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ORIGINAL ARTICLE

Determining Falling Patterns via Estimation of Horizontal Distance and Height

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ABSTRACT:
Whether by accident or foul-play, virtually thousands of fall-related fatalities occur each year. While a number of past studies address the relationship between falls and injury/death, only a small fraction seek to establish an objective index geared specifically towards determining the cause of a particular fall. The primary objective in the present study is to determine the range of attainable horizontal distances in various forms of active and passive falling patterns. The secondary objective involves the capturing of physical motions at the point of impact via 3D motion analyses in order to identify the defining physical characteristics of a particular form of fall. The introduction of live test subjects to these series of experiments adds the advent of fear and other psychological factors to the study which are crucial in simulating real-life cases. To corroborate this point, 5 subjects (3 male and 2 female) expressed their wishes to withdraw from the study, attributing their decision to feeling an inherent danger and fear of the physical aspects of the present study. The subjects (ten students) were made to fall from a height of 3.65m under 13 conditions of various natures. Footage of the subjects falling was captured on two high-speed video cameras (120 fields/second) which markedly improved the calculation of 3D coordinates along the subjects' flight path. After extensive calculations, we were successful in determining the maximum attainable horizontal distances (X) in passive falling patterns ($Z = -0.373X^2+0.586X+0.655$: Z=height). Additionally, we found that force applied to the abdominal area results in shorter horizontal distances in comparison to falls where force is directly applied to the posterior side of the body.

Keywords Suicide • Homicide • Human subjects • Psychological effects • Free-falls

Introduction

Over 9000 fall-related fatalities occur each year in Japan. These numbers are alarmingly high and come second only to traffic accidents within the context of "accidental deaths." Deaths attributed to free-falls occur in many forms: willful (suicide); being pushed/shoved from behind (homicide); or accidentally falling from an elevated working environment. Normally, the manner of the fall is clear and roughly a third of these fatalities can attributed to suicide. Regretfully, the manner remains unresolved in a handful of cases despite exhaustive investigative efforts. Cases such as these, where the manner (i.e. suicide, homicide, accident) cannot be determined, often result in legal disputes necessitating scientific intervention.

Among research that has been conducted in the field of fall-related deaths, this paper is preceded by works performed by Snyder [1] and Lewis [2] who address the correlation between body position and injuries, and Atanasijevic [3] who covers the issue from a height and injury perspective. While such research pertaining to free-falls and injury have been performed, very few have come up with an objective index that focuses specifically on the causes of these falls. In addition to carefully examining the data obtained from numerous fall-related cases, Fujiwara [4] employed the use of a life-sized dummy in a series of experiments in order to determine the distinct patterns and characteristics which aid in differentiating the mechanisms of injury in active and passive free-falls. Turk and Tsokos [5] sought to examine the cause of the falls by evaluating the relationship between height and injury from the viewpoint of forensic pathology. They concluded that a number of factors (i.e. the presence of underlying neurological/psychological impairments, results from a scene investigation, toxicological examinations, etc) must be taken into consideration when attempting to determine the cause of these falls, but ultimately failed to establish an objective index. In short, in addition to a thorough post-mortem examination of the injuries the deceased has sustained, a determination on the cause of free-falls requires the analyses of vast amounts of information (crime scene report, witness accounts, assessment on underlying motives (i.e. history of mental illness) etc.).

Christensen [6] applies the use of a life-sized dummy manipulated to simulate various body positions in a series of free-fall experiments from a height of 19.8m and reports that, without exception, the body always lands horizontally. Regretfully, whether these results can be applied to human victims remains questionable. It is imperative that psychological conditions such as fear be taken into consideration when assessing the cause of the fall in actual cases. Thus, it is highly advantageous to employ human subjects, and not dummies, in such experiments. Wishhusen [7] does just that and introduces human subjects (high-divers/swimmers) in his study which has the subjects fall from a height of 5m into a pool. While the mechanism of the fall is successfully simulated and addressed, the high-divers introduce a bias to the study that ultimately hinders the application of the results to actual cases. This is because high-divers—owing to their profession—lack a fear of heights which is commonly found in the average individual.

As demonstrated above, the issue of fall-related deaths and injury has been exhaustively studied; however, there is a considerable lack of studies geared specifically towards establishing an objective index which accurately reflects the realities of fall-related fatalities.

The objective of this study is to estimate horizontal distance (and point of impact), based on active and passive experiments using human subjects prone to the psychological effects of height. Furthermore, by assigning numerical values to the attainable distances of passive and active free-falls and examining body position during the fall from a three dimensional context, we attempt to isolate the characteristics which link physical motions at the time of the fall to the type of fall (i.e. active or passive).

Method

Subjects

A total of 10 test subjects comprised of healthy male and female university students were selected to participate in this study. Information relevant to this study (sex, age, height, weight, and results from a vertical jump test—to test physical ability) for each subject is given in Table 1. Because the purpose of this study lies in establishing a standard index for determining fall patterns, individuals falling short of a standard height-weight ratio (based on Japanese standards) were excluded from participation in this study and only those who fit this criterion were selected. All subjects were advised of the relevant dangers associated with this study prior to any experimentation and submitted written consent for the willful participation in this study (approved by Ethics Committees of the Graduate school of Human development and Environment, Kobe University).

Organization of Experiment

The set-up for the experiments is illustrated in Figure 1. Subjects were exposed to active (Table 2) and passive (Table 3) conditions and were made to fall from a height of 3.65 m. In order to form a well-rounded set of experiments which sufficiently encompasses the wide variety of fall-related cases medical examiners encounter, we established 13 distinct conditions at which to perform the assessment.

With regard to the active falling experiment with a running start, Act4, the conditions were originally set to have the subjects leap from the edge of the structure in which they were atop; in actuality, the subjects jumped from a point which was approximately 30cm from the pre-selected jump-point out of fear.

In the series of passive falling experiments which involved pushing or kicking: "back" refers to the center region of the dorsal side and the anterior aspect involved the application of force to the center of the abdomen. The same male aggressor was used to deliver an equal amount of force to all subjects. To prevent injury from occurring to the subjects, the aggressor used a gentle amount of force. Where both hands and feet were grabbed and the subjects tossed (Pas9), two aggressors swung the subject three times in a pendulum motion before releasing the subject over the ledge.

Subject safety was taken into consideration. The point of impact, including its vicinity, was covered with shock-absorbing mats.

