Journal of Criminal Law and Criminology

Volume 52
Issue 1 *May-June*

Article 13

Summer 1961

A Woman Falls on A Stairway

Conrad K. Rizer

A WOMAN FALLS ON A STAIRWAY

CONRAD K. RIZER

The author is Professor of Physics at Washington College, Chestertown, Maryland, and serves as a research consultant in problems involving forensic physics. He is the author of *Police Mathematics* (Charles C Thomas) and is a member of the American Academy of Forensic Sciences.—EDITOR.

The purpose of this study is to provide information and data on the fall of a woman on a stairway when she falls from an erect position. The reason for confining this study to women is that in the majority of cases of stair falls, which involve police investigation, the victim is a woman. In accidental falls, where the victim stumbles or catches a heel on the step after starting down the stairs, she would probably roll or tumble down the stairs. While the injuries might be painful, they are not usually fatal.

However, if the victim falls from an erect position, the body takes off into the air, traveling a short distance through the air, and landing in such a way that the head, neck, or shoulders are the first parts to strike the steps. The resulting injuries are usually serious and probably fatal. Oldenburger[1] has shown that if a person falls from an erect position, the distance from the point of departure to the point of landing is a maximum. Such information is important because if the victim falls a greater distance than this maximum before striking the steps or the floor below, she was either propelled by some one, or else she propelled herself. The probability of the victim propelling herself is so remote that it may be ignored.

Oldenburger[2] made a study of the possible motions of a human being falling from an erect position, using the fundamental laws of motion. He obtained his experimental data from measurements he took on his students, such as their centers of gravity, and the "angle of departure", that is the angle at which the centrifugal force equaled the gravitational force, resulting in the body taking off into the air. This angle of departure proved to be 55°. Multiple exposure photographs of a falling rod were also taken. The center of gravity of the rod was changed for each series of exposures by placing weights in different positions.

The results of the studies made by Oldenburger show that a person falling from an erect position, either forward or backward, falls like a pole. The body rotates like the hand of a clock until the gravitational pull along the axis of the body is balanced by the centrifugal force due to the rotation of the body. From this position the body takes off into the air, rotating with a constant angular velocity about the body's center of gravity, the center of gravity moving along a parabola.

Hellebrandt[3] and her co-workers found that the mean percentage height of the center of gravity of 445 young adult women was 55. That is, the young woman's stature multiplied by 0.55 was the distance of the center of gravity above the soles of the feet. Departures from this mean value varied over a singularly small range in spite of a wide disparity in tallness and weight.

Since a pole falls from an erect position in the same way as a person would fall, poles have been used in this study. This substitution is one of convenience, not of compromise. (In some cases police have let a dummy fall on a stairway in order to see where it would land. In such a case the center of gravity of the dummy should correspond to that of the victim.) The center of gravity of all poles was at 55 per cent of the pole's length above its base.

The step of a stairway consists of a horizontal tread and a vertical riser. The ratio of the height of the riser to the width of the tread is the tangent of the angle known as the rake. In this study rakes ranging from 30° to 48° are used.

This study includes both thoretical and experimental investigations of the trajectories of poles as they fall from erect positions.

THEORETICAL INVESTIGATION

When a pole falls from a vertical position, the foot of the pole remains in contact with its support until the long axis of the pole makes an angle of

[1] OLDENBURGER, R.: Human Trajectories, J. OF APPLIED PHYSICS, *13*, 460–469, 1942.

[2] IBID.

[3] HELLEBRANDT, F. A., TEPPER, R. H., BRAUNN, G. L., and ELLIOTT, M. C., The Location of the Cardinal Anatomical Orientation Planes Passing Through the Center of Weight in Young Adult Women, AM. J. PHYSIOLOGY *121*, 465–470, 1938.

55° with the vertical, the point of contact remaining fixed. At this angle the center of rotation changes from the foot of the pole to the pole's center of gravity, and from there on maintains a constant angular velocity about the center of gravity. Also, at 55° the path of the center of gravity changes from the arc of a circle to a parabola.

