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ABSTRACT

The angular momentum of a human body derived from both the angular velocity and angular displacement, utilizing cinematographic records has not been adequately assessed, prior to this study. Miller (1970) obtained the angular momentum but only during the airborne phase of activity. The method used by Ramey (1973) involved a force platform, but also had its limitations because it had restricted use to only force platform activities. The mass of segment, the transverse moment of intertia of segment, the angular velocity of segment i about its transverse axis, the projected distance between the c.g. of segment i and the c.g. of the whole body, and the angular velocity of the c.g. of segment i about the c.g. of the whole body, were used in this study to develop a formula to represent the angular momentum of a multi-segment body about one of its axes. Results indicated that the method used in this study yields an acceptable first approximation of the angular momentum of a human body in motion. This method can be used for numerous tests of different physical activities. (Cinematographic diagrams are included.) (MK)

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A COMPUTATIONAL TECHNIQUE TO DETERMINE THE ANGULAR DISPLACEMENT, VELOCITY AND MOMENTUM OF A HUMAN BODY

by

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New Orleans, Louisiana, May 1975

Purpose

The purpose of this study was to develop a general method for determining the angular momentum of a human body in motion from cinematographic records. A secondary purpose was to demonstrate that, should they be required, the angular velocity and the angular displacement which the body experiences in a given period can readily be determined from the obtained measures of angular momentum.

Review of Literature

Two methods have previously been developed for the purpose of determining the angular momentum of a human body.

Miller (1970) used cinematographic techniques to determine the angular momentum obtained during the airborne phase in a series of four dives. While the relative simplicity of her method is attractive, the fundamental requirement of a quasi-rigid phase in the motion (i.e. a phase in which the subject's body segments retain essentially the same positions with respect to one another) severely limits the motions to which it may be appropriately applied.

Ramey (1973) developed a method involving the careful coordination of force platform and cinematographic records to determine the angular momentum of a long jumper at the instant of take-off. His method, too, had serious limitations. First, the fundamental equation upon which it is based yields the <u>change in angular momentum</u> rather than the angular momentum <u>per se</u>. Second, the need to use a force platform effectively precludes the use of the procedure in real-life competitive situations.

Procedure

The angular momentum of a multi-segment body about one of its principal axes is given by the relationship:

$$H^* = \sum_{i=1}^{i=14} (I_i\omega_i + m_i r^2 \omega_{i/G})$$

where m_i = the mass of segment i; I_i = the transverse moment of inertia of segment i; ω_I = the angular velocity of segment i about its transverse axis; r = the projected distance between the c.g. of segment i and the c.g. of the whole body; and $\omega_{i/G}$ = the angular velocity of the c.g. of segment i about the c.g. of the whole body. The procedure developed in this study made use of this relationship to determine the angular momentum of the human body about its transverse axis.

The computer program written for the purpose performed eight basic steps (Figure 1). This computational procedure was used in the analysis of four activities -- a forward somersault, a Yamashita vault, a pole vault and a high jump -- selected first, because they each contained one or more phases during which the performer was airborne and second, because it seemed likely that the variation in the nature of the performances and in the quality of the selected films would assist in revealing the strengths and limitations of the procedure.

Results and Discussion

The results of the computation of angular momentum for the airborne phases of the selected activities are shown in Table 1.

The absence of suitable criteria against which to evaluate the results

$$H^* = \sum_{i=1}^{i=14} \Big(\underset{\text{(Local Term)}}{I_i \omega_i} + \underset{\text{(Transfer Term)}}{mr^2 \omega_{i/G}} \Big)$$