Filming

Using 2 high-speed cameras (FASTCAM-Rabbit, manufactured by PHOTRON) we collected data at 120 fields per second on each subject from the immediate left and left-frontal oblique. Data collection commenced with the initial movements before the fall and terminated at the time of impact. The distances between the subject and cameras A and B were 18m and 24m, respectively, with a distance of 17m between the two cameras. For subsequent image analysis, we marked the joints of the subjects with colored tape. With regard to the three dimensional analysis: X refers to the direction in which the subject jumps (or is tossed) from the platform; Y, to the left and right directions from the platform; Z, to the direction perpendicular to the horizontal plane; and the "origin," the coordinates identifying the final point of contact on the platform.

Data Analysis

Analysis on the filmed footage was performed using three dimensional motion analysis software (Frame-DIAS II V3 3D, manufactured by DKH). The data obtained from both cameras were uploaded onto a computer which subsequently translated the data into three dimensional coordinates based on the 23 reference points identified on each subject via colored tape markings. The center of gravity was determined for each data piece by calculating the 3-D coordinates estimated by the computer [8]. The margin of error, as a result of filming was 1.9cm, 1.5cm and 3.3cm for the X, Y and Z coordinates, respectively.

Data Processing

The following procedure was applied for data processing:

1. Subjects' origin of flight is determined via image analysis.
2. Task performance for each subject is captured on two cameras placed in different positions. Video footage is digitized following recognition of 23 reference points (such as the joints) marked by reflective tape. Next the coordinates for the subjects' center of gravity is extrapolated via the digitized coordinates of the x, y and z axes.
3. Because the coordinates for the center of gravity contain a margin of error, a function approximation was applied to all X, and Z coordinates from the point of origin to account for the changes occurring in time. Air resistance during freefall is virtually negligible. The test subjects travel in a uniform velocity motion along the horizontal plane (X and Y coordinates) and move in a uniform acceleration motion along the vertical plane (Z coordinates) after taking flight. Therefore, in this study, linear functions were applied to the changes in time occurring over the center of gravity as represented by coordinates X and Y, and non-linear function was applied to the changes in time occurring over the Z coordinates. In this fashion, the data was "smoothed" out.
4. Using the "smoothed" out results obtained in step 3 (i.e. the drop locus for each of the X-Y and X-Z planes), we came up with an equation to determine the drop locus for the center of gravity in each of the subjects.
5. Using the equation established in step 4, we next calculated the estimated point of impact (coordinates for X, Y and Z) for an individual who fell from a height of 50m and used the coordinates to estimate horizontal distance.

Results and Discussion

Each subject's center of gravity was calculated via the captured 3D images. Subsequent to this, the highest point along each subject's post flight path was further calculated. Based on these calculations, we estimated the horizontal distance at a simulated height of 50m for each set of experiments (table. 4). The results displayed in table. 4 show the individual results obtained for each subject performing a total of 13 falling (4 active and 9 passive variations) tasks; each task was performed only once. Additionally, 5 subjects (3 male and 2 female) conscientiously objected to participating in certain segments of the experiment due to a general sense of fear and/or feeling an inherent danger associated with the experiment. With particular regard to the passive set of experiments, 4 subjects (2 male and 2 female) refused to take part. This shows that the height selected for this study—while safe—is enough to instill fear in the subjects and is a manifestation of fear, which is a significant psychological factor associated with this study.

Drop locus and horizontal distance for active falls

Based on the results obtained from the active falling experiments, we calculated the drop locus for each of the subjects if they had fallen from a height of 50m and posted the results in Figure 2. The results were two-fold; the first of which involving Act1 and Act2, resulted in a horizontal distance of approximately 7 – 8m, whereas the second group consisting of Act3 and Act 4 resulted in a horizontal distance of 11 – 16m. In the former subset, the subjects leaped from atop the platform to fall in a relatively straight-down manner. Meanwhile, in the latter subset, the subjects had a running start and leaped off with one foot. The greater distance achieved in the latter subset can be attributed to the extra speed obtained from the running start. In addition, judging from larger gap inherent in the results obtained from the second subset, it can be assumed that physical ability (i.e. leg strength) is a factor that influences horizontal distance in active falls.

A lingering question in fall-related accidents is whether strong gusts of wind can influence the drop. According to our calculations the influence of wind is insignificant. To illustrate this point, the deviation for the point of impact for an individual 170 cm tall, getting a crosswind of 3m/sec and dropping from a height of 50m is only 27cm.

Physical ability and horizontal distance in active falls

In active falls physical ability is believed to be a factor that influences horizontal distance. For example, in the active falling experiments—with particular regard to Act3 and Act4 where an accelerated start is made prior to the jump—the subjects were able to gain a high take-off speed that resulted in the longer horizontal distance recorded. Herein lays the basis for the assumption that physical ability influences horizontal distance.

Because it was assumed to be a prominent factor in estimating horizontal distance, physical ability was included in the present study; measured by the height achieved in a vertical jump test. This test was introduced based on the assumption that a higher mark would result in a higher initial speed at the time of jump, which would in turn result in a greater horizontal distance.

Vertical jump, as opposed to long jump, tests were adopted for the purpose of gauging athletic ability in this study, predominantly because the latter can be heavily biased by the presence or absence of technique. The effectiveness of this hypothesis is reflected in the loose correlation observed in our results between the heights obtained on the vertical jump test and horizontal distance achieved in the various sets of experiments. With particular regard to subjects A (male) and H (female) who are actively involved in athletic competition, their superior leg strength allows them to achieve greater horizontal distances than their non-athletic counterparts.

The marks achieved on the vertical jump test for all subjects, along with its correlation to the estimated horizontal distance calculated for Act4 is given in Figure 3. As expected, for falls involving a running start, the horizontal distance was greater in individuals who displayed superior physical abilities because their greater muscle strength enables them to gain a higher initial speed. In contrast, for the active falling experiments without the use of a running start (e.g. Act1), there was no apparent correlation between physical ability and horizontal distance.

Additionally, with regard to age and physical ability, as a general rule of thumb, physical ability deteriorates with age. Thus, age is a factor that should not be neglected when applying the results presented herein to actual casework.

Passive Falling

Horizontal distance and the application of force to various parts of the body

Next, we sought to explicate whether force applied to different parts of the body results in varying estimated horizontal distances in passive falling.

