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Preferred Handrail Height for Spiral Stairs—A Fitting Trial Study

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Stairways are, in general, a thoroughly studied subject, but there is almost no scientific data available about spiral stairs. They are, however, widely used in homes, industrial sites and public buildings. The purpose of this study was to determine preferred handrail heights for a spiral stairway. The most preferred handrail height for descent was 105 cm. On the other hand, 95% of the participants regarded handrail heights between 95 and 100 cm satisfactory for descending. Participants' anthropometric data was combined with the handrail height preference to develop a draft of a model to predict preferred handrail height for other user populations.

spiral stairs handrail safety usability fitting trial

1. INTRODUCTION

Sanders and McCormick pointed out that stairs play an important role in many accidents at home, at work and leisure activities [1]. Annual societal cost for falls from stairs in the USA alone is over 2 000 000 000 USD, a cost equalling the annual cost of construction of the stair facilities [2].

Descending stairs seems to be more difficult than ascending. Miller and Esmay discovered that only 5% of the accidents occurred when going upstairs [3] (see also Davies, Hopkinson, Lawrence, et al. [4]). Also according to Nagata's comprehensive study (n = 1486) most stair accidents occurred during descending [5]. He found that 78% of male and 92% of female victims of stair accidents had been going downward when the accident occurred. Intermediate results by Sinisammal, Saaranen and Väyrynen also showed this inclination [6]. Fitch, Templer and Corcoran referred to many studies and concluded that stair accidents requiring medical care mostly occurred in descending [7]. Furthermore, Lockwood and Braaksma stated that more severe injuries and deaths resulted from accidents that occurred during descents than ascents, because victims generally fell farther in descent accidents [8]. Svanström found that 18% of the stairs on which accidents had occurred had no handrails [9].

The main purpose of the stair handrail is to prevent loss of balance, to help one regain balance, to help one pull oneself up a stair, or for directional guidance and stability for those with visual and balance deficits. Generally in descent, the hand is slid down the rail in a continuous motion to give the user a sense of security and for some greater postural stability [10]. Archea, Collins and Stahl found that it was quite normal a reaction to a misstep or a fall in descent to grab the handrail [11]. Older stair users often hold onto the handrail for additional stability in both ascent and descent.

Sanders and McCormick identified missing handrail as a common contributing element in many accidents related to stairs [1]. Fitch et al. indicated the role of missing handrails in many stair accidents, especially when the victim has been descending [7]. Svanström emphasized that the stairway should be made sufficiently narrow to allow the use of handrails on both sides [12].

Marletta also found the handrail important as it served to help prevent the initial occurrence of a slip or misstep as well as provided a means of recovery

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for the pedestrian once a fall had been initiated [13]. Properly designed handrails should reduce the incidence and severity of stairway falls [14]. Johnson stated that once a person started falling, there was a little chance that the fall would be arrested unless the person could grab and hold onto a handrail [15]. Maki, Perry and Mcllroy found some evidence that it was possible to grab a handrail and generate sizeable stabilising force very quickly in response to a postural disturbance, even when the hand was distant from the rail when loss of balance occurred [16].

There are many recommendations regarding the handrail height of straight stairs. For example, Chaffin, Midoski, Stobbe, et al. suggested a handrail height of 77.5–83.8 cm [17], Maki, Bartlett and Fernie 91–97 cm [18] and Standard No. EN ISO 14122-3:2001 90–110 cm [19]. Unfortunately, there are no research-based recommendations or guidelines available for the handrail height of spiral stairs.

People fall on stairs because of several factors acting singly or in concert [10]. Some of these accident-encouraging factors result from the way the stair is designed, some from the way it is constructed or maintained, some from the environment in which the stair is set, some from the way in which people use stairs and some from the characteristics of the stair users. The purpose of this study was to determine preferred handrail heights for a spiral stairway used typically in an industrial setting as an emergency exit. By applying this information, safety and usability of spiral stairs can be improved. The results may also facilitate the standardization process of spiral stairways in the future.

2. METHODS

2.1. Fitting Trial

A method called a fitting trial was used. This is an experimental study in which participants use an adjustable mock-up of a product to make judgements as to whether a particular dimension is *too big*, *too small* or *just right* [20, 21]. In other words, a fitting trial is an investigation of the relationships between the dimensions of an artefact and the dimensions of its users. In this case, the artefact was a spiral staircase and the dimension to make judgements upon was handrail height.

A fitting trial is one kind of psychophysical experiment, one in which people make subjective judgements concerning the objective properties of a physical object or events. Prior to this study, Irvine, Snook and Sparshatt [22] used a fitting trial to find acceptable and preferred tread width and riser heights for straight stairs.