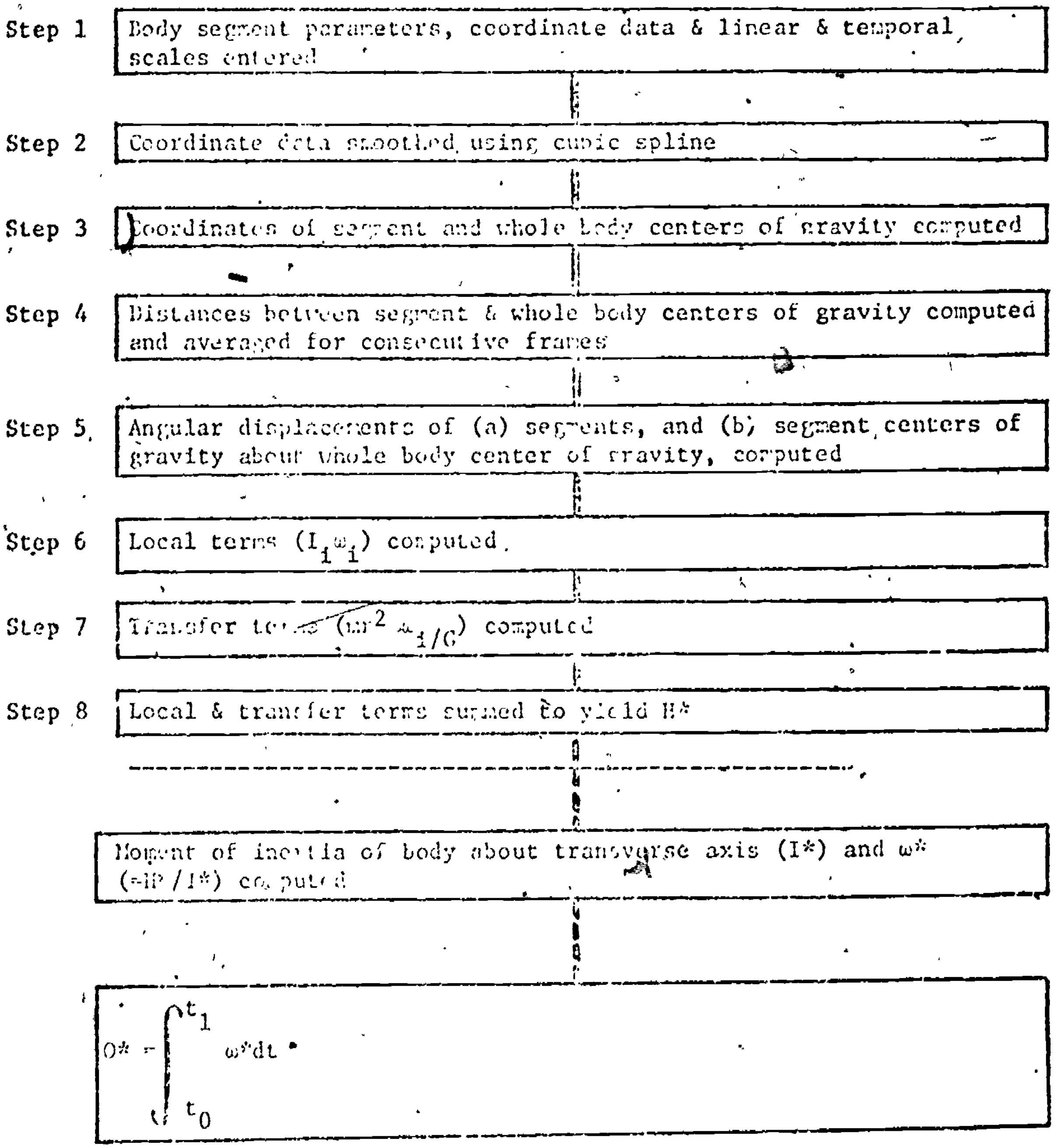

Figure 1

Table 1

Angular Momentum During Airborne Phases in Selected Activities

Activity	Angular Momentum (kg-m^2-sec^{-1})				
	$\overline{X}$	S.D.	Max	Min	Max Deviation From Mean
Front Somersault					
(a) Hurdle	-0.52	0.16	-0.70	-0.14	0.38
(b) Flight	6.83	0.32	7.40	6.53	0.57
Long Horse Vault					
(a) Pre-flight	7.23	0.33	7.84	6.91	0.61
(b) Flight	2.41	0.26	2.89	2.05	0.48
Pole Vault	-2.24	0.34	-3.00	-1.52	0.76
High Jump	0.63	0.32	-1.09	0.21	0.84

obtained using segmental methods is a long-standing problem in biomechanics. There are, for example, no generally accepted methods for evaluating the validity of the segmental methods in common use for the determination of whole body center of gravity locations, moments of inertia and radii of gyration. A similar situation obviously pertains in the case of derived parameters like angular momentum. In the absence of obvious alternatives, the mean of the angular momentum values computed for the airborne phase was taken as the criterion measure in the present study and variation about that mean was considered as indicative of the validity and reliability of the method employed.