After comparing the Pas1 (push to the back with both hands) and Pas5 (push to the chest with both hands) condition experiments, it was evident that a push to the back results in a greater estimated horizontal distance (Figure 4). These results were consistent in the vast majority of subjects. Similarly, under the single-handed conditions Pas2 (push to the back with one hand) and Pas4 (push to the posterior waist with one hand), all of the subjects—with exception to subject G—achieved greater horizontal distances (Figure 5). In this fashion, constant marks were observed under conditions Pas6 (gentle kick to the back) and Pas7 (gentle kick to the abdomen), as well, where a gentle kick was substituted for the push as the applied force. All but one (subject A) subject recorded greater estimated horizontal distances when the gentle kick was applied to the back in comparison to the same force being applied to a different portion of the body (Figure 6). While the manner in which the force was applied differs, these results collectively suggest that force applied to the back results in a greater horizontal distance.

The reduction in horizontal distance observed in the set of experiments involving the application of force to the anterior surface of the body is most-likely attributable to a greater area of the body's natural crumple zones that cover the anterior surface. It can be assumed, that these areas absorb the energy transferred from the force which translates into a loss of distance. Another probable theory would be the subjects' visual awareness of the delivery of force beforehand that jerks a natural defensive reaction to try and stay put. In contrast, when the force is delivered to the back, the subject is unaware of the danger and is unable to react. Furthermore, owing to the body's skeletal structure, the body has greater restriction over bending convexly; therefore, more energy is transferred from the applied force than if the subject had been pushed/kicked over the anterior surface. Thus, the body's natural defensive reaction and mental/emotional state are vital elements one should consider when determining the pattern of a fall.

The relationship between weight and horizontal distance in passive falling

Let us assume that in a passive fall—where force is applied by a separate party—the physical properties of the drop itself resemble that of an inanimate object. Thus, the physical abilities of a victim are not reflected in the drop locus. Instead, key factors that would influence the drop locus would be the victim's height, weight and figure. With particular regard to cases where an individual is thrown from a ledge, it can be assumed that an individual's weight—as well as the muscular strength of the aggressors—would have tremendous impacts on the drop locus.

Under passive falling condition Pas9, we attempted to establish a relationship between weight and estimated horizontal distance (Figure 7). The results showed a clear trend of lighter subjects achieving greater horizontal distances. Note: subjects B, D, I, J and E abstained from participation in the segment of the study and therefore their results could not be obtained.

The pinnacle of the drop locus for the subjects thrown in conditions Pas8 and Pas9 are given in Figure 8. The female subjects, who are lighter in weight, had greater susceptibility to the pendulum motion actuated by the aggressors, which resulted in a higher arc and longer horizontal distance. Not only are the lighter subjects easier to throw, but the initial speed at which they take flight in a horizontal manner is higher, which ultimately results in greater horizontal distance.

Given these results from the set of passive falling experiments where a subject is thrown by two aggressors, it is clear that a lighter weight results in a greater swinging motion, which results in a higher arc and greater initial horizontal speed that ultimately pave the way to greater values in horizontal distance.

In one subject, weight bared no influence on horizontal distance.

Maximum threshold for drop locus and horizontal distance in passive falling

Based on the results obtained from the set of passive falling experiments, we calculated the drop locus for a height of 50m. Whereas, the maximum estimated horizontal distance was 10.1m when dropped by a single individual (Pas6), the same distance grew to 12.5m (Pas9) when dropped by two individuals (Figure 9). These are the maximum values for the fall pattern index, and imply the peak threshold which can be achieved in passive falling. In short, any value that surpasses these threshold values implicates an active (and not passive) pattern of fall.

In the present study, we selected human subjects to perform a series of falling experiments. By doing so, we were successful in including such factors as fear and motor function, which could not be achieved from similar examinations using test dummies. As a result, the values we present herein pertaining to active and passive falling are more reliable than past endeavors such as that which is presented by Shaw [9] and other researchers.

Differences in drop locus after taking flight under different conditions

Without exception, the center of gravity reached its highest point in the drop locus immediately after taking flight in all of the experiments performed. The highest point in the drop locus is given in Figure 10. The average and standard deviation for this point in the active falling experiments are 0.47m±0.20m for X and 0.73m±0.18m for Z. In the passive falling experiments, X was 0.25m±0.09m and Z was 0.81m±0.07m. Hence passive, in comparison to active, falls could not achieve greater distances along the X (horizontal) direction because there was greater movement in the Z (vertical) direction.

From these results, we can assume that in an active fall the victim jumps in a forward—rather than upwards—motion. When actively falling from elevated areas it is relatively safe to assume that a victim feels a certain amount of fear. As such, it is hard to imagine that a victim would jump in an upward motion and thereby increase the amount of fear he/she must already be feeling.

Additionally, there is great variation in the positions of the X and Z coordinates between the active and passive sets of experiments. This can be attributed to the "will" of the subjects at the time they performed the active fall; the same "will" is absent in the passive falls where they were forced over the edge. Once the subjects took flight in the set of passive experiments (being thrown/pushed from the ledge) the physical properties of their drop are no different from an inanimate object falling to the ground, which resulted in the lesser degree of deviation between the individual results.

While the physical properties of a fall can be explained by the laws of physics, when attempting to determine the drop locus and attributing a fall pattern, it is imperative that the victim's psychological/emotional state be taken into consideration.

Conclusion

In fall-related cases, the distinction between passive and active causes is of paramount importance. In the present study, we selected 10 test subjects to simulate the 4 conceivable modes of active falling and 9 modes of passive falling in a series of experiments. Using the data obtained from two high-speed cameras, we were able to come up with the coordinates and drop locus for the center of gravity in each of the subjects by conducting a three-dimensional motion analysis. Based on these data, we calculated the maximum estimated horizontal distance under various falling conditions and came to the following conclusions:

(1) In comparing the passive and active forms of falling, we found that the latter results in greater horizontal distances. In an active falling experiment (Act4), the estimated horizontal distance was 16m for a fall originating from a height of 50m. On the other hand, the maximum horizontal distance estimated for a 50m fall was 10.m for a passive fall which involved the subjects being pushed over a ledge by a single aggressor (Pas6), and 12.5m in the set of experiments where the subjects were thrown over the ledge by two aggressors (Pas9) (Figure 2).

(2) Based on the estimated values of horizontal distance calculated in this study, we found a threshold value for horizontal distances that can not be achieved via passive falling, which can be given by the equation

Pas9: $Z = -0.373X^2+0.586X+0.655$

Pas6: $Z = -0.524X^2+0.216X+0.760$

（X: horizontal distance, Z: height）

(3) In the series of active experiments allowing an accelerated start prior to jumping from the ledge, we learned that physical abilities (i.e. scores achieved on the vertical jump test) heavily influence the drop locus, which in turn results in greater horizontal distance.

