BIOMECHANICAL PERSPECTIVES OF COMPETITION LANDINGS IN GYMNASTICS

SUBMITTED FOR THE DEGREE

DOCTOR OF PHILOSOPHY

BY

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1998

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FACULTY OF HUMAN DEVELOPMENT

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ABSTRACT

Dismounts from apparatus containing multiple rotations, performed by elite gymnasts during major competitions, require great courage and the highest level of movement precision. They also provide the final impression of a routine providing the key for a successful outcome of its evaluation by the judges. The subsequent landings therefore require the dissipation of substantial body momenta and precision of body control. The purpose of this study was to describe the linear and angular kinematics, the temporal characteristics involved in the execution of landings, the identification of kinematic parameters crucial for controlled and stable landings, and the development of landing profiles. Thirty two male subjects performed under real life conditions, at the highest level of gymnastics competition, the World Gymnastics Championships, were selected as subjects. Correlation coefficients, multiple analysis of variance (MANOVA), analysis of variance (ANOVA), factor analysis with the principle components method, and cluster analysis were performed to test the effects of kinematic parameter contribution on controlled landing techniques of each subject within each subject group, and between subject groups on four events (floor, rings, parallel bars and horizontal bar). Qualitative analysis revealed that gymnasts arrangement of body segments at landing touch-down differed on all events and also within groups. The ANOVA results indicated that there were both similarities and differences in the biomechanical landing parameters of the release, flight and landing phase across the four groups. The results from the factor analysis demonstrated that almost 70% of the total variance was attributed to the first three factors, with more than half of that variation (35.9 %) being associated with the first factor.

The results from the cluster analysis indicated that all landing performances were clustered in three distinct different subgroups of landing strategies. The results from the cluster analysis for variables suggested that the variables formed first in the analysis process are important indicators for successful landing strategies. The results obtained using this cluster procedure showed three cluster formations. It is suggested that the variables from the first cluster formation relating to the landing phase touch-down: center of mass horizontal velocity at touch-down, center of mass height at touch-down, center of mass vertical velocity at touch-down, and the angle trunk to horizontal at touch-down, constitute the most important linear kinematics variables, and the variables from the second cluster formation: ankle joint angle at touch-down, angle center of mass to ground contact and the horizontal at touch-down, angle thigh to horizontal at touch-down, hip joint angle at touch-down, shoulder joint angle at touch down, and the knee joint angle at touch-down, constitute the most important angular kinematic variables. These variables were considered for inclusion to the development of the landing profile shapes (LPS) because of their importance for controlled landings. Because of the differences in the variety and difficulty of dismounts on each event, the individual group results indicated the need for the development of separate landing profile shapes for each of the four events. Thus a landing profile shape, which constitutes a typical or classical posture, was developed for each of the four events. The successful attainment of a controlled competition landing is likely when efforts are made to achieve optimal release conditions, optimal rotational flight requirements, and optimal body segment coordination and timing during the landing phase.

ACKNOWLEDGMENTS

Firstly, I would like to express my appreciation to my Principal Supervisor Associate Professor William E. Morrison for his guidance, encouragement and support.

Secondly, I would also like to express my gratitude to Patrick McLaughlin, and Tim Wrigley, who assisted with the data acquisition and processing, Neil Diamond and Alfred Zomers who provided statistical advice during data processing.

Thirdly, I would like to express my appreciation for the support provided by the Department of Human Movement, Recreation and Performance, and CRESS.

Finally, I dedicate this thesis to my dear and loving wife, Jillian, for her very special encouragement, motivation and support throughout my studies, and to our beautiful boys, Thomas and Jack.

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CHAPTER 1

1.0 INTRODUCTION

The very last part of a gymnastics routine, the landing, makes the difference between winning or losing an Olympic gold medal. In spite of that, landings are still being relatively neglected in gymnastics training and indeed by gymnastic researchers.
The author's special interest in gymnastic landings, coupled with the limited number of biomechanical gymnastic publications on competition landings, provided an impetus for this research. Most of the available literature reports landings in experimental settings. Most landings in experimental settings have used drop landings from various heights and surfaces, which have very little application to competition landings. Experimental landings studies are usually based on pre-selected skills. Competition landings usually occur at the end of a routine, the last part of an exercise performance. The floor exercise is the exception where landings occur frequently. Landings in gymnastics are expected to be controlled, thus enabling the performer to land on a surface safely, without incurring injury. Gymnasts must meet the specific landing performance criteria imposed by the International Gymnastic Federations' (FIG) rules, the code of points (Zschocke, 1995). Brüggemann (1994b) indicates that "landings performed by elite gymnasts during major championships represent one of the most extreme conditions under which the body must respond to large impact forces. The most challenging landings follow difficult three-dimensional rotational skills which are performed at heights in excess of four meters" (p.295). Therefore, the landings following these advanced skills and dismounts occur at relative high velocities and subsequently result in high impact forces. The successful achievement of controlled landings is contingent upon the

extended body position during flight as preparation for the landing. Therefore, the correct technical execution and the biomechanical parameters of the preparatory elements (e.g. the preparatory wind-up giant swing before release on horizontal bar, the forwards upward swing before release on rings and parallel bars, and the round-off or flic-flac before take-off on floor), the release/take-off properties, and flight phase properties (regardless of the complexity of the dismount), before the landing phase, have to be considered in the analysis process. For this study landing performances from a variety of double backward somersaults were selected for analysis.

1.1 Aims of the Study

The aims of this study were to:

(i) describe the linear and angular kinematics, and temporal characteristics involved in the execution of competition landings;

(ii) quantify and identify kinematic parameters crucial for controlled competition landings;

(iii) determine the relative adjustment of identified kinematic parameters' interaction, necessary to achieve controlled landings;

(iv) identify the similarities and differences of landing parameters across four events (floor, rings, parallel bars and horizontal bar);

(v) establish landing profile shapes (LPS) for each group on four events which constitute biomechanically sound principles for controlled competition landings.

1.2 Scope of the Study

The research study was performed in the Department of Human Movement, Recreation and Performance at Victoria University, Footscray Campus, and the Biomechanics Laboratory, City Campus, Melbourne. Data collection was performed at the World Gymnastics Championships, Brisbane, 1994.

Thirty two male gymnasts participating in qualification competitions (for the individual apparatus finals), individual all round competition (competition II), and individual apparatus finals (competition III) on four events (floor, rings, parallel bars and horizontal bar), were selected as subjects. Competition landings were performed from tumbling skills and dismounts representing double backward somersaults executed by different subjects on all four events. Comparisons of selected parameter contributions for controlled landings, were made for each subject within each subject group, and between subject groups on each event. The analysed parameters were presented with respect to absolute time and percentiles. Correlation coefficients, multiple analysis of variance (MANOVA), analysis of variance (ANOVA), factor analysis with the principle components method, and cluster analysis were performed to test the effects on controlled landing techniques of individuals and subject groups on the four events.

1.3 Hypotheses

Research Hypotheses:

1. There are significant differences in landing techniques between the four events (parallel bars, horizontal bar, floor and rings).
2. There are significant differences in landing techniques between the four events due to the differences in horizontal and vertical velocities at impact.
3. There is a relationship between successful landing performances and the release properties.

1.4 Limitations

There are considerable limitations inherent in the collection of videographical data during real life performances, in particular at a World Championship competition. The potential limitations of this study are:

1. The number of subjects was limited by the championships constraints because it was a real life performance (not an experimental setting).
2. Data collection was performed at 25 frames/second thus providing limited information from ankle joint data analysis and calculations during the landing process.
3. The segment and motion analysis are limited by the use of estimates of body segment parameters provided by Dempster (1955).
4. Anatomical landmarks were at times difficult to identify during the digitising

process because of the hidden body parts during multi rotational skills performed by the subjects.

5. The ankle, heel and toe landmarks were difficult to pinpoint during digitising due to the landing surface depression.

1.5 Definition of Terms

The following terms have meaning specific to this study:

Landing Technique: Refers to the method by which the gymnast anticipates the landing impact by selectively activating the muscles to control the body segment motion during the landing phase with the landing surface.

Controlled Landing: Constitutes the selective process of a gymnast reducing all body momenta, from a dismount off apparatus, or from an acrobatic tumbling skill on floor, over time to zero with a single placement of the feet. This process should occur with a visually controlled upright body position, possessing symmetry of the whole body and its segments, performed in a rhythmical and harmonious manner, from landing touch-down to landing minimum. Subsequently, the gymnast position.

Preparatory Skills: Are skills preceding the release phase represented by the round-off should return to a still standing or flic-flac on floor, the forward upward swing in cross support on parallel bars, the forward upward swing from a giant swing on the rings, and the wind-up giant swing on horizontal bar (deterministic model-level 21).

Release/Take-Off Phase: Constitutes the last part of preparatory skills (e. g. round-off or flic-flac touch-down on floor, forward upward swing in cross support on parallel bars, end of giant swing on the rings, or the wind-up giant swing on horizontal bar), which signifies the beginning of the release/take-off phase, up to the last position of contact (last frame contact) with the floor/apparatus (deterministic model-levels 16-20).

Release/Take-Off: Relates to the position of the whole body and to positions of individual body segments at the instant of release/take-off (first frame non-contact) by the fingers from the horizontal bar or rings, hands from the parallel bars (rails), or take-off with the feet from the floor. This position signifies the beginning of the flight phase (deterministic model-levels 14-15).

Flight Phase: Relates to the linear (vertical and horizontal) and angular motion of the whole body during the time of flight (deterministic model-levels 11-15).

***Landing Phase*:** Relates to the temporal and spatial parameters from initial contact (first frame foot contact or touch-down) of the centre of mass (CM) to the CM minimum position during the landing. This point in time is theoretically associated with the time the velocity of the CM becomes zero (deterministic model-levels 4-10).

Landing Score: The landing score represents a qualitative evaluation of a single landing performance by a gymnast during the landing phase, evaluated by two independent internationally accredited judges and one gymnastics expert, by viewing the competition video tapes (deterministic model-levels 1-3).

Judge's Score: The judge's score represents a qualitative evaluation of a whole routine/exercise evaluated by a panel of six internationally qualified judges during the World Gymnastics Championships. The final score represents the mean value of the four middle scores, with the highest and the lowest scores being discarded.

1.6 Acronyms and Abbreviations

judgsco	=	judges score
lansco	=	landing score
cm	=	centre of mass
mcmhf	=	maximum centre of mass height during flight
cmht/d	=	centre of mass height at touch-down
cmhm	=	centre of mass height minimum
lpdispl	=	landing phase displacement
cmhr	=	centre of mass height at release
cmhdrt/d	=	cm horizontal displacement from release to touch-down
ftrt/d	=	flight time from release to touch-down
cmdt/dm	=	cm duration from touch-down to minimum
cmvvt/d	=	cm vertical velocity at touch-down
cmvvr	=	cm vertical velocity at release
cmhvt/d	=	cm horizontal velocity at touch-down
cmhvm/lt/d	=	cm horizontal velocity sidewards at touch-down
cmhvr	=	cm horizontal velocity at release
cmhvm/lr	=	cm horizontal velocity sidewards at release
acmght/d	=	angle: cm to ground contact and the horizontal at touch-down
aat/d	=	ankle joint angle at touch-down
aam	=	ankle joint angle minimum
akt/d	=	knee joint angle at touch-down
akm	=	knee joint angle minimum
aht/d	=	hip joint angle at touch-down

ahm	=	hip joint angle minimum
atht/d	=	trunk angle to the horizontal at touch-down
athm	=	trunk angle to the horizontal minimum
athht/d	=	thigh angle to the horizontal at touch-down
athhm	=	thigh angle to the horizontal minimum
aatt/d	=	arm-trunk (shoulder) joint angle at touch-down
aatm	=	arm-trunk (shoulder) joint angle minimum
avht/d	=	hip joint angular velocity at touch-down
avkt/d	=	knee joint angular velocity at touch-down
avat/d	=	ankle joint angular velocity at touch-down
t/d	=	touch-down
t/o	=	take-off
ESU	=	Event Synchronisation Unit
LPS	=	Landing Profile Shape
2-D	=	Two-Dimensional
3-D	=	Three-Dimensional
g	=	acceleration due to gravity: 9.81 ms^{-2}
r	=	Pearsons' product moment correlation coefficient
SD	=	Standard Deviation
ES	=	Effect Size

CHAPTER 2

2.0 LITERATURE REVIEW

The most important and crucial part of a gymnastics routine is the dismount, since it provides the final impression for its evaluation to the judges, and also signifies the termination of the exercise. Biomechanical literature on landings in gymnastics, in particular competition landings, is sparse. Previous research on gymnastics landing techniques have mainly been limited to two dimensional analysis without rotation (McNitt-Gray, 1989, 1991, 1993a) and (McNitt-Gray et al., 1993b, 1994), or with rotation (Panzer, 1987) all in an experimental setting. There are few landing studies reported having data collected during an actual competition setting. The only study of note addressing competitive gymnastics landings was performed by Takei et al. (1992), who investigated techniques used by elite gymnasts performing the 1992 Olympic compulsory dismount from the horizontal bar.

The literature review is separated into five sections. Section one provides an overview of landings, and section two to five covers the four events (floor, rings, parallel bars and horizontal bar) under investigation.

2.1 Overview of Landings

The code of points for artistic gymnastics for men (Zschocke, 1993) which stipulates the performance criteria to which gymnasts are obligated to adhere states, that "all dismounts from the apparatus, on floor exercise and vault must end in a standing position with the legs together" (Zschocke, 1993, p.24). The code of points also states that if the difficulty of the dismount does not correspond with the difficulty of the exercise, there will be a 0.2 deduction (medium error).

In landings, the primary factors affecting the motion and balance of the body are gravity, inertia, and momentum. Schembri (1983) states that landing can be interpreted as a controlled arrest of the body's descent and that technique and physical preparation are required for controlled landings. The above author also suggests that landings should be taught at a young age, and also, improper landing technique is a potential source for injury and judging deductions for competition gymnasts. Cheales (1997) suggested that "a controlled landing is characterised by the smooth transition from the dynamic flight phase of the dismount, to a motionless standing position, which signifies the termination of the exercise" (p. 1). He further states, that from a judges point of view, "a controlled landing is represented by the fact that there are no deductions. This includes stepping after contact, posture imperfections, and poor form including excessive leaning, legs apart, bent arms, etc" (p. 1).

Rolland (1987) suggests that balance is one of the key factors in controlled gymnastics landings and that in order to achieve a state of balance, the body must exert enough resistance to counter the tendency of these forces to throw it out of balance.

The only literature of note on gymnastics landings to date was by Brüggemann (1987, 1990,1993, 1994a), Takei et al. (1992), McNitt-Gray (1989, 1991, 1993a), McNitt-Gray et al. (1993b, 1994), Panzer (1987), and Nigg (1985a).

Brüggemann (1994a) indicates, that in landings, mechanical power and energy is spent first for acceleration and deceleration of body segments, and secondly, to overcome gravity, inertia, and momentum.

During competition, gymnasts must comply with specific performance guidelines that require them to bring the momenta of the body over time to zero, with a single placement of the feet" (Brüggemann, 1994a, p.109; McNitt-Gray, 1989, p.13). Also, "gymnasts must land safely in order to prevent injury. Sometimes these requirements are in conflict with each other, especially for landings with considerable horizontal and vertical velocities, and linear and angular momentum"(Brüggemann, 1994a, p.110). Landings performed at major competitions represent extreme conditions under which the body must provide adequate force absorption. Previous research on landing techniques have indicated that larger impact forces result when performing the more rigid competition style landings as compared to techniques which permit full joint flexion or a roll following feet placement (Nigg, 1985b). Gymnasts must also meet the specific landing performance requirements imposed by the rules of the sport. The current International Gymnastic Federations (FIG) Code of Points (Zschocke, 1993) is the official judges manual for the evaluation of gymnast's performances which requires, that the difficulty of dismounts performed from all apparatus be representative of the general difficulty demonstrated throughout the routine. It also specifies landing errors on each of the events. Any extra hops, steps or unnecessary segment motions during landings are met with specific deductions.

Hunter and Torgan (1983) indicated that dismounts should not be evaluated for the purpose of difficulty but rather for accuracy and that "dismount techniques and scoring should be reevaluated (p. 209). Their view was expressed due the number of injuries incurred on gymnasts lower extremities during the landing phase. This suggestion however appears to be unacceptable to the author, who has international experience as a former competitor, coach and judge at world gymnastic championships, because gymnasts should be physically and mentally better prepared before they attempt dismounts which require an advanced skill level.

The need to reduce impact forces as a means for reducing injuries and improving landing performance has stimulated interest in quantifying the mechanical characteristics of landing surfaces (Clarke et al., 1983; Denoth & Nigg, 1981; Valiant et al., 1987). Results from these studies indicated that the thickness and the deformation properties influence the degree and rate at which the surface becomes fully compressed. Human interaction with the landing surface compared to inanimate objects used in drop tests is very different. Albersmeyer et al. (1987) reported that landing forces were reduced by placing a landing mat over the force platform when landing from a specified height. These results were duplicated by the author in a study performed in the Biomechanics Laboratory at VUT's City Campus (Geiblinger and Chiu, 1994), and from a pilot study performed previously by the author in the Biomechanics Laboratory at the Footscray Campus.