The results shown in Table 1 reveal that the standard deviation was less than 0.35 kg-m^2-sec^{-1} in all cases and generally varied little within and among activities. In addition, every computation of the angular momentum during an airborne phase fell within 0.85 kg-m^2-sec^{-1} of the mean. On the basis of these results it was concluded that use of the computational method described in this paper yields an acceptable first approximation of the angular momentum of a human body in motion.

There are several possible sources of error which could account for the variations observed in the angular momentum values. Among these are errors due to the use of inappropriate segmental data, errors committed by the operator in the data reduction (film analysis) process, and errors due to segments moving out of the vertical plane of motion.

The effects produced by various combinations of available segmental data were examined using coordinate data obtained in an analysis of the standing front somersaults of eight gymnasts together with 20 possible combinations of different sets of data are shown in Figure 2. The results of this analysis

Combinations of Available Segmental Data

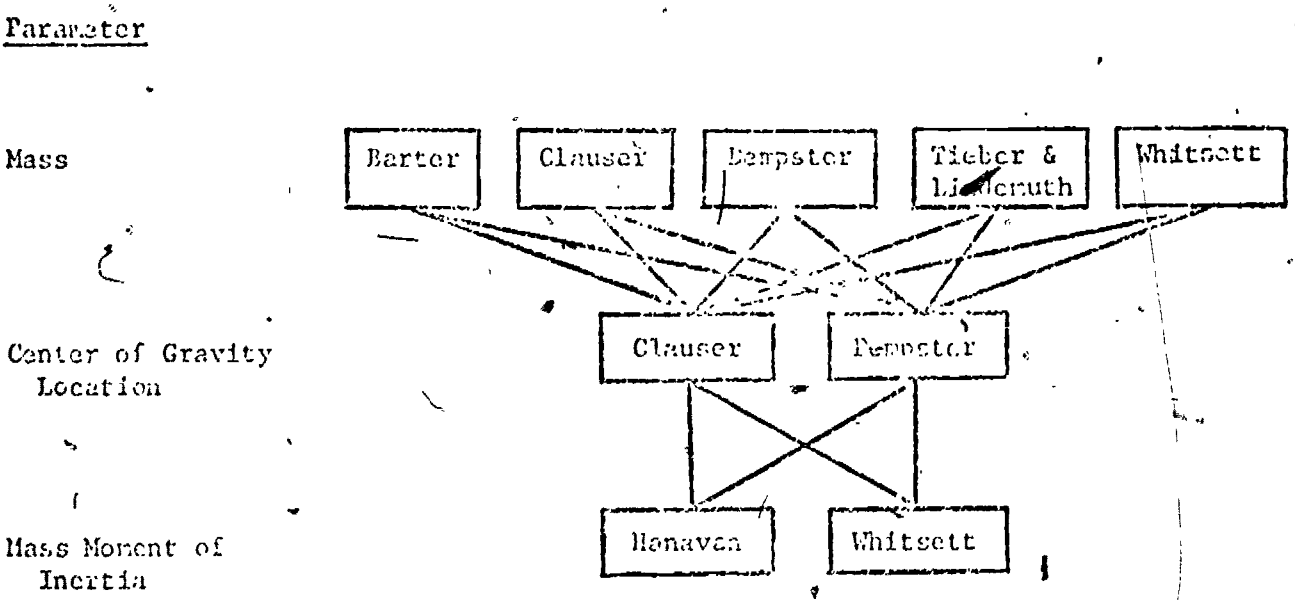

Figure 2

indicated that although no one combination yielded better results than another overall, for each subject some combinations were markedly better than others.

These findings suggest that improvements in the computational procedure are more likely to result from the selection of segmental data on a subject by subject basis than from the identifying of one combination of segmental data best suited to all subjects.

The accuracy with which the locations of segmental end-points can be determined is logically a function of several factors. Among these are the size of the projected image of the subject, the photographic quality of the recorded image, and the extent to which the segmental end-points are obscured during the course of the motion being analyzed.

The results obtained in this study would appear to demonstrate the influences of these several factors and, too, the influence of pronounced "out of the plane" motion.

Front somersault (Figure 3). The film of the front somersault was more suitable for analysis in every one of the respects listed than was the film for any of the other activities analyzed. It is hardly surprising, therefore, that the results obtained in the analysis of the front somersault were more consistent than those obtained for any of the other activities.