(4) Where two aggressors grabbed the hands and feet and threw the subjects off the ledge, the horizontal distance was 9-10m for individuals weighing 61.5-69kg, and 11.5m-12.5m for individuals weighing in at 48-52kg; meaning, lighter individuals achieve longer horizontal distances in passive falling. On the contrary, weight had no baring on horizontal distances for the set of passive experiments where subjects were pushed from the ledge by one aggressor.

(5) In the passive experiments, force applied to the anterior surface of the body resulted in decreased horizontal value, in comparison to the same force being applied to the posterior surface of the body (i.e. the back).

(6) In active falls, a victim jumps in a forward—and not vertical—motion. On the other hand, greater vertical motion was observed in passive experiments where a pendulum motion was applied to the subject before release over the ledge.

In this study, we identified and analyzed the fine-scale details inherent in various forms of falls and successfully compiled the probable ranges of horizontal distance which can be achieved in an objective index. This index has pragmatic applications to the veritable cornucopia of fall-related cases medical examiners encounter in real-life situations.

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Table 1 Physical characteristics of the subjects

Subject	Sex	Age (Years)	Height (cm)	Weight (kg)	Vertical Jump Test (cm)
A	Male	22	174.0	63.0	62
B	Male	21	175.0	70.0	55
C	Male	21	174.6	69.0	54
D	Male	21	165.0	61.5	53
E	Male	21	171.7	61.5	50
F	Female	22	155.0	48.0	37
G	Female	19	158.5	49.0	41
H	Female	21	164.0	52.0	55
I	Female	21	159.0	52.0	38
J	Female	21	161.0	52.0	34

Table 2 Four conditions for the active set of experiments

No.	Task
Act1	Two-leg jump
Act2	One-leg jump
Act3	Jump with a one-step start
Act4	Jump with a running start

Table 3 Nine conditions for the passive set of experiments

No,	Conditions Applied
Pas1	Push to the back with both hands
Pas2	Push to the back with one hand
Pas3	Push to the waist with both hands
Pas4	Push to the waist with one hand
Pas5	Push to the chest with both hands
Pas6	Gentle kick to the back
Pas7	Gentle kick to the abdomen
Pas8	Thrown by two parties grabbing both hands and feet (no pe ndulum motion)
Pas9	Thrown by two parties grabbing both hands and feet (with pendulum motion)

Table4. Drop profiles for all test subjects. Subjects B,D,E,I and J refrained from taking part in certain tasks. The "highest point" refers to the maximum height/distance achieved for each subject, which was measured from the point of origin to the maximum height/distance of the subjects' center of gravity post-flight. The "horizontal distance" refers to the estimated distance from the point of origin to the subjects' center of gravity estimated for a simulated height of 50m. This distance is estimated via calculating the drop locus from

the obtained test results.

Male Subj.	Task	Highest point (m)		Horizontal distance (m)
		Horizontal position	Vertical position	
A	Act1	0.51	0.84	7.99
A	Act2	0.65	0.82	10.01
A	Act3	0.77	1.01	11.47
A	Act4	1.08	1.07	16.73
A	Pas1	0.21	0.90	8.74
A	Pas2	0.35	0.88	9.59
A	Pas3	0.28	0.88	9.45
A	Pas4	0.37	0.93	9.06
A	Pas5	0.14	0.81	6.64
A	Pas6	0.23	0.92	8.33
A	Pas7	0.12	0.83	8.75
A	Pas8	0.26	0.67	7.25
A	Pas9	0.60	0.78	8.93
B	Act1	0.27	0.58	7.62
B	Act2	0.27	0.71	7.54
B	Act3	0.34	0.74	10.02
B	Act4	0.53	0.78	14.84
C	Act1	0.32	0.72	7.01
C	Act2	0.32	0.73	7.14
C	Act3	0.65	0.83	10.95
C	Act4	0.90	1.04	13.81
C	Pas1	0.21	0.81	7.86
C	Pas2	0.29	0.68	8.09
C	Pas3	0.31	0.86	7.70
C	Pas4	0.29	0.79	7.61
C	Pas5	0.18	0.80	6.99
C	Pas6	0.20	0.84	8.79
C	Pas7	0.13	0.76	8.07
C	Pas8	0.10	0.66	7.01
C	Pas9	0.51	0.60	9.87
D	Act1	0.44	0.74	7.62
D	Act2	0.40	0.84	7.43
D	Act3	0.48	0.86	9.34
D	Act4	0.81	1.02	14.30
E	Act1	0.37	0.50	7.64
E	Act2	0.36	0.73	7.67
E	Act3	0.41	0.77	8.28
E	Act4	0.94	0.77	13.62
E	Pas3	0.32	0.81	8.39
E	Pas4	0.28	0.78	8.06
E	Pas5	0.32	0.85	6.83
E	Pas6	0.05	0.92	8.09
E	Pas7	0.19	0.82	7.89
E	Pas8	0.23	0.68	6.76
E	Pas9	0.62	0.77	9.56

Female Subj.	Task	Highest point (m)		Horizontal distance (m)
		Horizontal position	Vertical position	
F	Act1	0.51	0.62	8.09
F	Act2	0.29	0.71	6.29
F	Act3	0.28	0.78	7.59
F	Act4	0.51	0.83	12.54
F	Pas1	0.30	0.75	7.46
F	Pas2	0.23	0.70	7.83
F	Pas3	0.23	0.76	6.67
F	Pas4	0.23	0.76	6.67
F	Pas5	0.22	0.66	6.91
F	Pas6	0.21	0.77	10.05
F	Pas7	0.45	0.79	8.21
F	Pas8	0.45	0.80	8.22
F	Pas9	0.77	0.85	11.60
G	Act1	0.37	0.56	7.62
G	Act2	0.36	0.55	8.26
G	Act3	0.43	0.61	9.63
G	Act4	0.53	0.73	12.32
G	Pas1	0.27	0.80	6.69
G	Pas2	0.26	0.66	7.31
G	Pas3	0.34	0.77	7.87
G	Pas4	0.23	0.74	7.84
G	Pas5	0.25	0.72	6.39
G	Pas6	0.19	0.76	8.22
G	Pas7	0.07	0.81	7.22
G	Pas8	0.48	0.79	7.89
G	Pas9	0.82	0.76	12.46
H	Act1	0.47	0.75	7.49
H	Act2	0.45	0.77	8.03
H	Act3	0.50	0.84	9.98
H	Act4	0.22	0.01	14.88
H	Pas1	0.33	0.82	8.27
H	Pas2	0.29	0.81	8.05
H	Pas3	0.43	0.84	7.44
H	Pas4	0.33	0.83	6.88
H	Pas5	0.20	0.87	7.00
H	Pas6	0.30	0.87	8.48
H	Pas7	0.28	0.86	7.57
H	Pas8	0.50	0.77	8.23
H	Pas9	0.90	0.90	12.11
I	Act1	0.42	0.64	7.55
I	Act2	0.30	0.61	7.78
I	Act3	0.37	0.74	8.86
I	Act4	0.49	0.80	11.51
J	Act1	0.29	0.45	6.82
J	Act2	0.26	0.61	6.52
J	Act3	0.35	0.66	7.76
J	Act4	0.38	0.76	10.81

