HOW CAN WE TEACH STUDENT TO ESTIMATE VERTICAL JUMP HEIGHTS USING GROUND REACTION FORCE DATA

Younghoon Park, Chang-hong Youm, Yun-mi Ha, Kuk-woong Seo, & Kook-eun Seo

Department of Physical Education, Pusan National University, Busan, Korea

The purpose of this study was to estimate vertical jump heights using ground reaction force (GRF) data and to suggest one practical example of biomechanical theory application to a real human motion. Vertical jump heights of impulse and flight time method were statistically smaller ($p<.001$) than three-dimensional video method. The causes of height differences seemed mainly from the fact that impulse was used to move jumper into the horizontal direction as well as into the vertical direction. Other important factors for accurate height calculation are jumper's mass and threshold value of GRF data collection. Vertical jump height calculation with GRF data showed an example of practical application of biomechanical theory to human motion and demonstrated a way of GRF equipment use for effective biomechanical theory education.

KEY WORDS: vertical jump height, ground reaction force, momentum-impulse, flight time.

INTRODUCTION:

Vertical jump (VJ) requires the harmony and quickness of the human body segments. VJ heights (VJHs) have the closest correlations with lower limbs muscle power (Markovic, Dizdar, Jukie, & Cardinate, 2004; Sipila, Koskinen, Taaffe, Takala, Cheng, & Rantanen, 2004). In addition to lower limbs muscle power, the use of upper limbs (Hara, Shibayama, Takeshita, & Fukashiro, 2006; Leeds, Vanrenterghem, & Clercq, 2004) and muscle's stretch-shortening cycle (Anderson, & Pandy, 1993; Enoka, 1988; Zajac, 1993) can improve VJ performance. Therefore lower limbs muscle power studies employ the akimbo jump motion (Aragon-Vargas, & Gross, 1997; Hatze, 1998; Markovic, & Jaric, 2007). The ground reaction force (GRF) system is widely used in biomechanical researches. The GRF system can be effectively used on the scene of education to explain the mass-gravitational acceleration-force and the momentum-impulse relation. The purpose of this study was to calculate VJHs with GRF data, to examine the appropriateness of the VJHs calculations, and to present a practical method of biomechanical theory application to the human body motion.

METHOD:

Data Collection: Fifteen male college students (75.2±7.2 kg, 181.1±6.0 cm, 22.5±1.6 year) volunteered to participate in this study. All subjects gave their informed consent. VJ experiment was conducted on a force plate (Kistler 9285, Switzerland) at biomechanical lab. For video analysis, an easily distinguishable hemispheric reflection marker (d=1.6 cm) was attached to L5 (lumbar) of each subject. 60 Hz NTSC digital video cameras (Sony DCR-VX2100) were installed at three spots where the reflection marker can be easily observed. The cameras were set at shutter-speed priority, 1/2,000 s, and manual focus mode. To synchronize video and GRF data, a synchronous signal generating system (VSAD-101-USD-V2, Visol, city of Gwangmyung, Korea) was prepared. The GRF amplifier (Kistler 9865A, Switzerland) was set at x/y 5,000 pC and z 10,000 pC and data were collected with sampling frequency of 1,020 Hz using a 12-bit A/D card (DT3002, DataTranslation, Marlboro, MA). Subject took a comfortable posture about 3 s on the force plate and jumped vertically toward a 2.75 m height target. The jump motion in this study was similar to the volleyball's standing jump blocking motion which is similar to the actual VJ motion while restraining the use of upper limbs.

Data Calculation: VJHs of one jump motion were calculated with three different methods. Kwon3D video motion analysis program (Visol, city of Gwangmyung, Korea) was used for the video analysis. As shown in equation (1), the JH of three-dimensional video analysis (H_{3D})

was calculated by obtaining the difference between the peak value of z-component of L5 marker position (H_{peak}) and the value of z-component of L5 marker at the moment of take off (TO) from the force plate surface (H_{TO}).

$$H_{3D} = H_{peak} - H_{TO} \quad (1)$$

Vertical component of GRF (Fz) was calculated using the KwonGRF program. Supposing m= subject mass, v_{T0}= vertical velocity of center of mass (COM) at the moment of TO, H_{TO}= COM height at the moment of TO (=0), g= gravitational acceleration, v_{peak}= vertical velocity of COM at the moment of the peak jump height (=0), and H_{peak}= COM height at he moment of the peak jump height, their relations can be represented as equation (2) in accordance with the law of mechanical energy conservation.

$$H_{jump} = H_{peak} - H_{TO} = \frac{v_{TO}^2}{2g} \quad (2)$$

Supposing t_{ST}= jump motion starting time (=0), and t_{TO}= TO time, the momentum-impulse relation can be summarized as $v_{TO} = \frac{1}{m}\int_{t_{ST}}^{t_{T0}}(Fz - mg)\,dt$. As shown in equation (3), JH by impulse ($H_{impulse}$)was calculated by applying v_{TO} to equation (2).

$$H_{impulse} = \frac{v_{TO}^2}{2g} = \left(\frac{1}{m}\int_{t_{ST}}^{t_{T0}}(Fz - mg)\,dt\right)^2/2g \quad (3)$$

When a=-g, v_1=v_{T0}, v_2=v_{TD}, t_1=t_{TO}, t_2=t_{TD}, and v_{TD}=-v_{TO}, which are corresponding to the VJ motion, flight time (FT) of the body (t_{flight}) can be expressed by the definition of acceleration as $v_{TO} = (gt_{flight})/2g$. As shown in equation (4), JH by the FT (H_{flight}) was calculated by applying v_{TO} to equation (2).

$$H_{flight} = \frac{v_{TO}^2}{2g} = \frac{gt_{flight}^2}{8} \quad (4)$$

Data Analysis: VJHs were compared by paired *t*-test of the SPSS 12.0 statistics program with the significance level of *.05*.