Gymnasts make a judgement through visual information about the speed at landing and the landing surface, and subsequently respond by adjusting the activation level of the muscles to an appropriate level of muscle tension. This is substantiated by investigations performed by Schmidtbleicher et al. (1981) and Melville-Jones et al. (1971) on EMG activity prior to landing impact which have demonstrated that muscles undergoing active lengthening after contact activate prior to contact. Ayalon and Ben-Sira (1987) reported that through repetitive landing skill practice and from the feedback provided during training, the segmental motion governed by the control strategies can be modified. Previous research (McNitt-Gray, 1989) has involved 2-D analysis which is due to equipment limitations, but it is apparent that movement patterns occur in all three planes. The assumption that landings are of two-dimensional nature when symmetry is maintained (McNitt-Gray, 1989) cannot be justified because of previous research activities. All landings are of three-dimensional nature regardless of the difficulty and complexity of previous skills preceding them. This is accentuated in landings with longitudinal rotations from flight, so-called twisting dismounts. Twisting dismounts will mostly produce asymmetric and subsequently, uncontrolled landings, thus create large forces on one of the lower extremities coupled with the body's inability to control the segmental geometry. Panzer (1987) reported vertical impact peaks of the magnitude from 14-18 BW during landings from double backward somersaults, and during asymmetric landings after double backward somersaults, the vertical reaction force on one leg reached magnitudes ranging from 8.8-14.4 BW.

For dismount skill acquisition, many dismounts can be performed in foam pits or on soft landing mats in one training session. However, controlled landings, the final part (landing phase) of the dismount, need to be practised specifically in order to acquire the skills necessary to control the landings. Factors such as anticipation, balance, coordination, orientation, quickness, power, symmetry, all are integral components of the landing process.

2.2 Floor Landings

According to the FIG code of points (Zschocke, 1993) the duration of a floor exercise should be between 50-70 seconds. The section for the "evaluation of the competition exercise", under the "classification of errors in exercise presentation", states, that for the type of error "loss of balance during landing of dismounts, and also in floor exercise for respective elements", must end in the basic stand. The landing performance criteria which are imposed on the gymnasts state that deductions are made accordingly for: "small error 0.1 deduction; slight unsteadiness in standing position or steps or hops. 0.1 per step (max. 0.4); medium error 0.2 deduction; touching floor with hands (or with one hand), incorrect body position (form), and large error 0.4 deduction; falling onto seat (deduction 0.5 points), pronounced support on floor with arms" (Zschocke, 1993, p.28). Brüggemann (1990) suggested that "the goal of landings in gymnastics is to absorb the kinetic energy after the flight while minimising the load on bones, ligaments and tendons. It is important that landings are practiced on different surfaces, therefore the gymnast must learn to adapt and train the tension of the leg extensor muscles to the specific landing situation. These situations are environment (surface) and skill (performance) dependent" (p.27). The relative contributions of the body segments, soft tissue and bones, vary depending on localised fatigue, task constraints, or fitness of the muscles responsible for the eccentric muscle action controlling the joint flexion. (McNitt-Gray, 1993a).

Adrian and Cooper (1989) state that when a body falls, its vertical force, kinetic energy, and momentum are directly related to the distance through which it falls, due to the exponential effect of gravity.

Laws (1984) suggests that a landing from a jump would have to be made with the centre of gravity behind the landing foot. The performer "must rid himself of all his linear momentum by leaning back so that his centre of gravity is to the rear of the support, allowing the floor to exert a retarding force to slow the forward motion against the body in order to allow the body to coast to a stop in a stable position" (p.31). Greater ability to accommodate unexpected events and distribute loads between musculo-skeletal structures may be of great importance when gymnasts repeatedly perform relatively difficult skills at high velocities. For example, an intermediate gymnast may have difficulty in generating the angular momentum and the vertical velocity necessary to consistently land a double back somersault. In order to initiate contact with the feet rather than the head or hands, the gymnast may need to flex the hips before contact.

In landings after somersaults on the floor, considerable reaction forces and segmental accelerations occur. Nigg and Spirig (1976) recorded tibia accelerations of more than 25g at landing after a simulated dismount from a height of 1.5m. Alp and Brüggemann (1993) measured the pressure distribution and the acceleration of the foot and shank during landing after gymnastic dismounts. Maximum foot and tibia peak acceleration was registered at approximately 40g. McNitt-Gray (1993a) examined the reaction forces at the mat/floor interface. Concerning landings after drop jumps from different heights, the above author found maximum peak forces ranging from 3.9 to 11 BW. Significant differences, $p < 0.05$, were reported in peak vertical force, time to peak vertical force, landing phase time, and lower extremity kinematics across different drop heights (McNitt-Gray, 1991; McNitt-Gray et al., 1993b). There were no significant differences to vertical impact peak between soft and stiff mats. On the other hand, lower extremity kinematics showed significant difference between mats with varying composition. These results indicate that changes in drop height and mat composition may lead to changes in landing strategies for female gymnasts. Nigg and Spirig's (1976) data and the recent findings of Alp and Brüggemann (1993) acknowledge the influence of mat composition on the loading of the body during landing.

2.3 Rings Landings

Rings dismounts are classified as movements with "rotations in the vertical plane with flexible horizontal axes of rotation" (Brüggemann, 1989, p.62). The aim of the movements in this category is the optimum production and transfer of mechanical energy. Dismounts are initiated by generating rotational kinetic energy during the downswing phase from a momentary handstand position. Thus the angular velocity of the body in the sagittal plane is maximised simultaneously with the maximisation of the moment of inertia relative to the body's centre of gravity. The main emphasis here is to generate high vertical velocity simultaneously with high angular momentum about the transverse axis. In the upward swing, before the hand release on the rings, a reduction in the moment of inertia relative to the altered position of the transverse axis, from accelerated and muscle controlled flexion at the hip and shoulder joints, through the CM occurs, thus producing an increase of rotation for the following dismount. With flexible axes of rotation, no rotation can appear about an external axis (Brüggemann, 1989). Brüggemann, (1989) suggests that "the analysis of the joint angle movements may provide insights into the mechanism for increasing rotation. If high angular momentum about the transverse axis is required then an increase in rotation generated through a rapid hip flexion does not appear to suffice for the angular momentum required" (p.70). The powerful closing of the arm-trunk angle is the most important technical component for increasing rotation in preparation for the dismount. Nissinen (1983) reported dynamometric and kinematic data of more than 60 backward and forward giant swings of an "up-to-date technique and found considerably higher reaction forces (6.5 to 9.2 BW) than ever recorded before" (p.783).

In the scientific report of the world championships in artistic gymnastics, Brüggemann (1989) presented four case studies of different rings dismounts. The dismounts analysed included: Tsukahara stretched (Belenky), Tsukahara tucked (Aquilar), double salto stretched (Chechi), and triple salto (Boda). Table 2.3.1 shows the vertical velocities of the CM at the moment of release which directly determine the elevation achieved during the flight.

Table 2.3.1 Vertical velocity of CM at release for various dismounts (Brüggemann, 1989)

Belenky	Tsukahara stretched	4.3 m/s
Aquilar	Tsukahara tucked	3.8 m/s
Chechi	Double salto stretched	4.6 m/s
Boda	Triple salto	4.0 m/s

Brüggemann stresses the fact that during the interpretation of the data it should not be forgotten that the absolute height is the direct sum of the flight elevation (which is determined by the vertical release velocity) and the height at the moment of release. The greatest absolute height was attained by Boda with his triple salto because for this skill the grip is held much longer than, for example, the stretched double salto. It can be determined that the absolute height of a triple salto is distinctly higher than for stretched double saltos because of the greater release height. However, compared with the triple salto, the stretched double saltos have greater velocity and angular momentum at the moment of release. If a high angular momentum about the transverse axis is required for a dismount (stretched double salto, Tsukahara stretched) then the increase in rotation generated by a rapid hip flexion does not appear to suffice for the angular momentum required. The powerful closing of the arm-trunk angle is an important technical component for increasing rotation. Dismounts which have great requirements for height and less for angular momentum (triple salto) are best facilitated by a rapid and early hip flexion.

Ludwig (1993) reports that for the production of a high angular momentum during the downward swing (before dismounts), the time of acceleration is more important than the forces respectively to the angular impulse. For the dismounts the maximum relative angular velocity of the trunk is higher than for the giant swings. These parameter considerations influence the outcome of the successful performance of the dismount and hence the subsequent landing.

2.4 Parallel Bars Landings

Dismounts on parallel bars are classified as movements with rotation in the vertical plane with fixed horizontal axes of rotation. The force of gravity acts in the plane of movement which during down swings is the main generator of the kinetic energy needed for the subsequent dismounts. In addition to the biomechanically necessary generation of maximum energy during the downswing, energy is also generated through internal forces (muscular forces). These together provide the energy transfer for successful dismounts. The biomechanical systems which a gymnast can use to generate or increase energy, are essentially those muscle groups which flex and extend the hip and shoulder joints in the sagittal plane. The piked back and double back salto dismount ideally characterises the possibilities for increasing energy during support swings.Few published articles deal with parallel bars dismounts. Brüggemann (1989) presented a number of case studies including salto and double salto backward piked dismounts, in the scientific report of the World Championships in artistic gymnastics, Stuttgart 1987. Fewer studies still, report on the biomechanical landing characteristics and technique of dismounts. Liu, et al. (1992) attempted to identify critical variables which can be used to improve stability in landings of tucked and piked double back somersault dismounts. It was concluded that stable landing performance was characterised by a mean landing CM angle of 67° and there were no significant differences between the means of the kinematic parameters investigated when comparing double tuck and double pike somersault dismounts. Prassas (1995) analysed the 1992 compulsory dismount (backward somersault from a handstand position with the body in a layout-piked-layout position) on the parallel bars from 18 subjects. The main purpose of this study "was to identify the differences in technique between the most and least skilful dismounts" (Prassas, 1995, p.160).

Brüggemann (1989) selected the technically optimal performed somersault backwards piked compulsory dismount, performed by Artemov (URS), for analysis. Artemov attained a height of 1.05m above the upper edge of the rails during the dismount, which was the highest of the analysed compulsory dismounts. This resulted in a maximum CM height during the dismount of 2.80m. For the double salto backwards piked the values for the maximum CM height above the bar for Li Jing was 0.83m and that for Artemov was 0.91m.

2.5 Horizontal Bar Landings

Dismounts on horizontal bar are classified as movements with rotation in the vertical plane about a fixed horizontal axis. Dismounts from the horizontal bar require the dissipation of substantial velocities and therefore large forces. Gervais (1993) and Alp and Brüggemann (1993) reported a maximum force of 7 BW for the giant swing prior to release. The maximum heights from dismounts were recorded at 4m or more. Kerwin et al. (1990) reported a release height for double somersault dismounts of 2.39 ± 0.24m, and for triple somersault dismounts 2.62 ± 0.13m. The bar height was 2.55m above the landing surface. The maximum height for double somersault dismounts ranged from 3.45 to 3.73m, with a mean value of 3.63 ± 0.13m, and for triple somersault dismounts 3.89 to 4.08m, with a mean value of 3.99 ± 0.08m. The mean flight time for double back somersaults was 1.26 ± 0.02 sec., and for triple back somersaults 1.32 ± 0.04 sec. They stated further, that a double back layout dismount requires a higher angular momentum (1.53 ± 0.12 $kg.m^2/s$, straight somersaults per unit flight time) than a triple back somersault (1.28 ± 0.11 $kg.m^2/s$) dismount, and thus that they differ significantly from each other in their release properties. Kerwin et al. (1993) provide a more detailed description of the release phase and its importance in the correct release timing for triple back somersault dismounts. They reported that body angles at release for triple back somersault dismounts ranged from -13° to -3.5°, confirming that none of their six competitors who were analysed released the bar with their mass centres above bar level. These factors are important considerations for the landing of such skills. Fink (1988) stated that the "release phase is the most important determinant in the successful performance of release-regrasp (flight elements) skills" (p.23). The same can be assumed to be true for dismounts. Therefore it is necessary for a gymnast to have several strategies of preparatory giant swings for the execution of different dismounts. Soon and Prassas (1995) reported a mean flight time for double back somersaults (DBS) of 1.20 ± 0.094 sec., and for triple back somersaults (TBS) 1.394 ± 0.064 sec. They stated that "the longer flight time of TBS was due to larger release velocity and CM release angle" (p.252). The landing angle CM to feet line with the right horizontal axis with the floor was for TBS was 90 ± 3.8° and for DBS 92 ± 5.44°.

Brüggemann et al. (1994b) stated, that "in any dismount the gymnast's objectives are to generate sufficient angular momentum to execute the number of somersaults and twists required by the particular skill, to obtain adequate height and thus have enough time in the air to complete the designated rotation, and to travel safely away from the bar while performing a dismount" (p.295). Brüggemann et al. (1994b) reported mean values of 4.79 ± 0.33 m/s and 1.04 ± 0.31 m/s for double tucked back somersault, 4.04 ± 0.10 m/s and 1.34 ± 0.67 m/s for double layout back somersault and 5.06 ± 0.28 m/s and 1.19 ± 0.39 m/s for triple tucked back somersault dismounts, respectively, for vertical and horizontal release velocities. Takei et al. (1992) examined the techniques used by elite gymnasts in the 1992 Olympic compulsory dismount from the horizontal bar. The authors performed an in-depth study of the double salto backward tucked dismount and reported that " successful dismount performance is likely when gymnast have a large vertical velocity (4.79m/s) at bar release, which ensures great height and long flight time" (Takei et al., 1992, p.207). Successful performance is also obtained when efforts are made to achieve "the tightest tuck position during the salto near the peak of the flight, extend the body rapidly and fully early in rotation before the vertical body position is reached well above the bar, maintain the extended body position during the remainder of the flight to display body style for virtuosity bonus points, and to simultaneously prepare for a controlled landing on the mat" (p.231). Because of the large landing impact forces during the landing process from the horizontal bar, the forces have to be dissipated over a relative long time through greater knee and hip joint flexion. Nigg (1985b) reported that landing techniques permitting greater knee flexion reduced the vertical load transmitted to the joints. Lees (1981) reported on reduction in impact peak force by using greater joint flexion during the landing process. Also, "the contributions of each segment to the ground reaction force curves were quantified by weighting the acceleration by the mass of each segment. Hard landings, characterised by minimal joint flexion, demonstrated acceleration of the two leg segments, while soft landings, characterised by a large joint flexion, demonstrated an initial negative acceleration of segments but displayed clear phasing of the segment motion" (Lees, 1981, p.209).

Table 2.5.1 Data of previously reported studies of dismounts

Parameters	Kerwin et al. (1990)	Brüggemann et al. (1994)	Takei et al. (1992)	Soon & Prassas (1995)
Time of flight (sec)	1.26 (Dl) 1.32 (T)	x x	1.25 (Dt) x	1.20 (D) 1.394 (T)
max. CM flight height (m)	3.63 (Dl) 3.99 (T)	x x	x x	x x
Horizontal release velocity (m/s)	x x	x x	1.27 (Dt) x	1.29 (D) 0.84 (T)
Horizontal velocity at landing (m/s)	x x	x x	x x	x x
Vertical velocity at release (m/s)	x x	4.79 (Dt) 4.04 (Dl) 5.06 (T)	4.79 x	4.89 (D) 5.98 (T)

Note: Dt = double backward somersault tucked dismount, Dl = double backward somersault layout dismount, T = triple backward somersault dismount

CHAPTER 3

3.0 METHODS AND EQUIPMENT

The methods and procedures used to select subjects and quantify kinematic parameters characterising the landing techniques are described in this chapter.

3.1 Subjects

Subjects were 32 male gymnasts competing at the World Gymnastic Championships 1994, Brisbane, Australia. Performances were analysed on four events (floor, rings, parallel bars, and horizontal bar), during qualification competition, individual all round competition (competition II), and individual apparatus finals (competition III). Table 3.1.1 represents the personal descriptive data of all subjects.

Table 3.1.1 Descriptive data of subjects (n=32)

Subject No	Competitor No	Country	Age (years)	Height (m)	Mass (kg)
1	204	KOR	X	X	X
2	118	BLR	21	1.68	65
3	274	UKR	X	X	X
4	249	RUS	21	1.66	67
5	253	RUS	X	X	X
6	203	KOR	20	1.71	76
7	232	CHN	17	1.68	70
8	133	BUL	22	1.63	55
9	283	USA	20	1.71	X
10	119	BLR	20	1.60	60
11	118	BLR	21	1.68	65
12	184	HUN	17	X	X
13	161	FIN	20	1.73	64
14	204	KOR	X	X	X
15	200	KZK	20	1.70	60
16	174	GER	22	1.63	55
17	264	SWE	X	X	X
18	132	BUL	X	X	X
19	250	RUS	X	X	X
20	243	FRA	X	X	X
21	235	CHN	X	X	X
22	192	ITA	20	1.62	61
23	238	PUR	22	1.78	73
24	246	ROM	18	1.70	63
25	247	ROM	20	1.68	66
26	185	HUN	X	X	X
27	175	GER	27	X	X
28	132	BUL	21	1.62	57
29	280	USA	30	X	X
30	170	GER	X	X	X
31	274	UKR	X	X	X
32	191	ITA	28	X	X

x = not known

3.2 Equipment and Data Capture

Performances on four gymnastic events were video recorded during competitions with six video cameras from the catwalks above the floor of the Brisbane Entertainment Centre. The competition area was lit by high power television lighting. Performances were filmed by pairs of cameras genlocked for time synchronisation. Routines at two apparatus were filmed at any one time at 50 fields/second (50 Hz), with professional standard cameras (3 Panasonic F-15 and 1 Panasonic Super-VHS MS4 camcorder) with 1/500th second shutter speed.

The camera positions are shown in Figure 3.2.1. All 50 Hz PAL signals were cabled to a central control room, where four PAL VCR's were located, and where EBU time-coding and recording was completed. During subsequent digitisation, time synchronisation of paired camera views was based primarily on the on-screen EBU time code (field-accurate). However, a back-up system was also used: a digital-to-analog converter in a notebook computer was triggered in software to send a pulse to an Event Synchronisation Unit - ESU (Peak Performance Technologies), which simultaneously displayed a white block on all recorded PAL video signals (approximately every second). The EBU video time code was also recorded on the audio track of the videotapes (channel 2) for field location by the Peak system.

