

# RELATION BETWEEN DOWNWARD AND UPWARD PHASES ON THE TRAMPOLINE BED DURING JUMPING

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## Abstract

*The time of flight in trampoline competitions relies on the jumping movement executed on the trampoline bed, which can be divided into a downward phase and an upward phase. These two phases of the jumping movement exhibit distinct characteristics. Therefore, the aim of this study was to investigate fundamental data regarding the vertical deflection length, time, velocity, and force involved in the vertical movement on the trampoline bed. The study involved ten trampoline athletes, including participants in the All Japan Championships and members of the Japanese national team. These athletes were instructed to perform 15 consecutive jumps on the trampoline bed, starting from a standing-still position, aiming for maximum height, and maintaining a straight trajectory in the center of the trampoline bed.*

*The findings revealed that all measured parameters were significantly greater in the downward phase compared to the upward phase. Interestingly, it was observed that the jumping height during a prolonged flight is predominantly determined by the actions in the downward phase of the trampoline bed, rather than the upward phase. As a result, the downward phase should be executed as an active jumping movement.*

**Keywords:** trampoline jumping, downward phase, upward phase.

## INTRODUCTION

Trampoline exercises enable athletes to achieve jumps exceeding 3 meters in height using a specialized trampoline apparatus (Ito et al., 2000). In trampoline competitions, athletes are scored based on the time spent in the air, as outlined in the Code of Points for Trampoline Gymnastics (2022-2024 CoPTG, 2021). Consequently, athletes strive for jumps with extended flight durations.

The competition trampoline apparatus typically comprises a trampoline bed equipped with 118 metal springs and

enclosed within a metal frame, featuring a nylon net (EUROTRAP LTD.). In this gravitational environment, the mechanical vertical jump height primarily hinges on the initial jump velocity. Subsequently, the jumper undergoes free fall before landing. When executing jumps on a trampoline, it becomes crucial to maximize the jumping velocity by harnessing the trampoline bed's elastic properties. Therefore, the jumping velocity is expected to be influenced by the trampoline bed's restoring force, as it rebounds from its lowest-sinking position

back to its original state (Matsushima, 2021).

Previous studies investigating the relationship between trampoline beds and jumping have utilized image analysis of test subjects' jumps to determine the length of vertical deflection on the trampoline bed and its correlation with time of flight (Yamada & Kumayama, 2012; Yamamoto et al., 1992). Ito et al. (2000) conducted research involving four subjects with varying levels of trampoline performance and found that individuals with longer vertical deflection on the trampoline bed did not necessarily achieve greater jump heights. Matsushima (2021) identified a significant positive correlation between the upward velocity, measured from the trampoline bed's lowest position to its return to the original position, and the time of flight. Furthermore, the length of vertical deflection on the trampoline bed, along with upward time and velocity from the lowest position to the original position, were employed as indices to characterize the trampoline bed's impact on the jumping movement.

In trampoline jumping movements, the downward phase occurs as the jumper descends from the landing to the lowest point, during which the trampoline bed is pushed downward through the extension of the hip and knee joints. Near this lowest point, the jumper typically adopts a near-straight posture and subsequently propels themselves upward directly, thanks to the restoring force of the trampoline bed returning to its original position (Ueyama & Fuchimoto, 2007; Matsushima et al., 2017; Matsushima & Yano, 2018a; Jingguang Qian et al., 2020). Essentially, the jumping motion on the trampoline exhibits significant variations between the

downward and upward phases, with the lowest point serving as the boundary.

The length of vertical deflection of the trampoline bed and the velocity of the upward movement are predominantly determined by the downward phase of the jumping movement, commencing with the landing. Consequently, this study aimed to explore the relationship between the downward phase of the trampoline bed and the subsequent upward phase, wherein the trampoline bed returns to its original position. The objective was to gather fundamental data on the vertical movement of the trampoline bed during the jumping process.

## METHODS

The subjects were ten trampoline athletes, 5 females and 5 males, participants in the All Japan Championships and Japanese national team members (age:  $19.5 \pm 1.6$  years, height:  $163.9 \pm 6.7$  cm, weight:  $58.5 \pm 8.2$  kg, athletic career:  $7.9 \pm 4.2$  years). Prior to participating in the experiment, the details of the experiment were fully explained to the subjects using the protocol of the Mukogawa Women's University research ethics review committee. Written consent was then obtained from the subjects.

The trampoline apparatus utilized in this experiment was a 4 x 4 Euro trampoline, measuring 5.20 meters in length, 3.05 meters in width, and 1.15 meters in height. This trampoline was manufactured by EUROT RAMP, a company approved by the International Gymnastics Federation.