In order to describe the motion of the pole after it takes off into the air, we will assume the original point of support for the pole to be the origin of a rectangular system of coordinates. Y values above the origin and X values to the right of the origin are positive. Through this system of coordinates and a time parameter, t, parametric equations are used to obtain the locus of the top of the pole as it moves from where the pole takes off into the air to where the top of the pole intercepts the line tangent to the outer edges of the treads of the stairway. The angular position of the pole upon its arrival at the tangent line is such that the head is the first part of the pole to intercept the line. The question of how near the head of the pole comes to the edge of a step when it intercepts the tangent line will be considered later. We will first find the coordinates of the intercept point for the path of the top of the pole and the tangent line for the stair treads for a given pole length and stair rake.

In order that sufficient data might be available for reference in actual cases of falls on stairways, and so that interpolation methods need not be used, nineteen pole lengths were selected, ranging from 4′6″ to 6′0″, and eleven stair rakes, ranging from 30° to 48°. Stairs with rakes in the lower thirties are frequently found in private and commercial dwellings. Basement stairs are more prone to have rakes in the middle forties.

Assuming that after take off the pole rotates at a constant angular velocity, ω (omega), about its center of gravity, the following parametric equations may be written:

$$x = h \sin 55° + vt \cos 55° + R \sin (55° + \omega t) \quad (1)$$

$$y = h \cos 55° - vt \sin 55° - 16.1\, t^2 + R \cos (55° + \omega t) \quad (2)$$

where

h is distance from foot of pole to center of gravity

R is distance from center of gravity to top of pole

v is velocity of center of gravity of pole at time of take off into the air

The h, R, and v values for the nineteen poles were determined and substituted in Equations (1) and (2). The resulting equations were then used for substituting time values. It was found that significant x and y values were obtained for times between 0.32 and 0.56 seconds in increments of 0.02 seconds.

The origin of the coordinate system is considered to be at the outer edge of the tread from which the pole falls. This means that the origin lies on the line tangent to the stair treads, the slope of the line being the tangent of the rake angle.

As the pole falls and rotates, a line through the origin and the upper end of the pole approaches the line tangent to the stair treads. When the two lines coincide, the top of the pole has arrived at the tangent line. The condition for coincidence is that the ratio y/x for the top of the pole shall equal the tangent for the stair rake. The small increments in the (x,y) values, obtained from the (x,y) values for Equations (1) and (2), made it possible to use an interpolation method in order to find the intercept coordinates. (Space does not permit the inclusion of this method.) These values were used in order to find the distance from the origin to the intercept points. It is now possible to arrange the data in tabular form for the nineteen poles and eleven rakes. (See Table I.)

For each pole length and range there are two numbers. The first one is the distance (in feet) from the take off point (origin) to where the top of the pole intercepts the line tangent to the outer edges of the treads, known as the flight interval. The second one is the number of steps in this interval. This number was obtained by dividing the interval by the distance between the outer edges of two successive treads for standard step dimensions.[4] These step values are included primarily to show range and distribution. They are also evidence that a step can be determined with a reliable degree of accuracy. In the case of an actual police investigation the number of steps in a flight interval is obtained by dividing the flight interval by the distance between the outer edges of two successive treads, known as the step interval.

Experimental Investigation

In order to compare the theoretical results with the experimental, a study was made using eight

[4] Encyclopedia Americana, *25*, 471–472, 1951.