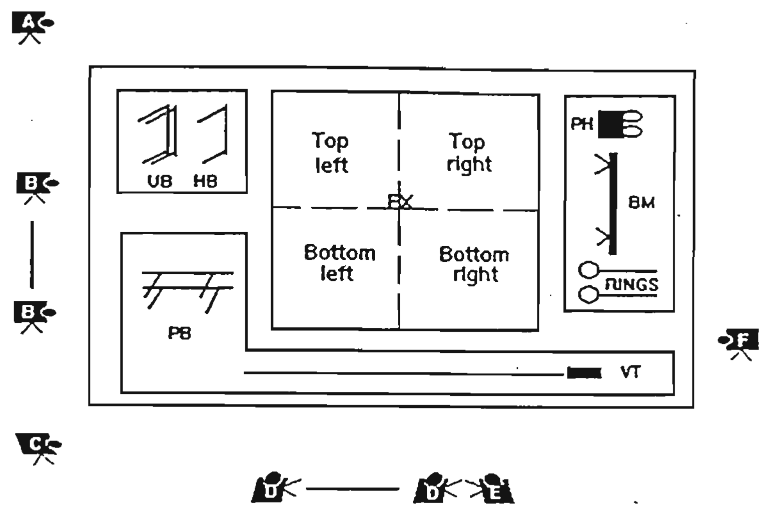


Figure 3.2.1 Camera positions used during the championships (apparatus oriented in exact positions)

A combination of two of these camera positions were used to video each apparatus (3-D analysis), as indicated in table 3.2.1.

Table 3.2.1 Camera combination for the events

Mens' Apparatus	Camera	Camera
Horizontal Bar	A	C
Parallel Bars	A	C
Floor - top right	B	E
Floor - top left	B	E
Floor - bottom right	E	F
Floor - bottom left	B	D
Rings	D	F

To obtain the three-dimensional data from dual two-dimensional views, the Peak calibration frame was filmed at various intervals during each filming day. This usually occurred before and after each session, but occasionally, time restrictions meant that it was not possible to place the calibration frame in the picture at the end of session. The two 2-D views of the calibration frame were used to construct a Direct Linear Transformation-DLT (Abdel-Aziz & Karara, 1971), which was then used to calculate the 3-D coordinates of the gymnasts from the digitised 2-D coordinates. This gives an approximate calibrated object space of 2.05m x 2.05m x 1.3m (refer to Figure 3.2.2). Linear and angular velocities and accelerations were calculated from the 3-D coordinates by finite differences method (Miller & Nelson, 1973).

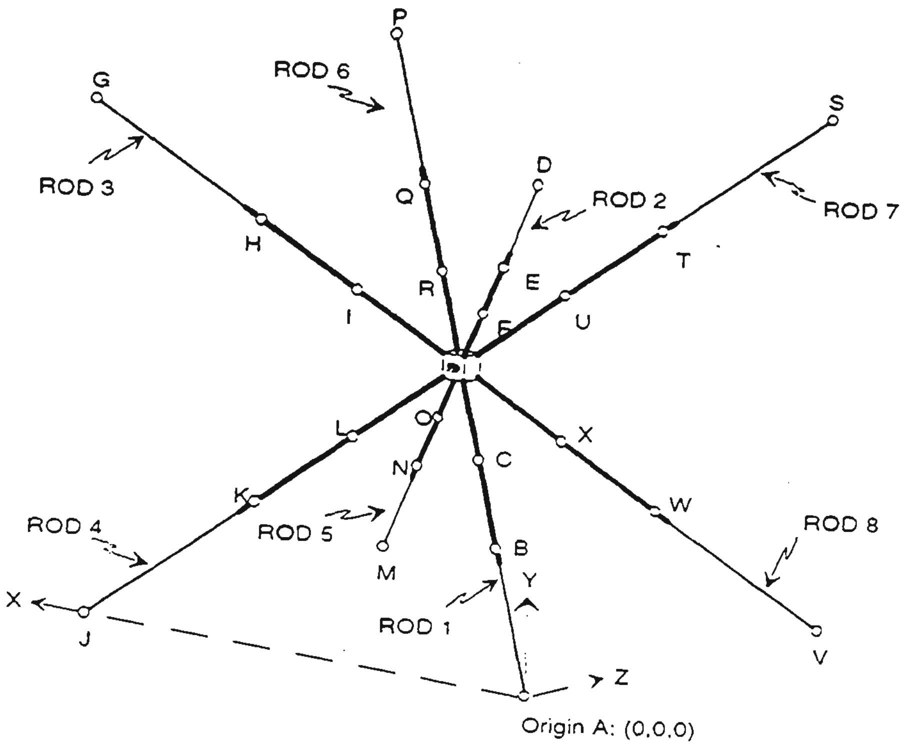


Figure 3.2.2 Peak system calibration frame (taken from Peak manual)

The size of each camera's field of view necessitated the placement of the calibration frame in multiple positions for each apparatus to ensure that all performances filmed were in a calibrated volume. These positions are detailed below. The long axis of the calibration frame (x) was approximately aligned with the direction of movement of the gymnast along the apparatus. Exact specifications of the calibration frame positions are given in Table 3.2.2.

Table 3.2.2 Calibration frame positions for each apparatus (from the perspective of the video cameras)

Floor:	Because of the size of the area, the floor area was divided up into four quadrants. For each of these quadrants, three calibration positions were filmed along the corresponding diagonal of the quadrant; (1) Central floor position (2) Between centre of floor and corner (3) Corner of floor
Rings:	(1) "Cube" directly between and level with the rings (the "Cube" is the central rectangular metal box)
Parallel Bars:	(1) "Cube" between uprights on near side (2) "Cube" at centre of apparatus (3) "Cube" between uprights on far side

*When the "cube" is between the uprights for this apparatus, the four medial arms (to the apparatus) fill the space back towards the centre of the apparatus, with the four lateral arms encompassing the end of the bars.

Horizontal Bar:	(1) Landing space near side of bar (2) Directly under bar, with central "cube" of frame sitting 15cm below the bar. (3) Landing space on far side of bar.

The dimensions of the calibration frame are presented in Table 3.2.3.

Table 3.2.3 Peak calibration frame dimensions (Batch no: A35)

ALL DIMENSIONS ARE IN MILLIMETERS

ROD	POINT	LABEL	FULL FRAME (24) X	Y	Z	INNER FRAME (16) X	Y	Z
1	1	A	0.0	0.0	0.0			
1	2	B	512.0	520.0	321.0	0.0	0.0	0.0
1	3	C	769.0	781.0	483.0	257.0	261.0	162.0
2	1	D	-12.5	2062.0	-10.0			
2	2	E	506.0	1551.0	316.5	-6.0	1031.0	-4.5
2	3	F	766.0	1295.0	480.0	254.0	775.0	159.0
3	1	G	2062.5	2062.0	-10.0			
3	2	H	1544.0	1551.0	316.5	1032.0	1031.0	-4.5
3	3	I	1284.0	1295.0	480.0	772.0	775.0	159.0
4	1	J	2050.0	0.0	0.0			
4	2	K	1537.5	520.0	321.0	1025.5	0.0	0.0
4	3	L	1281.0	781.0	483.0	769.0	261.0	162.0
5	1	M	2050.0	0.0	1286.0			
5	2	N	1537.5	520.0	965.0	1025.5	0.0	644.0
5	3	O	1281.0	781.0	803.0	769.0	261.0	482.0
6	1	P	2062.5	2062.0	1296.0			
6	2	Q	1544.0	1551.0	969.5	1032.0	1031.0	648.5
6	3	R	1284.0	1295.0	806.0	772.5	775.0	485.0
7	1	S	-12.5	2062.0	1296.0			
7	2	T	506.0	1551.0	969.5	-6.0	1031.0	648.5
7	3	U	766.0	1295.0	806.0	254.0	775.0	485.0
8	1	V	0.0	0.0	1286.0			
8	2	W	512.0	520.0	965.0	0.0	0.0	644.0
8	3	X	769.0	781.0	803.0	257.0	261.0	482.0

Over 200 hours of video tape recordings were taken during the five days of competition.

3.3 Data Analysis

After data capture the video tapes were duplicated (back-up copies) at Victoria University. All digitised trials were spot checked by the author and a reliability analysis was performed. All digitising was in calibrated volume except on rings were it was marginally outside the calibrated volume. The RMS error in digitising the calibration frame was 0.009 metres. The recommended procedures for three-dimensional motion analysis outlined by Bartlett et al. (1992) were used as a guide. Analysis of the 50 Hz PAL tapes were performed using a video data acquisition system (Peak Performance Technologies, Inc.-Peak 5, 3-D Motion Analysis System, Denver, USA). 2-D coordinates of Dapena's (1991) 21-point (14-segment) body model (Figure 3.3.1) were manually digitised (effective half-pixel resolution 1024x1024).

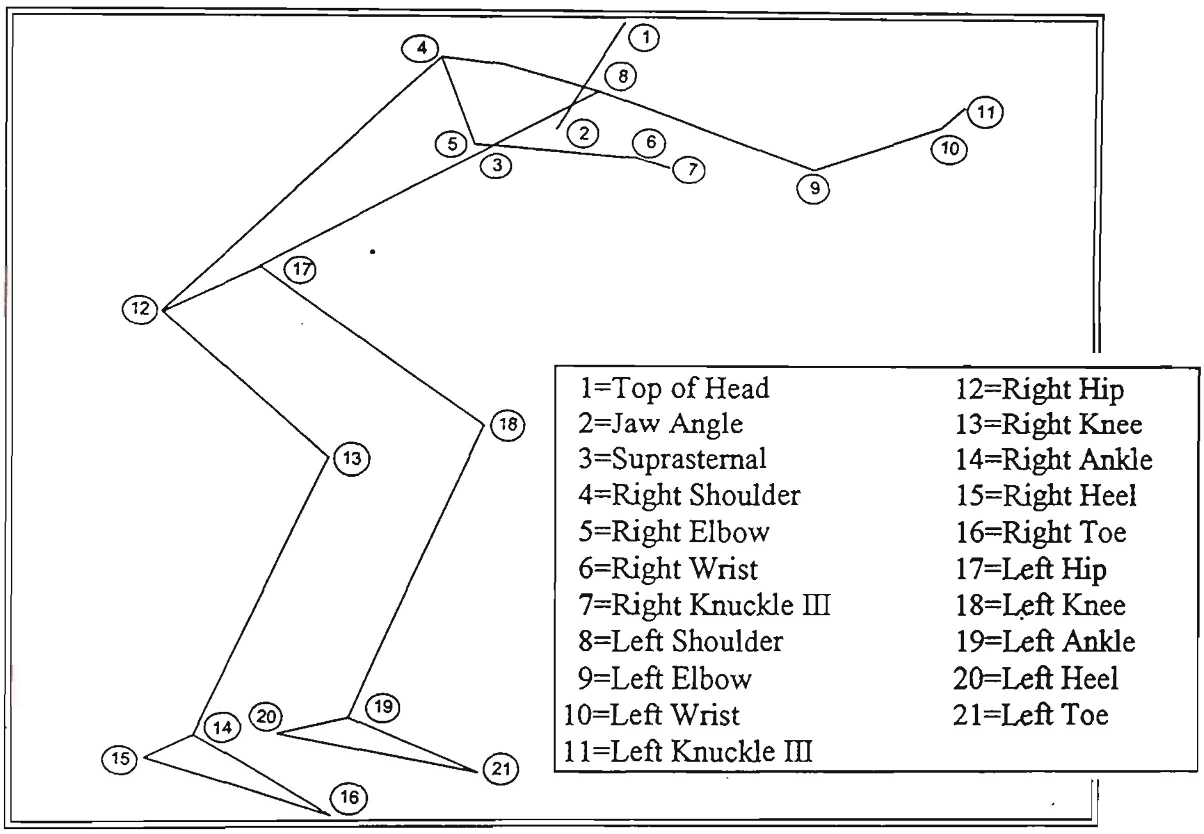


Figure 3.3.1 Twenty-one point body model by Dapena

The coordinates were filtered with an optimal Butterworth low pass digital filter (Winter, 1990), with an 'optimal' cut-off frequency determined independently for the X and Y coordinates of each body point. This was done from the residuals by the Jackson (1973) Knee Method (Peak 5 User's Manual), with the 'prescribed limit' set to 0.1.

(Winter, 1990), with an 'optimal' cut-off frequency determined independently for the X and Y coordinates of each body point. This was done from the residuals by the Jackson (1973) Knee Method (Peak 5 User's Manual), with the 'prescribed limit' set to 0.1. Digitisation generated positional data which when combined with 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 were obtained, they were cascaded with the spatial model to generate line model diagrams with the kinematic graphics as well as synchronised with the video tapes to provide the real life view and data characterisation. Total body centre of mass position was determined based on estimated segment centre of mass positions and proportions of total body mass according to Dempster (1955).

3.4 Deterministic Model

3.4.1 Development of the deterministic model for the dismount release, flight phase, and landing phase

The points awarded by the judges in competitions apply to the whole 'completed' routine, the final score, on all events. This final score takes into consideration the routines/exercise requirements such as difficulty, special requirements, exercise presentation and bonus points (Figure 3.4.1). Therefore, the final score (points awarded by the judges) was not taken into consideration in the development of the landing model.

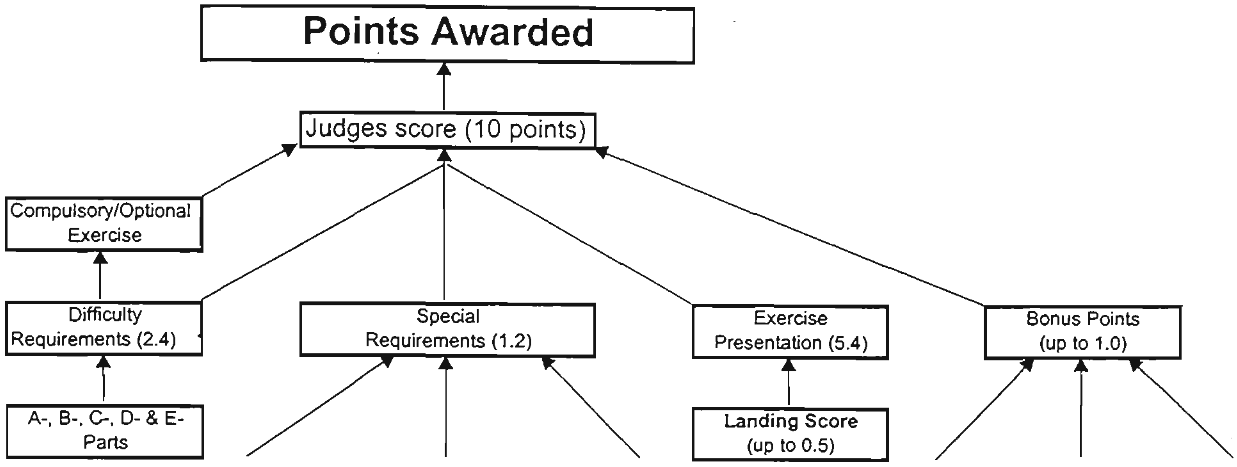


Figure 3.4.1 Flow chart of the points awarded by the judges for the whole routine

To achieve a successful landing performance, the gymnast must first complete successfully the release and flight phase of the dismount. Each landing was therefore evaluated in isolation independently by two internationally accredited judges and one gymnastics expert. Subsequently, it was necessary to construct a detailed theoretical biomechanical model for gymnastic landings including the release phase, release position, flight and landing phase, for the analysed dismounts and tumbling skills.

The author's model (the release phase in particular) is adapted from the model by Best (1995, pp.4-5), which represents a further development of the model by Hay (1993), and Hay and Reid (1988). The model by Takei (1988 & 1992 p.214) was also used by the author for the development of the landing score and the dismount criteria.

The major biomechanical determinants of competition gymnastics landing performances are presented in the model. The deterministic model is designed to show how the determinants are related to each other and how each parameter is determined. Newton's laws of motion provide the backbone of the model. Like any activity, the final result and each aspect of a performance is defined by actions that occur prior to that aspect of the performance. All of the boxes in the deterministic model are connected and the direction of the arrow represents "is determined by" (Best 1995, p.5). For example, the landing score is determined by the form during landing, body control during landing, and the recovery to still stand. Each box in the model can be expanded infinitively which means, that changing one small part of the performance at any level and phase will in some way, effect all other elements of the landing.

The model, from bottom (release phase) to top (landing score), represents how the landing develops both functionally and temporally as indicated by the arrows (Figure 3.4.2).

