute very lit-

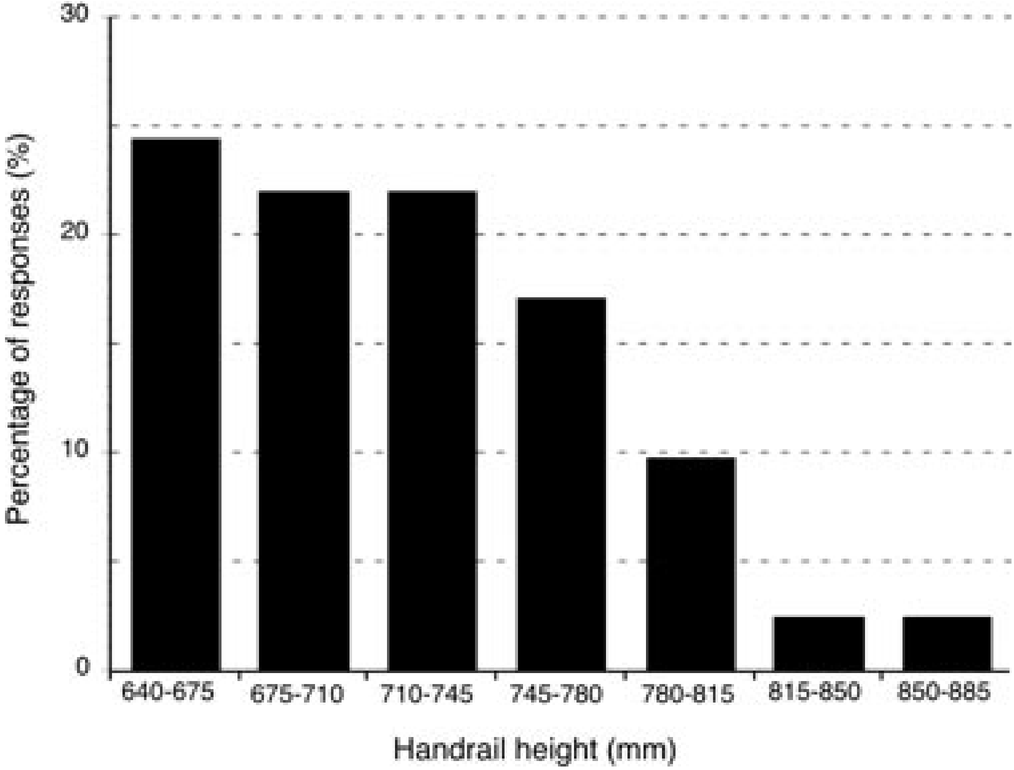

Figure 8. Optimal handrail heights chosen by subjects. The bars shows the percentage of subjects that raised or lowered the adjustable handrail.

tle to the prediction. Then, we obtained the following multiple regression model ($R^2 = 0.6311$) wherein handrail height (y cm) depends on body height (x_1 cm), body weight (x_2 kg), and elbow height (x_3 cm):

$$y = 0.219x_1 + 0.184x_2 + 0.125x_3 + 18.38 \quad (1)$$

In this model, body height was the largest and elbow height the smallest contributor to the estimated optimal handrail height. We then removed elbow height from equation 1 to obtain a simpler model ($R^2 = 0.6290$):

$$y = 0.294x_1 + 0.188x_2 + 18.63 \quad (2)$$

Although the R^2 of the second model was slightly lower than that of the first, heights estimated from equation 2 did not differ significantly from the heights measured in the experiment. When we removed body weight from equation 2, the R^2 of the model fell down to 0.4. Therefore, we consider equation 2 sufficient to predict the optimal height of staircase handrails for individuals.

Body height is a better predictor of optimal handrail height than other variables; the partial regression coefficients for body height and body weight were 0.439 and 0.279, respectively. Because elderly people often put weight on handrails, however, we consider body weight an important predictor in its own right. Thus, our model is more complete than Tokuda's regression model[24], $y = 1.249x - 82$(cm), which used only body height (x) to estimate optimal handrail height. His model suggests considerably higher handrail, because the experimental condition is different from ours as we described above.

