# BIOMECHANICAL ANALYSIS OF FEMALE GYMNASTS' LANDINGS: SAFETY CONSIDERATIONS

FACULTY OF HUMAN DEVELOPMENT

RESEARCH REPORT

BY

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AND

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FOOTSCRAY CAMPUS

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Finally, acknowledgment is also given to the respective families of the authors for their understanding and continued support.

## GENERAL COMMENTS ABOUT THE PROJECT

In **general**, this research project was a most worthwhile experience and a better insight into colaborative research was gained by all involved. The communication link between biomechanics theory and practical coaching knowledge of temporal and spatial factors together with safety considerations involved in gymnastic landings for female gymnasts was achieved. The disciplines involved in this study were biomechanics, health science and gymnastics.

**Subjects:** Originally, the principle investigator anticipated to use female elite gymnasts (National Squad members) as subjects from the Victorian Institute of Sport (VIS), Women's Artistic Gymnastics (WAG) Centre, Cheltenham. However, because of their training commitment and school commitment, the Head Coach Ms Fiona Bird did not release these gymnasts to act as research subjects. Because of her interest in the area of biomechanics however, she gave permission for ten (10) sub-junior elite female gymnasts accompanied by one assistent coach, to volunteer as subjects. Informed consent was obtained from subjects, parents and head coach. The subjects and the assistant coach were transported by mini-bus from the VIS Cheltenham venue to the Flinders Street biomechanics laboratory and returned again after data collection. Light refreshments for the gymnasts and research personell was provided during the data collection.

**Data Collection:** This project was the first ever project performed at the new Flinders Street biomechanics laboratory. All testing equipment and instrumentation for data collection, e.g. synchronization (genlocking) of 2 panasonic video cameras, force platform with computer and control station, was tested before data collection. All subjects were briefed regarding process, tasks to be performed, warm-up procedures, familiarisation, etc. Experienced research personell ensured successful data collection. Unfortunately, after data collection was successfully completed, one of the floppy discs with important force platform data was misplaced. Subsequently, the principle researcher had to organise another session of data collection. This was a very difficult organisational task, since there were problems in getting all subjects at the same time again, organising research personell, booking the facility and equipment, etc. A very unpleasent experience!
Funding of the project was allocated for personell only. All funding was spent on data analysis. Two research assistents took more than one hundred

hours for data analysis (digitizing on the Peak Performance Motion Analysis System). However, funding was available for only 95 hours. No funding was allocated for equipment modification (a specially designed sprung floor section mounted on the force platform), consumables (video tapes, floppy discs), or light refreshments for subjects and researchers. This made procedures quite difficult for the principle researcher, since the funding was allocated for "to cover costs for personell only!"

**Outcome of the Research Project:** Following completion of the research project :

1) A joint presentation was given at the 1994 Faculty Research Conference, Title:Biomechanical Analysis Of Female Gymnasts' Landings: Safety Considerations.

2) The research article was modified and the subsequent research article was accepted to be presented at the international conference " Asian Pacific Paediatric Nursing Conference" in June 1995.

3) The above research article was printed in the proceedings of this conference.

4) The final report has been presented to the VIS WAG Gymnastics Centre, Cheltenham.

## EXPENDITURE STATEMENT

Special Faculty Project Account: FRG011

Funding was approved for the sum of $1,425.00 and was used only to cover the cost for personell (two research assistents) doing data analysis on the Peak Performance Motion Analysis System. Two research assistents were paid $15.00 per hour for digitizing (data analysis) on the above system. Data analysis and data print out to complete the research project took more than one hundred (100) hours. However, funding was available for ninety-five (95) hours only. The total amount of the funding was used.

# BIOMECHANICAL ANALYSIS OF FEMALE GYMNASTS' LANDINGS: SAFETY CONSIDERATIONS

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Long hours of gymnastics training, combined with the difficulty and complexity of skills, produce a considerable load on the musculo-skeletal system. Previous research (Snook, 1979; McNitt-Gray, 1991, 1993; Brueggemann, 1993; McNitt-Gray et al. 1994) shows that modern women's artistic gymnastics has a high incidence of injury, especially in the lower extremities and the lumbar spine area. The purpose of this study was to measure the magnitude of the peak vertical ground reaction forces (PVGRF) during landing in selected skills performed on floor by junior female gymnasts. Subjects were 10 female sub-junior elite gymnasts from the Victorian Institute of Sport Women's Artistic Gymnastic Centre, and four Australian Gymnastics Federation level eight standard female gymnasts. Kinematic and kinetic data were captured on video (3-D) and force platform acquisition systems. Forces obtained via PVGRF indicate the load on the lumbar spine and thus the likelihood of contributing to injury.The relationship between the PVGRF and the linear and angular kinematics is assessed to identify landing techniques that reduce PVGRF. Comparison of the analysed kinematic and PVGRF data of the VIS and level eight gymnasts performing the "JSBLFP" indicated that higher PVGRF, longer landing phase times and greater knee and hip flexion were measured for the level eight gymnasts. The most crucial mechanical factors at landings are the maximum CM height before landing and the CM displacement from touch-down to the lowest CM position during landing. High loads and stresses placed on the lumbar region through repetitive "solid" gymnastic landings over a long period of time, causes increased risk of injury to the lumbar spine.

## INTRODUCTION

In the last decade an increased interest in gymnastics has occured in Australia. There is also a trend to begin training at a young age (4-6 years), and gymnasts are achieving high levels of skill development much sooner than in the past. Gymnastics training and competition places a considerable load on the musculo-skeletal system. It creates the potential for injury due to the forces applied to the body during performance and more importantly loading. The incidence of low back pain,for example, in gymnasts is considered high. The forces and moments that produce the greatest load on body structures are experienced during landings (Nigg et. al., cited in Brueggemann, 1987; Adrian and Cooper, 1989). The magnitude of these loads becomes considerable at high velocities. Therefore, the reduction in the likelihood of injury necessitates thoughtful planning and progressive physical preparation and conditioning of gymnasts. Every serious injury that occurs to a young gymnast imposes unnecessary trauma to those involved and decreases the enjoyment obtained from being physically active.

## LITERATURE REVIEW

Modern women's artistic gymnastics has a reputation for injury ( Brueggemann, 1987; McNitt-Gray, 1991, 1993; McNitt-Gray, Yokoi and Millward, 1994; Snook, 1979). The increase in participation, the difficulty and complexity of skills, the increased training hours, and the concurrent decrease in age of competitors have contributed to increased incidences of injury in this sport. Caine & Lindner (1985) suggested that injuries were the consequence of coaches' high expectations: young gymnasts are pushed too hard and prematurely.Physical and psychological stress from training

is often difficult to recognise and diagnose. This may result in the symptoms not being detected before they manifest into serious problems.
Low back pain is a common complaint among gymnasts. Repeated and excessive arching of the lumbar spine is a typical posture in the routines of gymnasts (Adrian and Cooper, 1989). The lumbar spine which links the lower extremities and the torso is responsible for the coordinated transfer of power through the body and plays an important role in the landing process. If such a posture occurs during landings on the floor, it is likely to contribute to injury. The greater the landing forces, the greater the risk of injury. An increase in stress causes an increase in the strain of biological tissues. Thus, a body will continue to deform with increased force applied to it until it fractures. Leglise (1987) indicated that this increase in stress was often followed by an increase in chronic injuries. While the incidence of spondylolysis and spondylolisthesis occurs in about 5-7 percent of the general population, it is present in 11 percent of European gymnasts and 29.4 percent of Japanese gymnasts. This and the fact that 37.95 percent of gymnasts in general suffer lumbar problems, highlights the vulnerability of gymnasts to these types of problems . Jackson et al. (1976) examined the lumbar spine of 100 gymnasts between the ages 6-24 years using radiographic images, and found that the prevalence of spondylolysis in female gymnasts was almost four times higher than the 2.3% believed to occur in white females. Rossi (cited in Meeusen & Borms, 1992) reviewed 1430 lumbar spine radiographs of Italian Olympic athletes and found signs of spondylolysis in 32.8% of 132 gymnasts and spondylolisthesis in 8.9%.

In their study of female gymnasts, Garrick & Requa (1980) found that 12.2% of injuries occurred in the spine . Golsdstein et al. (1991) studied three groups of top level female gymnasts of pre-elite, elite, national and olympic caliber with regard to back pain and injury. The groups were compared to a similar group of national caliber female swimmers. The study revealed that 9% of pre-elite, 43% of elite, and 63% of olympic level gymnasts had spine abnormalities, while only 15.8% of all swimmers had spine abnormalities. This findings indicate that increased intensity and length of training correlate with other studies which suggest that female gymnasts are prone to spine injuries.

Several studies had investigated the extent of injuries, but the majority of these studies looked at North American gymnasts. The results however indicate that the risk of gymnastic injury is proportional to the skill level of the gymnast. A study cited in Kolt (1992), on Canadian elite female gymnasts reported that 83% of the gymnasts sustained at least one injury in the duration of the study. However, the findings may have been influenced by the fact that these gymnasts were performing at the highest level of competition.

Caine et al. (1989) concluded that the ankle, knee and lower back tend to be the most frequently injured parts in young female gymnasts, 72.2% of reinjuries occur in the lower back, most of those characterized by gradual onset. Back pain in gymnasts may be due to a variety of causes, ranging from a hyperlordic back to vertebral body fractures and disorders of the invertebral disc (Micheli, 1985). Back problems seem to result not only from single episodes of macrotrauma, but also from the repeated microtrauma in gymnastic movements (turns, twists and hyperextensions). Pollhaene (cited in Brueggemann, 1992) analysed 49 female gymnasts and found that 81.7% of the gymnasts showed pathological alterations of the spinal columns. In comparison with other elite athletes this result is highly alarming. Hall (1986) conducted a study to evaluate the mechanical factors that potentially contribute to back problems. The study quantified the lumbar hyperextension and impact forces for 5 commonly used gymnastic skills: the front and back walkover, the front and back handspring and the handspring vault. The study found that during the front and back walkovers and during the back handspring, maximal lumbar hyperextension occured very near to the time that impact forces were experienced by either the hands or feet.

A study by McNitt-Gray (1991) determined the effect of impact velocity and landing experience on the preferred landing strategies used by female collegiate gymnasts and recreational athletes from three drop landing heights. The results indicated that significant increases in joint flexion (with the exception of ankle joint), angular velocity , and impact force resulted as impact velocity increased. The high incidence of injury and execution errors observed during landings performed under competitive conditions indicates that gymnasts have difficulty in satisfying both performance and safety objectives in landing gymnastic skills (McNitt-Gray,1993).

Too and Adrian (1987) found PVGRF values of 5-6 times body weight (BW) during landings from a vaulting box 0.85 meters high. A comparison was made of those gymnasts landing with a flat trunk (no increased curvature at the lumbar spine) and those with an arched trunk (increased curvature at the lumbar spine). Mean PVGRF were 5.47 BW and 6.62 BW for flat trunk and arched trunk respectively.

To date, the majority of studies investigating the epidemiology of gymnastic injuries have failed to include the spinal injuries associated with landing force. Lower back injury in the young adolescent should never be taken lightly, since the longer the young gymnast has significant lumbar symptoms, the longer it usually takes for them to be resolved (Meeusn & Borms, 1992). Although such skills have been studied in the past in female and male gymnasts ( Payne and Parker, 1976; Too and Adrian, 1987; Knoll and Krug, 1990; Brueggemann, 1993), few studies have been reported which examine kinematic and kinetic properties related to potential injuries, and in particular to the lumbar spine on female junior gymnasts. There is a need to accumulate kinematic and kinetic data of such skills to furnish normative information on various levels of performance.

Back pain in gymnasts may be due to a variety of causes, ranging from a hyperlordic back to vertebral body fractures and disorders of the invertebral disc (Micheli, 1985). Back problems seem to result not only from single episodes of macrotrauma, but also from the repeated microtrauma in gymnastic movements (turns, twists and hyperextensions). Pollhaene (cited in Brueggemann, 1992) analysed 49 female gymnasts and found that 81.7% of the gymnasts showed pathological alterations of the spinal columns.

To date, the majority of studies investigating the epidemiology of gymnastic injuries have failed to include the spinal injuries associated with landing force. Lower back injury in the young adolescent should never be taken lightly, since the longer the young gymnast has significant lumbar symptoms, the longer it usually takes for them to be resolved (Meeusen & Borms, 1992). Although such skills have been studied in the past in young female and male gymnasts ( Payne and Parker, 1976; Too and Adrian, 1987; Knoll and Krug, 1990; Brueggemann, 1993), few studies have examined kinematic and kinetic properties related to potential injuries, particularly to the lumbar spine. Therefore, there is a need to accumulate kinematic and kinetic data of such skills to furnish normative information on various levels of performance.

### Purpose

The purpose of the study was to:

- measure the magnitude of PVGRF as an indication of the loads placed on the musculo-skeletal system
- investigate the relationship between forces and linear and angular kinematics involved in the execution of the skills performed
- identify landing techniques which reduce PVGRF and consequently reduce the load on the lumbar spine.

## METHOD

### Subjects

Ten female sub-junior elite gymnasts (age 9 - 11) from the Victorian Institute of Sport (VIS), Women's Artistic Gymnastic (WAG) Centre Cheltenham, and four Australian Gymnastics Federation level-eight female gymnasts volunteered as subjects. Informed consent was obtained from subjects and parents. Personal descriptive data of the of the gymnasts is presented in Table 1.

Table 1. Descriptive Data of the Female Gymnasts

| | Age (years) | Height (m) | Weight (kg) |
|---|---|---|---|
| Range | 9-15 | 1.25-1.63 | 23.8-53 |
| Mean | 12.2 | 1.45 | 33.8 |

## Experimental Procedures

All subjects were provided with the opportunity to become familiar with the experimental set-up. Explanations were given as to the exact task to be performed and emphasis on technical requirements and safety considerations were provided. After a traditional warm-up period, all subjects had 3-5 practice trials prior to data collection in order to familiarize themselves with each task.

Each subject from the VIS group was required to perform one task: three jumps from a standing position on a spotting block 0.88 m high onto the force platform. Before data collection, all subjects were required to practice the jump several times on the floor followed by three practice jumps, jumping off the spotting block.

The level eight group gymnasts were required to perform three tasks. Firstly, three trials of round-off backward somersault, landing on the force platform; -the gymnasts were instructed to take three running steps before the round-off. Secondly, three trials of standing backward somersaults with take-off and landing on the force platform, and thirdly, three jumps from a spotting block 1.18 m high onto the force platform. For this task, the subjects were instructed to perform an armcircle backwards, starting with the arms held in a sideward position, prior to jumping off the block. The subjects were instructed to 'stick' the landing as they do in competitions.

## Data Collection

All data collection was performed at the Biomechanics Laboratory, Department of Physical Education and Recreation, Victoria University of Technology, Flinders Street Campus.