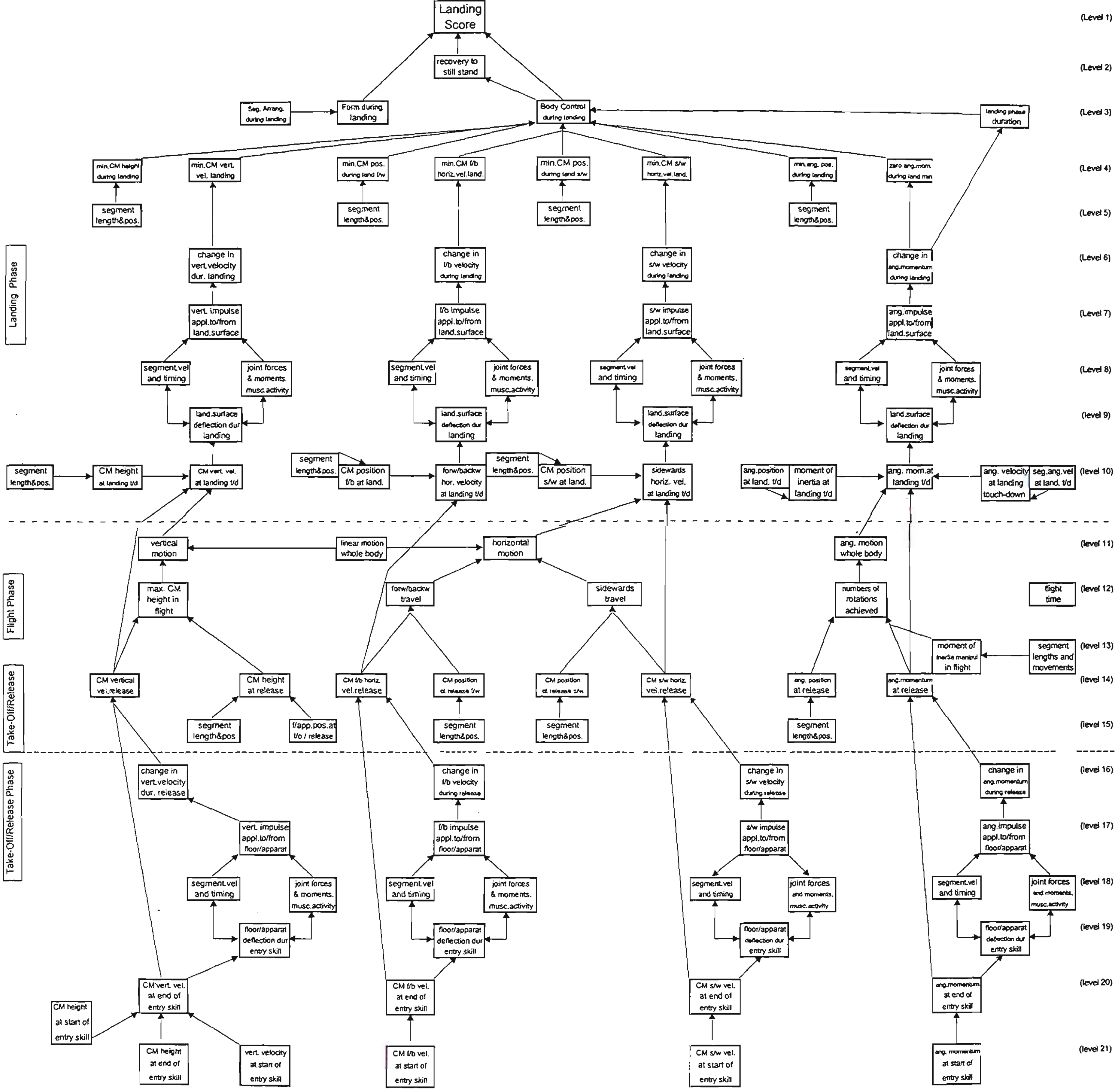


Figure 3.4.2 Deterministic model showing the release/take-off phase, release/take-off, flight phase, landing phase, and the biomechanical factors related to controlled landing performances

3.4.2 Description of the Dismount Release, Flight and Landing Model - Levels

The description of the levels (levels 7-21) of this model is based on the description of the diving model by Best (1995, pp.9-19).

Level 1: Landing Score. To get a true reflection of the landing performances, the dismount and landing of each gymnast was evaluated in isolation by two internationally accredited judges and one gymnastics expert by viewing the analysed videotapes.

Level 2: Recovery to still stand from the CM minimum position should be performed in a rhythmical and harmonious manner. This movement action constitutes the final part of the landing.

Level 3: A gymnast's form at landing constitutes a visually controlled upright position, which is considered by judges as an accepted, correct landing position.

Segmental arrangement at landing includes the position and symmetry of the whole body and its segments at landing.

Body control during landing includes the position of the various body parts in space and the manner in which they move from landing touch-down to the landing minimum position. This level presented the main determinant of the biomechanical parameters under consideration.

Level 4: This level represents the end of the landing phase, where the CM is at its minimum position and shows minimum values of all parameters presented. In this position the gymnast should be balanced and all his landing momenta (should) have come to zero with a single placement of the feet. Ideally, the gymnast should recover from this position harmoniously to a still stand.

Level 5: This level relates to positions of individual body segments at the CM minimum position.

Level 6: All activities in the landing phase have the intention of reducing the angular momentum and the change in velocities over time to zero. The absorption of the landing forces (timing) has to be optimal from landing touch-down to landing minimum. To reduce the body momenta too quickly would result in an unstable, and stiff landing.

Level 7: This level signifies a direct relationship i.e. the change in velocity (vertical, forwards/backwards and sidewards) and angular momentum (level 5) during the landing and is directly proportional to the impulse generated at the landing surface/gymnast interface (impulse-momentum relationship). The impulse relates to the force that the landing surface exerts on the gymnast during contact with the landing surface, and the time over which the force acts. The force exerted by the landing surface on the gymnast was related to the force the gymnast exerts on the landing surface (Newton's third law of motion). This latter point is demonstrated by the loop in the landing phase between levels 6 to 9.

Level 8: Segmental velocities and timing. The transfer of momentum from one segment to another is an important aspect in gymnastics. In ballistic activities such as throwing, kicking, jumping or landing, momentum is transferred along the kinematic chain. The kinematic chain runs from proximal to distal segments in throwing (because it is the momentum transferred to the ball that largely effects how far it travels). In gymnastic landings, the definition of the kinematic chain sequence is a little more complicated because it is the gymnast's CM velocity that has to be minimised. For maximum performance each segment's velocity (or angular velocity) must reach a maximum controllable velocity, and the timing of the maximum velocities must occur in sequence along the chain.

In gymnastic landings there is no doubt that the legs and trunk contribute largely to the absorption of the landing forces. This involves timing or sequencing of segmental velocities. An elite gymnast always looks smooth and seemingly effortless. This is almost entirely due to correct timing (of the kinematic chain).

Joint forces and moments. All human motion is related to the forces acting on the human. These forces include external forces (e.g. gravity, air resistance) and internal forces (e.g. the forces generated by the muscles or within a system). Without joint forces (and moments) there would be no landing surface deflection. The forces acting between the gymnast and the floor during the landing phase have to be controlled through muscular activity by generating joint forces and moments.

Level 9: Landing surface deflection is obviously very important in gymnastics performance. Timing muscular activity with such deflection is very important for the absorption of the forces. The landing surface deflection is determined by the joint forces and moments generated by the gymnast, the timing of segmental velocities, and the vertical velocity at the beginning of the landing phase (impact velocity).

Level 10: This level refers to the gymnast's state (angular and linear positions and velocities) at landing touch-down. The velocity at landing touch-down (impact velocity), may be considered as the vector sum of the horizontal and vertical velocities. It is at this point, where the axis of rotation changes (axis transfer) from the CM to feet contact on the ground as pivot point. Subsequently, horizontal velocity changes to its angular equivalent. The values of the CM velocity in the vertical, forwards/backwards and sidewards directions, and the values of the angular momentum at release are crucial in determining what happens in levels 4-10.

Consequently, level 14 assumes great importance because it details how release velocity and angular momentum are generated and will affect what happens in level 10.

It is important to note that the primary determinants of release velocity are represented in levels 15-19 of this model; e.g. vertical velocity at landing touch-down (level 10) is wholly determined by the vertical velocity at release and the change in vertical velocity of the CM during the release phase (level 14).

Level 11: This level relates to the linear (vertical and horizontal) and angular motion of_the whole body in flight. The mechanical factors that determine the linear and angular motions of the gymnast were identified by the method described by Hay and Reid (1988), Takei et al. (1988, 1992), and Best (1995). The angular distance through which a gymnast's body rotates while in the air depends on the gymnast's angular momentum at take-off/release, the average moment of inertia during the flight, and the time of flight. The linear trajectory of the CM during flight cannot be altered by the gymnast after release from the apparatus, or take-off from the floor.

Level 12: This level is still in the flight phase but constitutes the important characteristics that the gymnast is trying to achieve from the vertical, horizontal and angular motion described in level 3. These characteristics are:

- Vertical height reached by the CM
- Forwards/backwards horizontal distance travelled by the CM
- Sidewards horizontal distance travelled by the CM
- Number of angular rotations achieved (e.g. number of somersaults and twists).

At this level the dismount can essentially be broken down into the above four sub-divisions.

Level 13: This level constitutes those characteristics that can be manipulated during the_flight phase to affect the parameters described in level 6. The amount of angular momentum generated at release needs to be optimised and the moment of inertia has to be manipulated to optimise the number of rotations achieved prior to landing. This is done by changing segment positions relative to the gymnast's CM by tucking, piking or straightening the body.

Nothing appears at this level for the vertical and horizontal motion because linear motion cannot be manipulated by the gymnast during the dismount. Vertical, horizontal and sidewards travel cannot be manipulated during flight. Only rotational factors (e.g. somersaulting and twisting) can be affected during flight. Rotational changes are achieved by manipulating the whole body moment of inertia and this in turn is achieved by moving body segment positions relative to the gymnast's CM.

Level 14: This level refers to the gymnast's state (angular and linear positions and velocities) at the instant of release. The velocity at release (the start of a dismount), may be considered as the vector sum of the horizontal and vertical velocities at release. The angular distance through which a gymnast's body rotates while in the air depends on the gymnast's angular momentum at release and body segment configuration relative to the CM in flight.

The values of the CM velocity in the vertical, forwards/backwards and sidewards directions and the values of the angular momentum at release are crucial in determining what happens in levels 10-12. Consequently, levels 14-20 assume great importance because they detail how release velocity and angular momentum are generated. Also, the body position at the instant of release should be extended and symmetrical.

It is important to note that the primary determinants of release velocity are represented in levels 15-19 of this model; e.g. vertical velocity at landing touch-down is wholly determined by the vertical velocity at release and the change in vertical velocity of the CM during the release/take-off phase.

Level 15: This level relates to positions of individual body segments at the instant of release/take-off. The angular position of the body, the forwards/backwards and the sidewards position of the CM at release/take-off are wholly determined by the positions of the body segments.

Level 16: Levels 16-19 represent activities that occur during the release/take-off phase. All actions in the release/take-off phase have the intention of maximising change in vertical velocity while optimising the changes in forward/backward velocity and angular momentum and minimising the change in sidewards velocity (except on parallel bars were sidewards velocity should be optimised).

- Any change in sidewards velocity during the release phase will result in sidewards motion and waste energy that would better be used in generating vertical velocity (except for parallel bars).

- Too much change in forwards/backwards velocity will result in too much forwards/backwards motion and also waste energy that would better be used in generating vertical velocity.

- Too little change in forwards/backwards velocity will result in the gymnast travelling dangerously close to the horizontal bar on the downwards part of the flight phase.

- Too much or too little change in angular momentum during the release phase will result in over/under rotation in the flight phase. It will also waste energy that would better be used in generating vertical velocity.

- Too little change in vertical velocity during the release/take-off phase will result in the gymnast achieving less height and, ultimately, less time to perform the dismount. The change in vertical velocity should be maximised with the constraint that changes in forward/backward velocity and angular momentum have to be optimised and the change in sidewards velocity has to be optimised.

Level 17: This level signifies a direct relationship i.e. the change in velocity (vertical, forwards/backwards and sidewards) and angular momentum during the release phase and is directly proportional to the impulse generated at the gymnast interface (Newton's second law of motion). The impulse relates to the force that exerts on the gymnast's feet/hands while in contact with the floor/apparatus, and the time over which the force acts. This is demonstrated by the loop in the release/take-off phase between levels 17-19.

Level 18: Segmental velocities and timing. The transfer of momentum from one segment to another is an important aspect in gymnastics. The kinematic chain during the release phase on horizontal bar is quite complicated, because it is the gymnast's CM velocity that has to be maximised. However, there is no doubt that the wrists, shoulders and hips contribute significantly to high release velocities. Best (1995) suggests that "the optimal timing of segmental velocities is not known in any sport, but will be individual-specific and highly complex"(p.16).

Joint forces and moments. All human motion is related to the forces acting on the human. These forces include external forces (e.g. gravity, air resistance) and internal forces (e.g. the forces generated by the muscles or within a system). Without joint forces (and moments) there would be no apparatus/floor deflection. The forces acting between the gymnast and the floor/apparatus during the release/take-off phase have to be controlled using muscular activity and, hence, by generating joint forces and moments. Joint forces and moments, along with momentum transfer across limbs, are extremely important in impulse and CM velocity generated during the release/take-off phase.

Level 19: Sprung floor, rings, parallel bars (rails), and horizontal bar deflection is obviously very important in gymnastics. Timing muscular activity with such deflection is very important as was discussed earlier. The floor/apparatus deflection for example, effectively acts as a very powerful extra limb that can be used to generate impulses and velocities well over and above what would normally be possible. Comparing the vertical height achieved from a stiff surface to a sprung floor, or a stiff bar to a springy bar gives an idea of its importance.

The floor/apparatus deflection is determined by the joint forces and moments generated by the gymnast, the timing of segmental velocities, and the vertical velocity at the end of a preparatory element at the beginning of the release/take-off phase.

Level 20: This level refers to the gymnast's state (angular momentum and linear velocities) at touch-down from entry skills (e. g. flic-flac touch-down that signifies the beginning of the take-off phase on floor, the end of the forward upward swing from hang on the rings, the end of the forward upward swing in cross support on parallel bars, or the end of the wind-up giant swing on horizontal bar) that signifies the beginning of the release/take-off.

Level 21: The angular momentum, linear velocities and the CM height at the beginning of the entry skill (flic-flac flight prior to touch-down on floor, the beginning of the downward swing from or via handstand (giant swing) on the rings, the beginning of the downward swing from handstand on the parallel bars, or the beginning of the wind-up giant swing on the horizontal bar), determine the magnitude of the values in level 20.

3.5 Evaluation of the Landing Score

The final score given in competitions applies to the whole routines' requirements (combination, difficulty and execution) rather than a single skill or component under study. Thus, the final score of the performers on the selected events analysed was not taken into consideration for the theoretical landing model, because of its broad representation. Thus, each landing performance was qualitatively evaluated by two internationally qualified judges and one gymnastics expert. The judges viewed each performance independently on video at least three times, twice at normal speed and once in slow motion, for optimal evaluation purposes. The evaluation criteria included landing deductions as per code of points (Zschocke, 1993), and additional deductions for technical and form execution errors to a total of 18 points. Eight landing performances each on floor, rings, parallel bars and horizontal bar, were selected for analysis. Table 3.5.1 shows the factors for landing errors and the respective points for deduction. The final landing score for each landing performance was expressed as a percentage calculated from the points deducted.

Table 3.5.1 Judges score sheet for the evaluation of gymnasts' landing performances

Events: Floor ☐ Rings ☐ P.B. ☐ H.B. ☐

Error	Deductions	Gymnast 1	2	3	4	5	6	7	8
Unsteadiness	1								
Trunk bent forward-a little	1								
Trunk bent forward-excessively	2								
Small step	1								
2 feet hop	1								
Big step	2								
Big hop	2								
Several steps	3								
Light hand touch on floor	2								
Weight bearing on floor	3								
Full weight on hands	4								
Fall to seat or body	5								
Legs apart on landing-slightly	1								
Legs apart on land.-shoulder width	2								
Legs apart on land.-wider than s/w	3								
Deep knee bend	1								
Arms swinging/circeling-a little	1								
Arms sw/circ.-more than 1 full circle	2								
Sidewards mvt. of trunk on landing (or uncompleted twisting)-a little	1								
Same as above-excessively	2								
Total deductions	18								
Landing Score (%)									

According to the "Code of Points-Artistic Gymnastics for Men 1993, p.29, 4.2.3, Article 25, # 7; Technical Execution and Body Position Errors, the following points should be noted:

*small error = 0.1 deduction for slight unsteadiness in stand. pos. or steps or hops, 0.1 per step, max. 0.4

** med. error = 0.2 deduction, touching floor with hands (or with one hand), incorrect body position (form)

*** large error = 0.4 deduction, falling onto seat (deduction 0.5 pts.), pronounced support on floor with arms

Judge's Signature:_ _ _ _ _ _ _ _ _ _ _ _ _ _   Date:_ _ _ _ _

3.6 Data Reduction and Calculation of Variables

A minimum of 10 frames were digitised before take-off on floor or release from the apparatuses, and the same after CM minimum.

Center of mass (CM): The coordinate location of individual segment centres of mass were determined using the digitised coordinates of segment endpoints in conjunction with Dempster's (1955) data for segment masses, and segment mass centres.

CM height and position: The CM height and position for each performance, the gymnasts' CM position at (a) take-off or release, (b) maximum CM height during flight, (c) CM height at landing touch-down, and (d) CM minimum, were measured from the landing surface to the CM position. Landing mat deformation was considered during digitisation.

Linear displacements: The linear displacement from floor take-off or release from the apparatus and the CM with respect to the landing surface was determined. The CM displacement from first frame contact at landing touch-down and CM minimum displacement were calculated. The CM relative to the landing surface from landing touch-down to minimum shows a relatively higher value than the true displacement, because of the landing mat deformation during the landing process.

Linear velocities: The vertical and horizontal velocity values were taken at maximum at each phase. The ***vertical velocity*** at release shows a positive value whereas the landing impact velocity shows a negative value. The ***horizontal velocities*** for parallel bars, floor and rings show a negative value (movement direction is backwards), and on horizontal bar shows a positive value (movement direction is forwards).