TABLE I

DATA FOR THE LOCATION OF IMPACT BY A POLE ON THE STEP OF A STAIRWAY

Rake	Pole Length									
	4'6"	4'7"	4'8"	4'9"	4'10"	4'11"	5'0"	5'1"	5'2"	5'3"
30	6.1/5	6.2/5	6.3/5	6.4/5	6.5/5	6.7/5	6.8/6	6.9/6	7.0/6	7.1/6
31	6.2/5	6.3/5	6.4/5	6.5/5	6.6/5	6.8/6	6.9/6	7.0/6	7.1/6	7.2/6
32	6.3/5	6.4/5	6.5/5	6.6/5	6.7/6	6.8/6	6.9/6	7.1/6	7.2/6	7.3/6
33	6.4/5	6.5/5	6.6/6	6.7/6	6.8/6	6.9/6	7.0/6	7.1/6	7.3/6	7.4/6
34	6.5/5	6.5/6	6.6/6	6.8/6	6.9/6	7.0/6	7.1/6	7.2/6	7.4/6	7.5/6
35	6.5/6	6.6/6	6.7/6	6.9/6	7.0/6	7.1/6	7.2/6	7.4/6	7.5/6	7.6/7
36	6.6/6	6.7/6	6.8/6	7.0/6	7.1/6	7.2/6	7.3/6	7.5/7	7.6/7	7.7/7
37	6.7/6	6.8/6	7.0/6	7.1/6	7.2/6	7.4/6	7.5/7	7.6/7	7.7/7	7.8/7
38	6.8/6	6.9/6	7.1/6	7.2/6	7.3/6	7.5/7	7.6/7	7.7/7	7.8/7	7.9/7
39	6.9/6	7.0/6	7.2/6	7.3/7	7.4/7	7.6/7	7.7/7	7.8/7	7.9/7	8.1/7
40	7.0/6	7.1/6	7.3/7	7.4/7	7.6/7	7.7/7	7.8/7	7.9/7	8.1/7	8.2/7
41	7.2/6	7.3/7	7.4/7	7.5/7	7.7/7	7.8/7	7.9/7	8.1/7	8.2/7	8.3/8
42	7.3/7	7.4/7	7.5/7	7.7/7	7.8/7	8.0/7	8.1/7	8.2/8	8.3/8	8.5/8
43	7.4/7	7.5/7	7.7/7	7.8/7	7.9/7	8.1/7	8.2/8	8.4/8	8.5/8	8.6/8
44	7.5/7	7.7/7	7.8/7	8.0/7	8.1/7	8.2/8	8.4/8	8.5/8	8.6/8	8.8/8
45	7.7/7	7.8/7	8.0/7	8.1/7	8.2/8	8.4/8	8.5/8	8.7/8	8.8/8	8.9/8
46	7.8/7	8.0/7	8.1/7	8.2/8	8.4/8	8.6/8	8.7/8	8.8/8	9.0/8	9.1/8
47	8.0/7	8.1/8	8.3/8	8.4/8	8.6/8	8.7/8	8.8/8	9.0/8	9.2/9	9.3/9
48	8.1/8	8.3/8	8.4/8	8.6/8	8.7/8	8.9/8	9.0/8	9.2/9	9.3/9	9.5/9
	5'4"	5'5"	5'6"	5'7"	5'8"	5'9"	5'10"	5'11"	6'0""	
30	7.2/6	7.3/6	7.5/6	7.6/6	7.7/6	7.8/6	7.9/7	8.0/7	8.1/7	
31	7.3/6	7.4/6	7.6/6	7.7/6	7.8/6	7.9/7	8.0/7	8.1/7	8.2/7	
32	7.4/6	7.5/6	7.6/6	7.8/6	7.9/7	8.0/7	8.1/7	8.2/7	8.3/7	
33	7.5/6	7.6/7	7.7/7	7.9/7	8.0/7	8.1/7	8.2/7	8.3/7	8.4/7	
34	7.6/7	7.7/7	7.9/7	8.0/7	8.1/7	8.2/7	8.3/7	8.4/7	8.6/7	
35	7.7/7	7.8/7	8.0/7	8.1/7	8.2/7	8.3/7	8.4/7	8.6/7	8.7/8	
36	7.8/7	8.0/7	8.1/7	8.2/7	8.4/7	8.5/7	8.6/8	8.7/8	8.8/8	
37	7.9/7	8.1/7	8.2/7	8.4/7	8.5/8	8.6/8	8.7/8	8.8/8	9.0/8	
38	8.1/7	8.2/7	8.3/7	8.5/8	8.6/8	8.7/8	8.8/8	9.0/8	9.1/8	
39	8.2/7	8.3/7	8.5/8	8.6/8	8.7/8	8.9/8	9.0/8	9.1/8	9.2/8	
40	8.3/8	8.5/8	8.6/8	8.7/8	8.9/8	9.0/8	9.1/8	9.2/8	9.4/9	
41	8.5/8	8.6/8	8.8/8	8.9/8	9.0/8	9.1/8	9.3/8	9.4/9	9.5/9	
42	8.6/8	8.8/8	8.9/8	9.0/8	9.2/8	9.3/9	9.4/9	9.6/9	9.7/9	
43	8.8/8	8.9/8	9.0/8	9.2/8	9.3/9	9.5/9	9.6/9	9.7/9	9.8/9	
44	8.9/8	9.1/8	9.2/9	9.3/9	9.5/9	9.6/9	9.8/9	9.9/9	10.0/9	
45	9.1/8	9.2/9	9.4/9	9.5/9	9.6/9	9.8/9	9.9/9	10.1/9	10.2/10	
46	9.3/9	9.4/9	9.5/9	9.7/9	9.8/9	10.0/0	10.1/9	10.3/10	10.4/10	
47	9.4/9	9.6/9	9.7/9	9.9/9	10.0/9	10.2/10	10.3/10	10.5/10	10.6/10	
48	9.6/9	9.8/9	9.9/9	10.1/9	10.2/10	10.4/10	10.5/10	10.7/10	10.8/10	