Data was captured on video, in 3-D using two panasonic F15 video cameras at a rate of 50 fields per second. The cameras were synchronised (genlocked). The skills performed contained no excessively large frequencies that would have required a sample rate of greater than 50 Hz. A high speed shutter was engaged which provided a near instantaneous, sharp (1/1000th of a second) picture on each field. A PEAK system calibration frame, a structure of 24 spheres and rods of

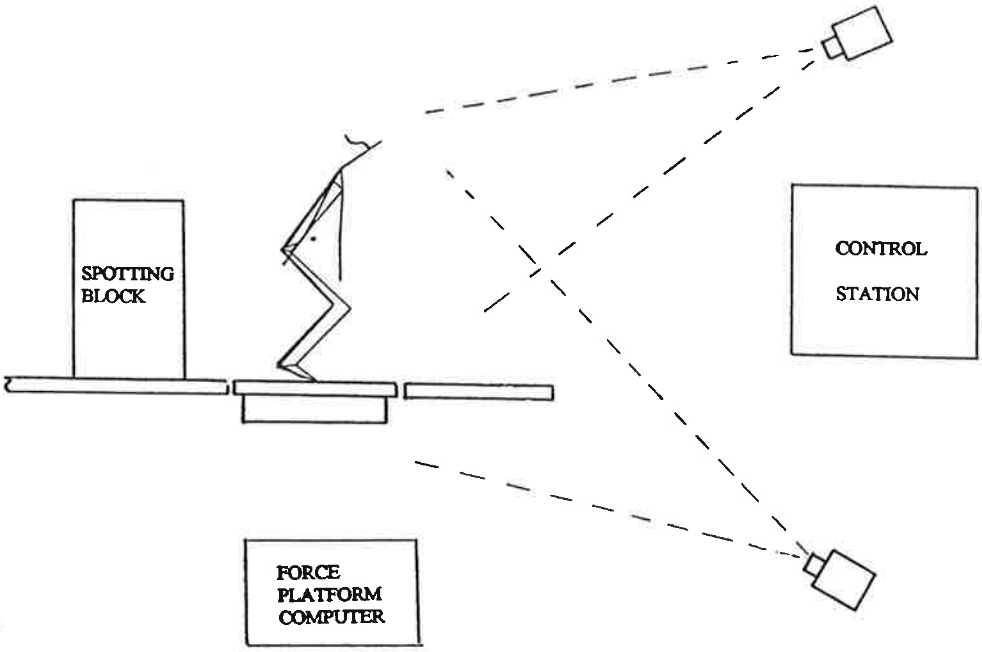


Fig 1. Schematic diagram of experimental set-up

The ground reaction forces (x, y, z) were measured by an AMTI force platform measuring 0.61 x 1.22m and registered on a 386 PC. The force platform was mounted in the floor of the laboratory and was covered with a specially designed sprung floor section, enabling measurements under realistic conditions (Fig 2).

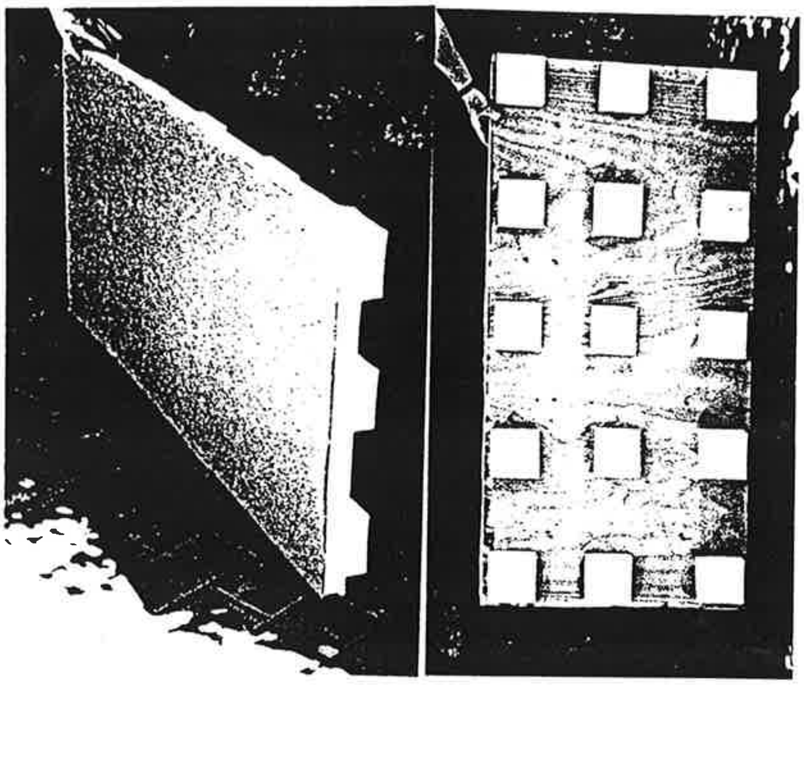

Fig 2. Sprung floor section used to cover the force platform

### Data Analysis

The best performance of each subject (determined by qualitative analysis) of each skill sequence recorded was then encoded and analysed using a video data aquisition system ( Peak Performance Technologies, Inc.- Peak 5, 3-D Motion Analysis System). The process included tape encoding (frame numbering and tape identification), spatial model development, using published body segment data from Dempster (1955), anthropometrics and angular orientation; project set-up (cameras used, lens, scaling factor, frame rate, picture per field etc). The raw data files were filtered using a fourth-order Butterworth recursive filter with optimal cut-off frequencies (3-6 Hertz) as determined by the software.

Digitisation generated positional data which when combined with the temporal data generated kinematic parameters; linear and angular positions, displacement and velocities on the three axes as well as a resultant. After the kinematic data was obtained, they were cascaded with the spatial model to generate line model diagrams with the kinematic graphics as well as synchronised with the videotapes to provide the real life view and data characterisation. These outputs were then processed to video for reporting as well as hard paper copy.

## RESULTS

Analysis of the linear and angular kinematics and PVGRF-time data of the landing phase characteristics of the tasks "jump from a spotting block", "round-off back somersault" and "standing back somersault", were performed.

### Reaction Forces

*Peak Vertical Ground Reaction Force-Time Characteristics (PVGRF).* Analysis of the PVGRF data indicated a considerable increase with increased impact velocity. Mean PVGRF for the "level eight group gymnasts" performing the JSBLFP were 1849 N (4.3 BW), for the ROBSLFP 1472 N (3.4 BW), and for the SBSTOLFP 1281 N (3.0 BW). The mean rise times to PVGRF after touch-down were 32, 37 and 22 ms, respectively. Mean PVGRF for the "VIS gymnasts" performing the JSBLFP were 1063 N (4.25 BW) and the mean rise time to PVGRF after touch-down was 29 ms.

Table 2. Mean PVGRF-Time Data

| | JSBLFP VIS n=4 | JSBLFP level eight n=4 | ROBSLFP level eight n=4 | SBSTOLFP level eight n=4 |
|---|---|---|---|---|
| PVGRF (N) | 1063 | 1849 | 1472 | 1281 |
| PVGRF in Bodyweight (BW) | 4.25 | 4.3 | 3.4 | 3.0 |
| Rise Times to PVGRF (ms) | 29 | 32 | 37 | 22 |
| Duration max. CM height to touch-down (ms) | 47 | 54 | 39 | 33 |
| Duration from touch-down to min. (ms) | 16 | 24 | 05 | 09 |

**Positions, Displacement and Landing Phase Duration**

*CM positions, displacement and landing phase duration for "jumping off the spotting block to landing on the force platform" (JSBLFP).* The mean CM positions for the "level eight group gymnasts" were measured at the start of the jump,- standing on the spotting block, max. CM height during jump, CM height at touch-down, and minimum CM vertical position during landing. The mean values were 2.03 m, 2.35 m, 0.93 m and 0.61 m , respectively. The duration from the max. CM height to touch-down was 0.54 sec., and from touch-down to min. CM position 0.24 sec.

The mean values for the VIS gymnasts were 1.53 m, 1.79 m, 0.78 m and 0.55 m, respectively. The duration from the max. CM height to touch-down was 0.47 sec., and from touch-down to min. CM position 0.16 sec.

*CM positions,displacement and landing phase duration for the level eight gymnasts performing a "round-off and back somersault to landing on the force platform" (ROBSLFP).* The mean CM positions were measured at take-off for the back somersault, maximum CM height during somersault, CM height at touch-down, and minimum CM vertical position during landing. The mean values were 1.04m, 1.50m, 0.82m and 0.72m respectively. The duration from the maximum CM height to touch-down was 0.39 sec., and from touch-down to minimum CM position 0.05 seconds.

*CM positions displacement and landing phase duration for the level eight gymnasts performing a "standing back somersault with take-off and landing on the force platform" (SBSTOLFP).* The mean CM positions measured at take-off was 1.03m, max. CM height was 1.20m, CM height at touch-down was0.65m and the min. CM vertical position at landing was 0.56m. The duration from the max. CM height to touch-down was 0.33 sec., and from touch-down to min. CM position 0.09 seconds.

Table 3. Mean CM Positions, Displacement and Landing Phase Durations

| | JSBLFP VIS n=4 | JSBLFP level eight n=4 | ROBSLFP level eight n=4 | SBSTOLFP level eight n=4 |
|---|---|---|---|---|
| CM height-standing on Spotting Block (m) | 1.53 | 2.03 | 1.04 | 1.03 |
| Max. CM height during jump (m) | 1.79 | 2.35 | 1.50 | 1.20 |
| CM height at touch-down (m) | 0.78 | 0.93 | 0.82 | 0.65 |
| Minimum CM height during landing (m) | 0.55 | 0.61 | 0.72 | 0.56 |
| Duration CM height to touch-down (sec) | 0.47 | 0.54 | 0.39 | 0.33 |
| Duration touch-down to minimum (sec) | 0.16 | 0.24 | 0.05 | 0.09 |

## Landing Angles

*Touch-down and minimum angles for "jumping off the spotting block to landing on the force platform" (JSBLFP).* The angle formed by the CM to the ground contact (toes) and the horizontal was measured at touch-down and referred to as touchdown angle. CM to ground contact, knee, trunk to horizontal, and thigh to horizontal mean angles were measured for both touch-down and minimum during landing.

The mean values at touch-down for the "level eight gymnasts" were 100°,160°, 83° and 71° (Fig 3. 1-4), and minimum during landing were 94°, 85°,53° and 30°(Fig 3. 5-8), respectively.

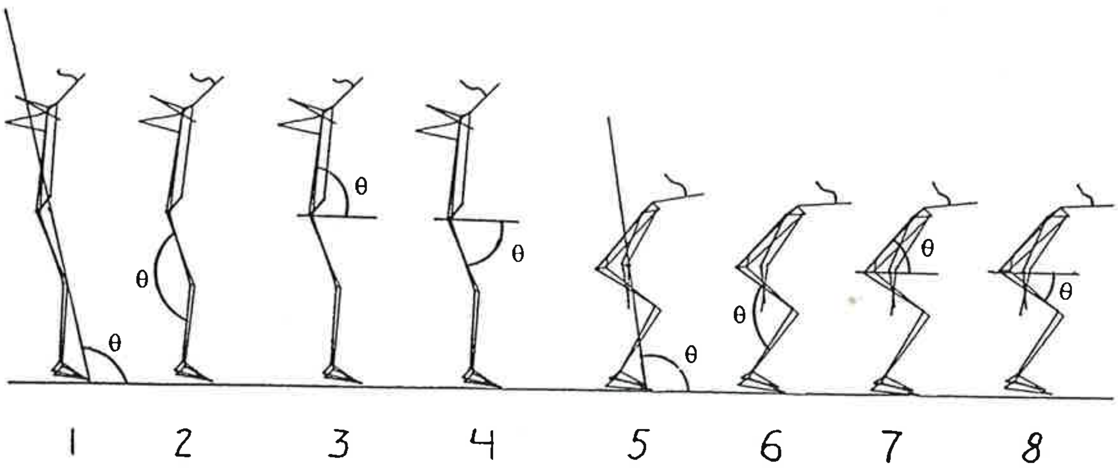


Fig 3. Mean Touch- down and Minimum Angles for ""Jumping off the Spotting Block to Landing on the Force Platform"

The mean values at touch-down for the "VIS gymnasts" were 101°, 169°, 85° and 76° (Fig 3. 1-4), and minimum during landing were 91°, 88°, 70° and 39° (Fig 3. 5-8), respectively.

*Touch-down and minimum angles for "round-off back somersault to landing on the force platform" (ROBSLFP).* The mean values at touch-down for the "level eight gymnasts" were 109°, 170°, 31° and 79°, and minimum during landing were 100°, 126°, 31° and 79°, respectively.

*Touch-down and minimum angles for "standing back somersault with take-off and landing on the force platform" (SBSTOLFP).* The mean values at touch-down for the "level eight gymnasts" were 81°, 142°, -24° and 90°, and minimum during landing were 81°, 105°, -24° and 79°, respectively.

Table 4. Landing Angles at Touch-down and Minimum CM Height

| (°) | | JSBLFP VIS n=4 | JSBLFP level eight n=4 | ROBSLFP level eight n=4 | SBSTOLFP level eight n=4 |
|---|---|---|---|---|---|
| CM to toe | touch-down | 101 | 100 | 109 | 81 |
| and horizontal | min. | 91 | 94 | 100 | 81 |
| Knee | touch-down | 169 | 160 | 170 | 142 |
| | min. | 88 | 85 | 126 | 105 |
| Trunk to hori. | touch-down | 85 | 83 | 31 | -24 |
| | min. | 70 | 53 | 31 | -24 |
| Thigh to hori. | touch-down | 76 | 71 | 79 | 90 |
| | min. | 39 | 30 | 79 | 79 |

**Landing Velocities**

*Vertical and horizontal velocity-time histories of the CM, hip, knee and ankle joints for "jumping off the spotting block to landing on the force platform" (JSBLFP).* The mean max. vertical and horizontal velocity values at impact for the "level eight gymnasts" were -4.75, -4.98, -4.99 -4.93 and1.06, 1.20, 1.55 and 1.66 m/s for CM, hip, knee and ankle, respectively. The values for the "VIS gymnasts" were -4.14, -4.56, -4.21, -4.24 and 1.35, 2.09, 2.48 and 2.37 m/s, respectively.

*Angular velocity-time histories* of the hip, knee and ankle joints are-6.02, -13.00, -18.39 and -3.25, -9.51 and -13.21 rad/sec, for the level eight and VIS gymnasts, respectively.

*Vertical, horizontal and angular velocity-time histories of the CM, hip, knee and ankle joints for "round-off back somersault to landing on the force platform" (ROBSLFP) and "standing back somersault with take-off and landing on the force platform"(SBSTOLFP) for the level eight gymnasts.* The mean max. vertical velocity values at impact were -3.50, -4.65, -5.45, -9.69 and -3.04, -4.04, -5.00 and -10.82 m/s, respectively. The mean max. horizontal velocity values at impact were

3.81, 5.12, 8.29, 9.07 and 0.64, 1.43, 1.63, and 1.89 m/s, respectively. The mean max. angular velocity values at impact were -3.59, -4.39, -17.83 and -3.59, -9.06 and -4.19 rad/sec, respectively.