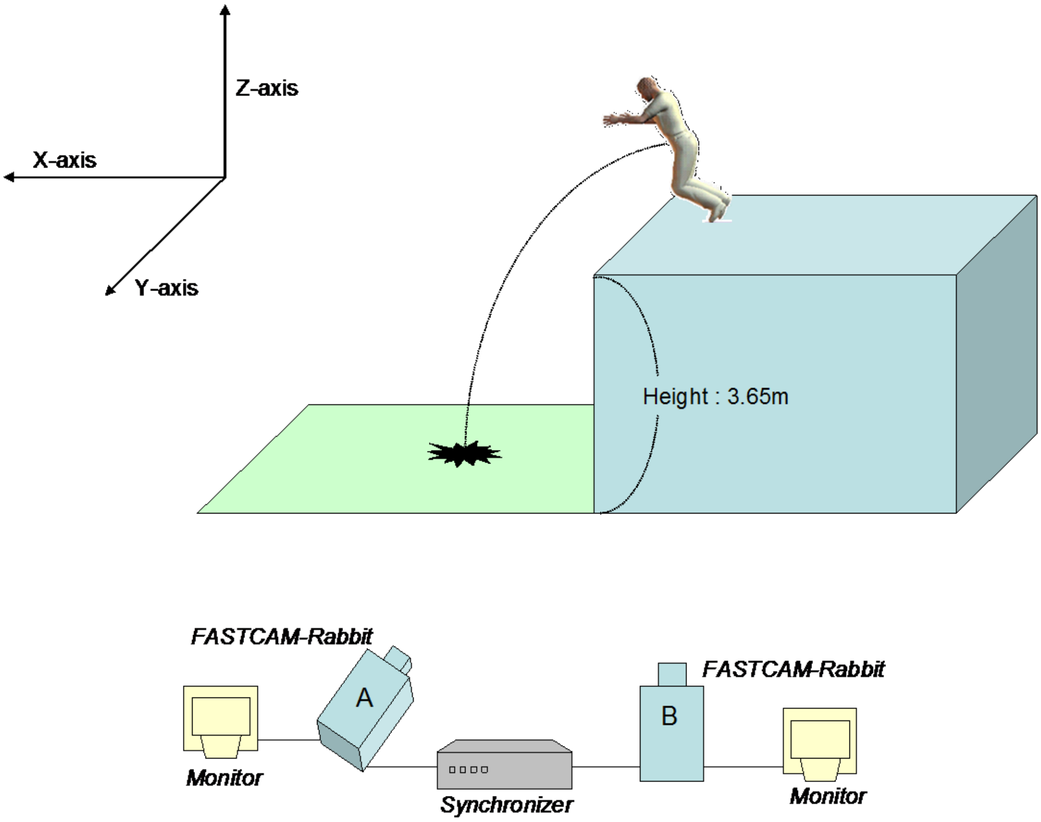

Figure 1　　Set up for the experiment

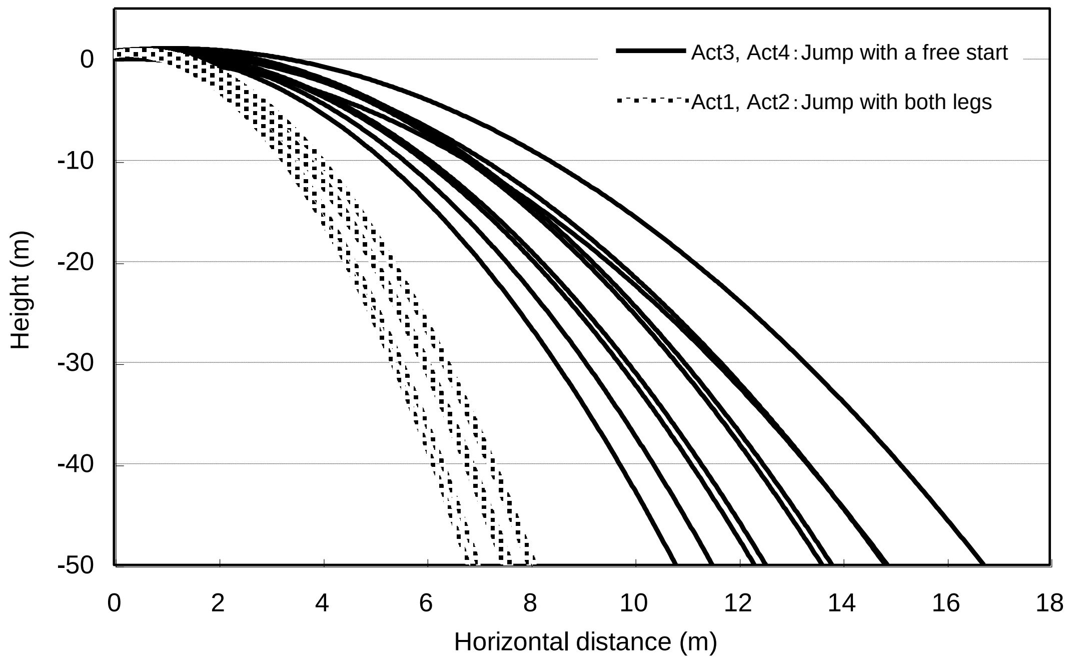

Figure 2　Horizontal distance estimated for a 50m fall based on the drop locus calculated for the active set of experiments for all subjects