Angular positions: The angular position values were measured in degrees at first frame contact with the landing surface and at CM minimum. The absolute angles for

CM to ground contact (toes) and the horizontal (acmght/d), angle arm-trunk (aatt/d), hip angle (aht/d), ankle angle (aat/d), and angle trunk to horizontal (atht/d), were measured to the front (anterior) side of the subject, and the knee angle (akt/d),), was measured to the rear (posterior) side of the subject (Figure 3.6.1).

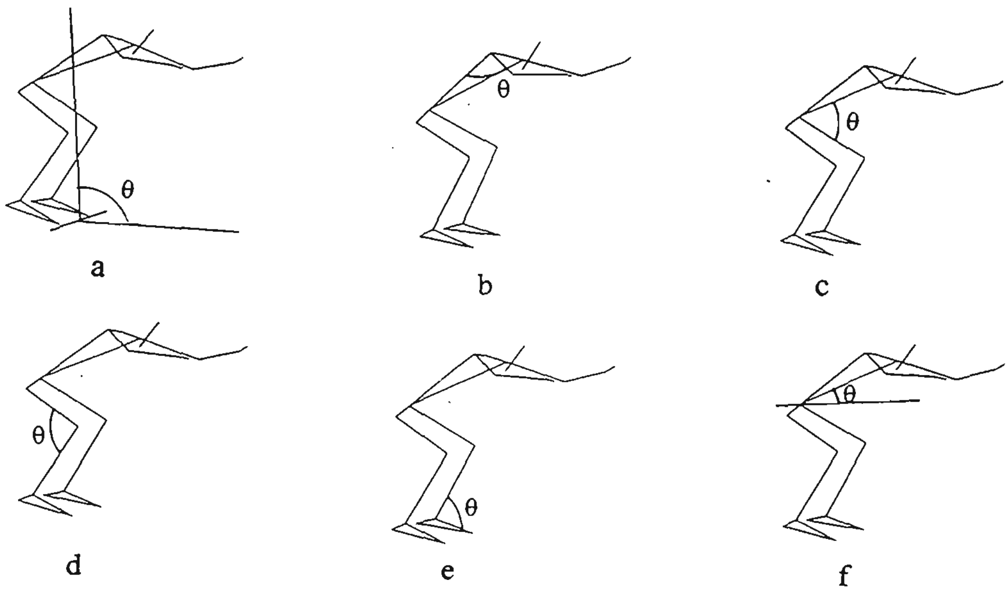


Figure 3.6.1 Landing touch-down angles (a) cmght/d, (b) aatt/d, (c) aht/d, (d) akt/d, (e) aat/d, (f) atht/d)

Angular velocity: The angular velocity values show negative values during flexion of the hips, knees and ankles (eccentric contraction) and positive values during extension of these joints.

Angle-angle diagrams: were produced to investigate the relationship between ankle and knee angles, knee and hip angles, and hip and shoulder angles during the landing phase. Sanders and Wilson (1992) suggest that "changes in these relationships indicate a change in angular kinematics and sequencing among joints" (p.598). Angle-angle diagrams have previously been used by Whiting and Zernicke (1982) to investigate similarities in lower extremity joint angular displacements in walking and running activities.

Angular velocity-joint angle diagrams for the shoulder, hip, knee and ankle angles were produced to provide a description of the respective angular velocity-joint angle relationship during the landing process.

Time of flight: The time of flight was considered as the time that elapsed between the first frame in which the gymnast was seen to have broken contact with the apparatuses (bar, rails, or rings) or toes leaving the floor surface, and the first frame showing that he was in contact with the landing surface.

Landing phase displacement: The displacement of the CM from landing touch-down to CM minimum position constitutes the landing phase displacement.

The selection of variables for analysis and discussion was based on the mechanical variables identified in the deterministic model for landings, developed by the author, and selected literature on diving, gymnastics and athletics (Best, 1995; Takei et al., 1992; Hay & Reid, 1988).

3.7 Statistical Analysis of the Data

A total of 25 parameters were measured for each group on four gymnastics events. The data analysis consisted of (a) the multiple analysis of variance (MANOVA), analysis of variance (ANOVA), factor analysis with the principle components method, and cluster analysis were performed to test the affects on landing performances for similarities and differences between subject groups on four events (floor, rings, parallel bars and horizontal bar); (b) investigation of the relationship between each variable for all subjects within each group for all four events (floor, rings, parallel bars and horizontal bar), was performed; (d) qualitative assessment of all landing performances analysed was performed by two internationally qualified judges and one gymnastics expert, to establish a landing score for each landing performance; and (d) correlations were computed between each variable and the judge's score in the model (Fig 3.4.2) for the identification of important associations among independent variables.

Hartley's F max test for homogeneity of variance was performed on all parameters to establish whether it was appropriate to perform the analysis of variance (ANOVA) test. Post-hoc tests (ANOVA) were conducted using the Tukey-B adjustment treatment.

Effect size data was also calculated among all groups for all variables. Jacob Cohen (1990) as quoted in Thomas et al. (1991) indicates "that the primary purpose of research should be to measure effect size rather than level of significance" (p.344). A large effect size which is not statistically significant may lead to further research, whereas a failure to report effect size may discourage further research. Thomas et al. (1991) made a case for presenting sufficient information in research papers to enable the effect size to be calculated. They utilised an arbitrary scale that classified effect size values in terms of importance. They claim that a value less than 0.41 (ES < 0.41) is indicative of a small effect, between 0.41 and 0.7 (ES < 0.7) a moderate effect, and greater than 0.7 (ES > 0.7) a large effect. The above authors also stated that "reporting ES's for the main comparisons of interest is a useful procedure to identify meaningfulness as well as significance of findings" (p.347). This convention will also be followed in the analysis of data presented in this thesis.

The significance level was chosen at $p<.01$. All statistical analysis of data was performed using the Microsoft Excel statistical procedures and SPSS.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

This study focused on the landing techniques performed by elite gymnasts on four events (floor, rings, parallel bars and horizontal bar). The results of the biomechanical analysis are provided in this chapter. The gymnast's landing performance was analysed for the complete landing phase. The release/take-off phase and the flight phase were also taken into consideration.

On each of the four events, controlled landing performances from the videos were chosen through qualitative analysis performed by the author. Conclusions based on the results were discussed in relation to controlled landings as performed by the gymnasts on four events. The discussion focuses on the motion of the segments during the landing phase. The landing phase was defined as the time from initial contact to the time when the body's centre of mass (CM) reached the minimum vertical position.

Comparisons between groups for each parameter were made relative to the group mean data using the MANOVA statistical procedure, and subsequent analysis of variance (ANOVA) at the $p < .01$ level was performed. A factor analysis was performed to help identify parameters that can be used to represent relationships of interrelated variables among the groups landing techniques. Also, a cluster analyses was performed to find how many subgroups amongst all cases were identified using similar landing techniques, and to find homogeneous groups of variables used by subjects who performed controlled landings. The relationship between each variable for all subjects within each group for all events were then presented. All raw data were included in the appendices section of this thesis.

Hartley's F_{max} test for homogeneity of variance was performed on twenty five parameters to establish whether it was appropriate to perform the analysis of variance (ANOVA) test. Ten out of the twenty five parameters were found to have heterogeneous group variances at the $p<.05$ level, and six parameters were found to be significant at the $p<0.01$ level. These parameters are highlighted in Table 4.0.1. With eight subjects in each of the four groups, the critical value of F_{max} at $\alpha=0.01$ was 5.75. Although the Hartley test results were largely positive, heterogeneity of the groups was a problem. The Hartley's F_{max} test for homogeneity of variance compares the largest or maximum variance with the smallest or minimum variance.

Table 4.0.1 Hartley's F_{max} test for homogeneity of variance

	Variable	highest/low	max. variance	min. variance	F-Score
*	avht/d	F/H.B.	69895	10715	6.52
	avkt/d	F/H.B.	107385.98	32390	3.32
*	avat/d	F/P.B.	65493	6890	9.51
*	acmght/d	F/H.B.	52	5	10.4
*	aatt/d	P.B/F	1619	136	11.9
*	aatm	H.B./P.B.	898	101	8.89
*	aht/d	F/P.B.	370	53	6.98
	ahm	F/P.B.	443	112	3.96
	akt/d	H.B./R	149	44	3.39
	akm	H.B./F	863	179	4.82
*	aat/d	H.B./R	120	13	9.23
*	aam	H.B./R	175	15	11.67
	atht/d	F/H.B.	214	71	3.01
	athm	F/H.B.	364	295	1.23
	cmhr	P.B./R	0.05	0.03	1.67
	mcmhf	F/R.	0.02	0	0
*	cmhdrt/d	H.B./R	0.3	0.01	30
	cmht/d	F/-	0.01	0	0
	cmhm	P.B./F.	0.01	0	0
	cmhvr	H.B./F	0.39	0.25	1.56
	cmvvr	R/F	0.25	0.11	2.27
	cmhvt/d	H.B./F	0.24	0.08	3
*	cmvvt/d	F/R	0.24	0.01	24
	ftrt/d	H.B./-	0.01	0	0
	cmdt/dm	-	0	0	0

The Hartley's F_{max} test showed that ten out of the twenty five parameters had heterogeneous group variances wherein six parameters were found to be significant at the $p<0.01$ level.

Comparisons between groups for the twenty five parameters were then made relative to the group mean data using the MANOVA statistical procedure.

Table 4.0.2 MANOVA test for fourteen parameters

Variable	F-Score	p value (F3, 28)
Maximum centre of mass height during flight	388.18	.000
CM duration from touch-down to minimum	4.23	.014
CM horizontal displacement from release to touch-down	64.13	.000
Centre of mass height at release	153.32	.000
Centre of mass height at touch-down	5.34	.005
CM horizontal velocity at touch-down	54.90	.000
CM horizontal velocity at release	66.65	.000
CM vertical velocity at release	64.89	.000
CM vertical velocity at touch-down	35.83	.000
Flight time from release to touch-down	64.99	.000
Ankle angle minimum	3.30	.035
Angle arm trunk minimum	4.07	.016
Angle CM to ground contact and the horizontal at touch-down	53.36	.000
Hip Angular Velocity at Touch-Down	8.71	.000

Presented in Table 4.0.2 are eleven parameters found to be significant at the $p<0.01$ level and three parameters found to be significant at the $p<0.05$ level.

One-way ANOVA's were performed on all parameters found to be significant at the $p<0.01$ level to establish whether that particular parameter was able to distinguish among the four groups. Subsequently, 11 one-way ANOVA's were calculated.

Post-hoc tests were conducted using the Tukey-B adjustment treatment, at the significance level of .05. The parameters are discussed in detail throughout the analysis in terms of means, standard deviations, effect size, and linear correlation matrix.

Presented in Table 4.0.3 are the variables that were found to be significant at the $p<.01$ level. Each of these variables will be discussed in relation to the release/take-off, flight phase and landing phase. Correlation coefficients were calculated among these parameters. This data will also be presented in this chapter at relevant stages.

Table 4.0.3 ANOVA and post-hoc tests for the variables found to be significant at the p<.01 level

Variables	p value	Sig. level	Significant differences among groups P.B. (G1)	H.B. (G2)	Floor (G3)	Rings (G4)
Release Phase						
CM horiz. velocity at release	0.0000	0.0010	3	3		2,1&3
CM height at release	0.0000	0.0010	2		1,4&2	2
CM vert. vel. at release	0.0000	0.0010	4,3&2			3&2
Flight Phase						
CM horiz. displ. release to t/d	0.0000	0.0010	2&3	3		2&3
Flight time release to t/d	0.0000	0.0010	3&2		2	3&2
Max. CM height in flight	0.0000	0.0010	4&2		1,4&2	2
Landing Phase						
CM height t/d	0.0049	0.0100	2		2	2
Landing phase displacement	0.0007	0.0010			1,4&2	
CM horiz. vel. at t/d	0.0000	0.0010	2&3	3		2&3
CM vertical velocity at t/d	0.0000	0.0010	3	4,1&3		3
Angle: CM to ground cont.& horiz.at t/d	0.0000	0.0001	2		1,4&2	2
Hip angular velocity at t/d	0.0003	0.0010		3,4&1		

All effect size data are reported in the table at the start of each section.

4.1 Release/Take-off

All group kinematic mean, standard deviation and effect size data from the release/take-off are presented in Table 4.1.1. The release/take-off relates to the position of the whole body and to positions of individual body segments at release from the apparatus or the take-off on floor. Release/take-off position (deterministic model levels 14-15) was considered as the first frame of non-contact with feet on the landing surface on floor, or hands on rings, rails on parallel bars and bar on horizontal bar.

Table 4.1.1 Kinematic data for all variables from the release/take-off position

Variables	P.B. (1) Mean S.D.	H.B. (2) Mean S.D.	Floor (3) Mean S.D	Rings (4) Mean S.D.
CM height at release	2.27 (0.23)	2.690.14)	1.12(0.06)	2.44 (0.16)
CM horizontal velocity at release	-1.02(0.20)	0.93(0.62)	-2.98(0.50)	-0.16(0.14)
CM vertical velocity at release	2.12 (0.45)	4.74(0.33)	4.34(0.47)	2.74 (0.50)

Effect Size Values b/w Groups					
1 v 2	1 v 3	1 v 4	2 v 3	2 v 4	3 v 4
-0.66	1.82	-0.27	2.48	0.4	-2.09
0.08	-1.74	0.76	-1.82	0.68	2.5
-2.21	-1.88	-0.52	0.34	1.69	1.35

4.1.1 CM height at release/take-off

This linear position value represents the distance of the CM, with the right heel on the floor, to the vertical height of the subject's CM position at the instant of release, first frame non-contact.

The mean CM height at release/take-off for group 1 (parallel bars) was 2.27 ± 0.23m, for group 2 (horizontal bar) 2.69 ± 0.14m, for group 3 (floor) 1.12 ± 0.06m, and for group 4 (rings) 2.44 ± 0.16m. This variable was found to be significant at the $p<.01$ level.

Effect size data for this variable indicate moderate differences between groups 1v2 (ES= -0.66), and a very large difference between groups 1v3 (ES= 1.82). Small effect size data was found between groups 1v4 (ES = -0.27), and the largest effect size data was found between groups 2v3 (ES = 2.48). Moderate differences between groups 2v4 were recorded (ES = 0.40), and large differences were found between groups 3v4 (ES= -0.52). There was very little difference in the amount of within group variability among all groups (G 1, S.D.= .23m; G2, S.D.= .14m; G 3, S.D.= .06m; and G 4, S.D.= .16m).

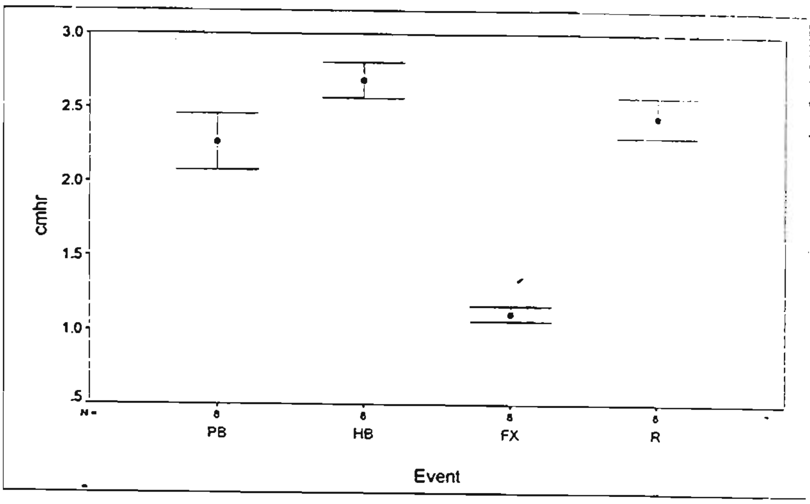


Chart 4.1.1 Group mean values for CM height at release/take-off

4.1.2 CM horizontal velocity at release/take-off

The CM horizontal velocity at release/take-off, which is determined by the precision and correct timing of the entry skill, represents a very important kinematic parameter relative to the whole landing process. It contributes to the successful achievement of a controlled landing.

The mean CM horizontal velocity at release/take-off for group 1 (parallel bars) was -1.02 ± 0.20m/s, for group 2 (horizontal bar) 0.93 ± 0.62m/s, for group 3 (floor) -2.98 ± 0.50m/s, and for group 4 (rings) -0.16 ± 0.14m/s. This variable was found to be significant at the $p<.01$ level.

The effect size data for this variable showed a very small difference between groups 1v2 (ES = 0.08), and high effect size data was recorded for groups 1v3 (ES=1.39). There was a moderate to large difference between groups 1v4 (ES=0.76), large effect size value for groups 2v3 (ES=-1.82), and again moderate differences between groups 2v4 (ES=0.68). The largest difference was evident between groups 3v4 (ES=2.50), which showed the difference on floor (-2.98m/s) compared to rings (-0.16m/s), to be 2.82m/s. There was no significant difference in the amount of within group variability among all groups (G 1, S.D.= .20m/s; G2, S.D.= .62m/s; G 3, S.D.= .5m/s; and G 4, S.D.= .14m/s).