Table 5. Mean Vertical, Horizontal and Angular Impact Velocity Data for CM, Hip, Knee and Ankle Joints

| ($ms^{-1}$) | JSBLFP VIS n=4 | JSBLFP level eight n=4 | ROBSLFP level eight n=4 | SBSTOLFP level eight n=4 |
|---|---|---|---|---|
| Vertical impact velocity | | | | |
| CM | -4.14 | -4.75 | -3.50 | -3.04 |
| Hip | -4.56 | -4.98 | -4.65 | -4.04 |
| Knee | -4.21 | -4.99 | -5.45 | -5.00 |
| Ankle | -4.24 | -4.93 | -9.69 | -10.82 |
| Horizontal impact velocity | | | | |
| CM | 1.35 | 1.06 | 3.81 | 0.64 |
| Hip | 2.09 | 1.20 | 5.12 | 1.43 |
| Knee | 2.48 | 1.55 | 8.29 | 1.63 |
| Ankle | 2.37 | 1.66 | 9.07 | 1.89 |
| Angular impact velocity (rad/sec) | | | | |
| Hip | -3.25 | -6.02 | -3.59 | -3.59 |
| Knee | -9.51 | -13.00 | -4.39 | -9.06 |
| Ankle | -13.21 | -18.39 | -17.83 | -4.19 |

## DISCUSSION

Selected kinematic parameters and vertical ground reaction forces in landings were examined to gain an insight into stresses and loads experienced by the gymnasts during the landing process. In this study, two groups of female gymnasts performed a simple landing task, a jump from a spotting block from different heights and two different types of back somersaults. For this particular skill, the gymnasts had a choice of landing techniques available. The landing surface resembled that of a gymnastics floor area. Comparisons of the analysed kinematic and PVGRF data of the VIS and level eight gymnasts performing the "jump off the spotting block to landing on the force platform" indicated that the PVGRF increased with increases in impact velocity. The level eight gymnasts tended to experience marginal higher mean peak impact forces (4.3 BW) compared to the VIS gymnasts (4.25 BW) in the JSBLFP, but recorded considerable differences in impact velocities (VIS gymnasts 4.14 and level eight gymnasts 4.75 m/s). These differences in reaction forces and impact velocities were probably due to the higher drop height (0.3m) for the level eight gymnasts. Too and Adrian (1987) found PVGRF values of 5-6 times body weight (BW) during landings from a vaulting box 0.85 meters high. In their study a comparison was made of those gymnasts landing with a flat trunk (no increased curvature at the lumbar spine) and those with an arched trunk (increased curvature at the lumbar spine). Mean PVGRF were 5.47 BW and 6.62 BW for flat trunk and arched trunk respectively. Rise times to PVGRF after touch-down were 32 ms and 29 ms for the level eight and VIS gymnasts, respectively. This findings are consistent with the study of Panzer et al. (1988) who reported that the time to PVGRF always occured 30-50 ms after touch-down and the softer the landing surface, the longer the delay of the time to PVGRF. The mounted sprung floor section on the force platform reduced the PVGRF and increased the rise-time to PVGRF. Landing techniques favoring slightly increased knee (VIS gymnasts 81° and level eight gymnasts 75°) and 50% more trunk to horizontal flexion (VIS gymnasts 15° and level eight gymnasts 30°) were preferred by the level eight gymnasts, when landing with higher impact velocities.

In this observation it was also noted that during the landing, when the impact forces were just past max., approx. 40-60 ms after touch-down, the knee angle was at minimum. However, the trunk was still moving forward and downward, subsequently placing high loads and stresses on the lumbar region through its momentum. If this occurs repeatedly over a long period of time, risk of injury is likely to occur.

Landing phase durations, defined as the elapsed time from touch-down to minimum CM height during landing, were compared between both groups across impact velocities. Impact velocities and landing phase durations were higher for the level eight gymnasts. Smaller minimum hip angles were observed for this group (VIS gymnasts 109°, level eight gymnasts 83°) and small differences in the minimum knee angles for both groups were recorded (VIS gymnasts 88°, level eight gymnasts 85°). This result suggests that the gymnasts adjust to the landing impact by absorbing the landing forces over a longer period of time. The increase in landing phase time, due to increased drop height observed between the two groups of female gymnasts in this study, is consistent with the trend observed by McNitt-Gray (1991). Therefore, in order to minimize the stress placed on the musculo-skeletal system during landings, the gymnast must effectively dissipate the large forces encountered during the landing phase. Examination of the video recordings indicates that landing techniques employed by the gymnasts differ across both groups. The temporal patterns showed that joints most proximal to the feet (point of initial contact) were brought to rest prior to joints more distal. All subjects used multijoint motion during landing from the two different heights.
The extended position of the joints at touch-down provides the subject with the option of using a large range of joint motion during the landing phase. The

availabilty of large joint ranges of motion provided the subject with the opportunity of using a number of joint flexion strategies. This may create a large safety margin, particularly, if the subjects need to modify their strategy during the landing. Joints closest to the point of force application demonstrated larger peak angular velocities than those positioned further away as observed in the JSBLFP and ROBSLFP. This was consistent with the findings of McNitt-Gray (1991). However, this was not the case for the SBSTOLFP where the knee angular velocity was more than 50% greater than that of the hip and ankle angular velocity. For example, if the hip joint is flexed prior to touchdown, as in landing a standing back somersault lacking sufficient rotation, less hip joint motion is available during the landing phase. If insufficient hip range (66°) motion is available, the knee joint is expected to play a greater role. The ROBSLFP which has linear and angular momentum before take-off, is very difficult to control during landings. The small landing target made it an increased challenge and subsequently more difficult for the gymnasts to "stick" the landing. The need to control the angular momentum during landings of somersaults may prohibit the use of extensive trunk motion. If the trunk and hips approach full flexion, landings from even low heights may significantly load the structures of the hip and lumbar area. This problem could be magnified during landings from greater heights and also applies to all joints of the lower extremities. In effect, the most crucial mechanical factors at landings are the maximum CM height before the landing, and the displacement from touch-down to the lowest CM position.
In conclusion, it is reasonable to assume, that in landings from a higher drop height, the degree of joint flexion, rate of joint flexion, impact peak velocities and landing phase times tend to increase. More research under more realistic conditions such as landings in competitions is required, to determine the changing role of joints and muscles during the force attenuation phase of landings, particularly if the ability of a particular body joint is compromised due to injury. This study may provide thoughts for modification of competition landings that provides safer landings and subsequently reduce the risk of injury particularly to young female gymnasts as the vertebral arches may not be completely ossified.

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FRAGS 93/085
7.10.1993

# FACULTY OF HUMAN DEVELOPMENT

VICTORIA UNIVERSITY OF TECHNOLOGY

18 October, 1993

Mr Helmut Geiblinger
Department of Physical Education
and Recreation

Dear Helmut,

Your application for a Faculty Research Grant was considered at the October meeting of the Faculty Research and Graduate Studies Committee. I am pleased to advise you that the committee has approved funding to cover your estimated costs in relation to "Personnel" - $1,425.00.

An extract of the minutes is attached for your information. I suggest you contact Associate Professor Terry Seedsman in relation to your remaining budget items.

Your money has been set aside for your project in a special Faculty account (FRG011). You will be able to draw on this money by completing one of the enclosed "requests for payment" slips and forwarding it to Anne Hicks, in the Faculty Office, to process.

On completion of the project, please send me a copy of the report, including your expenditure statement. You are also required to deliver the findings of your research at the 1994 Faculty Research Conference to be held in November 1994.

If you have any queries regarding this grant, please contact Anne Hicks on ext 4932.

Yours sincerely,

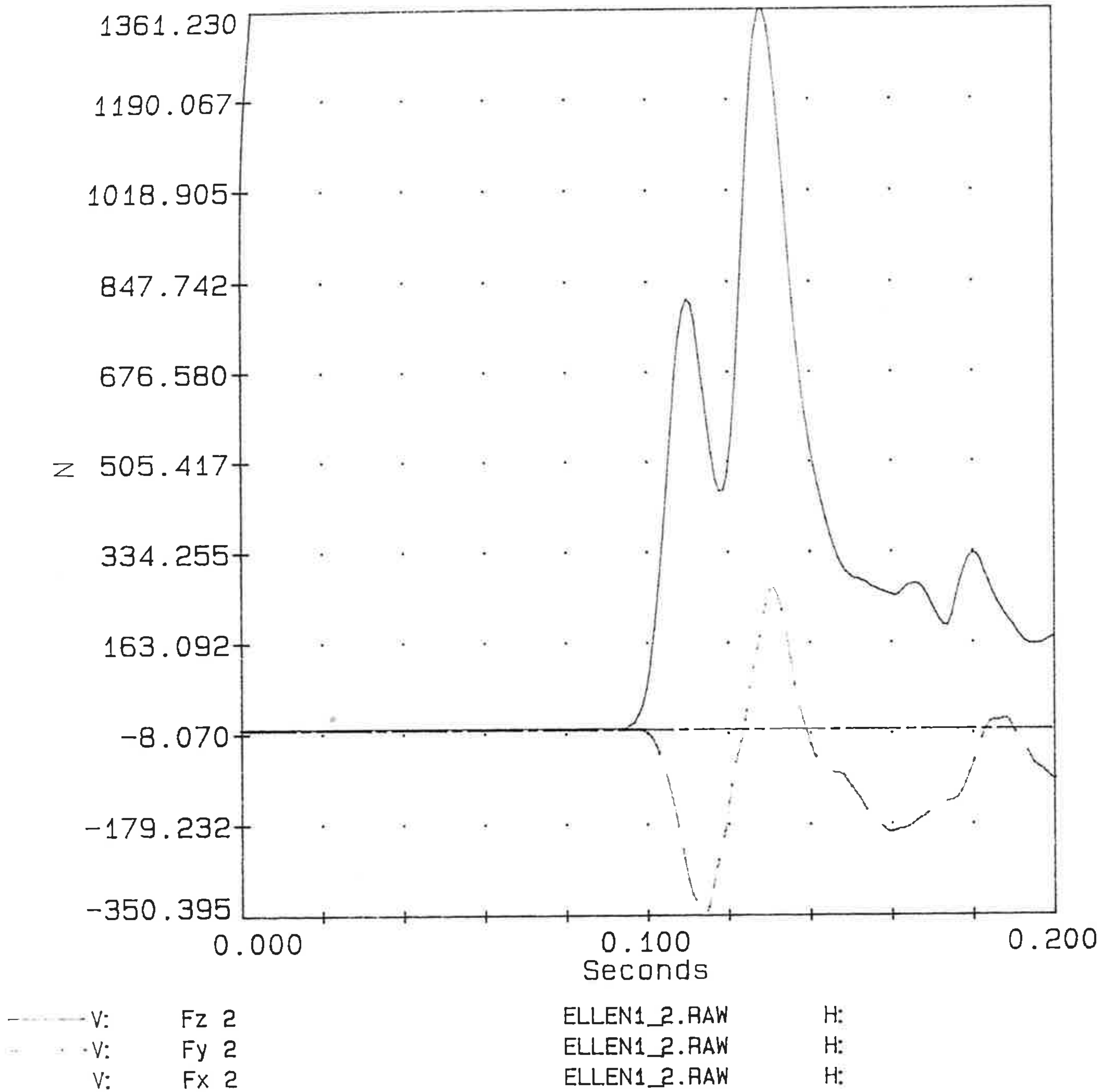
Professor David L Lawson
Dean
Faculty of Human Development

