FORCE MEASUREMENTS IN JOGGING USING BIOMECHANICS CINEMATOGRAPHY

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In order to measure force generation during jogging outside a laboratory situation, biomechanics cinematography (BC) may be a useful procedure. However, as useful as it may be, precise and practical force measurement procedures through BC have not been developed. Cinematography, a non-invasive technique, eliminates the need for any physical limitations or laboratory-controlled experimental procedures for the acquisition of data. Through the use of cinematographical procedures, data is easily obtainable and, if so desired, without disturbing the subject in any way. This guarantees a true-life performance as compared to one in which alternate experimental procedures could very easily cause the subject's performance to be unnatural.

The purpose of this study was to develop a method utilizing biomechanics cinematography (BC) exclusively for determining the vertical-force component of jogging. An attempt was made, via BC, to reproduce the vertical-force characteristics of jogging as recorded by a force platform.

DEFINITION OF TERMS

In order to produce clarity for this paper, several terms are defined below:

Biomechanics cinematography (BC): The acquisition and subsequent analysis of data specific to biomechanics research through the use of cinematographical procedures and computer techniques.

Jogging: A form of locomotion in which the gait is much slower than running, but faster than walking. (Walking is characterized by having no air-borne phase).

Stride: A measurement taken from the initial contact of one foot to the subsequent contact of the same foot.

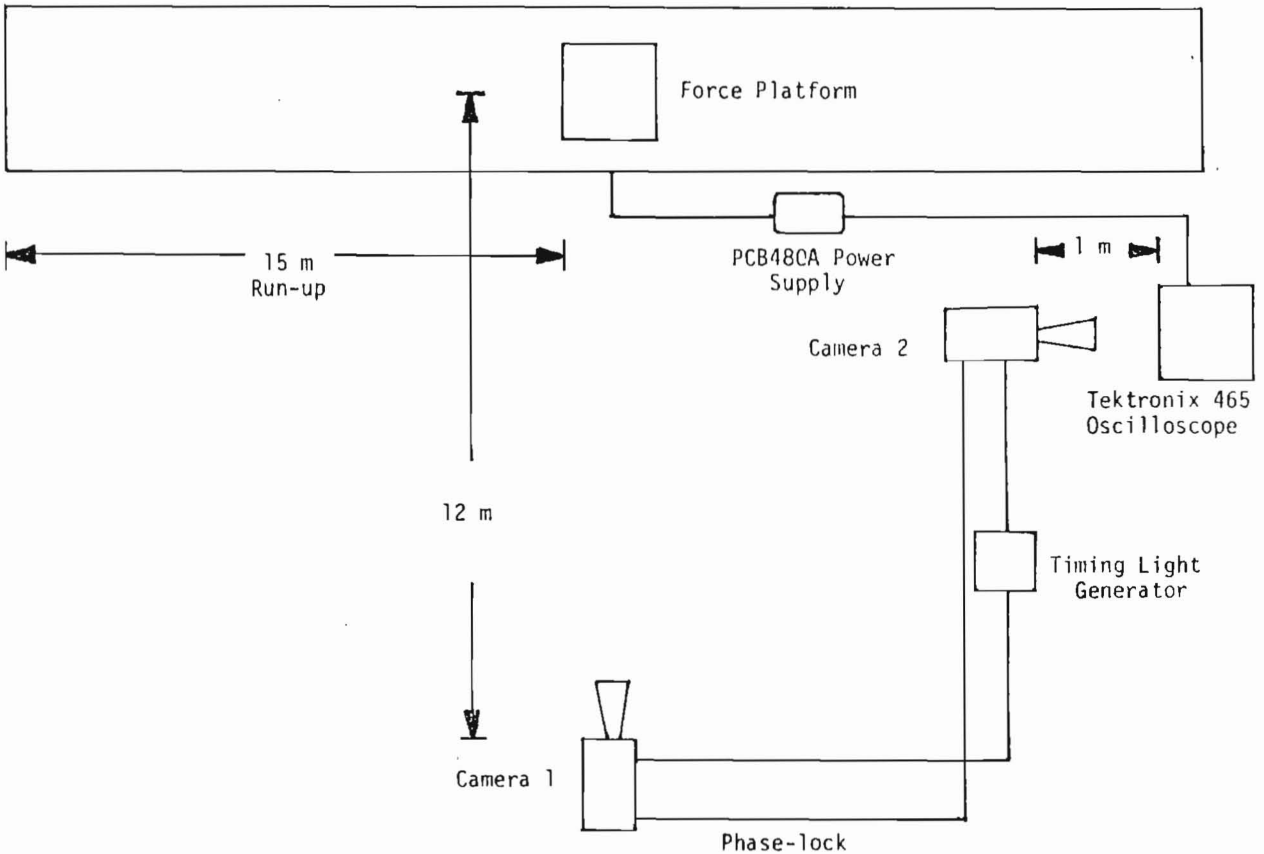

FIGURE 1
EXPERIMENTAL SETUP

Non-support phase: The period of a stride when the body is not in contact with the running surface. (A walking stride lacks a non-support phase).