Yamashita (Figure 4). Except for a smaller image size (brought about by the need to markedly increase the width of the optical field to accommodate the motion), the film of the Yamashita vault was of a quality comparable to that of the front somersault. The results, too, were of similar consistency.

Pole vault (Figure 5). The results for the pole vault were much less consistent than those for the two activities already considered. In this case, the projected image of the subject was very small; the film was of poor

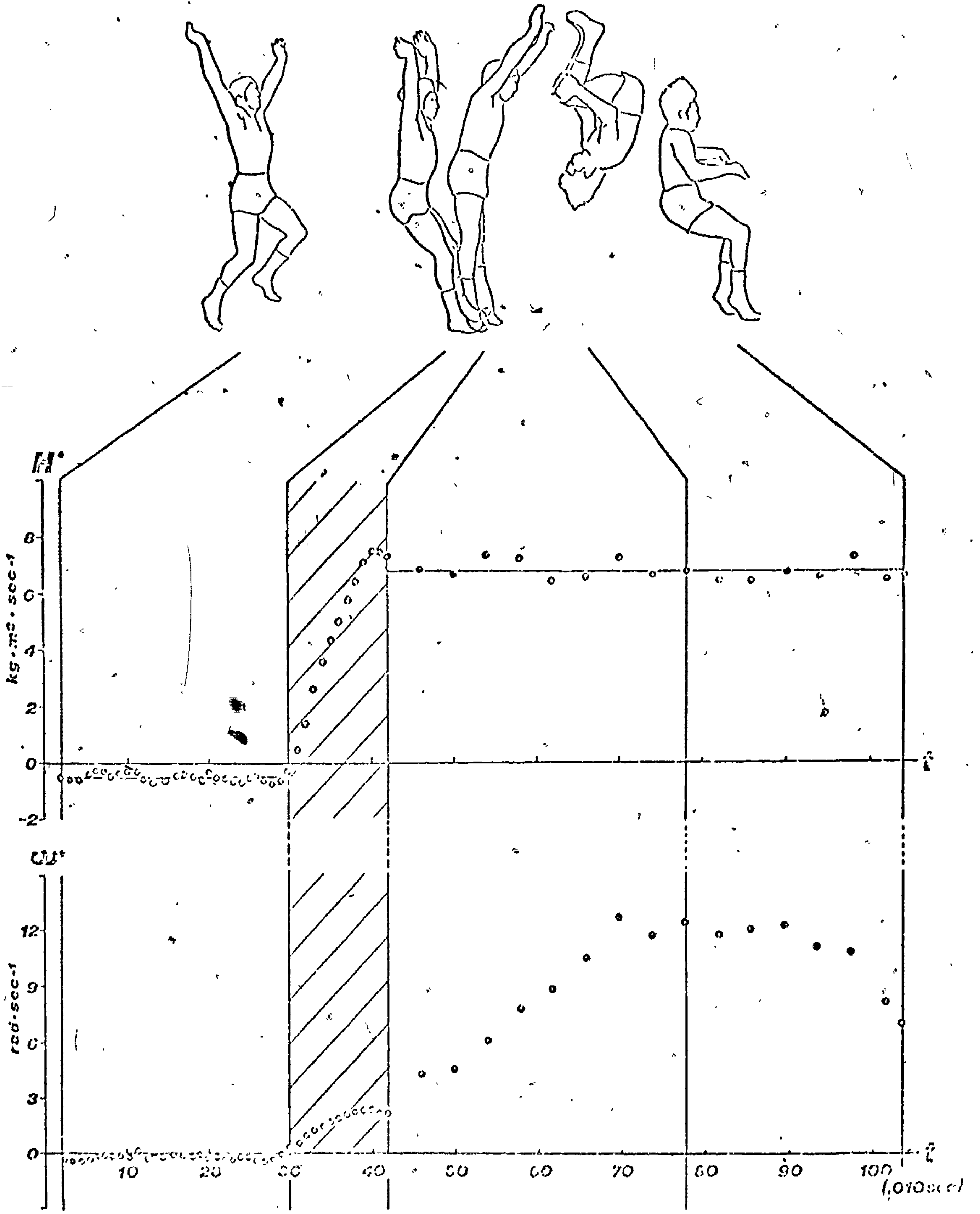
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Figure 3