cc Lee Chiu
Tim Wrigley
Terry Seedsman
Denis Hext

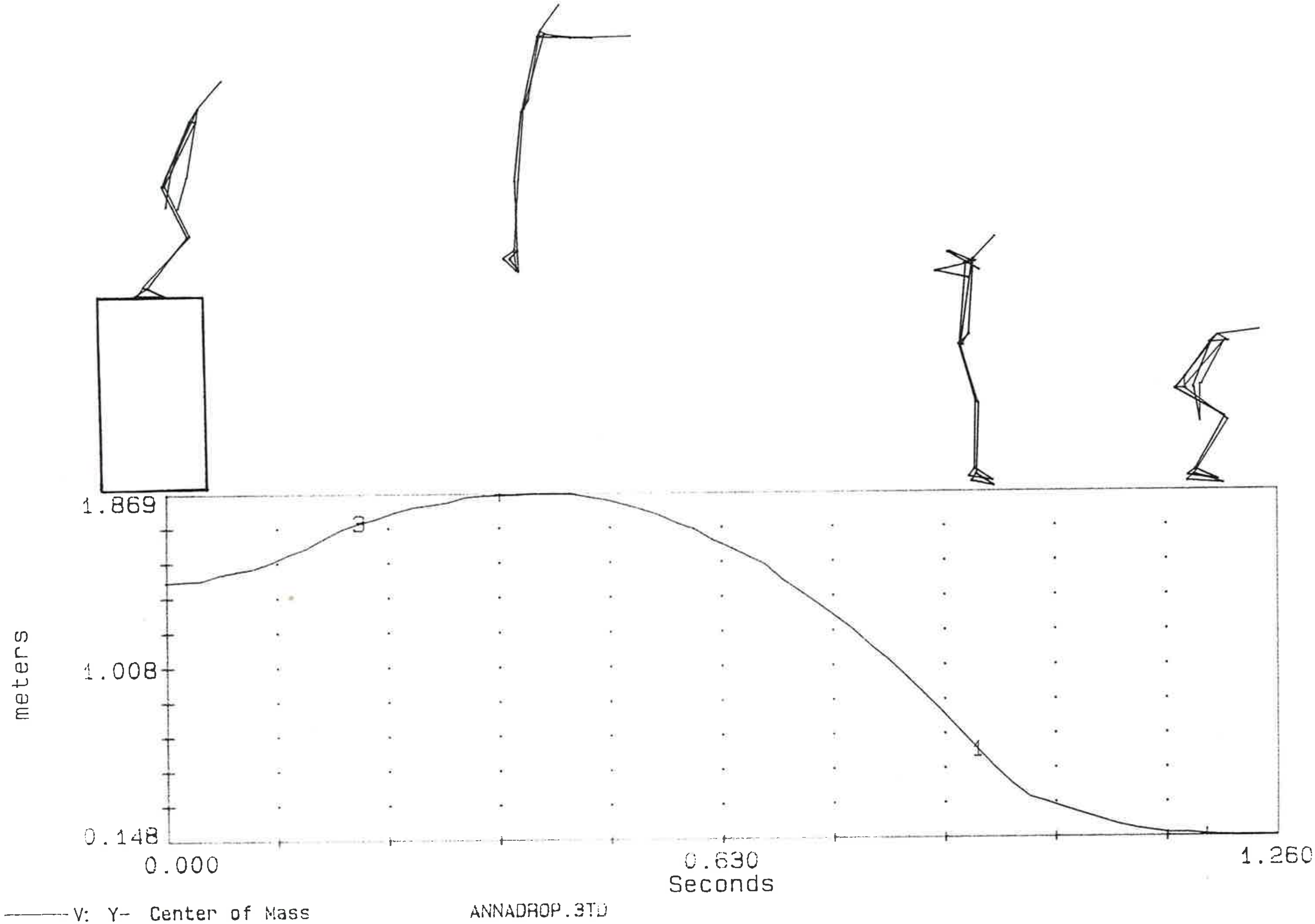
ref: ahlet025
e:anne/rags/let

le 2. Summary of Mean Kinematic and Mean Force Data: Level Eight gymnasts

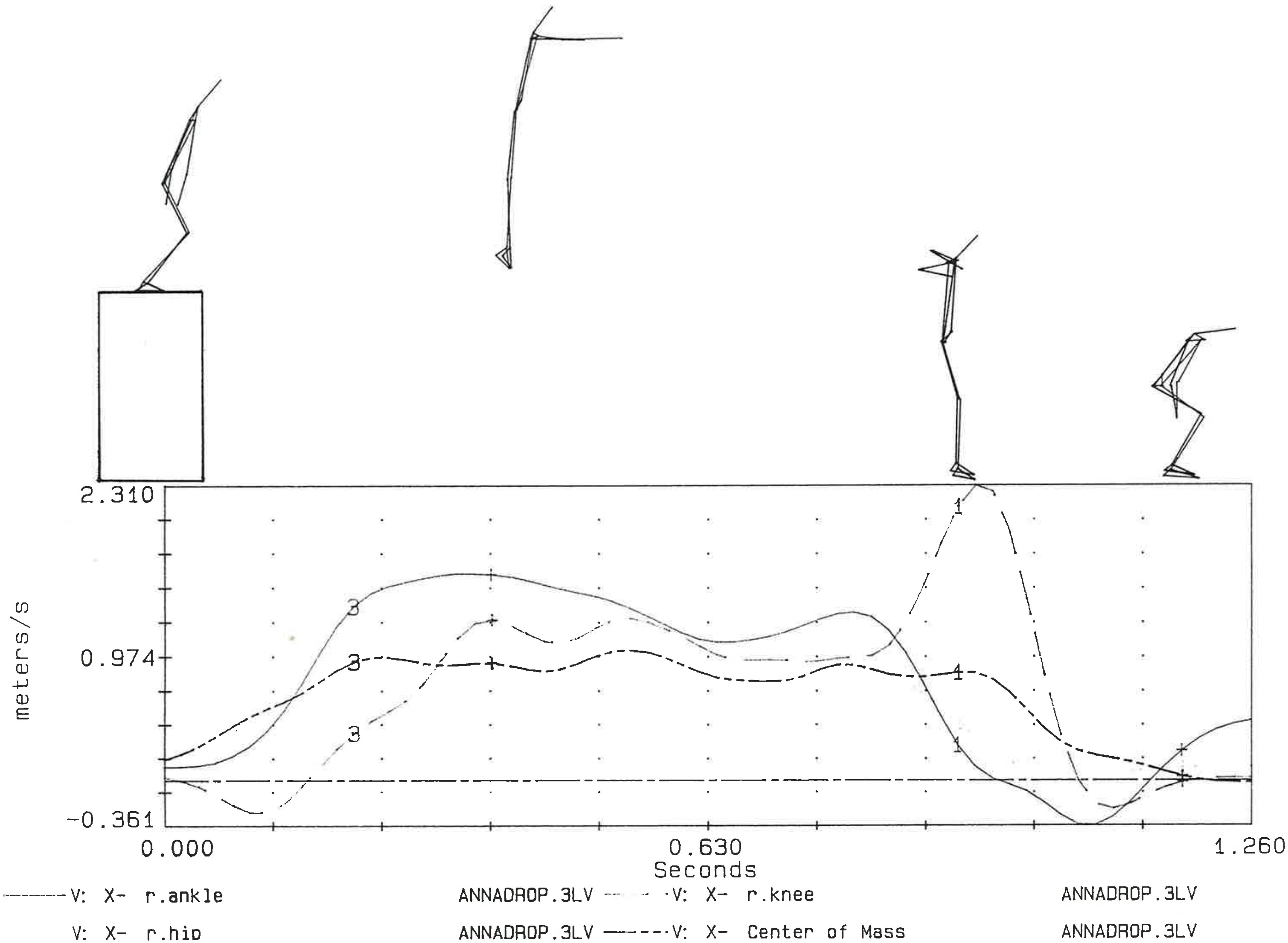
| | Jumping of spotting block landing on force platform (JSBLFP) n=4 | Round-off b/w somersault landing on force platform (ROBSLFP) n=4 | Standing backward somersault with take-off and landing on force platform (SBSTOLFP) n=4 |
|---|---|---|---|
| CM height during jump (m) | 2.35 | 1.50 | 1.20 |
| n. CM height during landing(m) | 0.61 | 0.72 | 0.56 |
| M height at touch-down (m) | 0.93 | 0.82 | 0.65 |
| height standing on spotting block | 2.03 | | |
| M height at take-off | | 1.04 | 1.03 |
| ration max.CM height to h-down (sec) | 0.54 | 0.39 | 0.33 |
| ration max. CM height to in. CM height (sec) | 0.78 | 0.445 | 0.425 |
| knee angle at touch-down (deg) | 160 | 170 | 142 |
| in. knee angle during landing (deg) | 85 | 126 | 105 |
| to horiz. at touch-down(deg) | 83 | 31 | -24 |
| trunk angle (deg) | 53 | 31 | -24 |
| igh to horizontal at touch-down (deg) | 71 | 79 | 90 |
| thigh angle (deg) | 30 | 79 | 79 |
| to ground contact angle touch-down (deg) | 100 | 109 | 81 |
| CM to ground contact angle | 94 | 100 | 81 |
| ax. vert. velocity (m/s) | | | |
| | -4.75 | -3.50 | -3.04 |
| p | -4.98 | -4.65 | -4.04 |
| knee | -4.99 | -5.45 | -5.00 |
| kle | -4.93 | -9.69 | -10.82 |
| ax. horiz. velocity (m/s) | | | |
| | 1.06 | 3.81 | 0.64 |
| p | 1.20 | 5.12 | 1.43 |
| knee | 1.55 | 8.29 | 1.63 |
| kle | 1.66 | 9.07 | 1.89 |
| ng. vel. at landing (rad/sec) | | | |
| p | -6.02 | -3.59 | -3.59 |
| ee | -13.00 | -4.39 | -9.06 |
| ankle | -18.39 | -17.83 | -4.19 |
| GRF (N) | 1849 (4.3 BW) | 1472 (3.4 BW) | 1281 (3.0 BW) |
| me to PVGRF after touchdown (ms) | 32 | 37 | 22 |

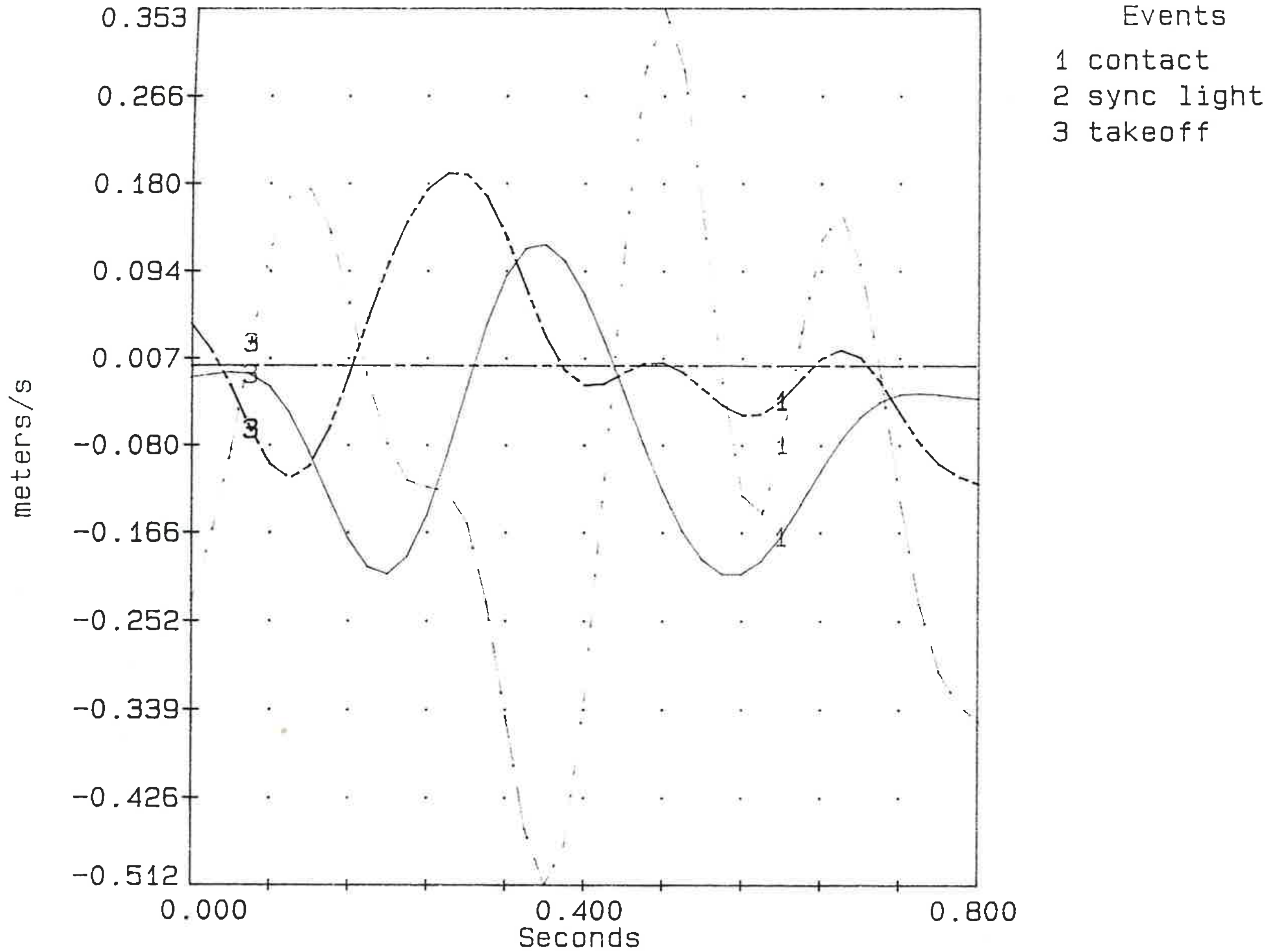

1361.230
1190.067
1018.905
847.742
676.580
505.417
334.255
163.092
-8.070
-179.232
-350.395
N
0.000
0.100
0.200
Seconds
V: Fz 2 ELLEN1_2.RAW H:
V: Fy 2 ELLEN1_2.RAW H:
V: Fx 2 ELLEN1_2.RAW H:

34ms

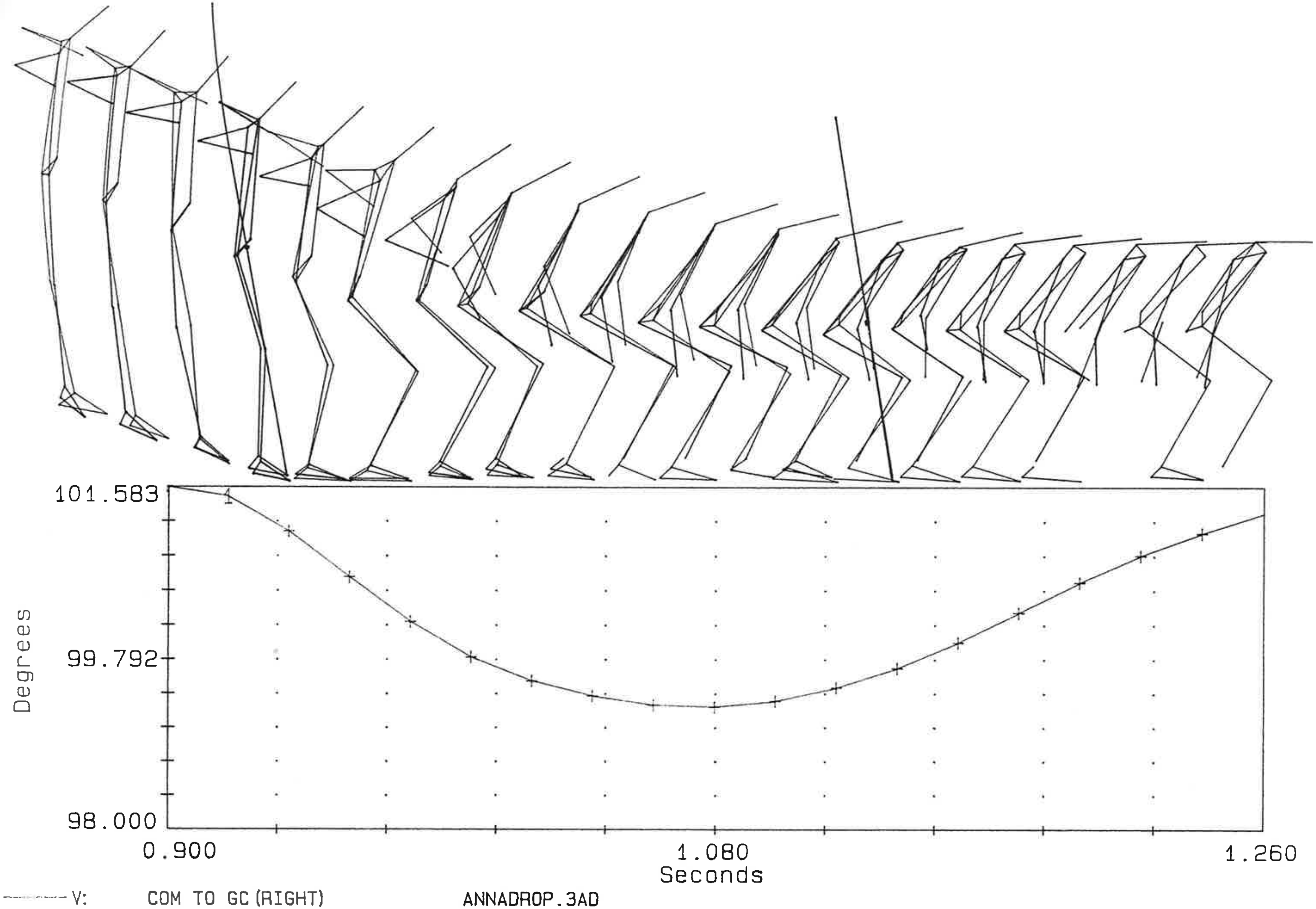


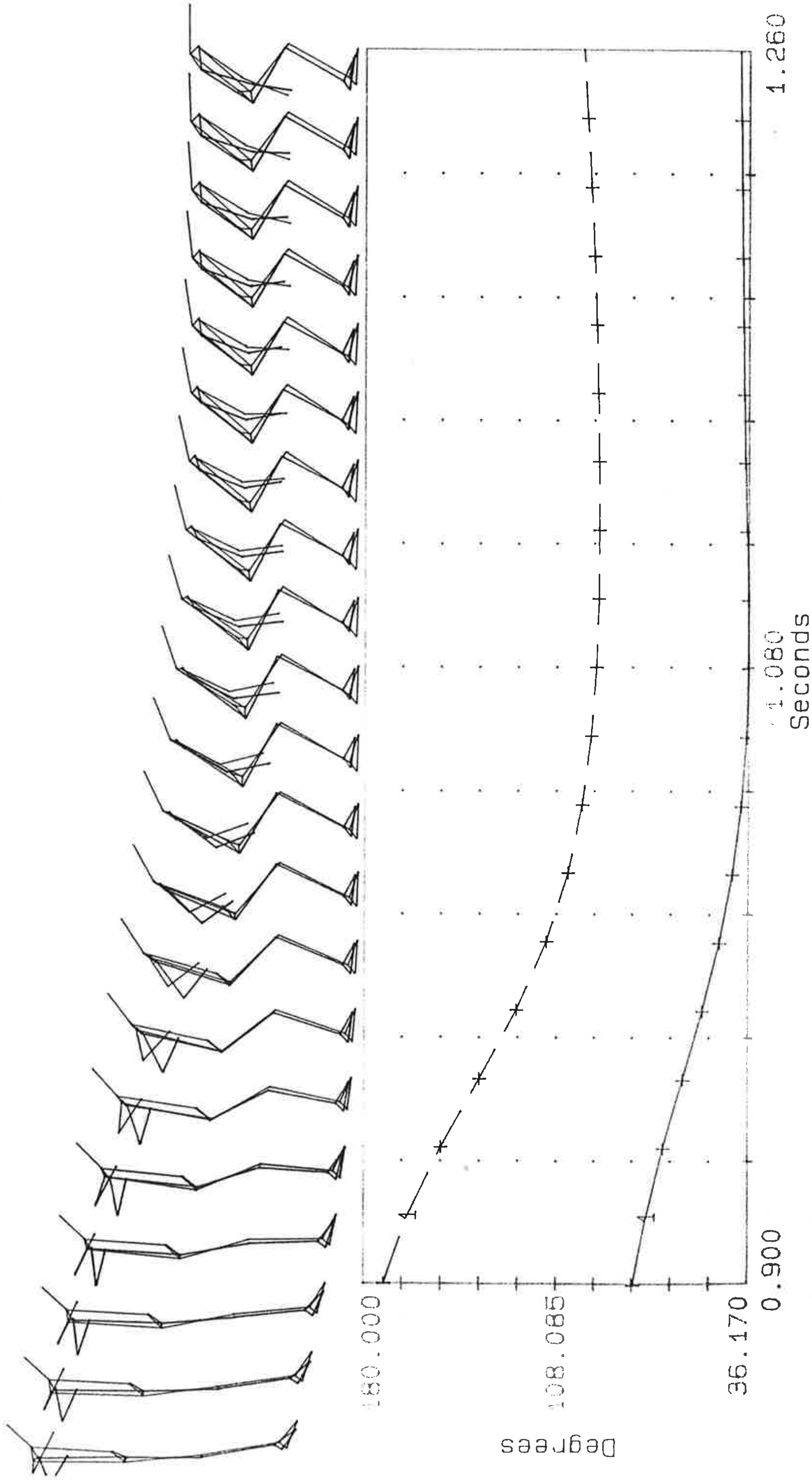
1.869
1.008
0.148
meters
0.000
0.630
1.260
Seconds
3
1
V: Y- Center of Mass
ANNADROP.3TD

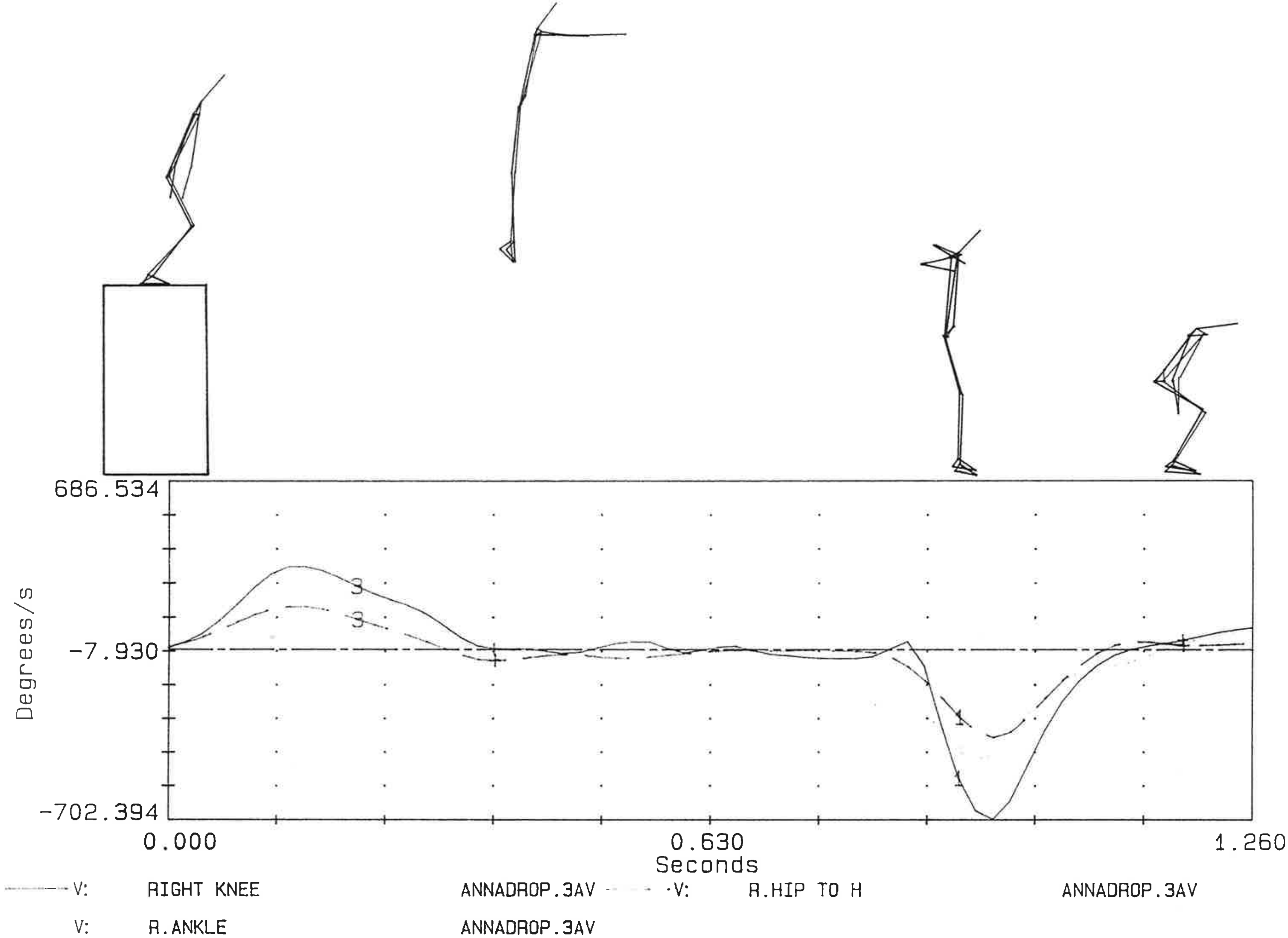

2.310
0.974
-0.361
meters/s
0.000
0.630
1.260
Seconds
1
3
V: X- r.ankle ANNADROP.3LV
V: X- r.knee ANNADROP.3LV
V: X- r.hip ANNADROP.3LV
V: X- Center of Mass ANNADROP.3LV

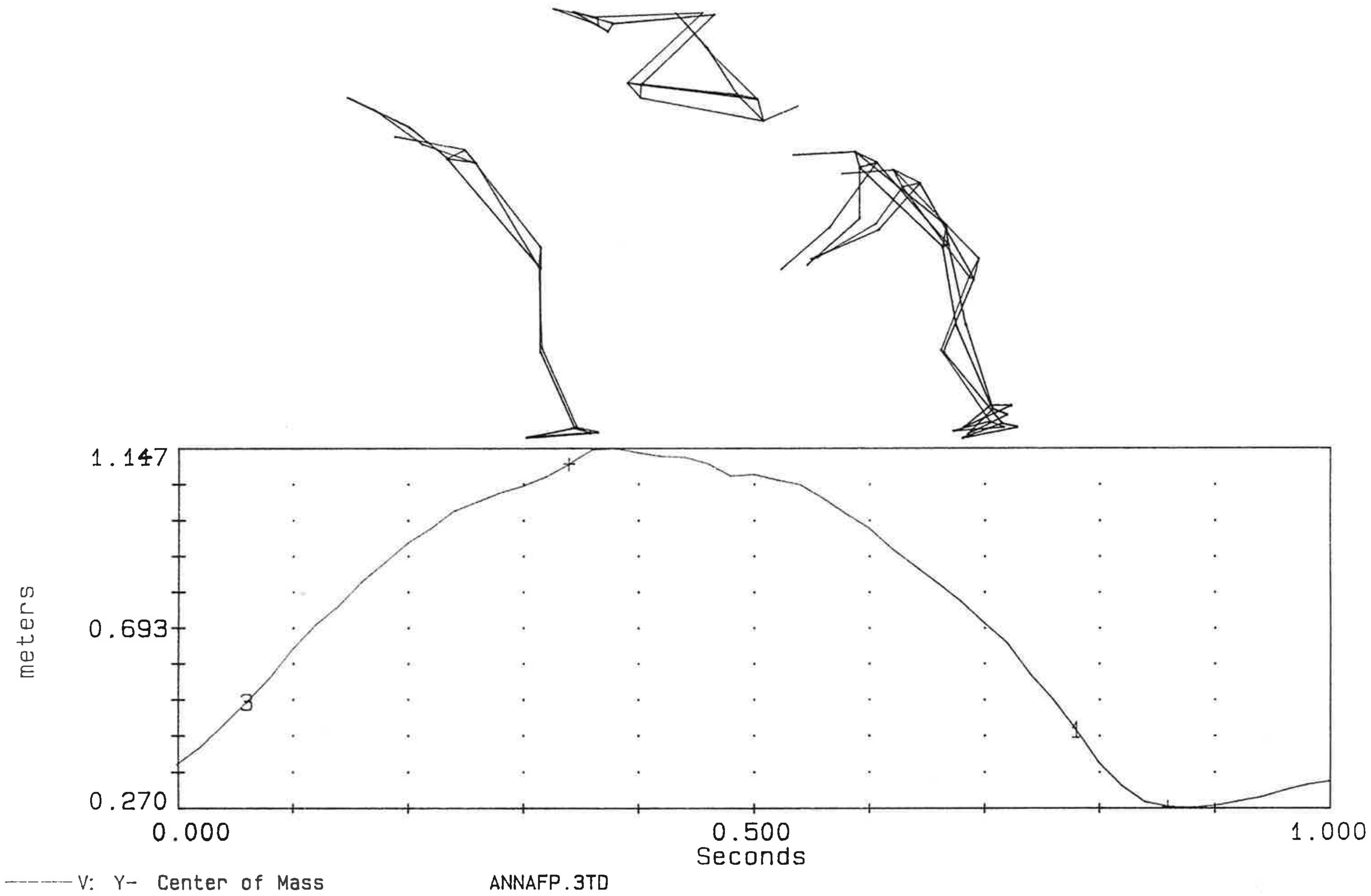



V: X- r.ankle ANNASBSS.3LV
V: X- r.knee ANNASBSS.3LV
V: X- r.hip ANNASBSS.3LV
V: X- Center of Mass ANNASBSS.3LV

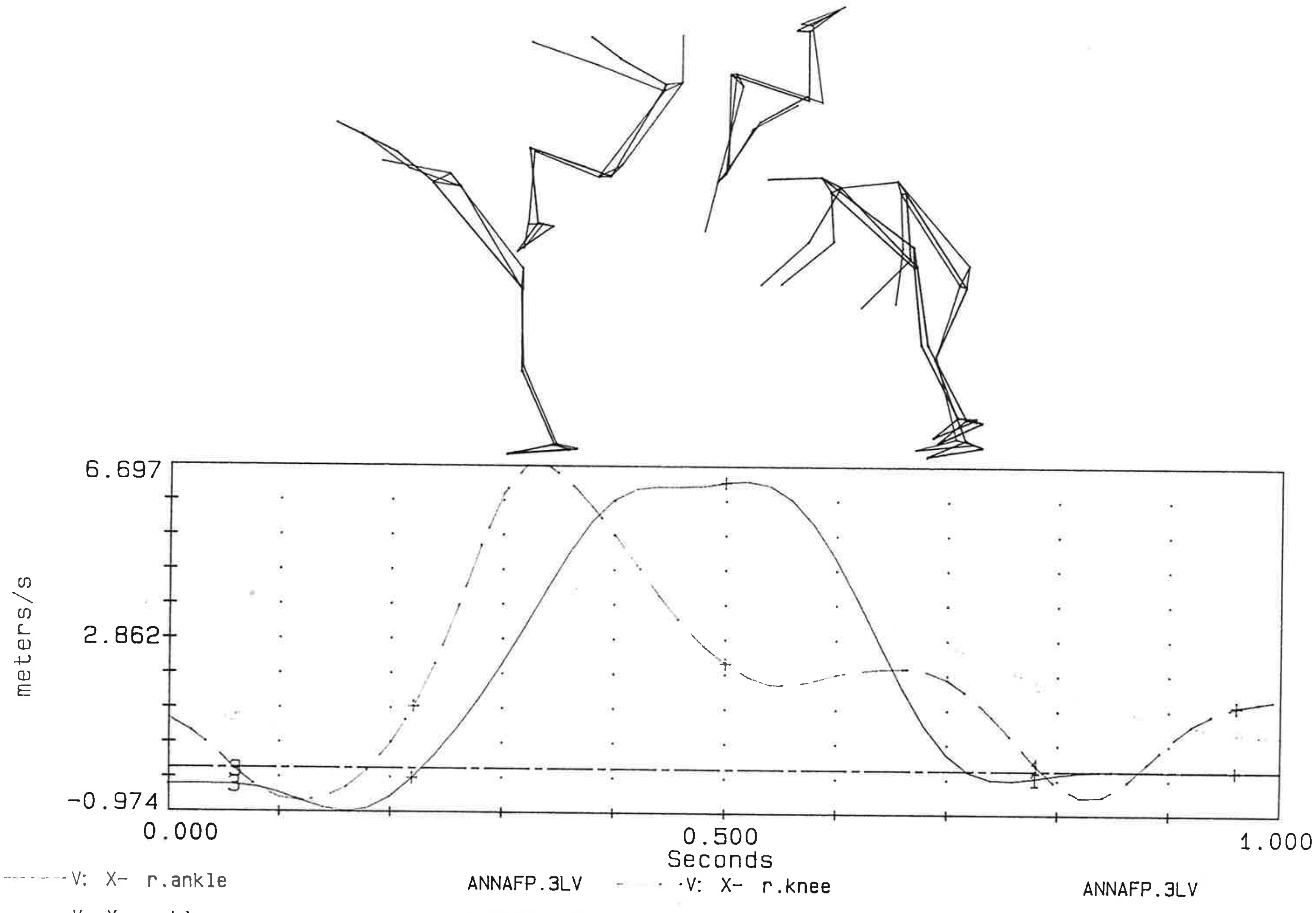

101.583
99.792
98.000
Degrees
0.900
1.080
1.260
Seconds
V: COM TO GC (RIGHT)
ANNADROP.3AD