Support phase: The period of a stride when either foot is in contact with the running surface. Each stride is composed of two support phases (i.e. right-support phase and left-support phase).

Foot-strike phase: That period of the support phase from the initial contact to when the foot is firmly fixed or flat on the running surface.

Mid-strike phase: That period of the support phase when the foot is firmly fixed until the instant the heel begins to rise off the surface.

Takeoff phase: That period of the support phase from the instant the heel begins to rise until the toes break contact with the running surface.

METHODS AND PROCEDURES

Subjects

The subjects in this study ranged in age from 27 to 62 years for the males, and 23 to 30 years for the females. Their weight ranged from 637.0 to 997.6 Newtons (N) and 517.4 to 570.4 N for males and females respectively.

The subjects first performed barefooted, and then repeated the test using jogging shoes. Each subject was given as many trials as needed to contact the force plate without altering the stride or looking at the force-measuring device. The subject decided which foot to use for contacting the force plate.

Apparatus

Two Photo Sonics 1PL 16mm (pin registered) cameras with Angenieux 12-120 zoom lenses were used. A phase-lock system was used to ensure synchronized data between the two cameras. Camera One, which recorded the side view of the subjects, was positioned with its optical axis bisecting the force platform and perpendicular to the joggers' plane of motion. The camera was leveled, 12 meters from the platform, at a height of 1.2 meters. Camera Two recorded the force platform output display from a Tektronix 465 oscilloscope. This camera was positioned 1.0 meter from the oscilloscope and adjusted so the entire screen from the oscilloscope encompassed the field of view of the camera

Both cameras operated at a frame rate of 100 FPS and with a shutter angle of 30°; this produced an exposure time of 1/1200 S. Ektachrome 7250 film with an ASA rating of 400 was forced one stop to produce an equivalent rating of 800 ASA. A Pentax 1° Spotmeter VI was used for all light measurements.

A timing-light generator was connected to both cameras. The timing-light generator was set at 10 Hz and switched to 100 Hz for roughly 0.1 seconds after the cameras reached operating speed. The marks produced on the film were used to determine the actual camera-frame rate and also served as reference points for matching of original frames on the two films.

A Stoelting's Force-Sensitive Platform was modified by the installation of a PCB208A04 piezoelectric-force transducer for measuring the vertical-force component. The transducer was powered by a PCB480A DC power supply. A Tektronix 465 oscilloscope produced the analog force signal from the transducer. The oscilloscope was operating with a sensitivity of 0.01 volts/division.

The force platform was fitted into a specially-constructed casing and leveled flush with the jogging surface. A 1.0 meter area on the force platform in the plane of motion was marked for later computation of projected size to real-life size.

Calibration

The transducer used for vertical-force measurement was calibrated by the manufacturer and reported to be linear to within 1% and to have a maximum compression of 4450N. The linearity was tested from 0.0 to 1200N in 225N intervals and found to be consistent with the manufacturer's claims. The modified force platform was checked for uniformity of measurements. The area of homogeneity was carefully marked and any trial by a subject with the foot contacting outside the specified area was discarded.

Data Analysis

The two synchronized films were initially edited and matched according to the timing marks on the edges of the films. Film One from Camera One, contained a record of the jogging activity while Film Two, from Camera Two, contained the force plate data from the oscilloscope. A Triad VR/100 pin-registered film analyzer was used to project the image onto a Bendix Digitizing Board (accuracy ±0.001 inch). A Bendix Cursor was utilized, via a Hewlett Packard 9864A digitizer, to enter a standard reference point and all subsequent coordinate points into a Hewlett Packard 9825B desk-top computer.