Characteristically, it has been found that the range of optima reported in ascending trials (from low to high) is placed higher than the range reported in descending trials (from high to low) [21]. To eliminate this systematic error, half of the participants (those with odd identification number, i.e., 1, 3, 5, etc.) used ascending and the other half descending procedure.

2.2. Spiral Stairway

The radius of the stairway used in the experiment was 120 cm and the direction of ascending was clockwise. With 17 steps (18 riser heights, each ~17.3 cm) the height of the whole stairway was 3.12 m.

For spiral stairs the run varies in proportion to the distance from the centre of the radius. For Europeans the distance between the inside of the handrail and the walking line is judged to be ~27 cm [10]. Equipped with this information the approximation of run of the spiral stairs was measured, resulting in 30 cm. Pitch was 30º.

The outer handrail (the only handrail) was designed in such a manner that the height could be altered from 80- to 120-cm heights, with 5 cm intervals. The handrail height was defined as the vertical distance between the tread surface and handrail centreline at the stair nosing. The diameter of the handrail was 3.4 cm, which is within recommended range (e.g., Marletta [13], Standard No. EN ISO 14122-3:2001 [19], Pheasant [20])

2.3. Participants

Twenty healthy males aged 25–55 participated in the experiment. Their mean age was 39.3 years (*SD* 9.59) (Table 1). The ages ~30 years are

TABLE 1. Summary of Participants' Characteristics (*N* = 20)

Parameter	*M*	Median	Mode	*SD*	Range
Age (years)	39.30	39.50	28[a]	9.59	25–55
Weight (kg)	81.50	84.00	84	12.16	61–103
Stature (cm)	176.95	177.00	174	6.65	162–189
Fingertip height (cm)	66.60	66.00	66	3.68	60–76
Shoulder height (cm)	147.30	147.00	147[a]	6.04	135–161
Upper limb length (cm)	73.45	75.00	75	3.69	65–80

Notes. a—multiple modes exist. The smallest value is shown.

overweighted, mainly because of the younger research staff's eager participation in the experiment.

2.4. Procedure

Prior to the laboratory experiments participants received information regarding the aims and method of the study. They were advised not to consume alcohol in the 24 h before the test, not to wear shoes with high heels, and only those physically healthy could participate.

Age, handedness (right/left), footedness (right/left), weight and contact information were recorded for each subject. The following anthropometric measurements were taken: stature, shoulder height, hand length and fingertip height. The first two measurements were taken without shoes. All participants followed the same procedure to evaluate the different handrail heights. It took about one hour per participant to go through the whole procedure. Since descending stairs is more hazardous than ascending, only the former was observed.

3. RESULTS

3.1. The Optimal Handrail Height

The most preferred handrail height for descent was 105 cm. This height was judged to be the most comfortable by 30% of participants.