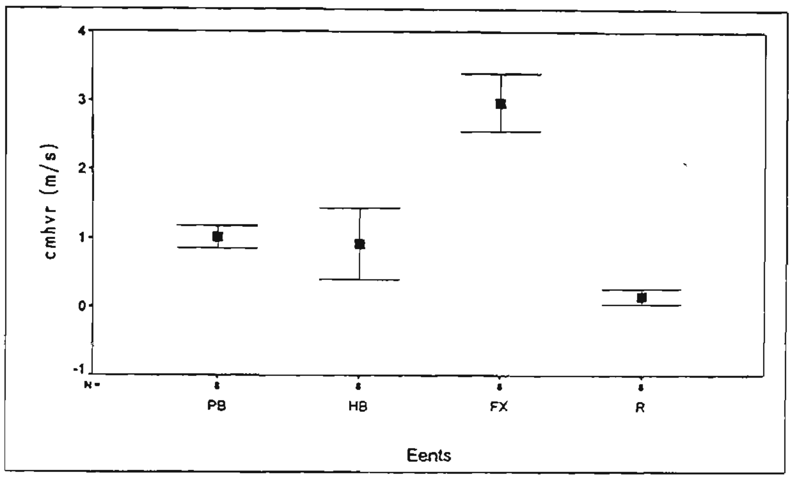


Chart 4.1.2 Group mean values for CM horizontal velocity at release/take-off

4.1.3 CM vertical velocity at release/take-off

The CM vertical velocity at release/take-off, which is determined by the precision and correct timing of the entry skill, determines the maximum CM height during flight, the largest vertical displacement and, subsequently, the vertical impact velocity. Its magnitude influences the outcome for the successful achievement of a controlled landing.

The mean CM vertical velocity at release/take-off for group 1 (parallel bars) was 2.12 ± 0.45m/s, for group 2 (horizontal bar) 4.74 ± 0.33m/s, for group 3 (floor) 4.34 ± 0.47m/s, and for group 4 (rings) 2.74 ± 0.50m/s. This variable was found to be significant at the $p<.001$ level.

The effect size data for this variable also show moderate to large differences between all groups. The largest effect size values were recorded for the groups 1v2 (ES = -2.21), with the value for parallel bars of 2.12m/s, compared to the value recorded for horizontal bar of 4.74m/s. A high effect size data was also recorded for groups 1v3 (ES= -1.88), the value of this variable on parallel bars was 2.12m/s, compared to that on floor of 4.34m/s, a difference of 2.22m/s, > 50% for floor. There were moderate differences between groups 1v4 (ES= -0.52), and low to moderate effect size was recorded for groups 2v3 (ES= 0.34). Large differences were also recorded between groups 2v4 (ES= 1.69), and groups 3v4 (ES= 1.35). All groups demonstrate low variability (G 1, S.D.= .45m/s; G2, S.D.= .33m/s; G 3, S.D.= .47m/s; and G 4, S.D.= .50m/s).

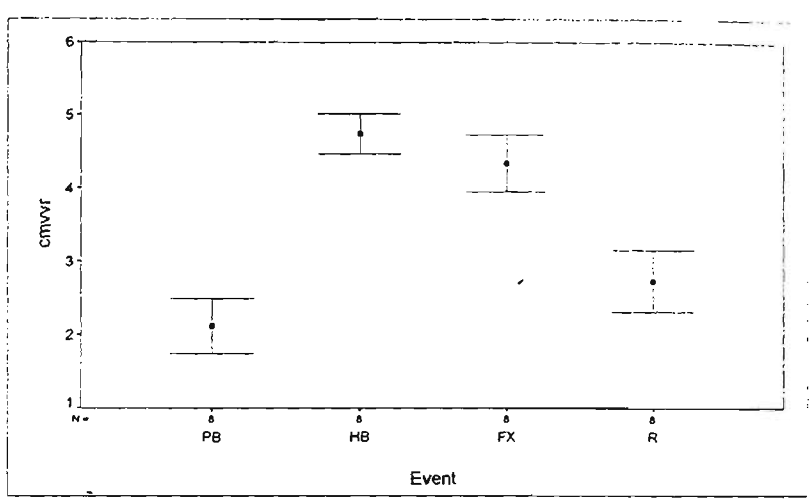


Chart 4.1.3 Group mean values for CM vertical velocity at release/take-off

4. 2 Flight Phase

The group kinematic mean, standard deviation and effect size data from the flight phase are presented below. The flight phase (deterministic model levels 11-15) includes all frames of non-contact between the release phase and the landing phase.

Table 4.2.1 Kinematic data and effect size for the flight phase

Variables	P.B. (1) Mean S.D.	H.B. (2) Mean S.D.	Floor (3) Mean S.D.	Rings (4) Mean S.D.
CM horiz. displ. release to t/d	0.46 (0.15)	1.13 (0.55)	2.25 (0.24)	0.16 (0.07)
Flight time release to t/d	0.86 (0.05)	1.25 (0.09)	0.99 (0.04)	0.91 (0.04)
Max. CM height in flight	2.53 (0.11)	3.83 (0.10)	2.18 (0.13)	2.77 (0.05)

Effect Size Values b/w Groups					
1 v 2	1 v 3	1 v 4	2 v 3	2 v 4	3 v 4
-0.77	-2.05	0.34	-1.28	-1.11	2.39
-2.39	0.80	-0.31	1.59	2.08	0.49
-2.05	0.55	-038	2.60	1.67	-0.93

4.2.1 CM horizontal displacement release/take-off to touch-down

These linear displacement values represent the differences between the CM position at the instant of release or take-off, first frame non-contact, to landing touch-down, first frame contact.

The mean CM horizontal displacement release/take-off to touch-down for group 1 (parallel bars) was 0.46 ± 0.15m, for group 2 (horizontal bar) 1.13 ± 0.55m, for group 3 (floor) 2.25 ± 0.24m, and for group 4 (rings) 0.16 ± 0.07m. This variable was found to be significant at the $p<.001$ level.

Effect size data for this variable show large differences between all groups except for group 1v4, which shows a low to moderate difference (ES = 0.34). Groups 1v2 show a large difference (ES = -0.77), and very large differences were recorded between groups 1v3 (ES = -2.05). A large mean difference was recorded between groups 2v3 (ES = -1.28), and groups 2v4 (ES = 1.11). The largest mean difference was recorded between groups 3v4 (ES = 2.39). This result suggests that the landing technique on floor compared to the rings has to be considerably different.

All groups demonstrate very low variability (G 1, S.D. = .15m; G 3, S.D. = .24m; and G 4, S.D. = .07m), except group 2 (G2, S.D. = .55m).

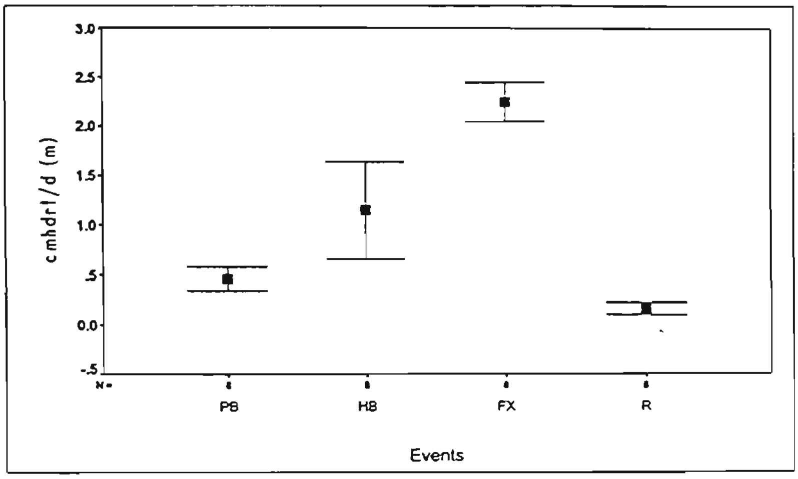


Chart 4.2.1 Group mean values for CM horizontal displacement release to touch-down

4.2.2 Flight time release/take-off to touch-down

The flight time from release/take-off to landing touch-down is a temporal quantity, indicating the flight duration of the subject's CM linear

displacement from release/take-off to touch-down.

The mean flight time release/take-off to touch-down for group 1 (parallel bars) was 0.86 ± 0.05sec, for group 2 (horizontal bar) 1.25 ± 0.09sec, for group 3 (floor) 0.99 ± 0.04sec, and for group 4 (rings) 0.91 ± 0.04seconds. This variable was found to be significant at the p<.001 level.

The effect size data for this variable shows for groups 1v2 the largest differences (ES = -2.39), and large differences between groups 1v3 (ES = -0.88). Low to moderate effect size data was found between groups 1v4 (ES = -0.31), and a large mean difference was evident between groups 2v3 (ES = 1.59), which indicates, that the difference on horizontal bar (1.25sec) to floor (0.99sec), was 0.26 seconds. This result suggests that a gymnast on horizontal bar has more preparation time for the landing than on any other event. There was also a large difference between groups 2v4 (ES = 2.08), and a moderate difference between groups 3v4 (ES = 0.49). All groups demonstrate very low variability (G 1, S.D. = .05sec; G2, S.D.= .09sec; G 3, S.D. = .04sec; and G 4, S.D. = .04sec).

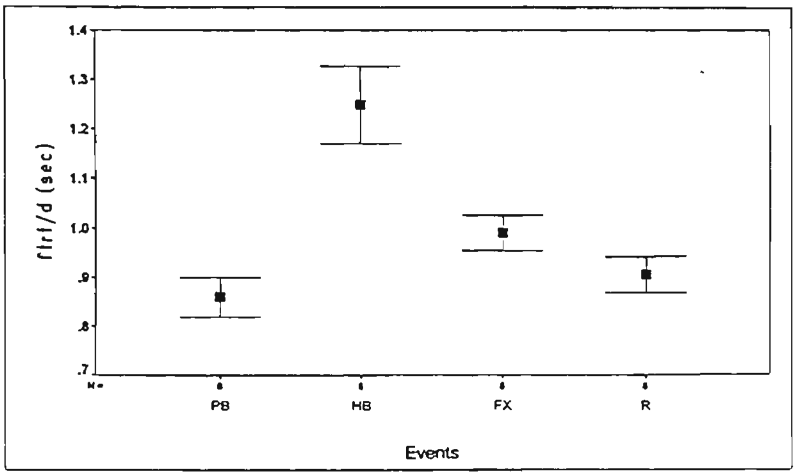


Chart 4.2.2 Group mean values for flight time release/take-off to touch-down

4.2.3 Maximum CM height in flight

This linear position value represent the difference between the CM position at its highest point during flight and the CM position (right toes on floor) at landing touch-down.

The mean maximum CM height in flight for group 1 (parallel bars) was 2.53± 0.11m, for group 2 (horizontal bar) 3.83 ± 0.10m, for group 3 (floor)2.18 ± 0.13m, and for group 4 (rings) 2.77 ± 0.05m. This variable was found to be significant at the $p<.001$ level.

Effect size data for this variable shows a large differences between groups 1v2 (ES = -2.05) and moderate differences between groups 1v3 (ES = 0.55). The largest differences were between groups 2v3 (ES = 2.60), and also very large differences between groups 2v4 (ES = 1.67). Small to moderate effect size data were recorded for groups 1v4 (ES =-0.38), and moderate differences between groups 3v4 (ES = -0.93). There was very little difference in the amount of within group variability among all groups (G 1, S.D. = .11m; G2, S.D. = .10m; G 3, S.D. = .13m; and G 4, S.D. = .05m).

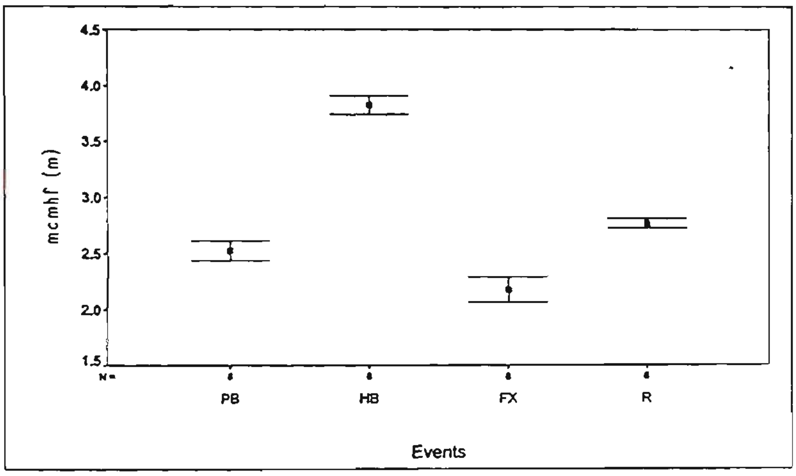


Chart 4.2.3 Group mean values for maximum CM height in flight

4.3 Landing Phase

All group mean kinematic, standard deviation and effect size data from the landing phase are presented in Table 4.3.1. The landing phase includes all frames from landing touch-down (first frame feet contact with landing surface), to CM height minimum (the lowest body position of the landing phase).

Table 4.3.1 Kinematic data for all variables from the landing phase

Variables	P.B. (1) Mean S.D.	H.B. (2) Mean S.D.	Floor (3) Mean S.D.	Rings (4) Mean S.D.	Effect Size Values b/w Groups 1 v 2	1 v 3	1 v 4	2 v 3	2 v 4	3v4
CM height t/d	0.74 (0.05)	0.84 (0.07)	0.72 (0.07)	0.76 (0.05)	-1.31	0.26	-0.26	1.57	1.05	-0.52
Landing phase displacement	0.17 (0.08)	0.25 (0.11)	0.08 (0.03)	0.18 (0.03)	-0.89	0.96	-0.11	1.86	0.78	-1.07
Angle CM to gr. cont.& hor.t/d	86 (5.80)	94 (2.20)	63 (7.24)	87 (4.17)	-0.6	1.80	-0.06	2.41	0.55	-1.86
CM horiz. vel. at t/d	-0.49(0.26)	0.93 (0.49)	-2.06(0.29)	-0.09(0.09)	-1.26	1.39	-0.41	2.65	0.90	-1.74
CM vertical velocity at t/d	-5.42(0.42)	-7.02(0.37)	-4.89(0.49)	-6.00(0.09)	1.79	-0.59	0.65	-2.38	-1.14	1.24
Hip angular velocity at t/d	221 (83)	602 (104)	398 (264)	254 (153)	1.73	0.81	0.15	-0.93	-1.59	-0.66

4.3.1 CM height at touch-down

This linear position value represents the distance from the right heel on the floor, to the vertical height of the CM position of the subject at touch-down. The mean CM height at touch-down for group 1 (parallel bars) was 0.74 ± 0.05m, for group 2 (horizontal bar) 0.85 ± 0.07m, for group 3 (floor) 0.72 ± 0.07m, and for group 4 (rings) 0.76 ± 0.05m. This variable was found to be significant at the $p<.01$ level.

Effect size data for this variable show large differences between groups 1v2 (ES= -1.31), and small differences between groups 1v3 (ES = 0.26) and groups 1v4 (ES =-0.26). The largest effect size data was found between groups 2v3 (ES = 1.57), large differences between groups 2v4 (ES = 1.05), and moderate differences between groups 3v4 (ES= -0.52). There was very little difference in the amount of within group variability among all groups (G 1, S.D. = .05m; G2, S.D. = .07m; G 3, S.D. = .07m; and G 4, S.D. = .05m).

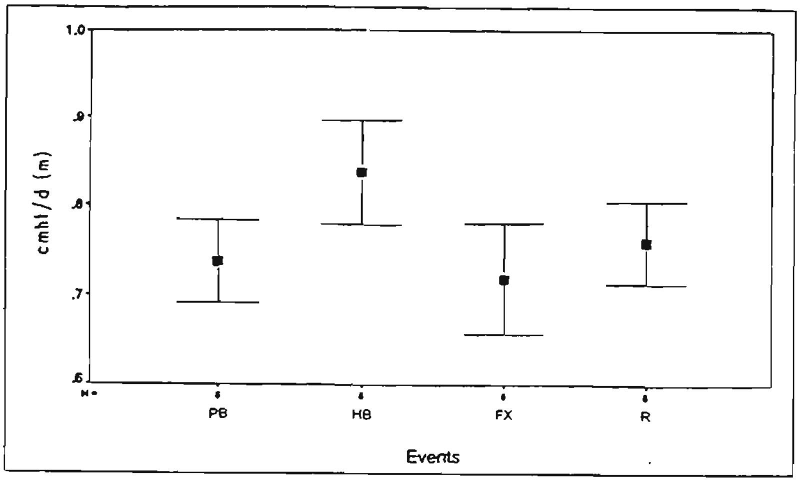


Chart 4.3.1 Group mean values for CM height at touch-down

4.3.2 Landing phase displacement

This linear displacement value represents the difference between the CM position at landing touch-down, from first frame contact, to the CM minimum vertical position. The mean landing phase displacement for group 1 (parallel bars) was 0.17 ± 0.08m, for group 2 (horizontal bar) 0.25 ± 0.11m, for group 3 (floor) 0.08 ± 0.03m, and for group 4 (rings) 0.18 ± 0.03m. This variable was found to be significant at the $p<.01$ level.

Effect size data for this variable show small differences for groups 1v4 (ES = -0.11). Groups 1v2 show large differences (ES = -0.89), and there were also large mean differences between groups 1v3 (ES = 0.96). The largest mean difference were between groups 2v3 (ES=1.86), which indicates, that the mean values for horizontal bar (0.25m), to those on floor (0.08m), present a difference of 0.17 meters, more than 3 times the landing phase displacement is required to reduce the impact forces from the horizontal bar. This result is consistent with the findings from previous studies by McNitt-Gray (1989, 1993b and 1994 et al.) that with increased impact velocities, longer landing phase displacements and durations were observed.

There was a difference in the amount of within group variability among all groups

(G 1, S.D.= .08m; G2, S.D.= .11m; G 3, S.D.= .03m; and G 4, S.D.= .03m).