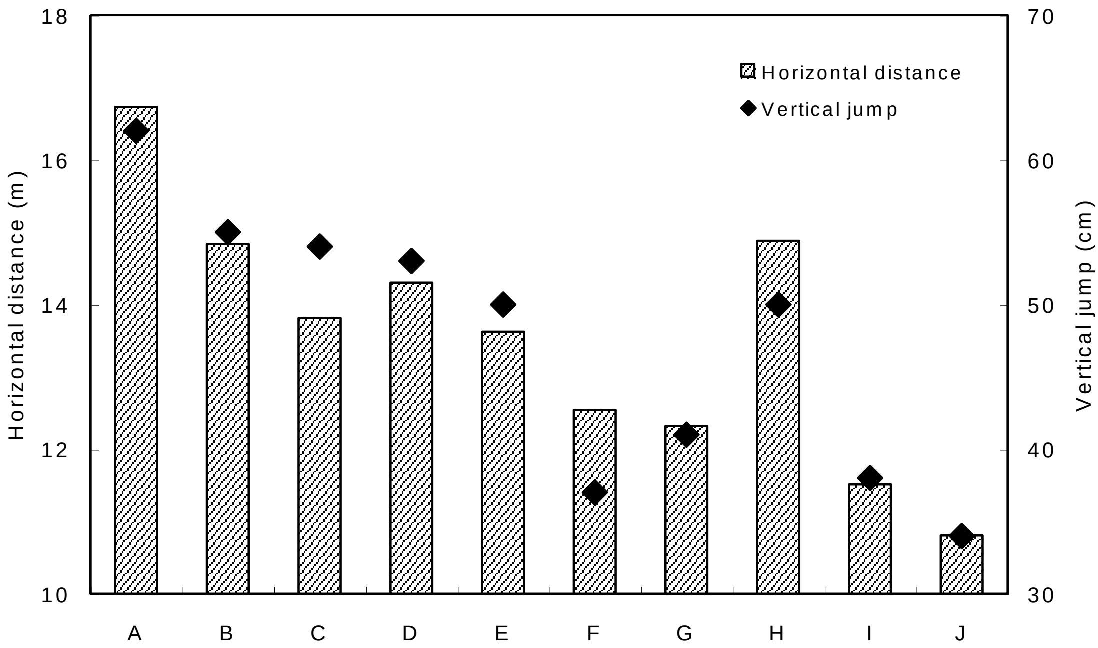

Figure 3 Estimated horizontal distance for a 50m fall in Act4 and marks received on the vertical jump test

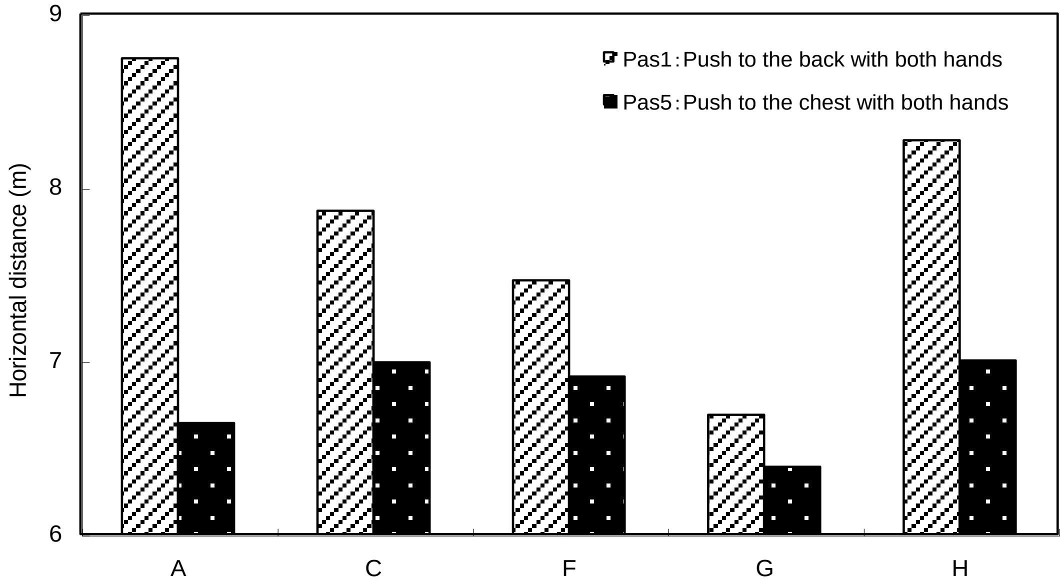

Figure 4 Comparison of estimated horizontal distance for a 50m fall for passive experiments Pas1 (Push to the back with both hands) and Pas5 (Push to the chest with both hands)

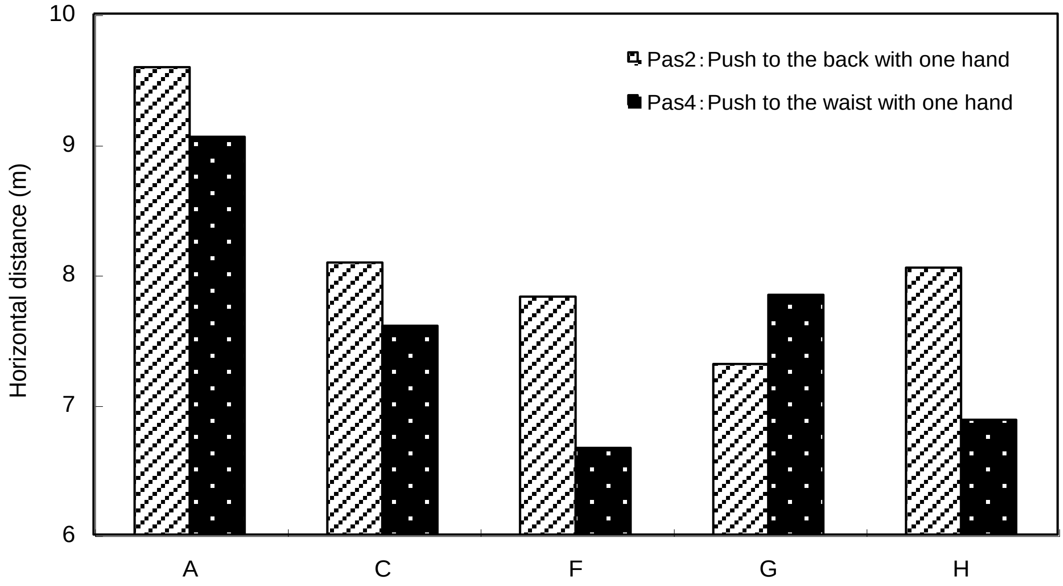

Figure 5 Comparison of estimated horizontal distance for a 50m fall for passive experiments Pas2 (Push to the back with one hand) and Pas4 (Push to the waist with one hand)