RESULTS:
Table 1 shows summarized results of VJHs and height differences obtained by three different VJH calculation methods. Values of Table 1 are mean of 15 subjects which were not normalized by subject's height.

Table 1 Summarized results of VJHs and differences (n=15)

subj	impulse (Ns)	v_{TO} (m/s)	t_{flight} (s)	jump height(cm)			height difference(cm)		
				H_{3D}	$H_{impulse}$	H_{flight}	H_{3D}-$H_{impulse}$	$H_{impulse}$-H_{flight}	H_{3D}-H_{flight}
mean ±sd	209.86 ±27.88	2.78 ±0.19	0.580 ±0.039	46.99 ±6.48	40.21 ±5.66	41.36 ±5.75	6.78 ±2.34	-1.15 ±1.96	5.63 ±2.87
t-value							11.20***	-2.30*	7.59***

* p<.05, *** : p<.001

H_{3D}, $H_{impulse}$, and H_{flight} were 46.99±6.48 cm, 40.21±5.66 cm, and 41.36±5.75 cm, respectively. The coefficients of variation (CV) of these values were 13.8 %, 14.1 %, and 13.9 %, respectively, which are similar to or smaller than the values of 13.4 %, 18.3 %, and 16.6 % of a previous study (Aragon-Vargas, 2000). H_{3D} was 6.78 cm and 5.63 cm greater (*p<.001*) than $H_{impulse}$ and H_{flight}, respectively. $H_{impulse}$ was significantly (*p=.038*) smaller than H_{flight}. The causes of these differences were not analyses in detail as they are not fit for the purpose of this study. They were used only for the examination of the appropriateness of the experiment result.

DISCUSSION:
In the study of jump, the JHs calculated by video analysis are generally accepted as criteria (Aragon-Vargas, 2000; Bobbert, & Van Soest, 1994; Pandy, & Zajac, 1991). The Kwon3D video analysis system shows a length measurement error of about 0.27 cm (Park, Youm, & Seo, 2005). The NTSC type digital video camera (Sony DCR-VX-2100) used in this study can resolve images at 60 Hz. But the actual human body movements are analogue. In the

case of a VJ, the maximum value of a position error which is likely to be caused by sampling frequency around the peak height is the freefalling distance for 1/120 s. The value is 0.034 cm ($=\frac{1}{2}gt^2=\frac{1}{2}\times 9.81\times(\frac{1}{120})^2\times 100$), which is negligible. When JH is calculated using the COM position of a computer body model in three-dimensional video analysis, the physical characteristics of a real subject are different from those of a computer body model. Therefore, the appropriateness of COM position method is questionable. Accordingly, it will be appropriate to calculate JH by using the reflection marker position of most proximal segment of the human body which is stabilized irrespective of the posture taken during jumping. Hence, VJ motion and H_{3D} calculation method in this study seem to be appropriate for the purpose of this study.

During the VJ, the human body moves in the anteroposterior direction as well as in the vertical direction and therefore about 3% of the muscle power is used for the non vertical directions (Hatze, 1998). Accordingly, it is logical that the JH obtained using vertical velocity of COM at the moment of TO (v_{T0}) is smaller than H_{3D}. V_{TO} is affected by the subject mass. The mean values of mass and impulse of the 15 subjects in Table 1 were 75.23 kg and 209.86 Ns, respectively. When these mean values are applied, v_{T0} and $H_{impulse}$ are 2.79 m/s and 39.68 cm, respectively. If the subject mass was measured 0.51 kg more than 75.23 kg by some reason, the $H_{impulse}$ becomes 39.14 cm, which 1.24% smaller than 39.68 cm. Thus, it is important to precisely measure the subject mass in $H_{impulse}$ calculation.

Precise FT determination is essential for the H_{flight} calculation. In general, knee joints are flexed to a greater extent in landing than in TO for shock absorption and therefore, the H_{flight} becomes greater than $H_{impulse}$ (Aragon-Vargas, 2000; Hatze, 1998). This study found that the standard deviation and CV of $H_{impulse}$ and H_{flight} were 5.66 cm, 14.1%, and 5.75 cm, 13.9%, respectively. These values seem to be comparable to the values of Aragon-Vargas (2000)'s 6.6 cm, 18.3%, and 6.7 cm, 16.6%, respectively. The JHs difference due to knee joint angle change should be considered as a limitation of the experiment on the human body.

FT in GRF data means the time interval between the moment when the GRF values become smaller than the threshold value and the moment when the GRF data become greater than the threshold value. Therefore, if the threshold value is set high, the FT becomes longer than the actual FT and the calculated JH becomes greater. This study set the threshold value at 10 N but the appropriateness of this value need to be verified by further study. The mean FT of the 15 subjects of this study turned out to be 0.5797 s. When this mean value was applied, H_{flight} was 41.19 cm. If the FT was measured 2 ms shorter than 0.5797 s due to a wrong threshold setting or sampling frequency, the H_{flight} becomes 40.90 cm, which is 0.69% smaller than 41.19 cm.

CONCLUSION:

After calculating male college students' VJHs using three-dimensional video analysis and the GRF data and examining the differences between methods, this study came to the following conclusion. First, H_{3D} was statistically greater than $H_{impulse}$ and H_{flight}. This seems to be caused by the fact that part of the impulse was used other than vertical direction. Second, subject mass and threshold value of GRF acquisition affect the results of the VJHs calculation and therefore these should be taken into consideration in GRF experiment. Third, this study demonstrates a practical method of biomechanical theory and equipment application to the human body motion.

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