For the trials, subjects were given instructions to execute 15 consecutive jumps on the trampoline bed, commencing from a stationary position, with the aim of

achieving maximum height. These jumps were to be executed in a straight and upward trajectory while remaining centered on the trampoline bed. To ensure readiness and prevent injuries, subjects underwent a thorough warm-up period before the trials.

A compact tension/compression load cell (KYOWA ELECTRONIC INSTRUMENTS CO., LTD.: LUX-B-2KN-ID) was attached between the spring (17th spring counting from the right end) and the frame at the center of the trampoline apparatus's side. The points of landing (where the subject made contact with the trampoline bed), the lowest point (when the trampoline bed extended farthest downward), and the takeoff (when the subject left the trampoline bed) were determined through analysis software (KISSEI COMTEC CO., LTD.: BIMUTAS II) based on the output of the load cell (see Figure 1).

The load cell's output when connected between the trampoline apparatus and the spring ranged from 3.000 to 3.015 V. We considered the point at which the output of the load cell first exceeded 3.016 V as the landing, the highest recorded value as the lowest point, and the moment when the output dropped below 3.015 V as the takeoff. In other words, the landing and takeoff correspond to the moments when the feet make contact with and leave the trampoline bed, respectively. The downward phase was defined as the interval between landing and the lowest point, while the upward phase encompassed the period between the lowest point and takeoff. Data were sampled at a frequency of 1000 Hz.

One video camera (CASIO COMPUTER CO., LTD.: EX-F1) was placed at the side of the trampoline apparatus to capture the jumping motion at a 300 fps and 1/1000 s shutter speed. The video camera was placed at the same height as the trampoline bed (1.155m) and at a distance of 5.550 meters from the center of the trampoline bed's lateral side. Trials were recorded and analyzed by the two-dimensional motion analysis method (Q'sfix CO., LTD.: Frame-DIAS4). The coordinate system used in this study was the X-axis for the horizontal direction and Y-axis for the vertically upward direction. The reference points and reference lengths for the calibration were set at both ends of the trampoline bed (4.280m) on the camera side in the X-axis direction. The discrepancy between the actual coordinates of the reference point and the coordinates calculated using the two-dimensional motion analysis method's real-length conversion method ranged from 1 to 2 millimeters.

The load cell's output was recorded on a PC. The durations from landing to the lowest point and from the lowest point to takeoff, as determined from the load cell's output, were calculated and synchronized with the landing in the motion analysis software video. To achieve this synchronization, the time closest to the calculated time from the load cell data, sampled at 1000 Hz, was selected to match the time in the motion analysis software, which operated at 300 frames per second (fps).

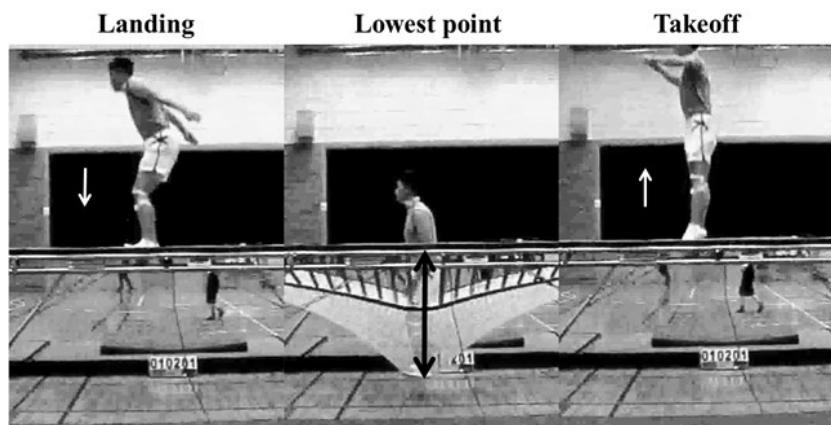


Figure 1. Definitions of the jumping phases.

Of the 15 trial jumps, 10 jumps, from the 6th to 15th jump, were included in the analysis. In trampoline competitions, the time of flight of athletes is measured based on the duration when the trampoline bed doesn't sink. Therefore, in this study, we used the time of flight ( $t$ , in seconds) derived from the load cell output data. This time represents the interval from when the subject takes off from the trampoline bed to when they land.

Additionally, we calculated the downward time ( $t_1$ , in seconds) from landing to the lowest point and the upward time ( $t_2$ , in seconds) from the lowest point to takeoff.

