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Fatal Falls from a Height: Two Case Studies

ABSTRACT: Two case studies are presented involving fatal falls of adult females from a height. One involved a launch at low speed from a balcony, and one involved a launch at high speed from the top of a cliff. Crime scene evidence obtained on the balcony itself provided a strong indication of homicide, but subsequent investigation showed that the fall was accidental. No crime scene evidence was obtained for the cliff fall since the fall initially appeared to be just another suicide from a popular suicide spot. Subsequent investigations indicated homicide based on measurements of cliff height, horizontal distance to the impact, and available runup distance, plus measurements of possible run, jump, and throw speeds. It was found that a female weighing 61 kg (134 lb) can be thrown at speeds up to 4.85 m/s by a strong male, more than enough to account for the estimated launch speed (4.5 m/s). Given the available 4.0 m runup distance, it was found that women of better than average rather than elite athletic ability can dive at speeds of about 3.5 m/s or jump feet first at speeds of about 4.0 m/s, both being less than the estimated launch speed. The decedent had no athletic ability and landed head first after falling through a height of 29 m.

KEYWORDS: forensic science, balcony, cliff, fall, run, jump, throw

In the absence of witnesses or an unambiguous suicide note, it is usually very difficult to determine whether a fatal fall from a height was the result of an accident, suicide, or homicide. At horizontal launch speeds less than about 2 m/s, it may even be impossible to distinguish between a jump, push, throw, dive, or accidental fall. Shaw and Hsu (1) showed how horizontal distance and height information can be used to determine the initial launch speed and concluded that an initial launch speed exceeding 2.70 m/s would indicate suicide. These authors based their conclusion on the fact that 2.70 m/s is a typical standing jump speed for an elite male athlete. Push speeds are typically only about 1.0 m/s since the net forward force is reduced considerably by the friction force acting backward at the feet. However, Shaw and Hsu did not consider the possibility that a person could be thrown at a speed exceeding 2.7 m/s or that a person could accidently run off a cliff top or an unprotected building site in the dark.

Two fatal falls are described in this paper: one involving a low-speed launch from a balcony, the other involving a high-speed launch from a cliff. The balcony fall was initially regarded as being suspicious, but sufficient evidence was available to show that the fall was accidental. The cliff fall was initially treated as a suicide, but subsequent evidence pointed to homicide. In both cases, the homicide squad contacted the physics department at Sydney University for assistance. Requests for help in the physics of a fatal fall are generally very rare since falls are more commonly examined by experts in biomechanics or pathology. The two falls are unrelated but are presented because their unique physical circumstances may be of interest or assistance to others investigating the cause of a fatal fall. A fall from a balcony can occur if a person leans over the balcony and overbalances. Fingerprints left on the balcony may help to establish the circumstances, but imprints of other body segments may be overlooked or may be misinterpreted. The balcony fall described in this paper was unique in that very clear body segment imprints were left at the scene, indicating a sequence of events that might well be common in other balcony falls.

The cliff fall fatality shows how distance and height information, when combined with other physical data, might be used to distinguish between suicide and homicide even at launch speeds as high as 5 m/s. By itself, a launch speed less than 5 m/s does not allow one to distinguish between suicide and homicide since a person can easily run and jump at that speed and since an adult can be thrown at speeds up to about 5 m/s, provided that a sufficient runup distance is available in each case. There may, however, be special circumstances where a launch speed between say 4 and 5 m/s could be identified either as a suicide or a homicide. For example, if the runup distance is restricted to less than a few meters, then a run and jump at 5 m/s become questionable. If the deceased is heavy or if the suspect is light or below average in strength, then a throw of even 4 m/s would be questionable. It may also be possible to rule out out a suicidal jump if the athletic ability of the deceased is known or can be reliably estimated as being less than that required to jump the distance. In this paper, new information is provided on the running and jumping ability of adult females, and new information is provided on the speed at which a female can be thrown. This type of information is not readily available for humans of less than elite athletic ability but can be of particular value in a forensic investigation into the cause of a fatal fall.