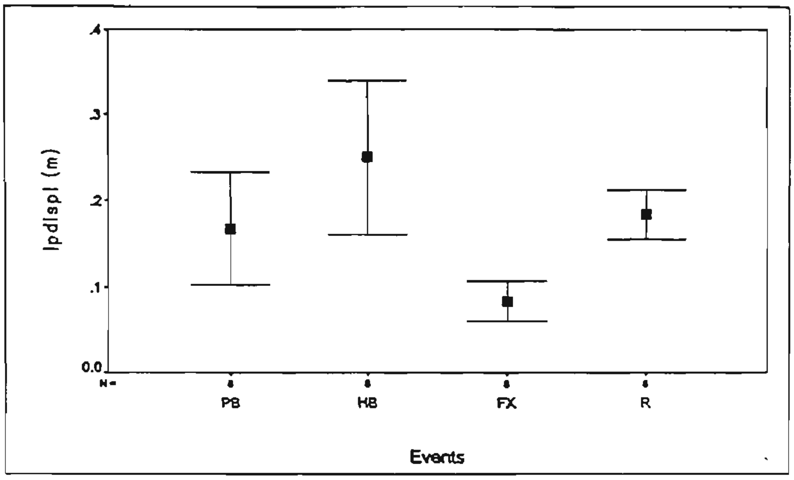


Chart 4.3.2 Group mean values for landing phase displacement

4.3.3 *CM horizontal velocity at touch-down*

The CM horizontal velocity at landing touch-down, which is a product of the horizontal velocity at release, constitutes an important kinematic parameter for the successful achievement of a controlled landing.

The mean CM horizontal velocity at touch-down for group 1 (parallel bars) was -0.49 ± 0.26m/s, for group 2 (horizontal bar) 0.93 ± 0.49m/s, for group 3 (floor) -2.06 ± 0.29m/s, and for group 4 (rings) -0.09 ± 0.09m/s. This variable was found to be significant at the p<.001 level.

The effect size data for this variable show moderate to large differences between all groups. Groups 1v2 show a high difference (ES = -1.26), were the value for this variable on parallel bars was -0.49m/s (the negative sign indicates a horizontal velocity in the backward direction), compared to the value recorded (0.93m/s) on horizontal bar (on horizontal bar, all analysed dismounts possessed a forward horizontal velocity). High effect size data was recorded for groups 1v3 (ES = 1.39), which indicates, that the value of this variable on parallel bars was -0.49m/s, compared to that on floor was

-2.06m/s, a difference of 1.57 m/s, which is 3 times the horizontal velocity a gymnast has to overcome on floor compared to that on parallel bars. Moderate effect size data were recorded between groups 1v4 (ES = -0.41). The largest effect size data was recorded for groups 2v3 (ES = 2.65) and large differences were also recorded between groups 2v4 (ES = 0.90). A large difference was also evident between groups 3v4 (ES = -1.74), which showed the difference on floor (-2.06m/s) compared to rings (-0.09m/s), was 1.97m/s. These results indicate that the landing techniques on all events are to be considerably different due to the differences in horizontal velocity at landing.

There were relatively low differences in the amount of within group variability among all groups (G 1, S.D. = 0.26m/s; G2, S.D. = 0.49m/s; G3, S.D. = 0.29m/s), except for group 4, which showed very low within group variability (G 4, S.D. = 0.09m/s).

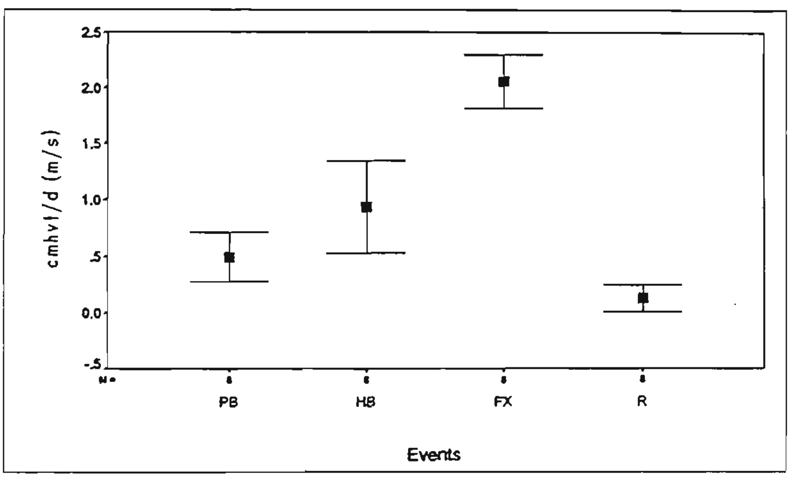


Chart 4.3.3 Group mean values for CM horizontal velocity at landing touch-down

4.3.4 CM vertical velocity at touch-down

The CM vertical velocity at landing touch-down (the vertical impact velocity), constitutes an important variable for successful landing performance. The mean CM vertical velocity at touch-down for group 1 (parallel bars) was -5.42 ± 0.42m/s, for group 2 (horizontal bar) -7.02 ± 0.37m/s, for group 3 (floor) -4.89 ± 0.49m/s, and for group 4 (rings) -6.00 ± 0.09m/s. This variable was found to be significant at the $p<.001$ level.

Effect size data for this variable also show moderate to large differences between all groups. Groups 1v2 show a very high difference (ES = 1.79), and moderate effect size data was recorded for groups 1v3 (ES = -0.59), and between groups 1v4 (ES= 0.65). The largest effect size values were recorded for groups 2v3 (ES= -2.38), which indicates, that the value on horizontal bar of -7.02m/s, compared to that on floor (-4.89m/s), showed an absolute difference of 2.13 m/s, with an impact velocity of >30% more on horizontal bar compared to that on floor. Large differences were also recorded between groups 2v4 (ES = -1.14), and groups 3v4 (ES = 1.24). These results indicate that the landing techniques on all events have to be adjusted considerably according to the different vertical impact velocities across events.

For this variable there were also relatively low differences in the amount of within group variability among all groups (G1, S.D. = 0.42m/s; G2, S.D. = 0.37m/s; G3, S.D. = 0.49m/s), except for group 4, which showed very low within group variability (G 4, S.D. = 0.09m/s).

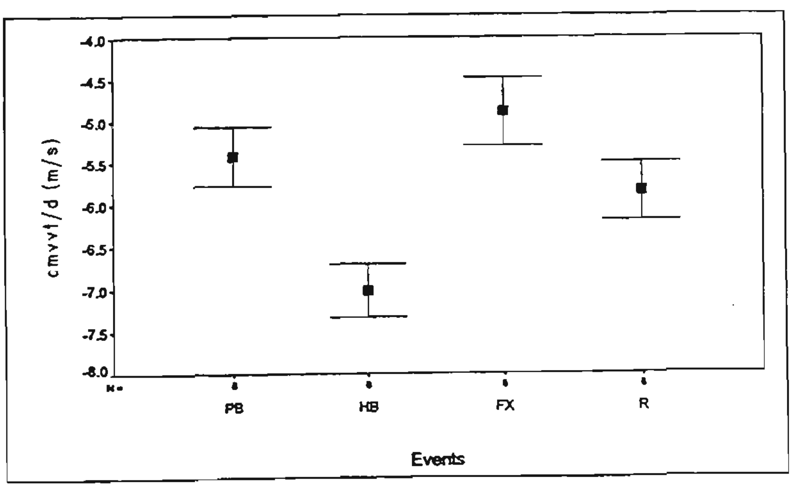


Chart 4.3.4 Group mean values for CM vertical velocity at landing touch-down

4.3.5 Angle CM to ground contact and the horizontal at landing touch-down

The mean angle CM to ground contact (toes contact with the landing surface) and the horizontal at landing touch-down, represents the "leaning angle", the most important angle for controlling falling backwards or forwards during the landing process.

The mean angle CM to ground contact and the horizontal at landing touch-down for group 1 (parallel bars) was 86 ± 5.80°, for group 2 (horizontal bar) 94 ± 2.20°, for group 3 (floor) 63 ± 7.24°, and for group 4 (rings) 87 ± 4.17°. This variable was found to be significant at the $p<.001$ level.

There are relatively large differences in group variability. Groups 2 and 3 represent the extremes for this variable, with group 2 (S.D. = 2.20°) representing the lowest values, and group 3 (S.D. = 7.24°) the highest value. The ANOVA and post-hoc test data indicate that group 3 has the smallest mean angle and is significantly different from groups 1, 2 and 4. The small mean "forward lean angle" can be attributed to the large CM horizontal velocity backwards (2.06m/s). The large within group variability (7.24°) is largely due to over- or under rotation of the double backward somersault. Group 2 is different to all other groups showing the highest value for the mean "lean angle" (94°). This is due to that horizontal bar landings result in landings with backward rotation and forward horizontal velocity. Groups 1 and 4 show an upright lean angle (86 & 87°) respectively, which can be attributed to a very small to moderate CM horizontal velocity backwards (0.09 & 0.49m/s).

All of the mean angular position values determined for each group are illustrated in Figure 4.3.5.

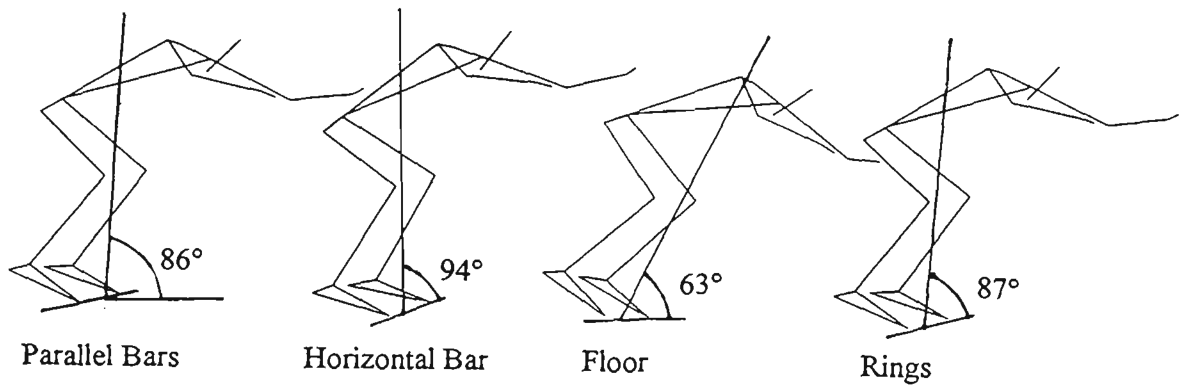


Figure 4.3.5 Group mean values for angle: CM to ground contact and the horizontal at landing touch-down

The effect size data for this variable (acmght/d) shows for groups 1v2 moderate values (ES = -0.60). Large effect size data was evident between groups 1v3 (ES =1.80) with mean values on parallel bars of 86°, compared to those on floor (63°), a difference of 23°. This result indicates that there are considerably different landing conditions for these events. A very low effect size data between groups 1v4 (ES = -0.06) was found, and, the largest effect size data was evident between groups 2v3 (ES = 2.41), which shows a value for the horizontal bar of 94°, and for floor 63°, a difference of 31°. This result indicates that completely different landing techniques are to be employed on these events. Moderate differences between groups 2v4 (ES = 0.55) were recorded. A very high effect size data was also recorded between groups 3v4 (ES = -1.86), which shows the acmght/d on floor (63°), to the rings (87°), a difference of 24°. This result indicates that different landing techniques also have to be employed on these two events.

4.3.6 Hip angular velocity at touch-down

The hip angular velocity at landing touch-down represents the speed at which the trunk segment meets the thigh segment during closing at the hip joint, at the moment of feet contact with the landing surface.

The mean hip angular velocity at landing touch-down for group 1 (parallel bars) was -221± 83 deg/sec, for group 2 (horizontal bar) -602 ± 104 deg/sec, for floor -398 ± 264 deg/sec, and for group 4 (rings) -254 ± 153 deg/sec. This variable was found to be significant at the p<.02 level.

The effect size data for this variable shows the highest value for groups 1v2 (ES = 1.73), which shows a value on parallel bars of -221deg/sec compared to horizontal bar -602 deg/sec, a difference of 381 deg/sec. This result suggests that the large difference in angular velocity between these two groups is due to the anticipation the subjects experience in landings on horizontal bar. Because the subjects showed a "kickout or rapid body extension immediately following the salto(s) backward in midair" (Takei et al., 1992, p.224), this provides them with more preparation time before landing, and are therefore able to land with a more extended body position. This allows the subjects to absorb the landing forces in an optimally controlled and timed manner. For example, during the first two frames at landing touch-down, subject 2 reduced the angular velocity from -734 to -256 deg/sec on horizontal bar, and subject 4 from -313 to -157 deg/sec on parallel bars.

Large differences in effect size data was recorded between groups 1v3 (ES=-0. 81), and the lowest effect size data was found between groups 1v4 (ES = -0.15). Large differences were found between groups 2v3 (ES = -0.93), and between groups 2v4 (ES = -1. 59); and moderate effect size data was recorded between groups 3v4 (ES = -0.66). There were very large difference in the amount of within group variability among all groups (G 1, S.D. = 83 deg/sec; G2, S.D. = 104 deg/sec; G 3, S.D.= 264 deg/sec; and G 4, S.D. = 153 deg/sec).

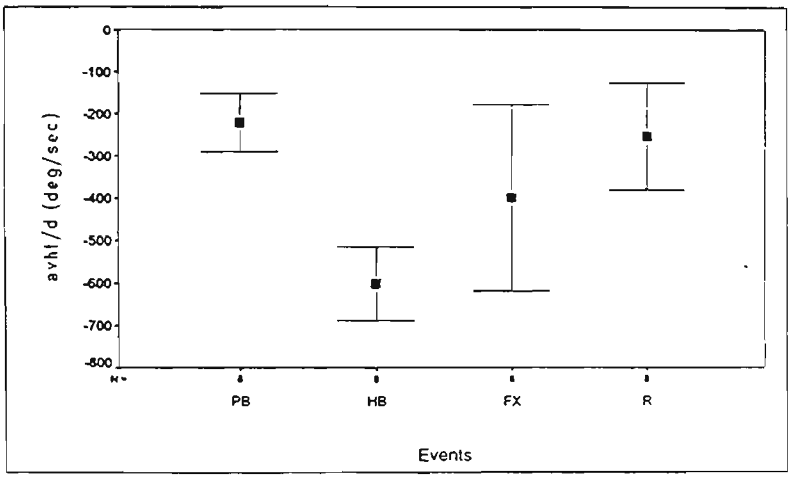


Chart 4.3.5 Group mean values for hip angular velocity at touch-down

4.4 Landing Score

The landing score has been included in this section because of its importance to the overall analysis of the landing performances. The landing score represents a qualitative evaluation of landing performances from video evaluated by two internationally qualified judges and one gymnastics expert.

Presented in Table 4.4.1 are the mean values and standard deviations for the landing scores for the four groups.

Table 4.4.1 Mean values and standard deviation for judges landing scores on parallel bars, horizontal bar, floor and rings, expressed in percentage

Event	Judge	Gymnast 1	2	3	4	5	6	7	8	Mean (%)	S.D.
Parallel Bars	1	83.34	94.44	72.22	88.89	83.34	77.78	72.22	66.67	79.17	9.27
	2	72.22	77.78	88.89	94.44	72.22	77.78	88.89	83.34	84.03	7.53
	3	77.78	88.89	77.78	88.89	77.78	77.78	77.78	72.22	79.86	5.89
	Mean	77.78	87.04	81.48	90.74	77.78	77.78	79.63	74.08	81.02	5.40
Horizontal Bar	1	61.11	55.56	77.78	72.22	66.67	61.11	72.22	77.78	68.06	8.27
	2	66.67	77.78	88.89	83.34	72.22	83.34	77.78	66.67	77.09	8.10
	3	61.11	61.11	83.34	72.22	61.11	66.67	77.78	72.22	69.44	8.40
	Mean	62.96	64.82	83.34	75.93	66.67	70.37	75.93	72.22	71.53	6.78
Floor	1	77.78	86.67	77.78	88.89	83.34	88.89	61.11	61.11	78.2	11.41
	2	83.34	83.34	88.89	94.44	66.67	88.89	61.11	55.56	77.78	14.55
	3	79.63	82.22	83.34	88.89	77.78	88.89	55.56	55.26	76.45	13.56
	Mean	80.25	84.08	83.34	90.74	75.93	88.89	59.26	57.21	77.46	12.74
Rings	1	72.22	88.89	88.89	55.56	77.78	83.34	77.78	83.34	78.47	10.89
	2	72.22	88.89	77.78	77.78	83.34	83.34	88.89	88.89	82.64	6.26
	3	77.78	88.89	83.34	61.11	77.78	83.34	77.78	77.78	78.47	8.10
	Mean	74.07	88.89	83.34	64.82	79.63	83.34	81.48	83.34	79.86	7.37

The mean landing score on floor was 77.46 ± 12.74%, for the rings 79.86 ± 7.37%, for parallel bars 81.02 ± 5.40%, and for horizontal bar 71.53 ± 6.78%. This variable was found to be significant at the $p<.02$ level.