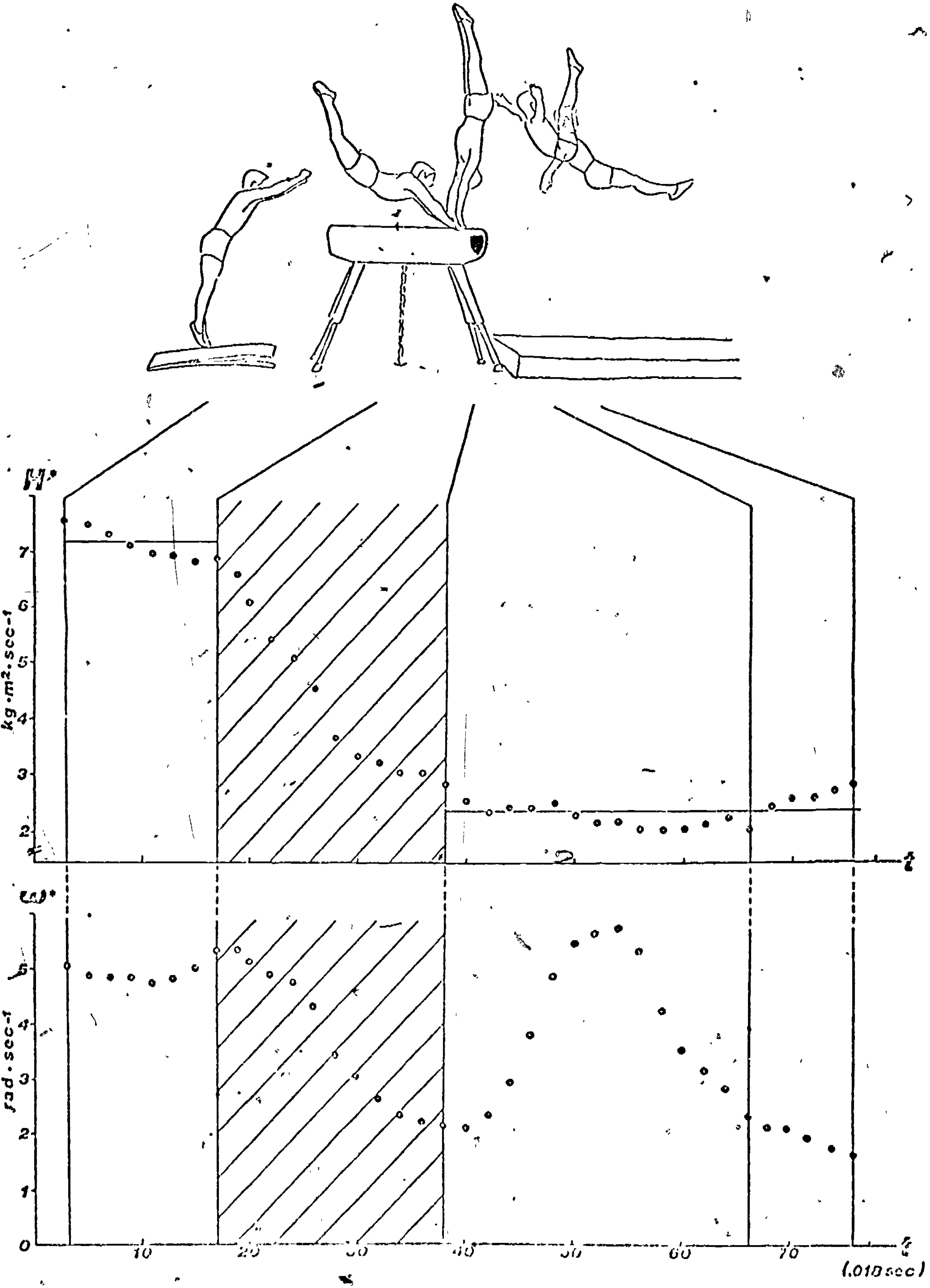
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Figure 4