180.000
108.085
36.170
0
Degrees
0.900
1.080
Seconds
1.260

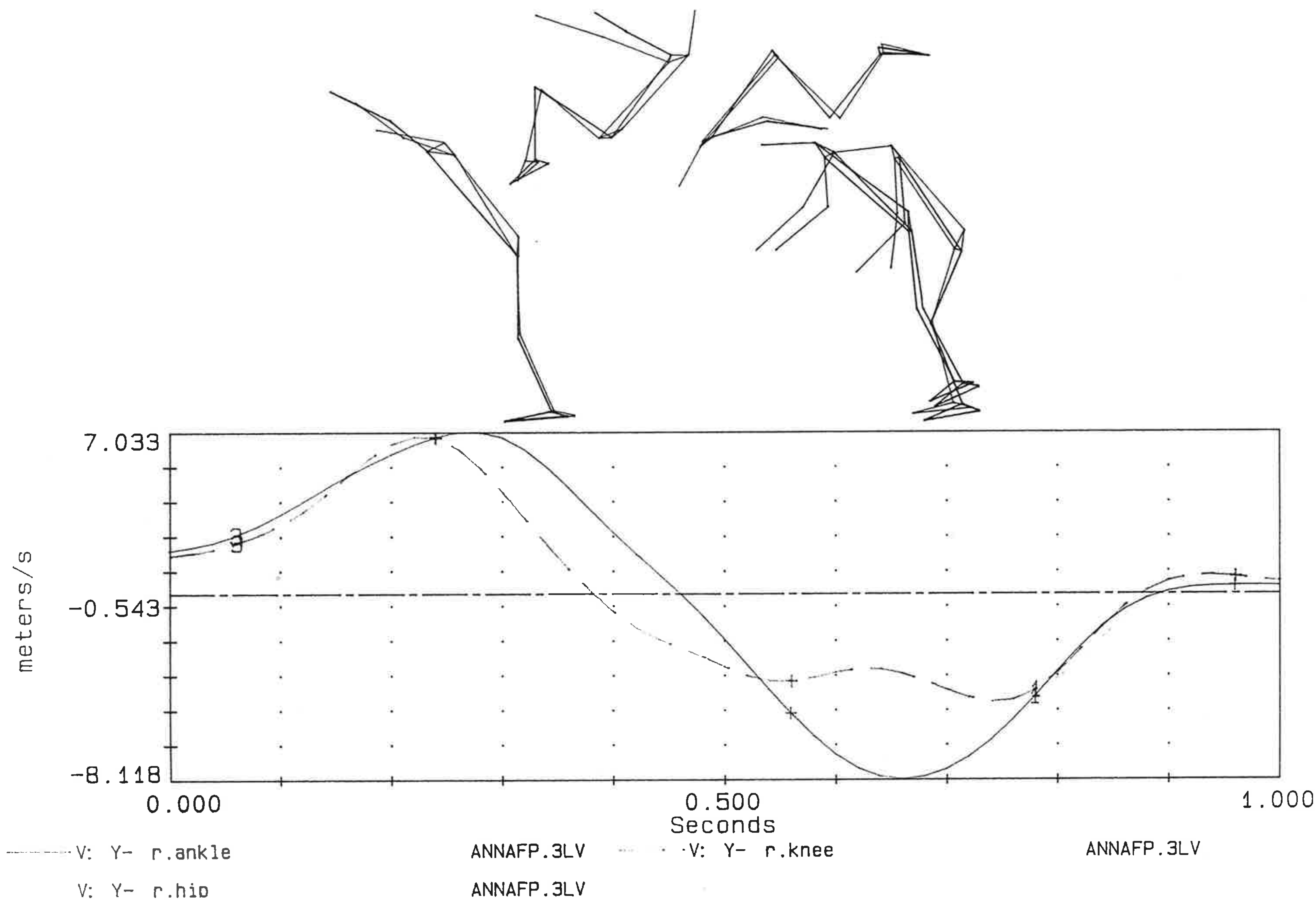

686.534
-7.930
-702.394
Degrees/s
0.000
0.630
1.260
Seconds
V: RIGHT KNEE ANNADROP.3AV
V: R.HIP TO H ANNADROP.3AV
V: R.ANKLE ANNADROP.3AV
3
3

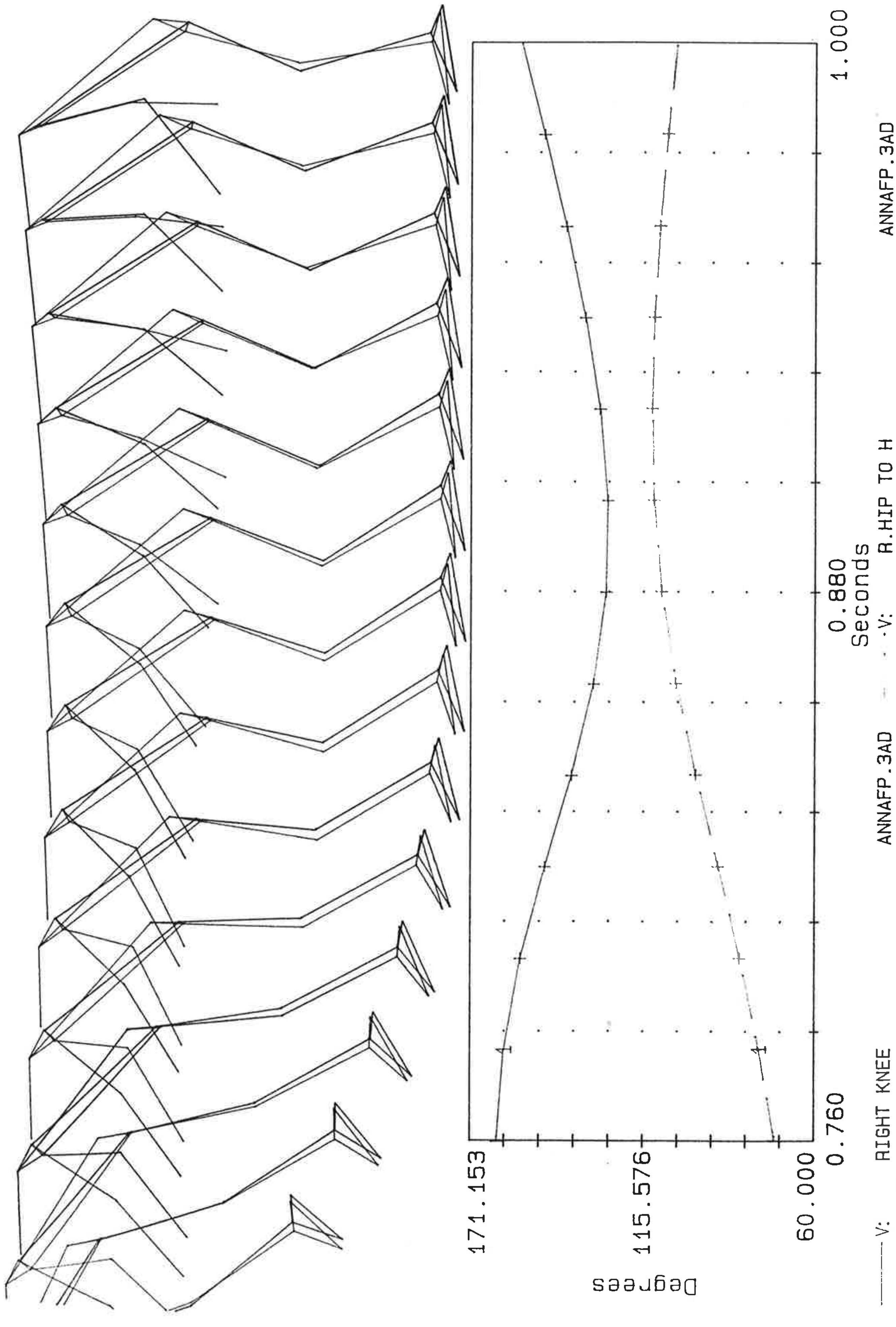


1.147
0.693
0.270
meters
0.000
0.500
1.000
Seconds
3
1
V: Y- Center of Mass
ANNAFP.3TD

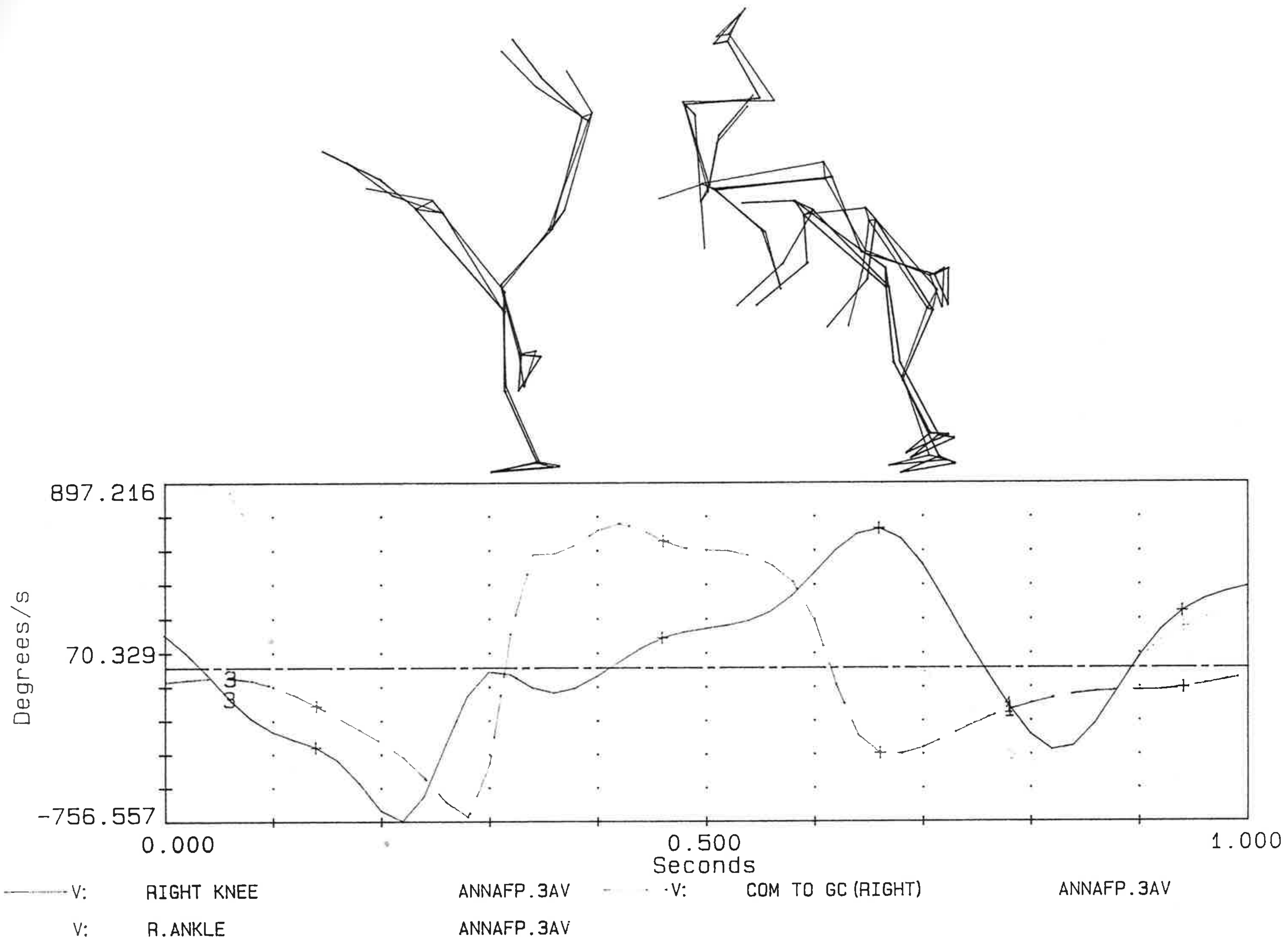


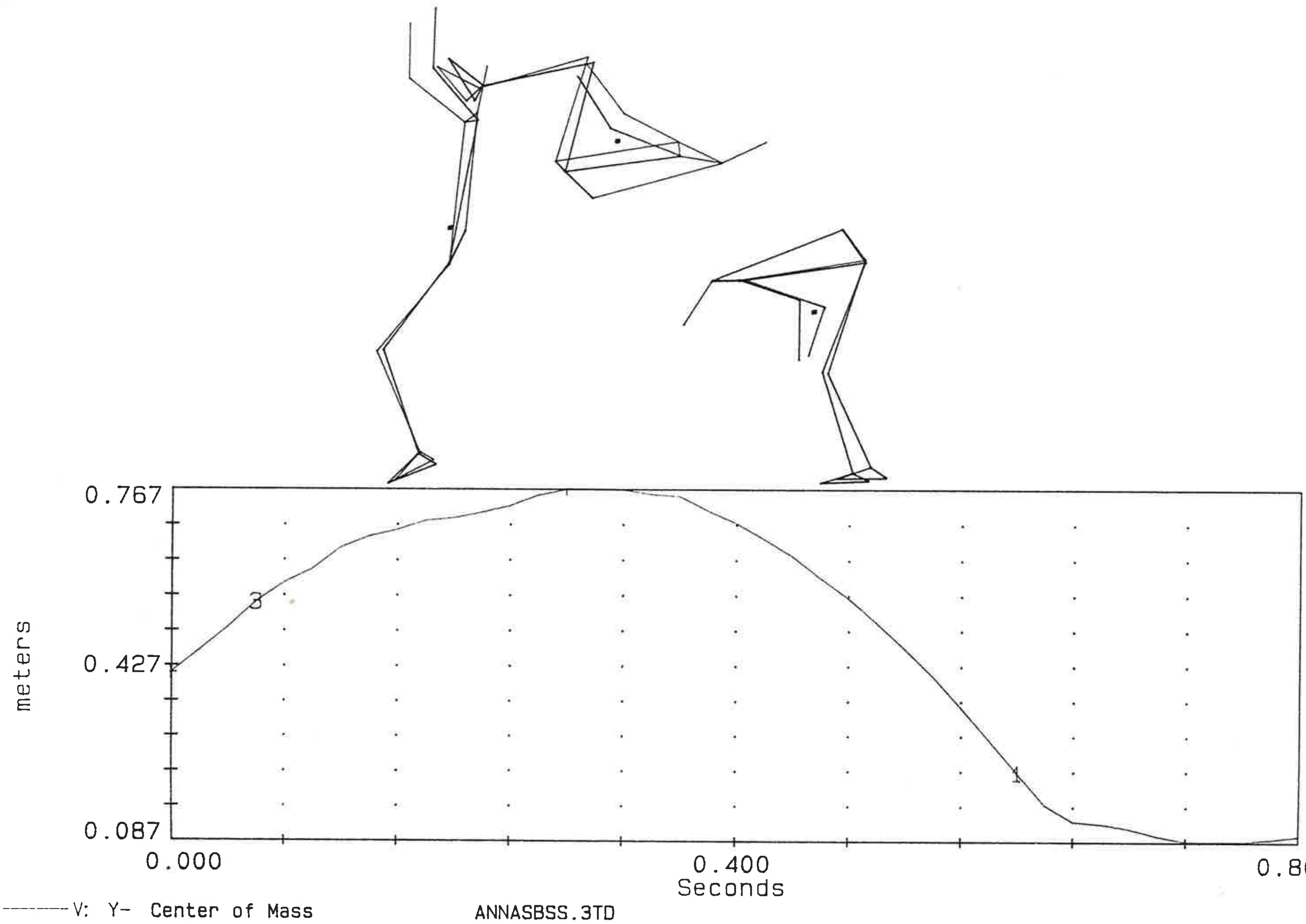
6.697
2.862
-0.974
meters/s
0.000
0.500
1.000
Seconds
V: X- r.ankle
ANNAFP.3LV
V: X- r.knee
ANNAFP.3LV