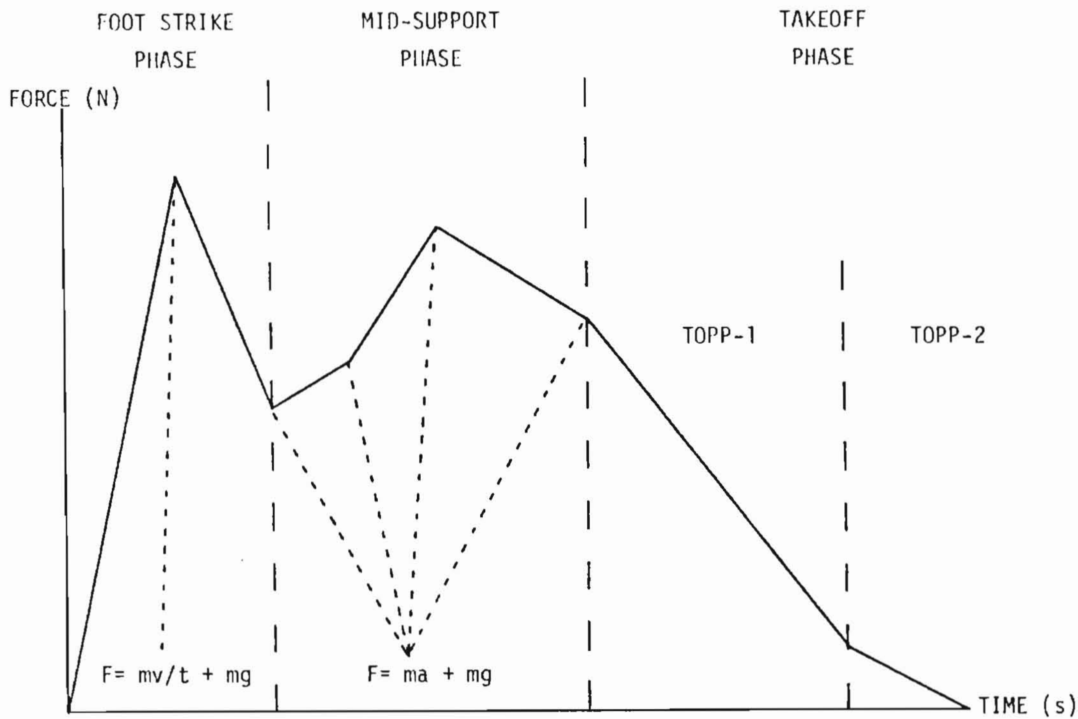

FIGURE 2

SCHEMATIC DIAGRAM OF CINEMATOGRAPHICAL CALCULATIONS

The calculations of the vertical force components were for the three phases of the total support phase. These phases include: (1) foot-strike phase, (2) mid-support phase, and (3) takeoff phase (Figure 2).

Foot-strike phase

The equation of uniformly-accelerated motion due to gravity was used to determine the velocity with which the subject was descending from the flight phase in jogging when foot contact occurred. The maximum height reached by the center of mass of the body during the flight period was determined. The height of the center of mass of the body at the instant of foot contact was also computed. The difference between the two heights represented the actual distance the body accelerated at 9.8 m/s^2.

By the equation:

$$V = 2gd$$

where

V= final velocity

g= acceleration due to gravity

d= displacement,

the velocity at impact was determined. The length of time of the foot-strike phase, in relation to the total contact time with the force plate, was derived from calculating the mean percent for all subjects as determined in the temporal phase of this study. The force of impact, (foot-strike phase), was then calculated by the equation:

$$F = mv/t + mg$$

where

F= force of impact

m= mass of the body

v= velocity at impact

t= time of "foot-strike phase"

g= acceleration due to gravity

Mid-support phase

The forces along the force-time curve during this phase were computed by

$$F = ma + mg$$

where

F= vertical force component

m= mass

a= vertical acceleration of the center of mass of the body

g= acceleration due to gravity

Takeoff phase

In order to minimize the error within the cinematographical analysis of the takeoff phase of the jogging stride, a technique was devised which divided the takeoff phase into two parts, "TOPP-1" and "TOPP-2". "TOPP-1" is that portion of the takeoff phase which begins the instant the heel rises off the running surface; the end of the mid-support phase. "TOPP-2" originates at the termination of "TOPP-1" and continues until the toes break contact with the running surface (i.e. the end of the entire support phase). The point of differentiation between "TOPP-1" and "TOPP-2" is the point at which the angle between the force-time curve and the tangent at that point is largest, when the force-time curve begins to tail off as force values approach zero. Elapsed time for the "TOPP-2" portion was determined in the preliminary temporal study by computing the mean percent time of the "TOPP-2" portion of all subjects. The initial force value for "TOPP-2" was measured by the force plate, and that force, as a percent of total subject weight, served to find the initial "TOPP-2" force when BC procedures were used. The entire takeoff phase was then graphically represented by two straight lines; one line from the final point in the mid-support phase to the initial point of the "TOPP-2" portion, and the second line from the initial "TOPP-2" to the instant the toe breaks contact with the running surface.