We determined the length of vertical deflection ( $l$ , in meters) of the trampoline bed by digitizing the lowest point and takeoff using motion analysis software. To calculate the velocity of downward movement ( $v_1$ , in meters per second) from landing to the lowest point of the trampoline bed (as per formula (1)), or the velocity of upward movement ( $v_2$ , in meters per second) from the lowest point of the trampoline bed to takeoff (as per formula (2)), we divided the length of vertical deflection ( $l$ , in meters) of the trampoline bed by the corresponding time ( $t_1$  or  $t_2$  in seconds)).

The average downward force ( $f_1$  (N)) and upward force ( $f_2$  (N)) for the downward phase were calculated using formula (3) and formula (4) respectively.

The mass ( $m$  (kg)) is the body weight. The velocity ( $v_3$ ) immediately before landing on the trampoline bed from the highest point of the jump and the velocity ( $v_4$ ) immediately after taking off from the trampoline bed were calculated using formula (5):

$$v_1 = l / t_1 \quad (1)$$

$$v_2 = l / t_2 \quad (2)$$

$$f_1 = (mv_3) / t_1 \quad (3)$$

$$f_2 = (mv_4) / t_2 \quad (4)$$

$$v_{3,4} = \sqrt{2g(g t^2 / 8)} \quad (5)$$

Each calculated value is presented as the mean  $\pm$  standard deviation. We employed statistical analysis, including paired t-tests, to compare the means of each parameter between the downward and upward phases. Pearson's correlation coefficient was used to assess the correlations between different variables. A significance level of  $p < 0.05$  was applied, and the analysis was conducted using Microsoft Excel 2016.

## RESULTS

The calculated means  $\pm$  standard deviations of time of flight (t (s)), length of vertical deflection (l (m)), downward time (t<sub>1</sub> (s)), upward time (t<sub>2</sub> (s)), downward velocity (v<sub>1</sub> (m/s)), upward velocity (v<sub>2</sub> (m/s)), downward force (f<sub>1</sub> (N)), and upward force (f<sub>2</sub> (N)) are presented in Table 1.

Table 1  
*The measured values (mean  $\pm$  standard deviation).*

Time of flight (s)	Length of vertical deflection (m)	Downward time (s)	Upward time (s)
1.657 $\pm$ 0.129	0.842 $\pm$ 0.074	0.156 $\pm$ 0.011	0.169 $\pm$ 0.010
Downward velocity (m/s)	Upward velocity (m/s)	Downward force (N)	Upward force (N)
5.421 $\pm$ 0.601	5.000 $\pm$ 0.467	3034 $\pm$ 582	2821 $\pm$ 483