Case 1: Balcony Fall

A young woman fell to her death over the balcony rail of the harborside apartment she shared with her male partner. They had spent the afternoon together drinking and socializing in a bar and returned to their apartment around 6 pm. Neighbors heard them arguing afterwards, but the partner claimed they were only arguing about whether or not they should have dinner at home or in a restaurant. When detectives arrived on the scene they discovered a face print on the outside of a glass panel on the balcony, shown in Fig. 1. The balcony had a metal hand rail 1.0 m above the balcony floor. Glass panels were fixed between the hand rail and another

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metal rail near the floor of the balcony. The outside surface of each panel (facing the harbor) was coated with a thin layer of an unidentified white powder, which may have been salt from the harbor. The face print was clearly apparent without the need for fingerprint dust. The photograph in Fig. 1 was taken at night from inside the apartment looking out towards the harbor. The image extends from the white hand rail at the top of the photo to the white rail at floor level. The hand rail is not clearly visible in Fig. 1. The photograph is upright so the image is exactly as seen by the detectives viewing the glass panel from within the apartment. The balcony floor at the bottom of the photograph is overexposed and therefore appears white, but the floor can also be seen as a reflection in the glass panel in the bottom half of the photograph. A sliding glass door leading from the apartment onto the balcony is also reflected in the glass panel. The leg of a wood chair on the balcony floor is just visible in the lower left corner of the photograph.

According to the woman's partner, she went out onto the balcony while he remained inside. He saw her leaning over the balcony with her hands on the rail in such a way that her hands were well separated, her fingers were underneath the inside edge or balcony side of the rail, and her thumbs were on top of the rail. She appeared to be unsteady and he asked her to come inside. A few minutes later he glanced around and saw her fall over the balcony head first as if she had overbalanced from the same position that he observed previously. However, the imprint on the glass panel showed that she was upright and looking back into the apartment from a position outside the balcony. Furthermore, she landed feet first on a concrete footpath below and had then fallen backwards sustaining fatal head injuries. The detectives became suspicious of the partner's version of events. In their opinion, if the woman fell head first, then her face print on the glass panel would not be upright and she would most likely have landed head first on the footpath, three floors below.

The balcony rail was 120 mm (4.7 in) wide, and would have pressed firmly into her wrists if she managed to hang on with her fingers still around the inside edge of the rail. Given that it would be impossible to support her own weight in this manner, she would have let go of the rail either with both hands at once or one hand at a time. Both hands at once would imply a head-first fall. By letting go with one hand, she would have been able to hang on with the other hand and place her free hand on the balcony ledge 1.0 m below the rail. The ledge extended 235 mm past the glass panel on the outside of the balcony. If she then let go of the rail with her other hand she could have swung into an upright position with both hands on the ledge. Given that the ledge would then have pressed outward against her hips or upper legs, she may then have leant forward towards the balcony, hitting her head on the glass panel. The suggested sequence of events is depicted by the stick figure diagrams in Figs. 2 and 3.

The imprint on the glass panel is entirely consistent with the above interpretation of events and is also consistent with the location of finger marks found in the dust underneath the balcony rail. The author had the opportunity to carry out experiments with a similar balcony and railing where the balcony ledge was located 1.3 m above a floor. A male volunteer was able to repeat the essence of the maneuver in slow motion for safety, reaching down with his hand on the ledge before swinging around to support himself in an upright position with both hands on the balcony ledge.

In Fig. 1, the lower portion of the imprint closest to the floor (shown as head position 1 in Fig. 4) shows an impression of the woman's head when she first contacted the panel in an inverted position. The middle part of the imprint shows her breasts pressed onto the panel while in the inverted position. She was wearing a strapless dress, which was straight across the top, as is normal engineering practice in strapless dress design. The elliptical imprint shaped like a coffee bean is almost certainly an impression of her right shoulder while her right hand was still holding onto the rail. When a person stretches one arm backward it is usual to find that a dimple is formed at the top end of the upper arm.

The upper facial impression (head position 2 in Fig. 4) shows the impact that occurred when she swung into an upright position. The impression appears to be a complete profile but the impression is too narrow to extend from her nose to the back of her head. The author was able to form a similar impression on a glass panel covered in chalk dust by pressing sideways on the glass. The feature that appears to be her nose is in fact an outline of her cheek bone. There is also a smudged image of her left hand as she let go of the rail to support herself with her left hand on the balcony ledge.