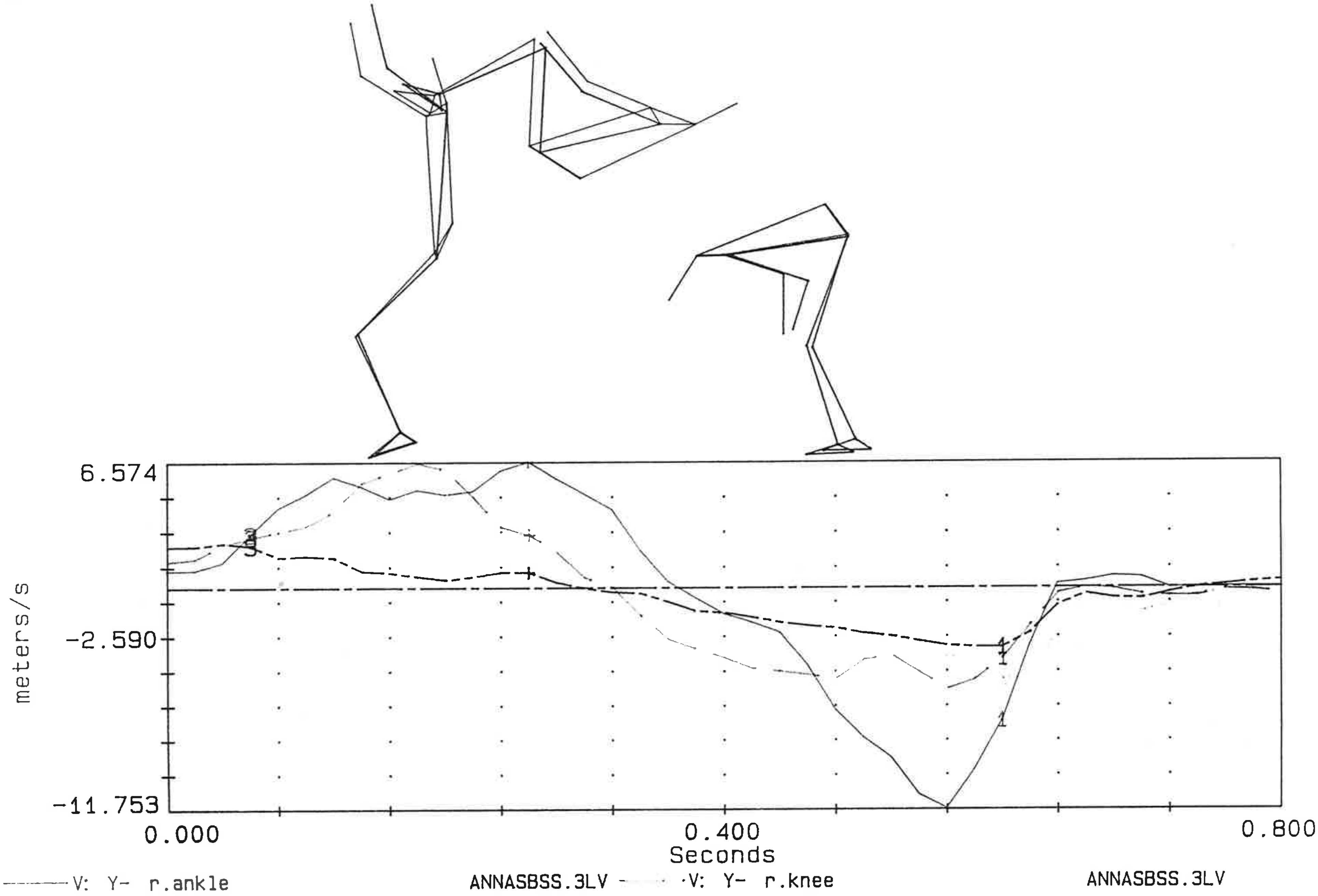

7.033
-0.543
-8.118
meters/s
0.000
0.500
1.000
Seconds
V: Y- r.ankle
ANNAFP.3LV
V: Y- r.knee
ANNAFP.3LV
V: Y- r.hip
ANNAFP.3LV

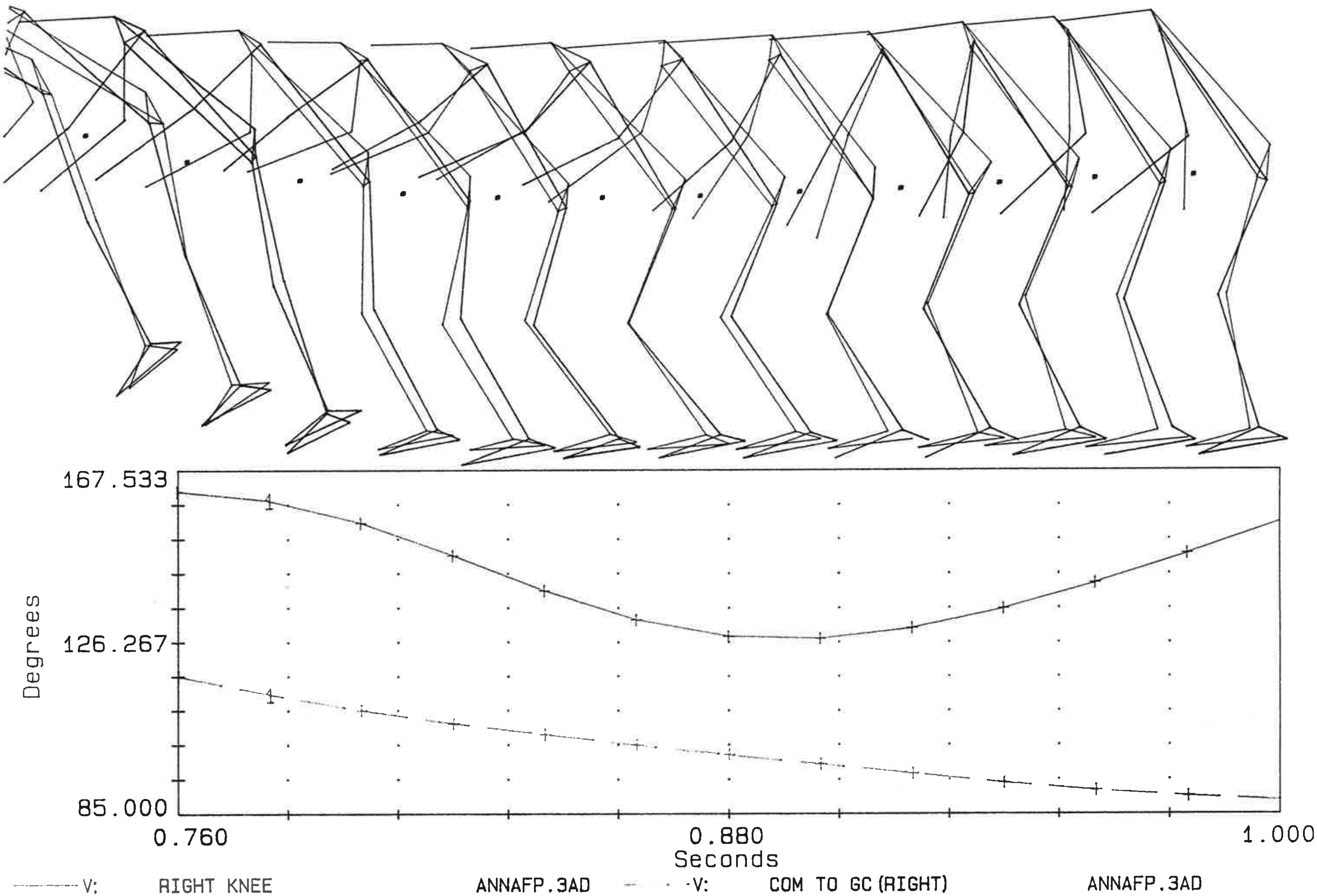


171.153
115.576
60.000
Degrees
0.760
0.880
Seconds
1.000
V: RIGHT KNEE ANNAFP.3AD
V: R.HIP TO H ANNAFP.3AD

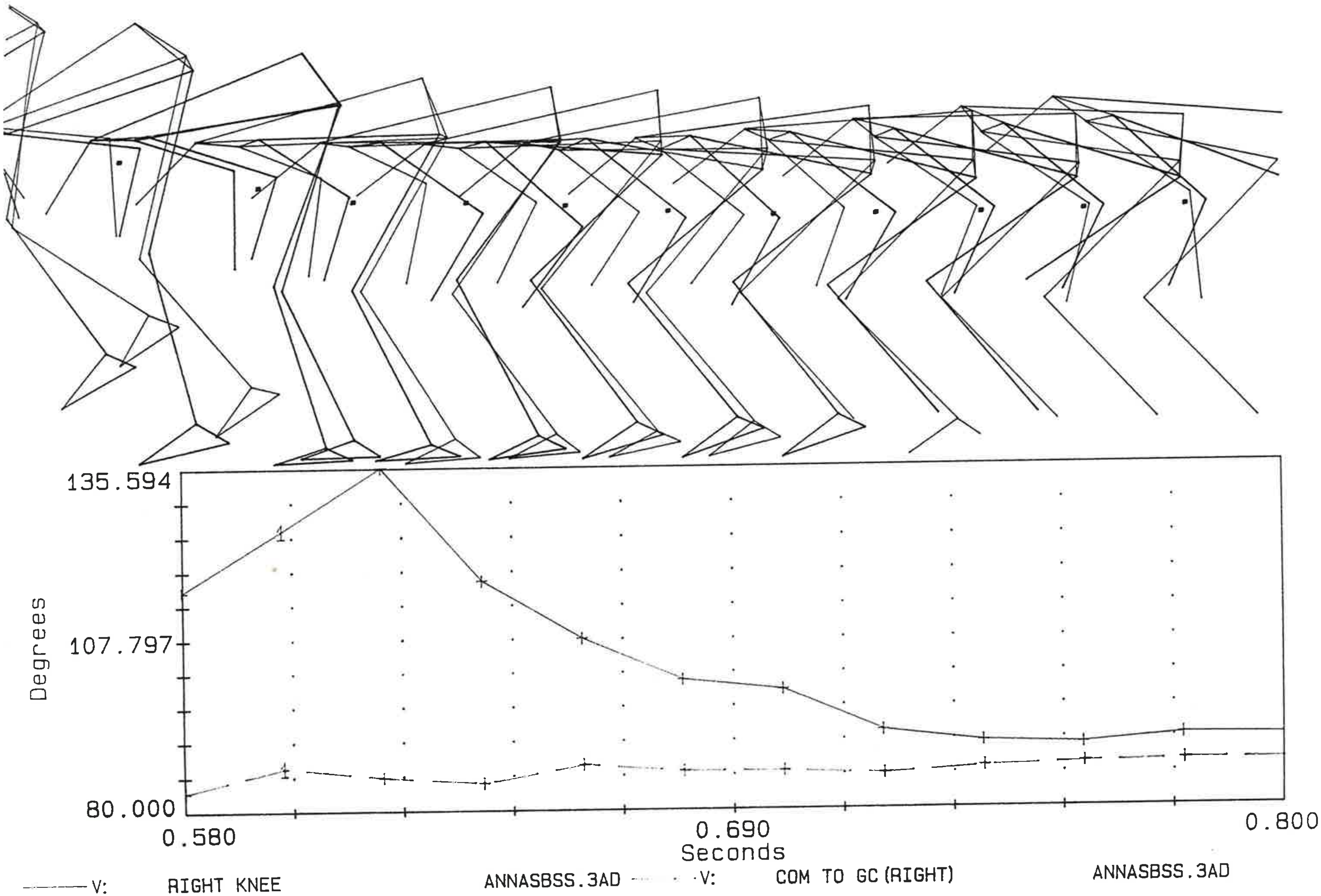

897.216
70.329
-756.557
Degrees/s
0.000
0.500
1.000
Seconds
V: RIGHT KNEE ANNAFP.3AV
V: COM TO GC (RIGHT) ANNAFP.3AV
V: R.ANKLE ANNAFP.3AV


0.767
0.427
0.087
meters
0.000
0.400
0.800
Seconds
3
1
V: Y- Center of Mass
ANNASBSS.3TD


6.574
-2.590
-11.753
meters/s
0.000
0.400
0.800
Seconds
V: Y- r.ankle
ANNASBSS.3LV
V: Y- r.knee
ANNASBSS.3LV



167.533
126.267
85.000
Degrees
0.760
0.880
1.000
Seconds
V: RIGHT KNEE
ANNAFP.3AD
V: COM TO GC (RIGHT)
ANNAFP.3AD


