ICIC Express Letters
Part B: Applications
Volume **7**, Number **5**, May **2016**

ICIC International ©2016 ISSN 2185-2766
pp. 1007–1012

SIMULATION OF FALLING OF HUMAN USING A ROBOT

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Received October 2015; accepted January 2016

Abstract. *Accurate evaluation of turnover or fall accidents is necessary to understand the relation between HIC (Head Injury Criterion) and the way of falling. In order to investigate this problem, we have done the experiment in JARI using human-type robot which simulates the human accidental damage. The precise data of acceleration has been taken from three points of the robot (head, chest and pelvis), Using the acceleration data of head point, HIC has been calculated for two experiments. Furthermore, we construct the speeds and locations of the three points using the acceleration data of chest and pelvis. We found that there are two types of falling posture, convex and depression of the upper body, and this posture of falling is related on the largeness of HIC. Finally, we found the HIC of convex posture is smaller since the pelvis absorbs the shock of the impact.*
Keywords: Collision Impact Index (CII), HIC, Acceleration data, Fall, Collision, Dummy robot, Japan Automobile Research Institute (JARI)

1. Introduction.

A falling or dropping of human is one of the big problems, which makes rapidly worse the quality level of elderly people's life. The probability is 20% that old men over 65 years fall inside their houses, and it is said that about 60% among them suffer a fracture by the fall [1,2]. The death rate by fall is less than one person per 100,000 people below 65 years old; however, it becomes 28 persons in those over 80 years old. Even if in facilities such as a hospital, it has been reported that there are many accidents that old men aged over 65 fall on a toilet at night when under an obstacle or medicine such as sleep stabilizer or sedative. Therefore, many investigations have been proposed by both theoretical and experimental sides on the evaluation of the injury due to falling accident [3-9].

On the head injury, an index of HIC has been proposed. HIC is Head Injury Criterion, which connects between the value of HIC and the damage of the head. The meaning of the HIC is as the following. If HIC is larger than 1000, about half would be damaged seriously, and if HIC is larger than 2000, almost all would be damaged seriously. The aim of our experiment is to investigate the damage of human under large HIC, i.e., larger than 2000. It is dangerous if we use the true human for the experiment, so we use the robot which simulates the human body size and weight. Even if it is under highly dangerous situation, we can accurately detect the acceleration inside the body using the acceleration censors. The acceleration while falling is measured with 3 acceleration censors inside the body: head, chest and pelvis. From this acceleration data, we can construct the falling pattern of the whole body.

It has been not clear the relation of HIC and the motion of the whole body. In this paper, we make clear the relation with HIC by the simulation of the motion of the whole body while falling. In this paper, we pay strong attention to the reason why the HIC is different on the same straight backward falling of the two experiments, i.e., Nos. T15 and T16. They are similar by the visual observation; however, the precise acceleration data of the two falling are different a little.

Therefore, the aim of this paper is to investigate the relation between the precise falling pattern and its HIC. This leads finally to understanding deep meaning of HIC.

2. **Explanation of HIC.** Head Injury Criterion (HIC) is generally used to express the level of impact to the head in cases of traffic accidents by car or motor bike, or fall accidents in a daily life. The HIC can be used to assess safety related to various accidents, personal protector, and sport equipment. National Highway Traffic Safety Administration (NHTSA) defined HIC in 1972. HIC is derived from the time change of acceleration.

HIC is defined as the following equation,

$$\text{HIC} = \left[\frac{1}{t2 - t1}\int_{t1}^{t2} a(t)\right]^{2.5} (t2 - t1) \quad \text{at the max value} \tag{1}$$

where $a(t)$ is acceleration (usually its absolute value), and $t1$ and $t2$ are the initial and final times (in seconds) of the interval during which HIC attains a maximum value. Normally the maximum time duration of HIC, $t2 - t1$, is limited to a specific value, 15ms or 36ms.

The accelerations of two experiments T15 and T16, which is natural backward falling are shown in Figure 1. Using these data, HIC calculated by Equation (1) is 5475 for experiment T15, and 6771 for T16. Although the two experiments have a similar initial condition, the difference is very large, about **24**%. The reason of this difference is the main problem in this paper.