As it turned out, there was no need to investigate the trajectory of the fall since the impressions left on the glass panel were almost as clear as a series of security video images. The balcony rail was

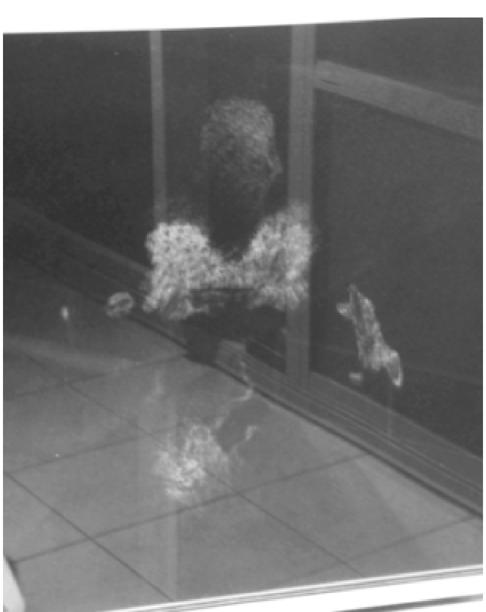

FIG. 1—*Imprint on outside of the glass panel viewed from inside the apartment. The photograph shows the entire 1.0 m high glass panel from the balcony rail at the top of the photo to the balcony floor at the bottom of the photo.*

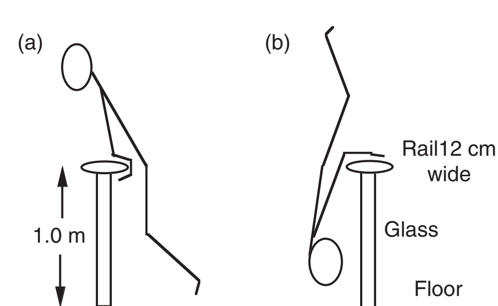

FIG. 2—*Stick figure diagram showing how the decedent overbalanced.*

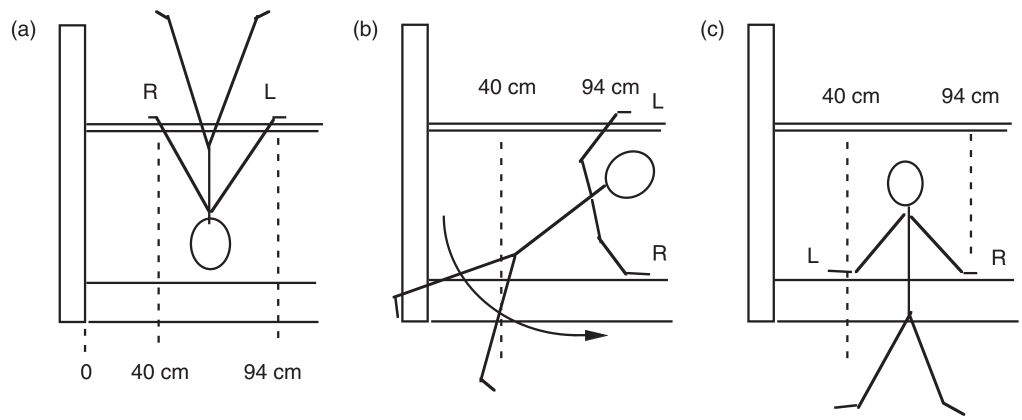

FIG. 3—*Viewed from outside the balcony, the decedent swung from the inverted position (a) into the upright position (b), leaving two separate images of her head on the glass panel.*

at the minimum height required by local building regulations, as are many thousands of other balcony rails in Sydney. Alcohol consumption was probably a contributing factor to the fall and so was the wide balcony rail, which prevented the woman from hanging on when she overbalanced. The autopsy revealed a blood alcohol concentration of 0.172%, but no other drug was present.

Case 2: Cliff Fall

A 25-year-old female, 1.74 m (5 ft 8 in) tall and weighing 57 kg (126 lb) was found a large distance out from the base of a vertical cliff, wedged head first in a deep cavity formed by large rocks at the base of the cliff. She had suffered extensive impact injuries to her head and upper body, but there were no injuries to the lower part of her body and there was no damage to shoes or clothing below the waist. The autopsy indicated no alcohol consumption and no other drug was present. As the area involved was a well-known suicide spot, the case was initially treated as just another suicide. No crime scene was established, and no photographs were taken. Indications of suicide included the fact that her mother had previously committed suicide, she had attempted suicide herself several years earlier and she had just visited her doctor complaining of depression. Surtees (2) has studied many falls at Beachy Head in England, a famous tourist and suicide spot, and lists these and many other factors as being indicative of suicide.