Length of handrail extensions

Subjects preferred handrail extensions 150-600 mm long (mean = 401 mm). Although longer rails are easier to use, the average house in Japan is not large enough to accommodate them. Rails that are too short can encourage falling, because the hand that is gripping the rail goes behind the body at the rail end. Thus, we recommend extending staircase handrails by 400 mm ± 1 S.D., or 320 to 480 mm.

CONCLUSIONS

Necessity of staircase handrails

From our survey of over 2,800 elderly people, 21.4% of subjects aged 70-74 years used handrails when walking up and down stairs, as did 38.0% of those 75-79 years old and 41.3% of those over 80. Yanase and colleagues also found that handrail use and subject age were correlated; in their study, about 60% of subjects over 75 years old used staircase handrails[26]. Our analysis using logistic regression showed that older subjects and female subjects uses handrails significantly more. It also showed that visual problems with adapting to bright or dim lighting

Table 4. Correlation between preferred handrail height and body measurements.

	Handrail height	Finger thickness	Palm length	Body height	Body weight	Elbow height
Handrail height	1					
Finger thickness	0.210	1				
Hand length	0.492**	0.589**	1			
Body height	0.581**	0.519**	0.740**	1		
Body weight	0.502**	0.299	0.523**	0.506**	1	
Elbow height	0.560**	0.445**	0.685**	0.911**	0.495**	1

* $p < 0.05$, ** $p < 0.01$

and dynamic acuity were also considerable in necessity of handrails on stairs. Thus, handrails seem to be indispensable to elderly people.

Of our 41 subjects, 65.9% (or 70.8% of those over 75) wanted handrails along stairs, at the toilet, along corridors, and in the bathroom. Only 12% of subjects had fallen while walking (including up or down stairs); however, 34.2% reported being saved by a handrail when they nearly fell. Handrails should therefore be installed both in the homes of elderly people and in public areas.

Optimum diameter of staircase handrails

Thick rails cannot save elderly people from falling if their hands are too small to grip the rail effectively. Handrails 33-35 mm in diameter were preferred in our experiment. The Japanese Ministry of Construction (now called the Ministry of Land, Infrastructure, and Transport) recommends handrails 28-40 mm in diameter in their Design Guidelines of Dwellings for the Aging Society[27] (hereafter called "Guidelines"). Our recommendation is within that of the "Guidelines", although we contend that the maximal diameter, 40 mm, is too thick.

Optimal height of staircase handrails

Subjects seemed to place their weight on the handrails while stepping down. The optimal handrail height ranged from 666-778 mm in our experiments. Because our female subjects were slightly smaller than average elderly Japanese women, we recommend handrails in public areas to be 670-780 mm high. The "Guidelines" recommend a handrail height of 750 mm, which concurs with our suggestions. When installing rails for a specific individual, his or her body height and weight may be used in the regression model equation (2) to determine the optimal height.

Optimal length of handrail extensions

In our study, subjects preferred handrail extensions that were 400 mm in length. A shorter rail increases the risk of falling. The "Guidelines" recommend 200-mm extended rails; if there is enough room, however, a longer rail is preferable.

DISCUSSION AND FUTURE WORK

In addition to staircases, long handrails are often used in hallways. Although we did not investigate horizontal hallway banisters in this study, we assume that they require different dimensions because they are used for a different purpose. The necessity of the staircase handrail was studied through self-reporting subjects in both experiments. Video recordings could be used to determine the actual use of handrails, especially in homes.

The elderly subjects who participated in our experiments to determine the optimal dimensions of handrails were sampled in a farm village in Japan, away from urban centers. In Japan, people tend to be shorter in farm villages than in cities. The body-height data in the HQL data bank[25] were collected mostly in cities; few were collected in villages. The optimal handrail dimensions that we determined in this study may therefore be a little lower and thinner than other researchers have proposed because of our sampling area. In addition, the average height of elderly Japanese men and women is about 5 cm shorter than today's young people. It is necessary to study more subjects from other areas to determine general recommendations for public areas. However, because the populations of farm villages throughout Japan are aging rapidly, we hope that our study will help to maintain the independence of the people living in such areas. Our recommendations for the size and height of handrails, obtained from this study, are currently being used for products distributed by the Matsushita Electric Works. Their effectiveness was confirmed by analysis of the weight subjects put on their legs while walking up and down stairs[28]. Physiological analysis is necessary for further verification of the utility of handrails.

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