RESULTS

The total elapsed time of the support phase ranged from 0.18 to 0.23 S with a mean of .21 S. The time of the "foot-strike" phase varied between 0.03 to 0.05 S. For all trials, the mean "foot-strike phase" time was 21% of the total support-phase time. The

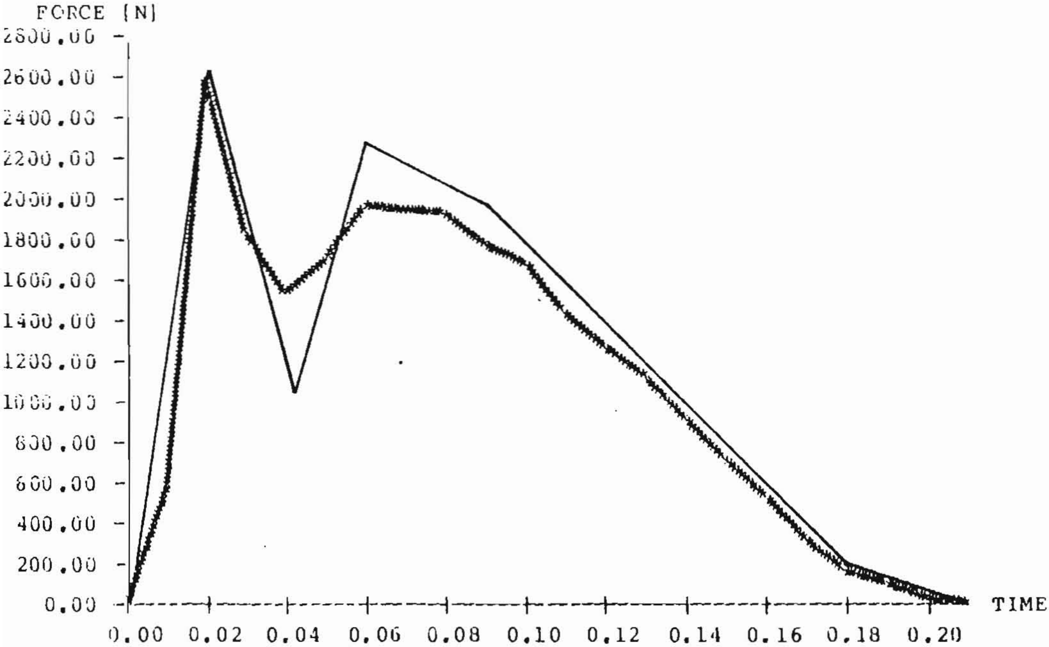

FIGURE 3

COMPARISON: CINEMATOGRAPHY(-) vs FORCE PLATFORM(*)

SUBJECT GS-3

"TOPP-2" portion of the takeoff phase ranged from 0.02 to 0.04 S, or a mean 14% of the total support phase. In other words, the "TOPP-2" portion of the takeoff phase began when 14% of total support-phase time remained. At this instant, vertical force turned out to be .33 of each subject's weight.

The calculations of the vertical-force measurements from BC resulted in an initial peak, the duration of which was assigned 21% of the total time of the support phase, followed by a second peak which descended gradually and tailed off toward zero. The final portion, "TOPP-2", of the cinematography measurements, was assigned 14% of the total time of the support phase, as mentioned in the previous paragraph.

During the foot-strike phase, the mean maximum-vertical force measurements were 2419.3 and 2520.0 N for the force plate and BC respectively. This phase gives BC an error of 100.7 N, or .04. During the mid-support phase at .09 S from initial foot contact, the mean force plate measurement was 1840.3 N, while for BC, the calculations produced a mean force of 2015.9, or a mean error of 175.5 N. For the total mid-support phase, the error for BC was 62.5 N.

The mean vertical force measurement during the takeoff phase at the start of "TOPP-2" was 218.0 N for the force plate, and 223.8 N using BC; an error of 5.77 N, or .03.

The above results indicate that, within the limitations of this study, it seems that biomechanics cinematography can be a precise and practical tool in the determination of vertical-force characteristics in jogging. Further, BC eliminates the need for any physical limitations or laboratory-controlled experimental procedures for the acquisition of data. This, of course, further suggests that with innovative adjustments in BC procedures, competitive events, where direct measurement is not possible, can benefit from indirect biomechanics cinematography.

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