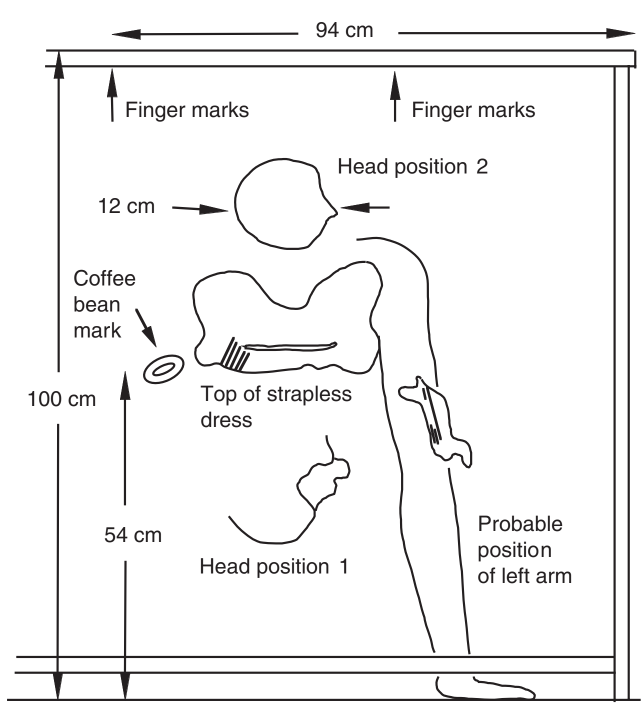

FIG. 4—*Interpretation of photograph shown in Fig. 1.*

A period of several years elapsed before an inquest was held. The coroner returned an open finding, noting that there were suspicious circumstances, particularly concerning evidence presented by her gym instructor boyfriend and evidence that she was seen near the cliff, a few hours before her death, arguing with her boyfriend. A second man was seen standing near them. The coroner also noted that the female had landed at an unusually large distance from the cliff, indicating a high launch speed. No attempt was made before or during the coroner's inquest to estimate the launch speed or to obtain accurate measurements of the cliff height or the landing distance. The police were instructed to continue their investigations. Several years after the inquest, I was asked by the homicide squad to conduct various experiments in an attempt to determine whether the woman may have jumped or whether she may have been pushed or thrown. Because of the lack of crime scene evidence, and because the exact landing point had been of no previous concern, there was some confusion regarding the actual impact point. Two possible cavity locations were identified about 4 m apart, point A and point B, as shown in Fig. 5. Calculations and measurements are presented below for both impact points since they serve to illustrate different aspects of the problem. Subsequently, it was established after several site inspections with a member of the original cliff rescue team that cavity B was not deep or wide enough to allow for the fact that the decedent was found wedged up to her waist.

Launch Speed Calculations

If a person is launched in a horizontal direction at speed V and takes T seconds to fall, then that person will land at a horizontal distance $D = VT+d$ from the launch point, where d is the takeoff distance. In a jump, the takeoff distance is the horizontal distance from the back foot to the center of mass (CM) at the instant of launch. If a woman jumps off a cliff, then her CM may be 0.5 m beyond the edge of the cliff at launch even though her back foot must be behind the edge. If a woman is thrown off a cliff, her CM could be 0.7 m beyond the edge of the cliff at the instant of launch.

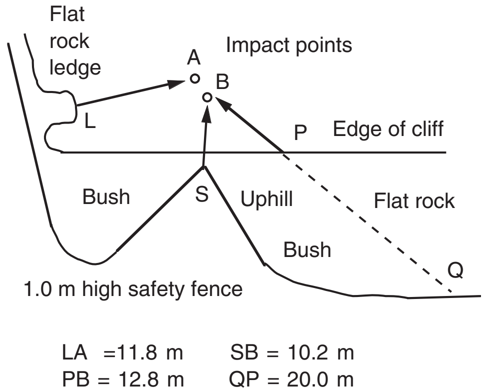

FIG. 5—*Plan view of cliff top showing the assumed landing point B and the correct landing point A. A runup distance of 4.0 m was available between the safety fence and point L.*

The phrase "takeoff distance" should not be confused with the phrase "runup distance," which may be 20 m or more in a long jump.