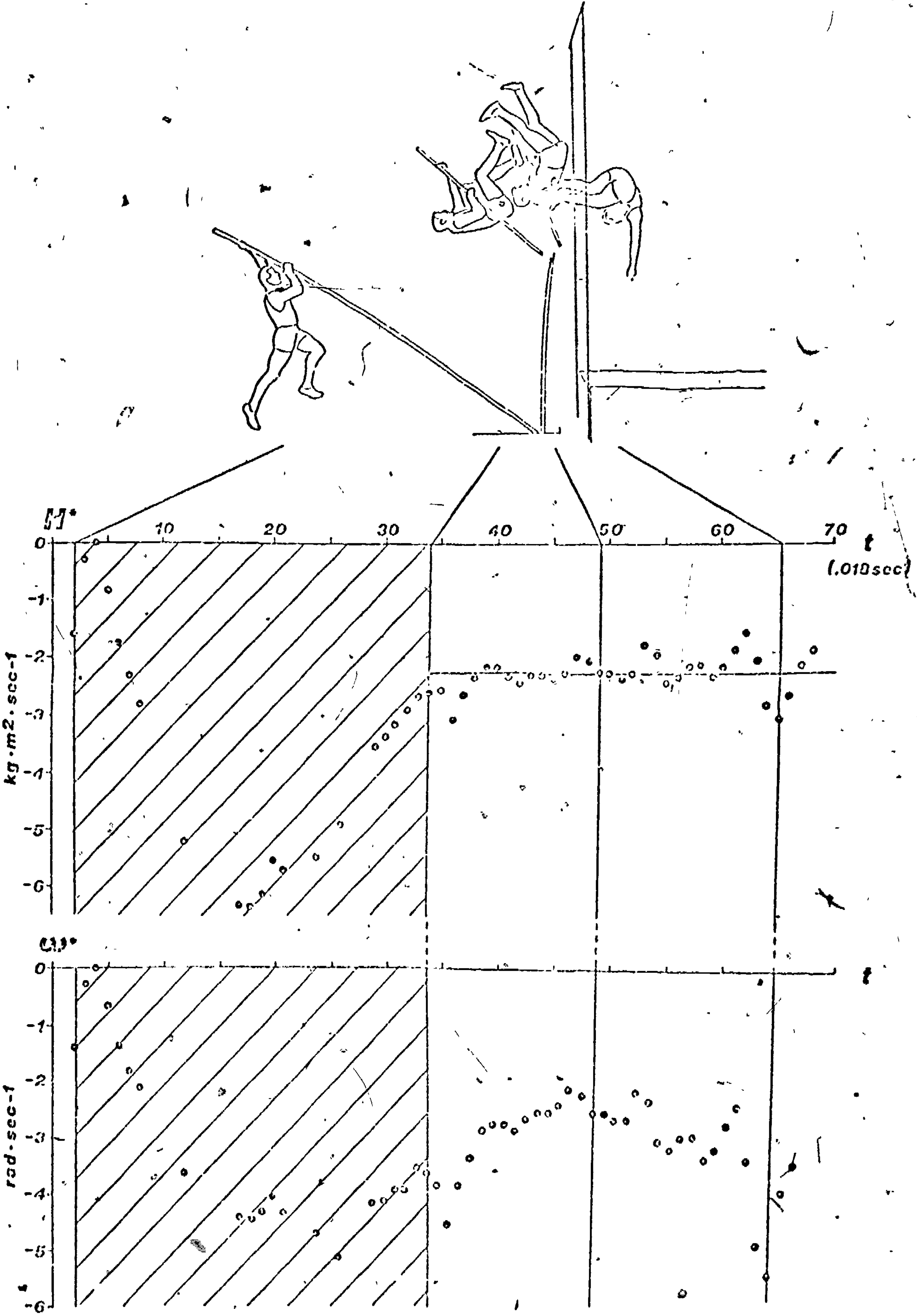
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Figure 5

quality; critical segmental end-points were very difficult to locate during the final stages of the motion, and the subject clearly deviated from the vertical plane of motion during the final phases. Considering these several serious limitations, the results shown in Fi[illegible]ht well be regarded as a testimony to the robustness of the computational procedure employed.

High Jump (Figure 6). The conditions under which the analysis of the high jump was conducted were similar to those for the pole vault. Thus, while the angular momentum values computed for the approach run are consistent with what might have been expected, those for the final flight phase must be regarded as somewhat suspect.

No discussion of the procedure described here would be complete without reference to its versality *vis-a-vis* other methods designed for the same purpose. This method, unlike its predecessors, can be employed to determine the angular momentum of the human body in a wide variety of activities. It does not require a period of quasi-rigid body motion (as does the Miller technique) and it is not limited to measurement of the change in angular momentum or to essentially experimental-type situations (as is the Ramey technique). In short, it is the most versatile of the methods currently available.