135.594
107.797
80.000
Degrees
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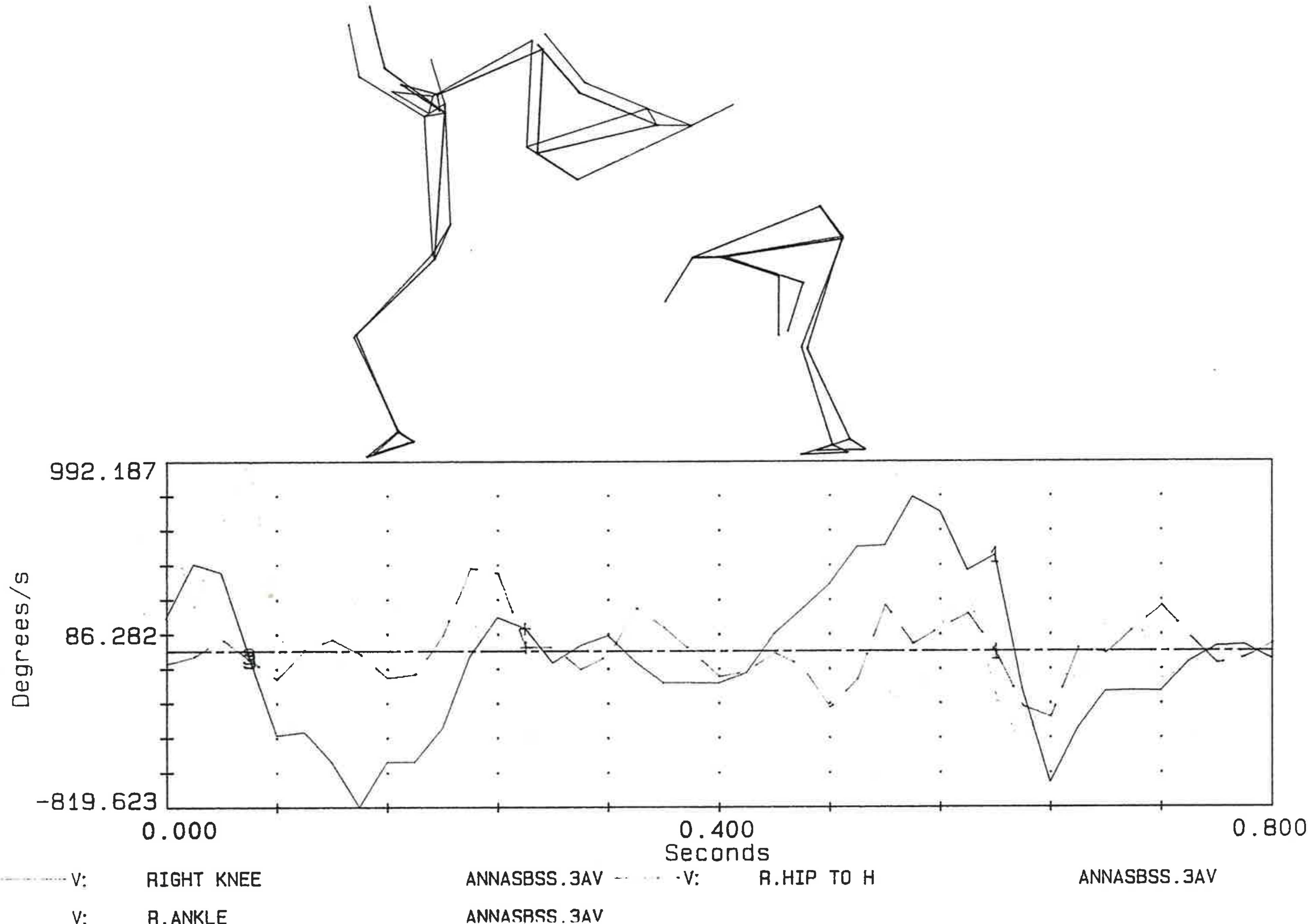
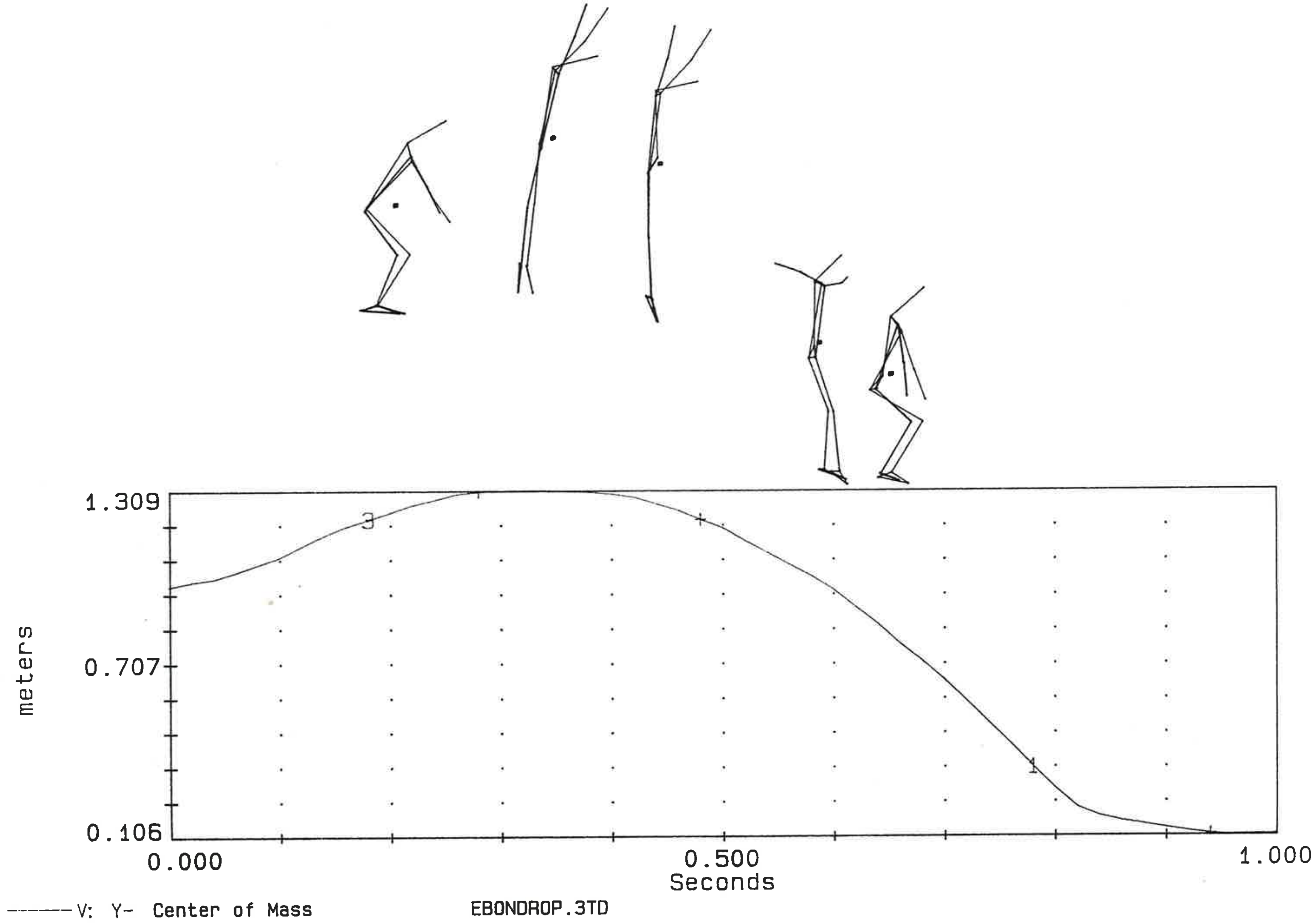
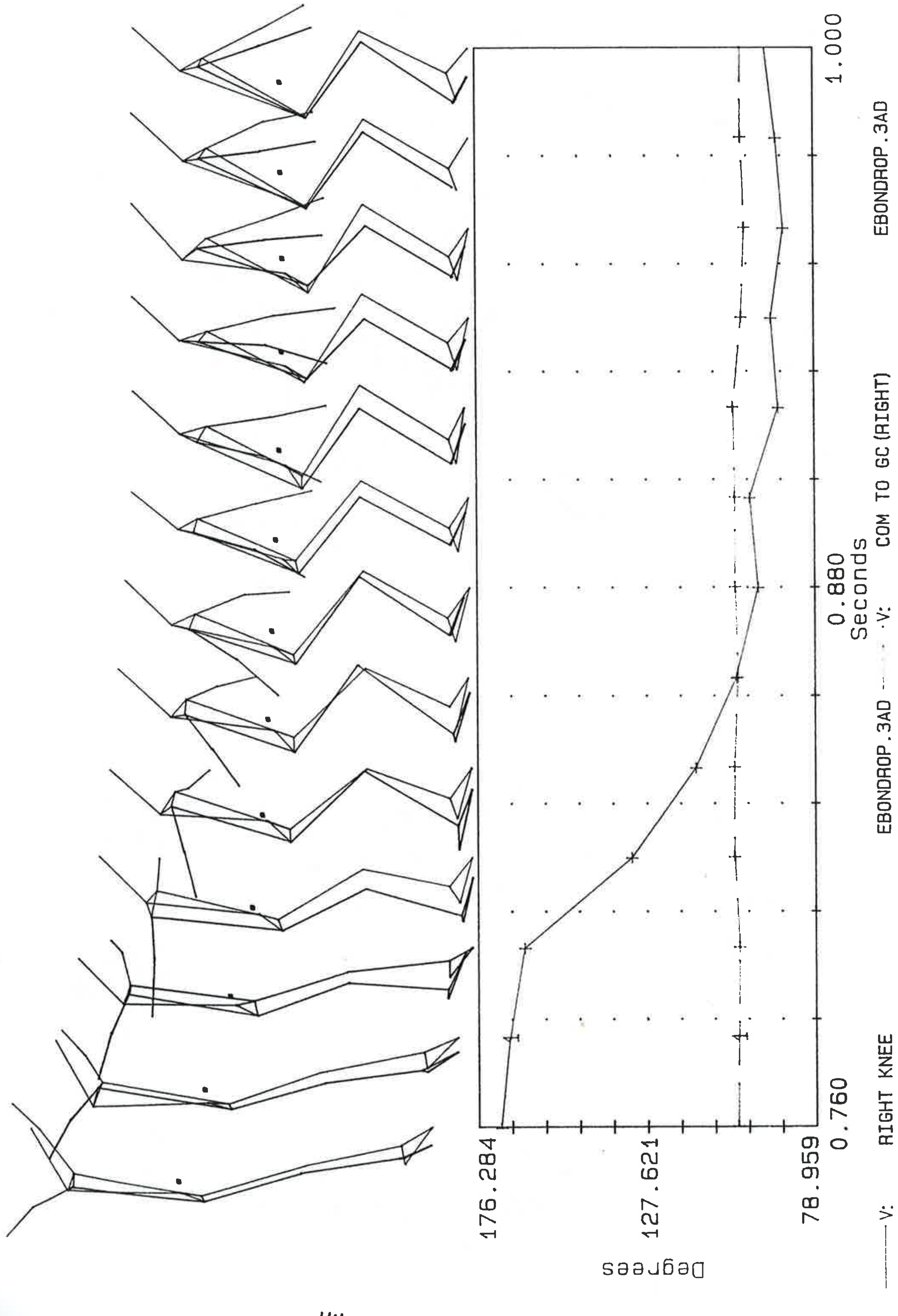
0.690
0.800
Seconds
V: RIGHT KNEE
ANNASBSS.3AD
V: COM TO GC (RIGHT)
ANNASBSS.3AD

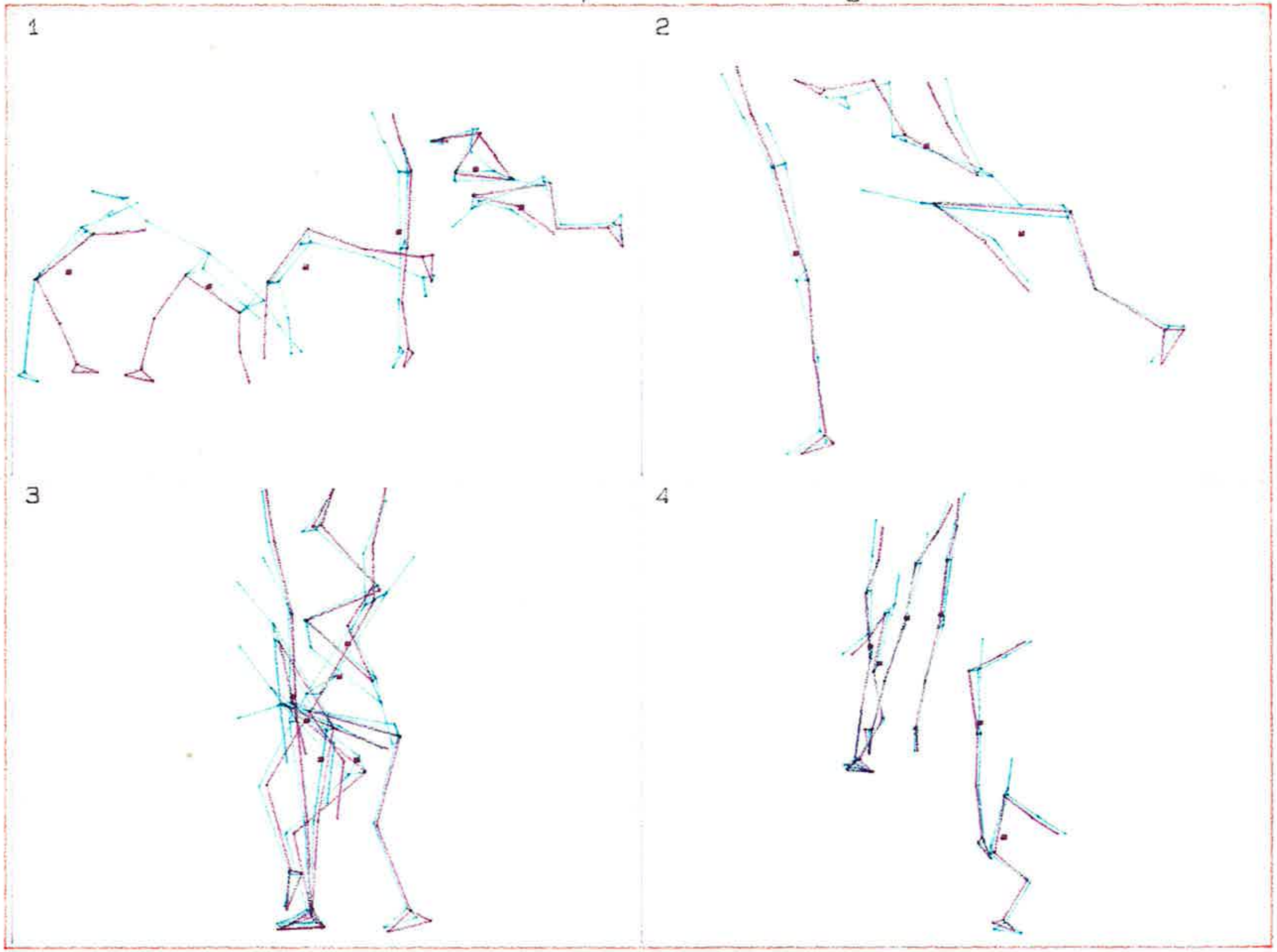


992.187
86.282
-819.623
Degrees/s
0.000
0.400
0.800
Seconds
V: RIGHT KNEE ANNASBSS.3AV
V: R.HIP TO H ANNASBSS.3AV
V: R.ANKLE ANNASBSS.3AV


1.309
0.707
0.106
meters
0.000
0.500
1.000
Seconds
3
1
——— V: Y- Center of Mass
EBONDROP.3TD


176.284
127.621
78.959
Degrees
0.760
0.880
1.000
Seconds
V: RIGHT KNEE EBONDROP.3AD
V: COM TO GC (RIGHT) EBONDROP.3AD

cassie 13.1.94 - force plate landings and take-offs




1 cassie robs toff fp
13.1.94

2 Roff bss land on fp
13.1.94

3 stand back somi
13.1.94

4 jump off block