The distance *VT* is called the flight distance. At low launch speeds, less than about 10 m/s, the horizontal speed remains essentially constant through the air since air resistance remains small at low speeds. It is only when falling from heights greater than about 100 m that air resistance needs to be considered for accurate calculations of fall time or flight distance. Otherwise, the fall time T is given to a good approximation by $H = gT^2/2$, where H is the fall height (in m) and $g = 9.8\,\mathrm{m/s^2}$. For example, if $H = 20$ m, then $T = 2.02$ s, or if $H = 40$ m, then $T = 2.86$ s.

Launched at an angle above the horizontal, the fall time and flight distance will be slightly larger than given above, as described by Shaw and Hsu (1). The launch angle cannot be determined from crime scene evidence, and hence there will be a small uncertainty in estimating the launch speed. Similarly, the precise launch point may not be known apart from the fact that it cannot be more than 0.7 m beyond the edge of a cliff or building. Nevertheless, one can estimate a possible range of launch speeds from crime scene evidence, with improved precision if the launch and impact points are both known accurately.

Point B in Fig. 5 indicated either a 5.8 m/s jump following a possible 20 m runup across the cliff top from Q to P, or a 4.35 m/s throw from point S located just inside a 1.0 m high safety fence 1.2 m from the edge of the cliff. The horizontal distance PB was 12.8 m while SB = 10.2 m. The fall height from S was 26.9 m, including a vertical lift to shoulder height. The fall height from P to B was 23.8 m. The launch speeds here are quoted assuming zero takeoff distance, or equivalently, a launch from a point about 0.5 m back from the fence or edge of the cliff. Launch speeds assuming a takeoff distance of about 0.5 m are slightly smaller, as summarized in Table 1.

The alternative impact point A indicated either a 4.85 m/s jump following a possible 4.0 m runup or a 4.77 m/s throw, both from ledge L in Fig. 5 (assuming a horizontal launch and zero takeoff distance). The ledge was 29 m above the impact point, the closest point of the ledge being a horizontal distance LA = 11.8 m from the impact point. Throw speed was calculated assuming a launch from shoulder height. Slightly lower horizontal jump or throw speeds, about 4.50 m/s, would be sufficient to reach A from L if a takeoff distance of about 0.5 m is allowed and if a person were to jump upwards at about 10° to the horizontal. A launch from points S or P to point A would be possible for an Olympic champion

TABLE 1—*Launch speeds.*

Path	Method	*D*	*H*	*d*	*VT*	*T*	*V*
PB	Jump	12.8	23.8	0.5	12.3	2.204	5.58
SB	Throw	10.2	26.9	0.6	9.6	2.343	4.10
LA	Jump	11.8	29.0	0.5	11.3	2.433	4.64
LA	Throw	11.8	30.0	0.6	11.2	2.474	4.53

thrower or runner, respectively, but would be impossible for a person of lesser athletic ability.

The challenge was to try to distinguish one possibility from another given that no data were available concerning female run or jump speeds after a short runup, and no data were available concerning the speed at which a 57 kg female could be thrown. Furthermore, most research into athletic ability or the biomechanics of athletic performance concerns elite athletes rather than the general public. Consequently, a number of experiments were undertaken by the author to estimate the relevant speeds, as described in the following sections. The information obtained is somewhat case specific but could well be relevant in other case investigations.

Experimental Procedures

Run, jump, dive, and throw speed measurements were undertaken by filming subjects with a video camera mounted in a fixed position on a tripod, using a standard length scale or known object in the field of view to calibrate the distance scale. The time scale was determined by the 25 frames/s operating speed of the camera. All measurements were made by plotting the position of the subject's CM over a sufficient number of frames to obtain a speed result within $\pm$ 2%. A linear fit to the data was used for horizontal speed measurements, and a parabolic fit was used for vertical speed measurements, assuming a vertical acceleration of 9.8 m/s^2. The analysis was performed using appropriate motion analysis software after transferring selected film clips from the video camera to a computer.

Four male subjects were chosen for throwing experiments from the police force. Each male threw a 61 kg female volunteer into a swimming pool, from the side of the pool, using a variety of different throwing techniques. Tests were conducted where each male threw the volunteer on his own and where two males acting together threw the volunteer. All throws involved a short runup before throwing, typically over 2 or 3 m, but none of the throws were preceded by a runup exceeding 3.5 m since the throwers would then have risked falling into the pool themselves. Throw speeds were measured by filming each throw and by estimating the position of the center of mass on a frame-by-frame basis. Alternatively, if the volunteer maintained the same orientation of all body segments after launch, a simpler measurement of launch speed could be obtained by plotting the coordinates of any suitable segment such as the head or a distinctive mark on her swimming costume.