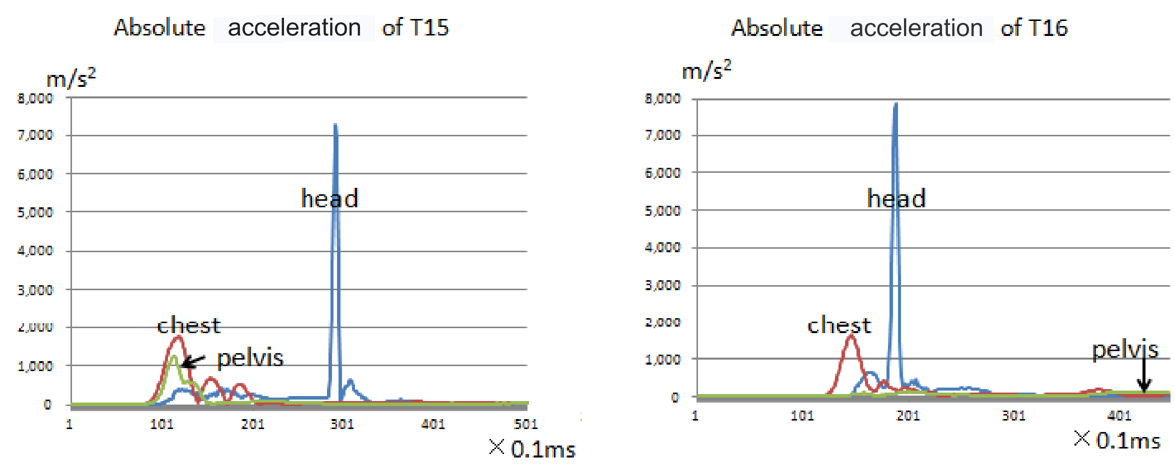

Figure 1. Absolute acceleration of three points of experiment T15 and T16

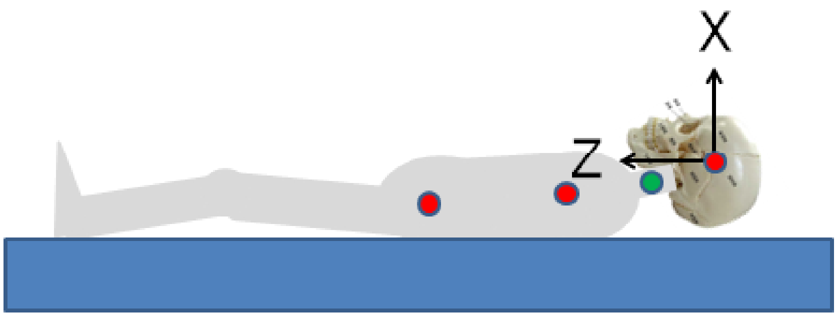

Figure 2. The axes of the three censors fixed with the body

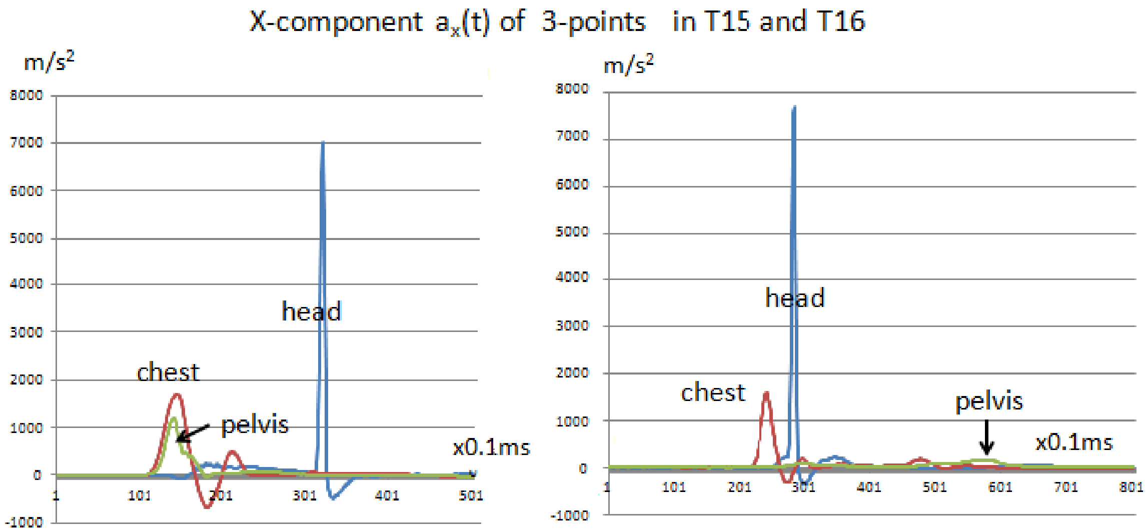

Figure 3. x-component of acceleration data of experiments T15 and T16

3. **Boundary Conditions for Calculations.** We solve a very narrow time period (within 100ms), and then the direction of the coordinate changes little. The axes are set as Figure 2, and we use only the x-component of acceleration. The important point is to understand that the x-component is the major acceleration during the collision. This is shown by the fact that Figure 3 is similar to Figure 1. The absolute value coincides with the x-component during very short time of hitting of the head.