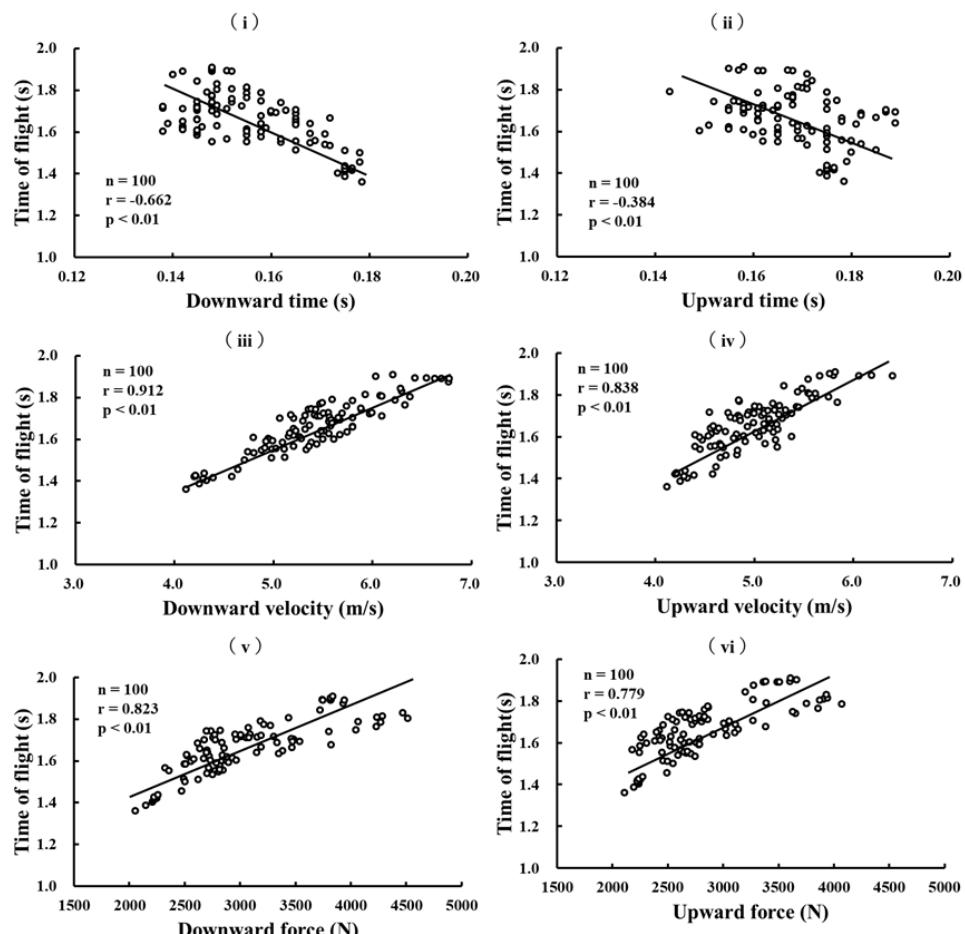


Figure 2. Correlation between the time of flight and downward and upward phases of time, velocity, and force.

The downward time was significantly shorter than the upward time ( $p < 0.01$ ). The downward velocity was significantly faster than the upward velocity ( $p < 0.01$ ). The downward force was significantly greater than the upward force ( $p < 0.01$ ).

As shown in Figure 2, correlations were shown between the time of flight and each variable.

## DISCUSSION

A competitive trampoline bed is known for its remarkable elasticity, which allows it to stretch significantly during jumping movements. This elasticity plays a crucial role in facilitating high vertical jumps by utilizing the bed's restoring force to return to its original position.

In our study, we focused on comparing the downward and upward phases of the trampoline bed. We observed that the downward phase was notably shorter, faster, and stronger than the upward phase. During the downward phase, the extension of the hip and knee joints is more pronounced compared to the upward phase. Additionally, the trampoline bed experiences downward pressure due to the dorsiflexed position of the ankle joint (Matsushima & Yano, 2018b).

In the downward phase, the knee and hip joints contribute to generating substantial force, while the ankle joint, in its dorsiflexed position, exerts prolonged pressure on the trampoline bed. The greater range of motion in hip and knee joint extension during the downward phase resulted in significant differences in time, velocity, and force when compared to the upward phase.

It's worth noting that leg extensor strength (Ito et al., 2000) and anaerobic power (Baba, 2019; Baba, 2021) have a significant impact on increasing the vertical deflection length of the trampoline bed.

In terms of correlations with time of flight, all variables showed higher correlation coefficients during the downward phase compared to the upward phase (Figure 2). This suggests that the downward phase of the trampoline bed may influence the upward phase. During the upward phase, several factors, including

frictional forces and the conversion of energy into vibrations, may contribute to the observed lower velocity and force compared to the downward phase.

In the downward phase, the jumping movement is active, as it involves pushing down on the trampoline bed. In contrast, the upward phase is passive, characterized by straightening the body at the lowest point and receiving the restoring force from the trampoline bed. Consequently, both velocity and force in the upward phase tend to be inferior to those in the downward phase. Gravity also plays a role in this difference.

The quality of the jumping movement during the downward phase and the skill of pushing down on the trampoline bed likely determine the initial velocity and time of flight. Matsushima (2021) categorized trampoline athletes' jumping movements based on two variables: the length of vertical deflection and upward time. Athletes with longer vertical deflection lengths and shorter upward times demonstrate superior jumping skills. It's worth noting that these jumping skills are also essential during the downward phase.

To enhance lower extremity movements for rapid pushes on the trampoline bed, power training is crucial. For instance, previous research has indicated that powerlifting training can improve lower extremity power output (Chiu, et al., 2009; Hori, et al., 2009).

The elastic trampoline bed becomes more elastic as the length of vertical deflection increases. Incremental load testing was performed in this study. It's important to note that the averages within each phase were calculated for all variables except the length of vertical deflection. Consequently, the maximum values for

time, velocity, and force are expected to be higher than those reported in this study.

In a previous study by Yamamoto et al. (1990), a force plate was positioned on one of the legs of a mini-trampoline apparatus to measure the floor reaction force during free-fall. Their results revealed the existence of two maximum values of the vertical reaction force. Notably, the force required increases as the trampoline bed is pushed down to its lowest point.

## CONCLUSIONS

The jumping height for a long flight is determined by the downward phase of the trampoline bed rather than the upward phase. The downward phase was significantly shorter, significantly faster, and significantly stronger than the upward phase. The downward phase should be performed as an active jumping movement.

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