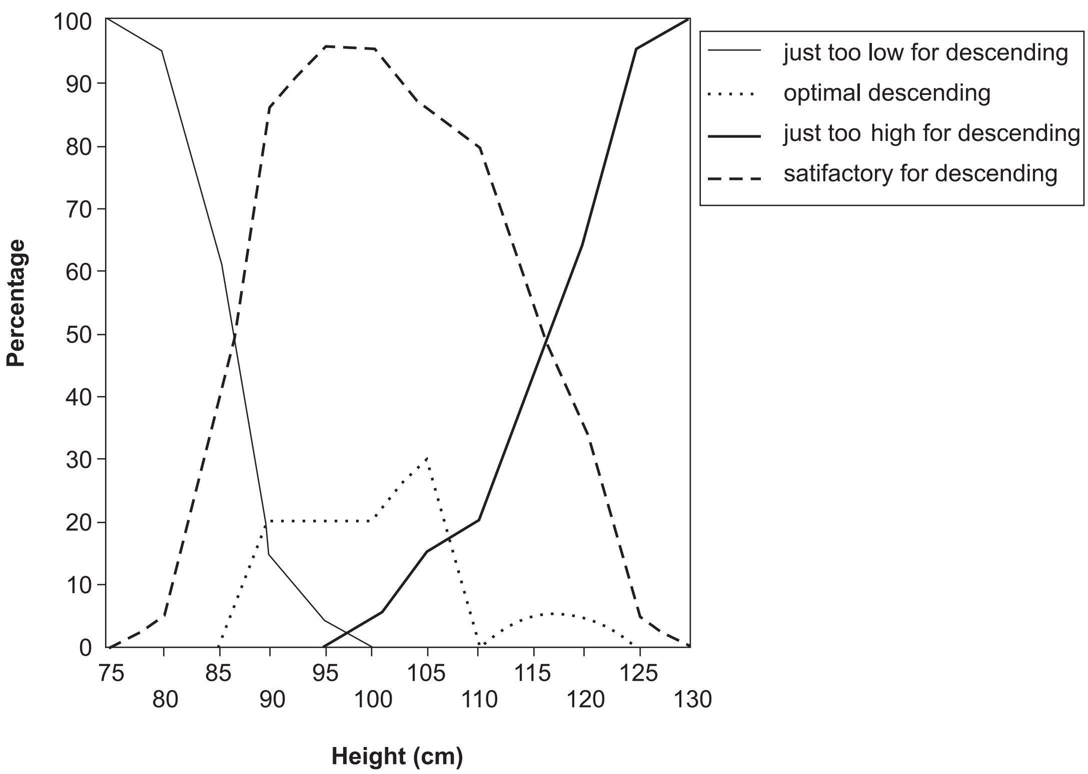

Figure 1. The results of the fitting trial.

Ninety-five percent of the participants regarded the handrail heights between 95 and 100 cm satisfactory for descending. Figure 1 shows the results from the fitting trial. The vertical axis represents the percentage of participants. The horizontal axis represents handrail heights in centimetres.

3.2. The Model

The main results from the fitting trial, i.e., the optimal handrail heights for descending and the data regarding the participants' anthropometric dimensions were taken through a regression analysis to find out which, if any, had statistically significant relationships. Finding some would make it possible to develop a model to predict an optimal handrail height for any given user population. The results of this analysis are summarized in Table 2.

In Table 2, there are two independent variables with very small *p* values, stature (.016) and shoulder height (.020). In other words, stature and shoulder height seem to have the strongest relationship with handrail height preferences.

TABLE 2. The Main Results From the Statistical Analysis for the Optimal Handrail Height for Descending

Parameter	*p* value	Adjusted R^2
Age	.505	–.029
Weight	.121	.080
Stature	.016	.243
Fingertip height	.069	.126
Shoulder height	.020	.224
Upper limb length	.450	–.022
Shoe length	.009	.285
Handedness	.207	.036
Footedness	.976	–.056

R^2 is the proportion of variation in the dependent variable explained by the regression model. The values of R^2 range from 0 to 1. Small values indicate that the model does not fit the data well. Adjusted R^2 attempts to correct R^2 to more closely reflect the goodness of fit of the model in the population.

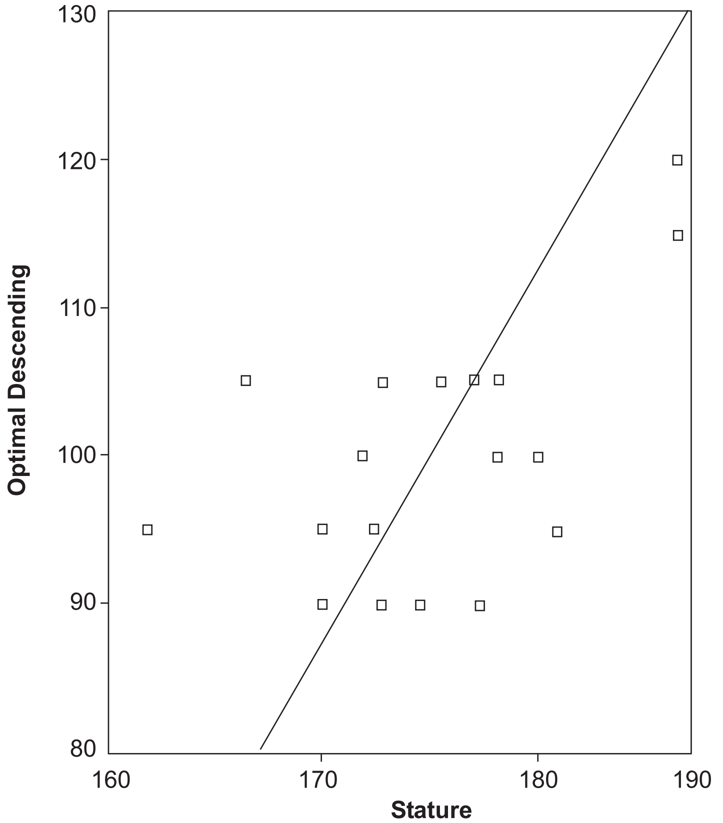

Figure 2. The relationship between stature and preferred handrail height for descending.

Both variables, stature and shoulder height, have a strong ability to explain the variations in the preferred handrail heights. Shoulder height explains 22.4% and stature 24.3% of the variation in the handrail height preference for descending. However, from the practical point of view, stature is the best choice to be included in the model since stature is easy to measure or acquire otherwise.

Unfortunately, with a sample of 20 participants, it is quite difficult to tell whether the relationship between stature and handrail height preference is linear, quadratic, cubic or other polynomial. For simplicity, but also due to the lack of a bigger number of cases, it is assumed here that the relationship is linear.