At first, we should set up the initial conditions for the integration. In general, two constants are necessary for the integration. We determine the constants as following conditions.

(1) The initial velocity should be determined so that the position is symmetric at the point of $a = 0$ of both sides of the acceleration peak.

(2) The initial position is adjusted so that the minimum point is the height of the sensor, which is around 100mm.

Using the acceleration of three censors, we obtain the velocity after integration. Figure 4 shows there is a big difference between T15 and T16. Especially the velocity of pelvis is not sharply rising in T16. This is an important feature of T16, which we explain in a later part.

Another important difference is the head. The velocity of head in T15 has a sharp slope just before the sharp rising. This is also connecting with a small HIC of T15.

Now we show the location of the three points in Figure 5, which is obtained from the integration of their velocities. In this calculation, the time giving the minimum point is

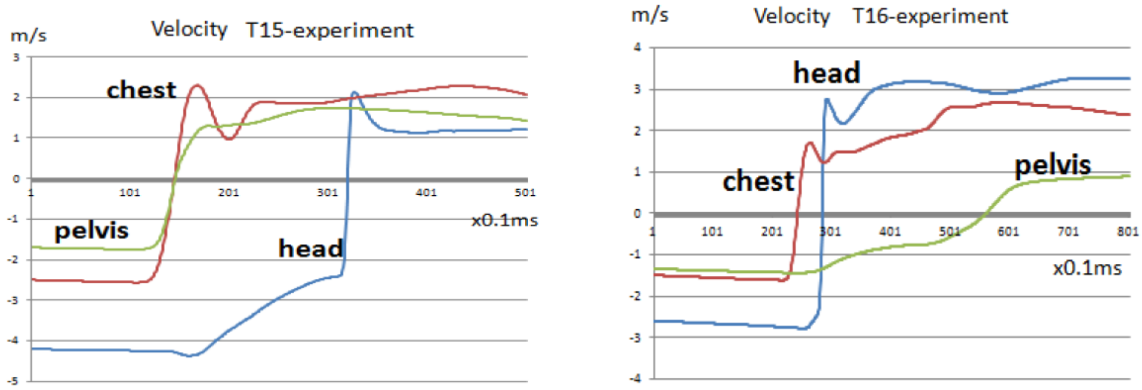

FIGURE 4. Time evolution of the velocity at three points, head, chest, and pelvis for T15 and T16

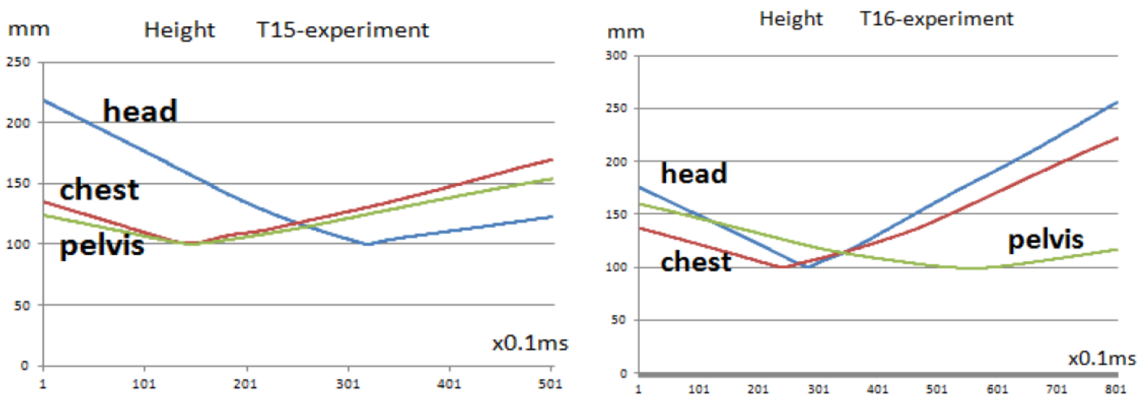

FIGURE 5. Time evolution of the height at three points, head, chest, and pelvis for T15 and T16

determined uniquely; however, the height is determined by the initial condition. Although the solutions of the location seem to be similar, they show three important different facts.