Female subjects were chosen for run, jump, and dive speed measurements from cadets at a police academy. The female subjects took part in a number of different running trials that provided a benchmark of their athletic ability. None of the male or female subjects were of elite standard in terms of athletic ability. Two series of tests were undertaken, the first involving 13 female subjects of age between 20 and 35. The tests were undertaken on a gymnasium floor and involved three trials each for a 20 m sprint, a jump following a 4.5 m runup, and a jump following a 5.0 m runup, all at maximum speed. It was established from this series of tests that the average athletic ability of the 13 subjects was essentially the same as that of much larger samples of the adult female population.

The maximum runup distance to point L was subsequently found to be 4.0 m rather than 4.5 m or 5.0 m, so additional jump speed measurements with a 4.0 m runup were undertaken as part of a separate experiment to determine the difference between feet-first and head-first jump speeds. The second series of tests were undertaken at a swimming pool using seven of the original female 13 subjects. Six of the seven subjects in the second tests were of above average standard in athletic ability, and one was of average athletic ability, as described in more detail in the following section. Each subject ran along a 4.0 m path toward the deep end of the pool and completed three feet-first jumps and then three dives. The subjects were requested to run and jump or dive as fast as they could.

It was determined that the decedent had no athletic ability at high school, and was not subsequently involved in athletic activities apart from the fact that she kept fit at gym classes. Consequently, one could reasonably assume that she was about average or below average in terms of running or jumping ability rather than being a superior or elite athlete. It was assumed that if none of the 13 subjects in the first tests or none of the seven subjects in the second tests could jump or dive at the necessary speed, then neither could the decedent.

Female Run and Jump Speeds

The athletic ability of the subjects tested in this paper was established by comparing their running speeds with two previous measures of female running ability. One of those measures was a large study (3) undertaken in 1985 of the time for a 50 m sprint for 1000 15-year-old female high school students selected at random from the entire high school population in Australia. The average run speed was 5.87 m/s (standard error 0.011), ranging from 4.8 to 6.8 m/s. The second measure was obtained from the police academy that routinely conducts fitness training and tests of all students. one hundred and seventy four females of age between 20 and 35 were timed for a 40 m sprint in 2003, with an average run speed of 5.89 m/s (standard error 0.033) and a range from 4.4 to 7.1 m/s. One can conclude that the run speed of an adult female is essentially the same as that of a 15-year-old female, unless the female in question happens to be an elite athlete whose athletic ability improves as a result of physical development and intensive training over a number of years.

In the first series of tests conducted by the author, 13 female police cadets were instructed to run as fast as possible over a distance of 20 m on a gymnasium floor. The average run speed at the 20 m mark was 5.52 m/s, ranging from 4.7 to 6.3 m/s. These results are consistent with the two larger studies in that the maximum run speed is known to increase with run distance up to about 30 or 40 m for most athletes. The 13 women therefore represented a good cross section of athletic abilities, and by coincidence happened to include one who had previously been a champion hurdler at high school. She had also played netball at the state level and was still active in playing netball on a regular basis, at age 30, when the run and jump tests were conducted. She was clearly a better athlete than the other women, and she therefore provided a good benchmark as to whether it was physically possible for a woman of above average athletic ability to jump the relevant distances.

The same 13 police women were filmed to determine the speed at which they could jump on a horizontal surface (the gymnasium floor) after a runup of either 4.5 or 5.0 m. For the 4.5 m runup, the average horizontal jump speed was 4.11 m/s, ranging from 3.1 to 4.8 m/s. For the 5.0 m runup, the average horizontal jump speed was 4.35 m/s, ranging from 3.72 to 5.15 m/s.

Seven of the original 13 police women took part in the swimming pool jump tests. Based on their performance in the gymnasium run and jump tests, they were of better than average athletic ability. This was confirmed by checking their individual 40 m sprint speeds from independent fitness tests conducted at the police academy. The average 40 m sprint speed for five of those seven subjects was 6.41 m/s, ranging from 5.92 to 6.75 m/s. Two of the seven subjects did not take part in the 40 m sprint tests. A summary of the individual performances of all 7 subjects in all trials is shown in Fig. 6. Also shown for comparison in Fig. 6 is the minimum horizontal launch speed (4.5 m/s) required to reach point A from point L, assuming a launch from the extreme edge of ledge L.