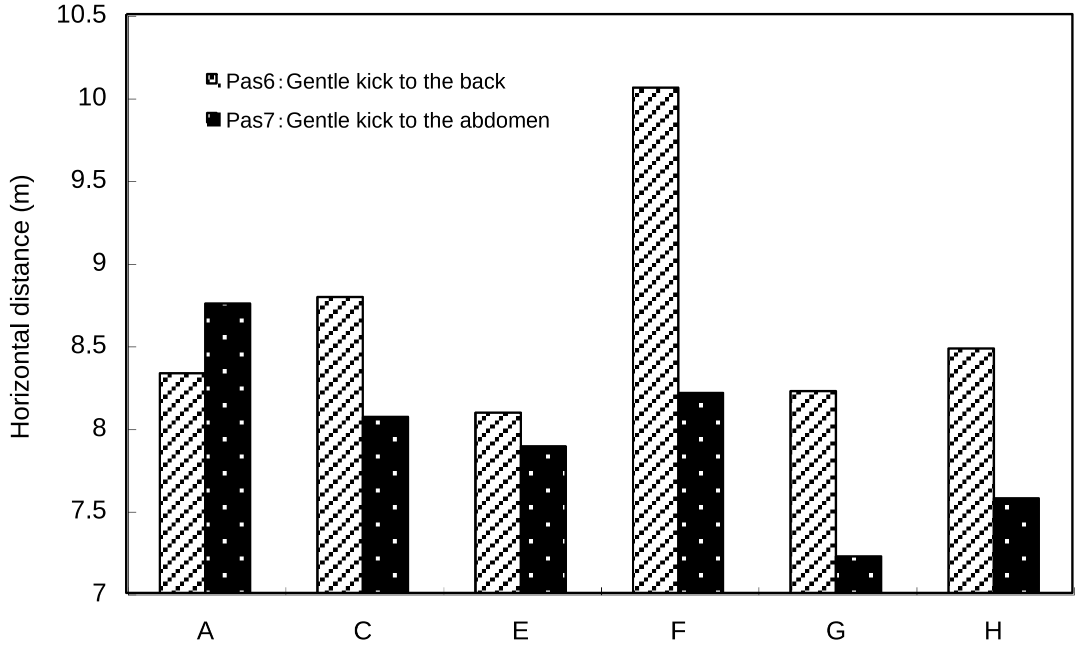

Figure 6 Comparison of estimated horizontal distance for a 50m fall for passive experiments Pas6 (Gentle kick to the back) and Pas7 (Gentle kick to the abdomen)

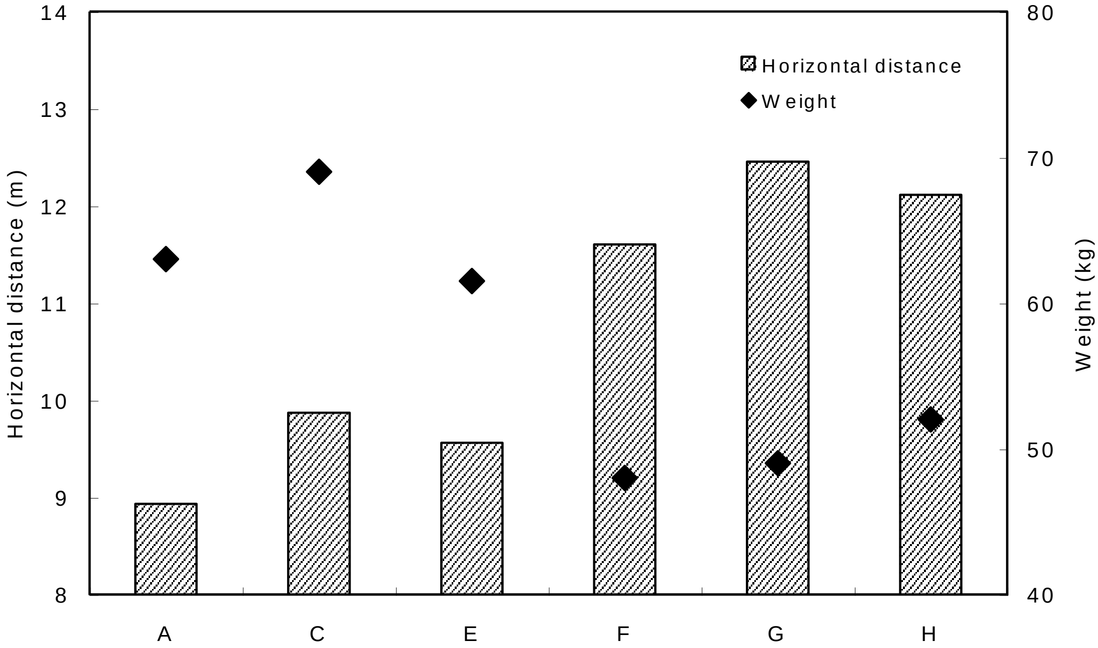

Figure 7 Relation between weight and passive falling condition Pas9 (Male subjects: A, C and E; Female subjects: F, G and H. Subjects B, D, I and J abstained from participation in this segment of the study)