(1) The chest and pelvis attached the floor at the same time in T15; on the other hand, the pelvis reaches very late at the floor in T16.

(2) The moving of the pelvis in T16 is slower than in T15, which is also seen from Figure 4.

(3) The head reaches late in T15; on the other hand, the head hits almost at the same time with the chest in T16.

From these features, we can construct the falling patterns. There are at least two patterns of the falling. One is the pattern where the body line is convex and head is late; the other is the pattern where the body line is depression, and pelvis is late.

4. **Relation between HIC and Falling Pattern.** HIC (Head Injury Criterion) is defined as Equation (1), which includes the acceleration and time interval. This definition is simply rewritten as

$$\mathrm{HIC} = \left[\frac{1}{t2 - t1}\int_{t1}^{t2} a(t)dt\right]^{2.5}(t2 - t1) = \bar{a}^{2.5}\Delta t \tag{2}$$

where $\bar{a}$ is the average of the acceleration, and Δt is the time interval $t2 - t1$.

If the acceleration peak is approximated with the Gaussian curve as

$$a(t) = Ae^{-\frac{1}{2}\left(\frac{x}{\sigma}\right)^2} \tag{3}$$

where A is the peak value of the acceleration. Here we use the integrated value

$$\int_{-\infty}^{\infty} a(t)dt = A\sigma\sqrt{2\pi} \tag{4}$$

We take the time interval 4σ as $t2 - t1$, and then we obtain

$$\bar{a} = A\sqrt{\frac{\pi}{8}} = 0.626A \tag{5}$$

Using this average, we obtain a simple expression of HIC as

$$\text{HIC} = 0.310A^{2.5}\Delta t \quad \text{in unit of g} \tag{6}$$

Here we comment $A\Delta t$ is the velocity change, and then we can obtain the gross estimation of the ratio of HIC from the velocity change. The velocity change is 4.5 in T15, and 5.3 in T16 from the calculation. Then the ratio of the velocity change of T16 to T15 is 1.18. On the other hand, the ratio of HIC of T16 to T15 is 1.24, since HIC is 5475 for experiment T15, and 6771 for T16. This fact implies that the ratio of HIC is similar to the ratio of the velocity change.

As shown in Figure 3, the peak value of T15 is $A = 7000$, and $A = 7700$ for T16, and $dt = 12$ and 12.5 for T15 and T16 respectively. Using these values we obtain HIC = 5072 for T15, and HIC = 6705 for T16, and the ratio is 1.32. These values approximately reproduce the experimental value of HIC.

5. **Conclusions.** Accurate evaluation of falling has been performed to understand the relation between HIC (Head Injury Criterion) and the way of falling. HIC has been calculated for two similar experiments, using the acceleration data of the head point. Furthermore, we construct the speeds and locations of the three points of the robot, i.e., head, chest and pelvis using the acceleration data of the chest and pelvis. From the precise simulation, we found that there are two types of falling, even if their falling are the same backward falling. There are two types of falling posture, convex and depression of the upper body, and this posture of falling is related on the largeness of HIC. In this paper, we derived a simple formula of HIC assuming that the peak shape is like a Gaussian curve, HIC $= 0.310A^{2.5}\Delta t$, which is that HIC is proportional of 2.5th power of the peak value and the time interval. The calculated values are close to the experimental values. This fact insists that our estimation is good for an understanding of HIC. We further found this difference is owing to the two types of falling posture, convex and depression of the upper body. In the case of T15, the pelvis and chest firstly touch down and then head speed reduces greatly, which reduces the acceleration between the hitting of the head. This fact brings that the HIC of T15 is smaller than that of T16 where the head touches down in an early time. HIC of convex posture is smaller since the pelvis absorbs the shock of the impact. Therefore, we can conclude that HIC is finally determined by the posture of falling.

Acknowledgment. This work is partially supported by New Energy and Industrial Technology Development Organization (NEDO). The authors also gratefully acknowledge for experimental help of the stuffs in Japan Automobile Research Institute (JARI).

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