Jumps with no runup or with one step and a jump were measured for several women and were all at speeds less than 3.2 m/s. Since the jump speed was significantly lower than the required

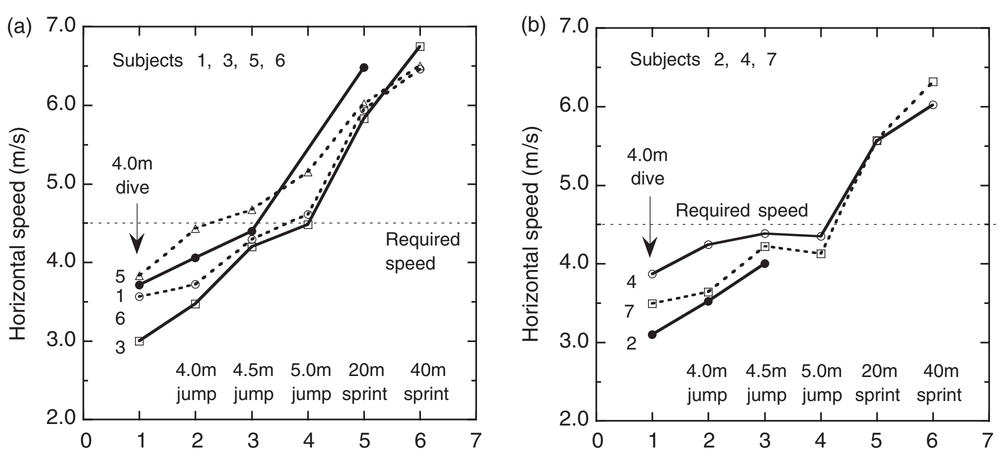

FIG. 6—*Results for all seven subjects involved in the swimming pool tests (events 1 and 2). Each data point represents the average of three trials for each subject and event. Events 3–6 were undertaken prior to the pool tests. Subjects 1 and 2 did not take part in all five events. Subject 2 was of average athletic ability, while the other six subjects were all above average.*

speed, no further attempts were made to establish a population average for a larger sample of women.

The 20 m runup path from Q to P involved an uphill run over the last 8 m, at an incline angle of 4°. One woman was filmed while sprinting the first 20 m on level ground and the next 12 m up a 4° incline. An extended runup on the flat section was allowed so that the runner would be close to top speed as she started the uphill run. Within experimental error, no change in run speed was detected over the two sections in three separate trials. Presumably, run speed would decrease after a long uphill run, but a short uphill run up a gentle slope was found to have no discernable effect on run speed.

Feet First vs Head First Jump Speeds

A significant aspect of this case was the fact that the decedent landed head first. Consequently, an important consideration was whether the launch was feet first or head first. Almost any amount of rotation about any axis would be possible in a low-speed launch, including a triple somersault or no rotation at all. However, high-speed running or jumping is generally accompanied by very little rotation of the body. No rotation is generated during normal running strides, as evidenced by the fact that a person can run a long distance without falling over. Some forward rotation occurs for elite athletes in the long jump, and is generally attributed to the backward braking force applied during the jump step (4–7). For example, Elliott and Newton (4) measured the angular momentum of nine male athletes in the long jump. For an average jump distance of 5.95 m and an average horizontal jump speed of 6.79 m/s, the average rotation speed was 1.0 rad/s. Herzog (5) measured the angular momentum generated in the long jump for two elite female athletes, and the results indicated forward rotation speeds of 0.3 and 0.8 rad/s, the difference being attributed to different jump styles. The jump distances were each about 5.5 m for the two females.

Even though forward rotation is generated in a high-speed long jump by an elite athlete, a much smaller rotation speed would be expected for a low-speed jump after a short runup. The average jump distance of the 13 police women studied was only 2.2 m after 4.5 and 5.0 m runups. In fact, about half of the subjects tested had a higher horizontal jump speed than their previous run stride since they were still accelerating when they jumped. Consequently, a low-speed jump after a short runup can be regarded as almost equivalent to a running stride, in which case almost no rotation would be expected. Nevertheless, if the decedent did in fact jump, then she did rotate as a result of the jump and would therefore have applied a braking force rather than an accelerating force during the jump step. The significance of the braking force is that it acts to increase the rotation speed, but it also acts to decrease the jump speed. Given that the required jump speed was higher than one would normally expect for a female of average athletic ability and given that the decedent landed on her head, the only plausible manner of achieving such a result is to dive head first at maximum speed, using the maximum available runup distance, with less than a 90° rotation during the fall.