poles, each one being 1.25 inches in diameter and with lengths as listed in the data. The poles were painted white and fitted with shaft collars and rubber tips. The purpose of the shaft collar was to control the position of the center of gravity. The collar was placed so that the center of gravity was 55 per cent above the lower end of the pole. The stairs used for the pole falls had a rake of 33°42′, with a rise of 7.00 inches and a tread of 10.50 inches. The stairs were of iron with cement treads. Eleven of the steps were numbered from 0 to 10, the zero step being the one from which the poles fell. In order to identify which steps were struck by a pole as it fell and also the sequence and severity

TABLE II

Pole	Step Struck	Pole Length (in inches)	Average Distance from Bottom of Pole to Main Impact Mark (in inches)
1	6 and	60.8	48.9
	7		60.1
2	6 and	61.1	48.4
	7		60.3
3	7	65.5	59.0
4	7	67.1	58.3
5	7 and	71.5	56.9
	8		70.3
6	7 and	72.8	56.0
	8	77.3	69.3
7	8	77.3	67.1
8	8	79.0	67.5

of the impacts, the outer edge of each tread was coated with a different color of wax crayon.

The procedure used for the pole falls was to have one person release a pole from an erect position while a second person observed the fall, checking the step which received the major blow. Each of the eight poles was released for a fall ten times. After each fall the positions and sizes of the marks were measured. The poles were then repainted, and the centers of gravity checked. The data for the eight poles appear in Table II.

From the data of Table II the following observations may be made:

1. The pole lengths fall into four groups of approximately 5.0, 5.5, 6.0, and 6.5 feet, with two poles in each group.
2. For a given pole, the step struck was the same for each of the ten falls.
3. Poles 1 and 2 struck both steps 6 and 7. The marks for step 6 were smaller than for step 7. Also, poles 5 and 6 struck steps 7 and 8. The marks for step 7 were smaller than for step 8. These double impacts illustrate the possibility of both the head and shoulders receiving blows.
4. The distances from the bottom of a pole to the main impact marks, for a given step, did not vary more than an inch for the mean value.

After a pole was released for a fall it travelled through the air from the time of take off to the time of impact. After the initial impact a rocking motion set in, causing many small marks to be made on the lower end of the pole. These marks were made by steps 6 through 10 for all poles. These marks would probably appear as bruises and small cuts on the limbs of a person falling down stairs. The upper part of a pole also had small marks on it, which were made by the steps below the one inflicting the major blow.

One of the most significant results of this study is that, for the selected comprehensive ranges of statures and rakes, the range of possibly struck steps is narrow. For the most usual stature and rake values the impact step would be the 7th or the 8th.