Figure 2 shows a scatter diagram for stature and handrail height preference in descent. A regression line is fitted in the graph to give some impression of the possible trend. A bigger number of cases would boost the accuracy and reliability of the model.

Since the relationship is assumed to be linear, the model to predict preferred handrail height for a given user population becomes quite simple. The general regression line equation can be used, resulting in

$$\text{optimal handrail height} = \text{constant} + \beta \bullet \text{stature of 50th percentile male} + \text{error}.$$

Constant and β can be taken from Table 3.

Applying the values from Table 3 gives the following equation for calculating optimal handrail height for a given user population:

$$\text{optimal handrail height} = -15.5 + 0.654 \bullet \text{stature of 50th percentile male} + \text{error}.$$

4. DISCUSSION

Perhaps the most fundamental aspect of a handrail is its height. If the shape, size and clearance for hands are designed in a poor manner, the correct height of the handrail can make the difference. Even if it is impossible to grab the handrail because of the bad design, it may be possible to lean on it, which may give enough support to prevent a pedestrian falling down.

In case of an emergency, the importance of decent handrail height is highlighted. When people have to move quickly on stairs, e.g., to get out of a burning house, the handrail may save lives by providing support at an adequate height. It was out of reach of the present study to try to find the optimal handrail height for rushing and running pedestrians. This aspect should be studied further in the future.

In the present study it was assumed that the preferred handrail height is actually the optimal handrail height for any user population. This argument is justified because the preferred handrail height is the most comfortable handrail height thus being the height that most efficiently encourages people to use handrails whenever they use stairs, straight or spiral. This change in behaviour, in turn, should be observable as a reduction in stair accident rates and also as reduced severity of stair accidents.

One factor that reduces the universal applicability of the results of the present study is the limited number of its participants (n = 20). This leaves room for random error which may impact the results. For example, the age distribution is a little skewed with overweight ~30 years. This distribution does not exactly reflect the age distribution of the work force in the Finnish industry.

TABLE 3. Results of Regression Analysis for Stature and Optimal Handrail Height for Descending

		Coefficients[a]						
		Unstandardized		Standardized			95% CI for B	
Model		B	*SE*	β	*t*	Sig.	Lower Bound	Upper Bound
1	(constant)	–15.532	43.504		–.357	.725	–106.929	75.866
	stature	.654	.246	.532	2.663	.016	.138	1.170

Notes. a—dependent variable: optimal descending; CI—confidence interval.

The fact that all the participants were male should not introduce a major bias in the experimental setting since most industrial workers in Finland are male. On the other hand, because females were not included in the study, it is not possible to use the developed model to estimate optimal handrail heights for female user populations. Even if the stature seems to be able to predict the optimal handrail height for males, it is not known if this is the case with females. For this reason female participants should also be included in the future.

If the user population is defined as the general public, the task of determining one optimal handrail height becomes very difficult, even impossible. This is mainly due to the fact that handrails are, in essence, mostly used by small children and the elderly. These two user groups have very different characteristics, e.g., in terms of anthropometry. Two, or even more, separate handrails at different heights may provide a good solution in stairways used by heterogeneous users.

The problem with the behaviour of stair users has remained unsolved. Pedestrians usually do not seem to accept the importance of handrails as "an insurance" for safe stair use. Handrails may remain unused even if they are within reach. Or, even if stair users acknowledge the importance of handrails, they may reason that no accident will happen at this particular time. And they are right, of course, for an accident is very improbable at any single stair usage time.

There seem to be at least two ways to increase the frequency and probability of handrail use. First, employees can be obligated to use handrails whenever they are using stairs. This is an analogous approach with the obligation to use helmets in many working sites. This policy has in fact been adopted by some advanced companies in the chemical industry. The limitation in the obligation solution is that it is applicable in the occupational setting only.

The second way to increase handrail use would be to design the handrails in such a manner that as many people as possible would find their use easy and comfortable. Comfort-based handrail height assessment acknowledges humans as emotional and occasionally nonrational beings. This essential aspect has attracted less attention in the past than it would have deserved. The stress has been on biomechanics, force generation and other "hard" factors. To promote safety on stairs it may prove to be equally important to study "soft" factors related to handrails, i.e., emotions, ease of use and, in essence, the pleasure of using handrails. Templer did not study the optimal handrail height but pointed out that handrails should be installed at a height that would be comfortably at hand during stair use [23]. This was the approach adopted in the present study. The aim was to find such a handrail height for spiral stairs that would be as comfortable as possible to as many participants as possible.

The recording of participants' anthropometric data offered a route to a bigger picture. An anthropometric dimension that closely correlates with handrail height preference was found, and it became possible to develop a model that will give an estimate of preferred handrail height for any given population.

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