Conclusions

On the basis of the foregoing analysis it was concluded that the computational procedure developed in this study was acceptably accurate for first approximations, that it showed potential for further development and that it was highly versatile.

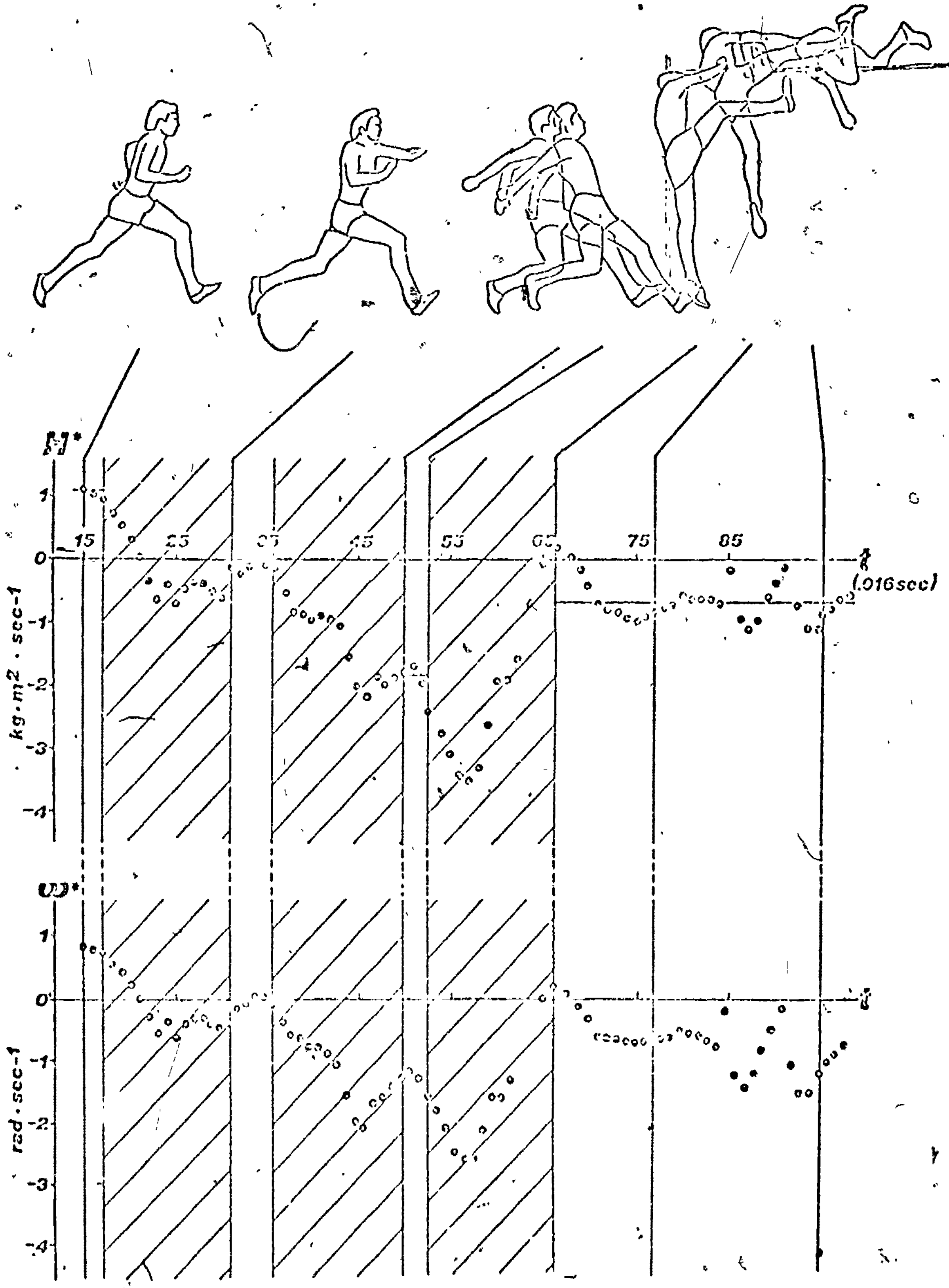
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Figure 6