How This Study May be Used by the Police

The procedure to be used in determining whether a woman has been the victim of an accidental fall or of violence at the hands of another person follows:

1. Measure the height of the victim. This measurement should include footwear worn at the time of the fall.
2. Measure the rake of the stairs on which the fall occurred. This may be done with some form of protractor. The rake is the angle between the horizontal and a straight line touching the outer edges of the steps. In practice this line may be established by using a board across two successive step edges. The angle between the board and the horizontal is the rake. If the step used as a horizontal surface is not horizontal (this should be checked with a level), a board may be placed on the step and adjusted until the level indicates that the board is horizontal. The rake is then the angle between the sloping and horizontal boards.
3. Measure the normal or perpendicular distance from the outer edge of one step to the outer edge of the next step. This is the step interval.
4. In order to find the flight interval, refer to Table I, using the victim's measured height and the step's rake.
5. In order to find the step struck by the victim (if the fall is accidental) the flight interval is divided by the step interval. In most cases there will be a remainder for this division. If there is no remainder, that is, if the step interval divides into the flight interval a whole number of times, without a remainder, it means that the top of the victim's head just reached the step whose number is being calculated. But if there is a remainder, it means that the step struck is below the top of the head. How far below is described in the next paragraph.
6. Multiply the number of the step found in the

above calculation by the step-interval and subtract the product from the flight interval. This difference indicates how far below the top of the head the step struck the victim. This distance should be measured on the victim in order to see if there are injuries on the part of the body concerned, such as the head, neck, or shoulders. If the difference is nearly equal to the step interval, it may be that the top part of the head had received injury from the step below that calculated in No. 5.

As an illustration of the application of this procedure the following case is cited. A 19 year-old girl and her fiance had spent the evening with friends at a tavern. At this party the youth had been taunted with the information that the girl had been sharing her favors with other men. When the couple left the tavern for the girl's home, they decided to walk. On the way they stopped to have sexual relations behind an apartment house. This place was easily reached from the street by means of a wide area way. The couple stopped very near an outside stairway leading down to a basement entrance to the apartment house. Why such a location should have been chosen is hard to understand unless the youth had planned to do violence to the girl. Any place in the area way would have been safer for a rendezvous than where he took the girl.

The next morning the girl was found unconscious and bleeding from nose and head wounds. She was lying in front of the basement door, her body being altogether clear of the ten steps leading down to the basement. She was taken to a hospital and died twelve hours later without regaining consciousness. A careful investigation of the step's surfaces brought to light no evidence that the girl had been in contact with these surfaces. The pavement at the foot of the stairs was wide enough so that she could have landed on it without touching the steps. The medical examiner reported that death was caused by a fractured skull, complicated by blood clots inside and outside of the brain. There was no excessive amount of alcohol in the girl's system. The question was whether she had lost her balance or had been pushed down the stairs. Let us see how this study may be used to help answer this question.

The girl measured 5 feet 4 inches from the soles of her shoes to the top of her head. The stair rake was 45°. The step interval measured 13.3 inches or 1.1 feet. We now look for a height of 5 feet 4 inches and a rake of 45° in Table I. At the point where the column for 5 feet 4 inches intersects with the row for 45°, we find the numbers 9.1 and 8. As previously explained, only 9.1, the flight interval concerns us (see No. 4 above). In order to find which step the girl would have struck if she had lost her balance the flight interval, 9.1, is divided by the step interval, 1.1. The result of the division is 8 plus a remainder. The number 8 means the eighth step from the top of the stairs is the one sought. The remainder is ignored in this calculation. Multiplying the step interval by the number of steps, $1.1 \times 8 = 8.8$ feet, we have the distance the outer edge of the eighth step was below the top of the stairs. In practice this distance should also be measured with a tape as a check. The difference between the flight interval, 9.1 feet, and 8.8 feet is 0.3 feet or 3.6 inches. One would expect to find injuries at this distance of 3 inches below the top of the head if the girl had lost her balance. As cited above, the eighth step was unmarked, and none of the girl's wounds appeared to have been caused by a blow on the edge of a step. Thus all the evidence would indicate that she may have been pushed or propelled in some manner in order to land clear of the steps without striking the eighth step.

This method should be used only in order to determine whether the woman could have fallen accidently from an erect position at the top of the stairs. Since the above calculations show that she did not fall in this manner, a very careful and through analysis of all other evidence should be made in an effort to determine what may have happened.