A second series of measurements was therefore undertaken to determine the jump speeds of seven adult females for feet-first jumps and head-first dives into a swimming pool, allowing for a 4.0 m runup. The results are shown in Fig. 6 and indicate clearly that (a) a head-first dive results in a lower horizontal launch speed than a feet-first jump, and (b) the launch speed for a head-first dive is too low to account for the head-first landing at point A even for a woman of above average athletic ability. Furthermore, only one of the more athletic group of seven cadets could have jumped feet first from point L and landed at point A, but she would have landed feet first and she had previously been a high school hurdling champion.

Throw Speed Measurements

Many different throw techniques were tried using several strong policemen throwing one or two at a time. Most of the throw techniques resulted in horizontal launch speeds less than 3 m/s, including a technique where one male held the volunteer by the legs and another male held the volunteer under the arms. The volunteer was swung back and forth several times and then thrown sideways into the pool. Apart from the fact that the decedent landed on her head rather than on her side, this technique resulted in a maximum horizontal launch speed of only 2.7 m/s.

Throw techniques where the volunteer was pushed on the legs or arms all resulted in low-speed throws and tended to generate excessive rotation of the volunteer. A throw technique whereby the volunteer was supported across the shoulders of the thrower resulted in throw speeds between 3.2 and 4.1 m/s, but this technique also resulted in a sideways launch.

The highest throw speeds resulted using a "spear throw" technique, which avoided the problems encountered using the other techniques. The volunteer was thrown head first by a single strong male who supported the volunteer at shoulder height with one hand on her chest and the other hand between her legs. In this manner, the thrower was able to push firmly on her body in line with her center of mass, thereby avoiding rotation of the body. The thrower was able to take several running steps before pushing the volunteer in a horizontal direction at launch speeds between 3.8 and 4.85 m/s depending on the strength and technique of the thrower. Essentially, all of the runup momentum of the thrower was transferred to the volunteer during the launch, so there was no danger of the thrower overbalancing during the throw. The highest throw speed (4.85 m/s) was achieved by a male thrower 1.93 m (6 ft 4 in) tall weighing 105 kg (231 lb). In almost all throw attempts using this technique, the volunteer entered the water head first with essentially no rotation about any axis.

Conclusions

The report that I submitted to the homicide squad regarding the balcony fall was sufficient to clear her partner of any further suspicion. The coroner subsequently returned a finding of accidental death. Not all such falls would be accidental; hence, most unwitnessed falls are treated initially as being suspicious by the police. Each case needs to be considered on its merits. The case presented above was unusual in that the partner observed that the decedent had fallen head first and pathology revealed that she landed feet first. Both versions of the event were correct as indicated by evidence left on the balcony itself as the woman struggled outside the balcony to prevent herself from falling.

My initial conclusions regarding the cliff fall were that the decedent had most likely fallen to her death as a result of a high-speed run across a 20 m platform leading up to the edge of the cliff. This conclusion was based on an incorrect identification of the landing point, on measured female run speeds and on preliminary measurements of the speed at which a 61 kg female volunteer can be thrown into a swimming pool. Subsequent identification of the correct landing point required additional jump and dive experiments to be undertaken with a short 4.0 m runup, as well as a more thorough investigation of possible throw speeds. It was then found that throw speeds up to 4.85 m/s were possible using a "spear throw" technique, more than enough to account for the possibility that the decedent was thrown from the cliff top in a manner that resulted in a head-first landing. It was also found that a head-first running dive after a 4.0 m runup resulted in a horizontal launch speed of less than 4.0 m/s for all seven adult female subjects tested, six of whom were above average in athletic ability. Only one of the seven subjects was able to perform a feet-first jump at sufficient speed (at least 4.5 m/s) to have reached the landing point, but such a jump would be inconsistent with a head-first landing. Given that the decedent was reliably estimated to be average or below average in athletic ability, I concluded that she could not have jumped or dived at sufficient speed to land where she did.

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