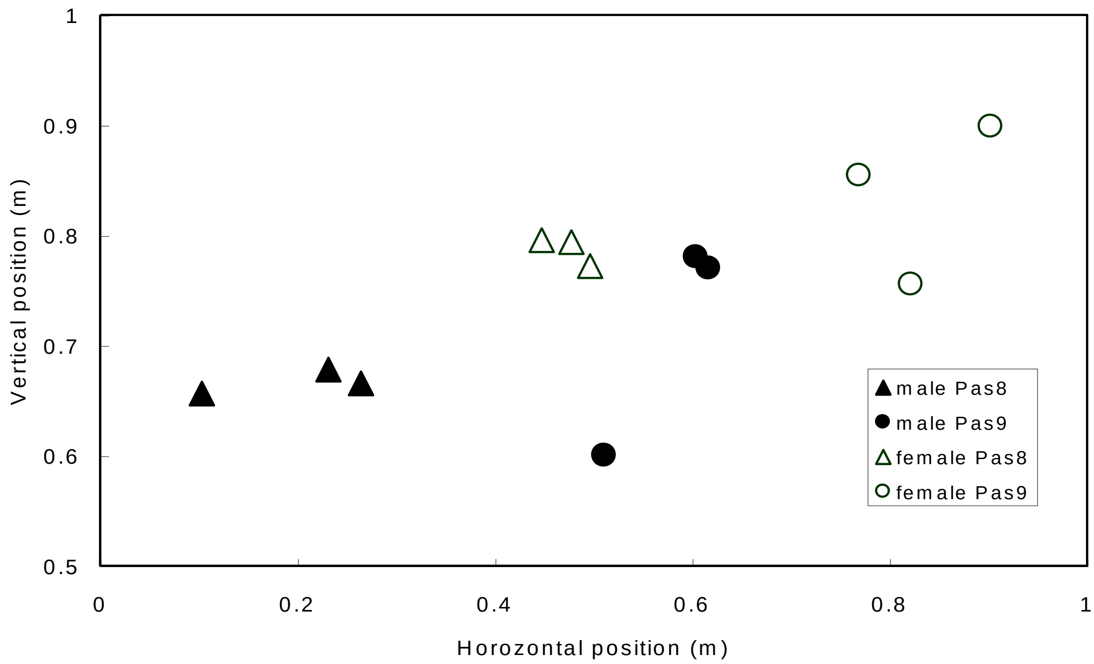

Figure 8 Pinnacle of the drop locus after taking flight under conditions Pas8 and Pas9.

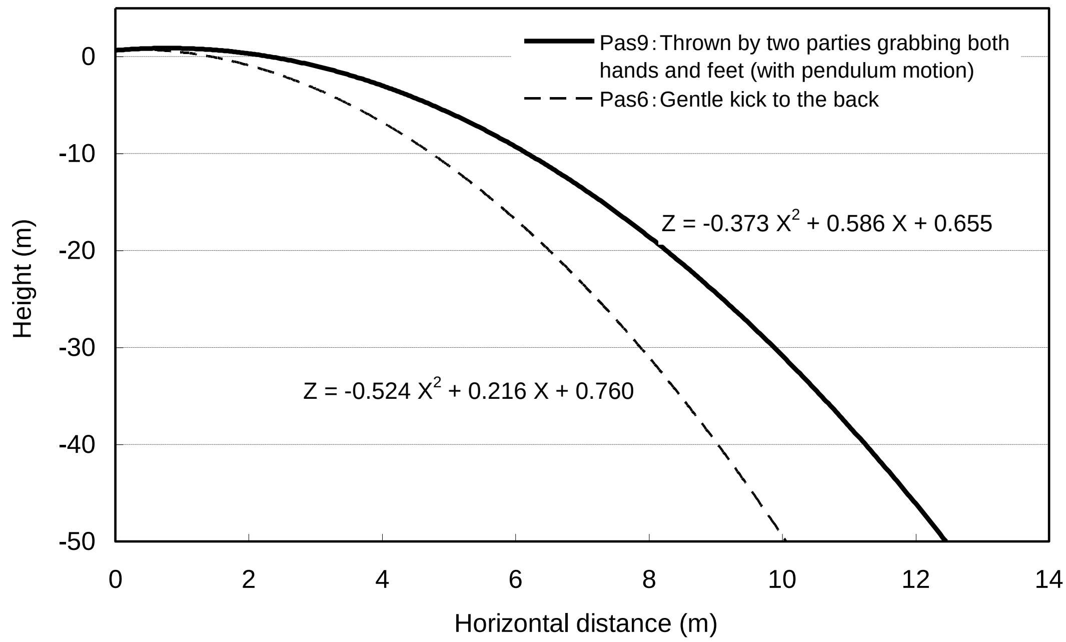

Figure 9 Horizontal distance and maximum drop locus for passive experiments involving 1 or 2 aggressors applying force to the subjects

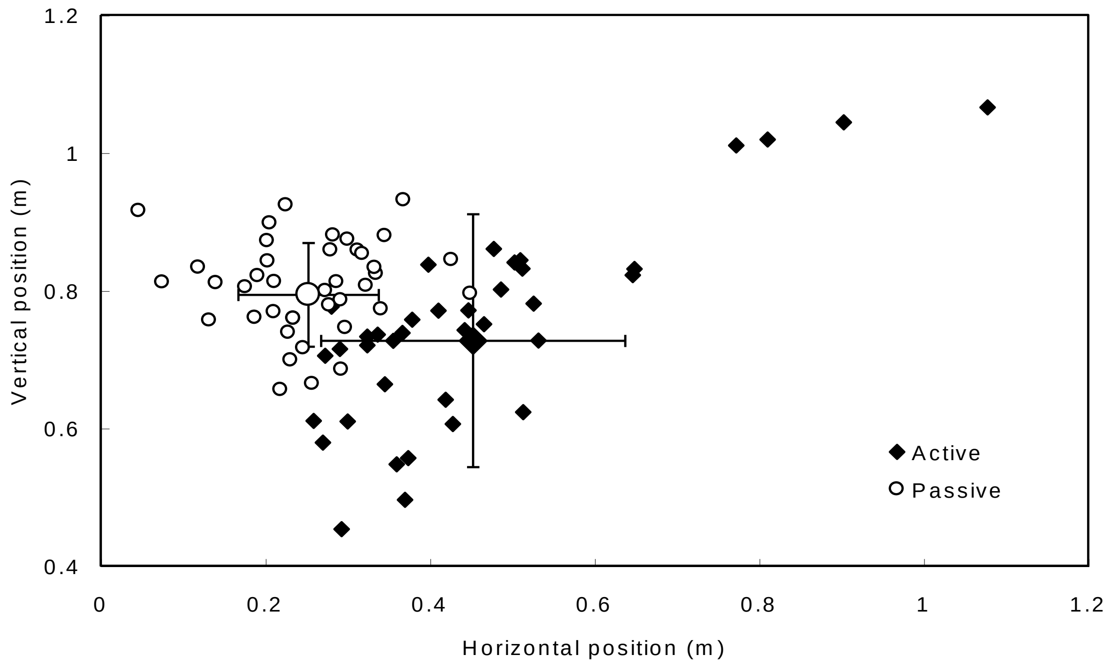

Figure 10　Highest point in the parabola for each subject's center of gravity after taking flight