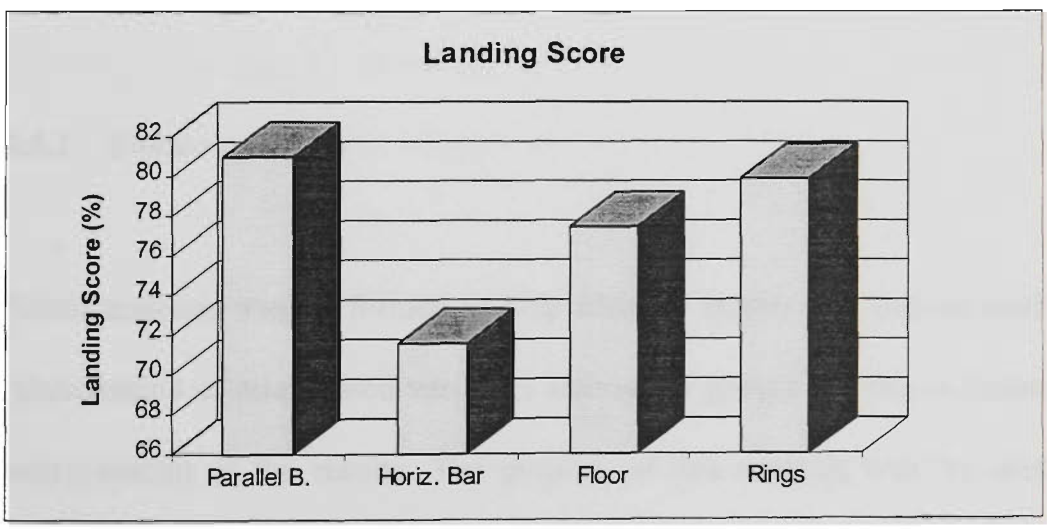


Chart 4.4.1 Group mean values for the landing scores of the four events investigated

The largest effect size value was recorded for groups 1v2 (ES = 2.20); large effect size data was also recorded for groups 1v3 (ES= 0.76), groups 2v3 (ES = -1.45), and, for groups 2v4 (ES = -2.03). Low differences in effect size data was recorded between groups 1v4 (ES = 0.17), and moderate difference between groups 3v4 (ES = -0.59). Groups 1, 2 & 4 demonstrate relatively low variability (G 1, S.D.= 4.54%; G 2, S.D. = 6.78%; G 4, S.D.= 7.37%) compared to group 3 (S.D. = 12.74%).

4. 5 Identification of Different Landing Techniques

The attempt to identify several distinctly different landing techniques are reported here. This investigation involved applying a factor analysis to help identify factors that can be used to represent relationships of interrelated variables among the groups landing techniques, and a cluster analysis was performed to (1) find how many subgroups amongst the 32 cases (subjects) were identified using similar landing strategies, and (2) find homogeneous groups of variables used by subjects who performed controlled landings.

4.5.1 Factor Analysis

Factor analysis was performed to help identify factors that can be used to represent relationships of interrelated variables among the groups landing techniques and to aid interpretation of the results. The purpose of this analysis was "to identify the not-directly-observable factors" (Norusis, 1994, p.48), which constitute good landing techniques among groups, based on all variables measured.

For example, landing technique might be expressed as:

landing technique = a (release) + b (flight phase) + c (landing phase)

or

controlled landings = a (optimal release properties) + b (optimal flight properties)

+ c (optimal landing properties)

This analysis was performed using the principle components method available on the SPSS statistical software package. In this method, variables are assumed to be exact linear combinations of factors. All release variables, flight phase variables, and the variables from landing touch-down (landing impact variables), were considered for analysis. The results of these tests, as well as the results from a principle factor analysis scree plot, suggested 4 factors were recognised out of 19 variables. Table 4.5.1 shows the orthogonal rotated factor pattern for these 4 factors after varimax rotation. In general, most of the variables were strongly associated with factors 1 & 2 in all three phases. Although a few variables exhibited moderate to high factor loadings (i.e. 0.6-0.8). Appendix 4 includes rotated factor matrix, final statistics (communality, factors, eigenvalue, and percentage of variance) factor scree plot, and factor plot in rotated factor space.

Table 4.5.1.1 Orthogonal rotated factor pattern for the nineteen variables analysed

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Release/Take-Off				
CM horiz. displ. release to t/d	98			
CM horiz. velocity at release	92			
CM height at release	-78			
CM vert. vel. at release	66	64		
Flight Phase				
Max. CM height in flight		77		
Flight time release to t/d		72		
Landing Phase				
CM horiz. velocity at t/d	97			
Angle: CM to ground cont.& horiz.at t/d	-72			54
CM height t/d		83		
Angle: trunk to horizontal at t/d		75		
Hip angle at touch-down		71		
CM vertical velocity at t/d		-62		
Angle arm trunk at touch-down		53		
Knee angle at touch-down			82	
Knee angular velocity at t/d			76	
Ankle angle at touch-down			72	
Hip angular velocity at t/d			59	
Ankle angular velocity at t/d				81
Angle: thigh to horizontal at t/d				72

Note: Table includes factor loadings of 0.5 or higher; decimal points are omitted

Almost 70% of the total variance is attributed to the first three factors, with more than half of that variation (35.9 %) being associated with the first factor. The remaining 16 variables together account for only 30.1% of the variance. Thus, "a model with three factors will be adequate to represent the data" as suggested by Norusis (1994, p.54), which is also evident in Table 4.5.1 and from the factor scree plot. Norusis (1994) suggests that "several procedures have been proposed for determining the number of factors to use in a model. One criterion suggests that only factors that account for variances greater than 1 (eigenvalue >1) should be included. Factors with a variance less than 1 are no better than a single variable, since each variable has a variance of 1" (p. 54).

A very interesting observation can be obtained from the rotated factor matrix. Factor 1 includes all variables from the release phase and two variables from the landing phase, and the first three variables (cmhvr, cmhdrt/d, and the cmhvt/d) are directly related to one another. It is the authors belief that the CM horizontal velocity at release (take-off), which determines the CM horizontal displacement from release to landing touch-down and the subsequent CM horizontal velocity at landing touch-down, is the most crucial variable for controlled landings. The CM height at release (cmhr) and the CM vertical velocity at release (cmvvr) are also deemed to be important release properties. The angle CM to ground contact and the horizontal at landing touch-down (acmght/d) constitutes the most crucial angle for controlled landings.

Factor 2 includes the variables from the flight phase, the landing phase and one variable from release/take-off. The variables which are identified in factor 1 and 2 constitute the most important variables for controlled landings.

Factors 3 and 4 contain variables of angular positions and angular velocities conclusively.

The three-dimensional factor plot in rotated factor space (see Appendix 4) illustrates the variables using the factor loadings as coordinates.

The regression factor score chart (Appendix 4) provides a visual illustration of the distribution of the four events. The gymnasts landing performances on floor and horizontal bar represent separate distinct groupings, and the gymnasts landing performances on rings and parallel bars are grouped together. This result suggests that the gymnasts landing performances on horizontal bar are quite different to those of all other groups. This can be explained that landing performances on horizontal bar proceed more complex dismounts possessing backward rotations and a <u>forward</u> horizontal velocity (0.93m/s), and a large vertical impact velocity (-7.02m/s). The gymnast's landing performances on floor also constitute multiple three-dimensional acrobatic tumbling skills with backward rotations, however, with a relatively high <u>backward</u> horizontal velocity (2.06m/s), and a vertical impact velocity of -4.89m/s. The third group, the gymnasts landing performances on parallel bars and rings also constitute multiple three-dimensional dismounts with backward rotations, but with a relatively small <u>backward</u> horizontal velocity of 0.49 and 0.09m/s, and a vertical impact velocity of -5.42 and -6.0m/s respectively.

4.5.2 Cluster Analysis

Cluster analysis was employed to describe the multivariate aspect of the data. This procedure grouped similar performances into a small number of groups (clusters) based on certain criteria. The criterion used in this cluster analysis to group similar landing techniques was that they have similar landing characteristics coming from relatively homogeneous groups of subjects.

Romesburg (1979) states that "cluster analysis is the generic term of data analysis techniques for appraising similarities among a group of subjects or cases (or gymnasts when related to gymnastic landing performances), described by measurements made on their attributes" (p.144). Cluster analysis provides an objective procedure for describing and classifying phases of motion. Wilson and Howard (1983) used the cluster procedure to describe the movement pattern adopted in subjects executing a dynamic movement, the backstroke swim start. The objective of the cluster procedure used was to describe the movement with a minimum of modal action patterns (MAPs) or representative postures which are different from each other and can distinguish between the movement patterns for subjects and trials.

There are a number of algorithms to perform cluster analysis, however, they fall into one of two general approaches. For this study, agglomerative hierarchical clustering was used, where "clusters are formed by grouping cases into bigger and bigger clusters until all cases are members of a single cluster" (Norusis, 1994, p.85). The agglomerative schedule displays the cases or clusters combined at each stage, the distance between the cases or clusters being combined, and the last cluster level at which a case (or variable) joined the cluster, so you can trace the merging of clusters.

A methodological problem in applying cluster analysis involves the decision on "which variables will serve as the basis for cluster formation, how will the distance between cases be measured, and what criteria will be used for combining cases into clusters?" (Norusis, 1994,p. 83).

The variables considered for analysis were those which seemingly have a direct influence on controlled landing performance. Subsequently, twenty-one variables were identified from the release, the flight phase, and the landing phase.

The decision on whether or not to standardise the input variables provides another methodological problem in applying cluster analysis. There is considerable debate in the literature with some studies recommending the procedure and others suggesting that it may not be desirable.

Milligan and Cooper (1987) found variable standardisation can improve recovery of the true cluster structure but is only one of several considerations in cluster analysis. They concluded that minimisation of different forms of error in the data and the selection of an effective clustering method appear to offer a greater return in terms of cluster recovery.

However, it is generally conceded that variables should be transformed if there are large variances involved, as variables with large variances tend to have more effect on the resulting clusters than those with small variances. To further complicate the problem there are numerous approaches to variable standardisation. There are many different definitions of distance and similarity. Selection of a distance measure should be based both on the properties of the measure and on the algorithm for cluster formation. The most commonly used distance measure is the 'squared Euclidean distance', which is the sum of the squared differences over all of the variables. The squared Euclidean distance has the disadvantage that it depends on the units of measurement for the variables. The SPSS software package also offers a 'Z-score' formula which transforms variables to have a mean of 0 and a standard deviation of 1. Milligan and Cooper (1987) concluded from a study of seven different variable standardisation methods, including the Z-score formula, that standardisation by division by the range of the variable consistently aids in cluster recovery and was robust across a variety of conditions. These conditions included separation distances, clustering methods, error conditions, and coverage levels.

4.5.2.1 Cluster Analysis for Cases

For the cases (subjects, landing performances) analysis, the 'squared Euclidean distance'(interval) for variable standardisation was selected and the method for standardisation chosen was Z-scores.

Norusis (1994) states that "clustering methods fall into three groups: linkage methods, error sums of squares or variance methods, and centroid methods" (p. 97). For this analysis, the cluster method "average linkage between groups, often called UPGMA (unweighted pair-group method using arithmetic averages), was selected. This method, defines the distance between two clusters as the average of the distances between all pairs of cases in which one member of the pairs is from each of the clusters. This differs from the linkage methods in that it uses information about all pairs of distances, not just the nearest or the furthest. For this reason it is usually preferred to the single and the complete linkage methods for cluster analysis" (p. 97).

The 'transform values' group allows you to standardise data values for either cases or variables before computing proximities. For this study, separate computations were performed for both cases and variables.

Once the distance measure was computed, the 'transform measures' group was applied and 'absolute values' were used for the distances since only the magnitude of the relationship is of interest. The 'cluster membership' alternatives display the cluster to which each case is assigned at one or more stages in the combination of clusters. The 'range of solutions' (2-6 clusters) was chosen because it requests membership of each case at each stage within a range.

Although the purpose of cluster analysis is to reduce the data to several distinct subgroups, there are no satisfactory methods for determining the valid numbers of clusters.

The agglomeration schedule, cluster membership, icicle plot, and dendrogram of cases using the average linkage between groups method, illustrate the results produced by the hierarchical clustering solution (Appendix 5).

The results indicate that all landing performances are clustered in three distinct different subgroups of landing strategies. It is highly interesting and of particular note, that at step 29 (stage 3) of the analysis, all cases (subjects landing performances) from group 2 (horizontal bar) and group 3 (floor), made up two distinct different clusters (cluster 1 & 2), and all cases from groups 1 and 4 made up the third cluster (cluster 1, group 3: cases # 17-24; cluster 2, group 2: cases # 9-16; and cluster 3, group 1 and 4: cases # 1-8 & 25-32). This translates to the fact that landing strategies adopted by gymnasts on horizontal bar differed to those performed on floor, and that landing strategies on parallel bars and rings are similar but different from those on horizontal bar and floor. These results are consistent with the results obtained from the factor analysis performed previously. These results are also consistent with observation from qualitative analysis and practical experience by the writer, that horizontal bar landings, were gymnasts experience backward rotations with forward horizontal velocity (0.93± 0.49m/s) require different landing strategies to those on floor, were gymnasts experience backward rotations with backward horizontal velocity (2.06 ± 0.29m/s).

The indication that landing strategies on parallel bars and rings are similar, thus forming the biggest cluster, is due to minimal horizontal velocity backwards (parallel bars 0.49 ± 0.26m/s, and for rings 0.09 ± 0.09m/s) experienced by the gymnasts at landing touch-down.

At stage 4, group 3 consisted of 2 clusters (cluster 1: cases # 23 & 18; cluster 2: cases # 17, 19, 20, 21, 22 & 24); the clusters in group 2 and 1 & 4 remained the same, which made a total of 4 clusters.

In row 5, group 3 consisted of 3 clusters (cluster 1: cases # 23 & 18; cluster 2: cases #, 22,21 & 19; cluster 3: cases # 24, 20 &17), the clusters in group 2 and 1 & 4 remained the same, which made a total of 5 clusters. The breakdown from one cluster in stage 3 to three clusters in stage 5 is probably due to the fact that landings with backward rotations with backward horizontal velocity are most difficult to control and subsequently different landing strategies were adopted by the gymnasts in group three (floor).

In row 6, group 2 was reduced to 2 clusters (cluster 1: cases # 13, 15 & 10; cluster 2: cases #, 12, 11, 16, 14 & 9), the clusters in group 3 and 1 & 4 remained the same, which made a total of 6 clusters. This result suggests that the reduction to 2 clusters on horizontal bar is probably due to the different types and difficulty grades of the dismounts performed by the gymnasts. Cluster one represents the subjects who performed a triple backward somersault dismount, and cluster two represents the subjects who performed double backward somersaults with either 1 or 2 twists.

These findings suggest that there is a need to develop separate landing profile shapes (LPS) for each and within each event. Therefore it was also necessary to perform a cluster analysis for variables to find important indicators for successful landing techniques.

4.5.2.2 Cluster Analysis for Variables

For the variables (kinematic parameter) analysis, the "Ward's method" for combining clusters was selected. This frequently used method calculates the means for all variables in each cluster. Then for each variable the squared Euclidean distance to the cluster means is calculated. These distances are summed for all of the variables. At each step, the two clusters that merge are those that result in the smallest increase in the overall sum of the squared within cluster distances (Norusis, 1994, p.99). The method for standardisation chosen was 'standard deviation of 1'.

The results from the cluster analysis for variables suggests that the variables formed first in the analysis process are important indicators for successful landing strategies. The stages of cluster formation are illustrated in Table 4.5.2.2.1 (Appendix 5).

Table 4.5.2.2.1 Stages of cluster formation showing agglomeration coefficient

Stage	Variable	Coefficient
1	cmhdrt/d	0.848
	cmhvt/d	
2	cmhvr	2.07
3	cmht/d	9.52
	ftrt/d	
4	mcmhf	20.22
5	cmhr	51.97
	cmvvr	
6	cmvvt/d	107.00
	atht/d	
7	aat/d	343.57
8	acmght/d	1958.92
9	athht/d	6252.42
	aht/d	
10	aatt/d	13895.59
11	akt/d	32110.18
12	avat/d	59746.18
13	avht/d	100553.33
14	avkt/d	228137.94

The results obtained using this procedure shows three cluster formations. It is suggested that the variables from the first cluster formation relating to the landing phase touch-down: cmhvt/d, cmht/d, cmvvt/d, and the atht/d, constitute the most important linear kinematics, and the variables from the second cluster formation: aat/d, acmght/d, athht/d, aht/d, aatt/d and the akt/d, constitute the most important angular kinematic variables for inclusion to the development of a landing profile shape (LPS). Subsequently, these variables are most crucial for controlled landings. Prior to landing touch-down, the variables from the release: cmhdrt/d, cmhvr, cmhr, cmvvr; and the variables from the flight phase: ftrt/d and mcmhf, are important indicators for successful landings. These results, which show that the variables from the release phase are formed first in the cluster formation, are consistent with those from the factor analysis.

One of the concerns was to find the most appropriate data analysis for this study. Factor analysis and principle components analysis have already proved useful in identifying subgroups of landing performances within all subjects. However, Romesburg (1979) reported that "all numerical methods are founded upon assumptions, and the assumptions implicit in principle components analysis and factor analysis for example, are often at odds with the objective of finding similarities among objects if applied inappropriately" (p.145).

Subsequently, it was considered that cluster analysis might prove to be the most useful way of examining the data for similarities in landing strategies amongst the subjects.

4.6 Individual Group Results

The results of the biomechanical analysis for the individual groups landing performances are presented in this section as follows: (a) linear kinematics: CM positions and displacements, horizontal and vertical velocities; (b) angular kinematics: angular positions and displacements, angular velocities, angle-angle diagrams and angular velocity-angular displacement diagrams; (c) temporal characteristics of the flight and landing phase, (d) kinematic parameter interaction related to the landing score on the deterministic model for each of the four events, and (e) development of the landing profile shape for each event. The discussion focuses on the motion of the gymnasts total body CM and body segments during the landing process in relation to the landing variables. Group mean values, and the highest and lowest values were central in this discussion. Conclusions based on the results are discussed in relation to landing techniques adopted by gymnasts during their landing performances. In order to identify important associations among independent variables, correlations were computed among all variables. The correlational analysis was chosen to establish the strength of relationships between the known causal mechanical factors and the landing score. The aim here was to use highly correlated variables (landing performance indicator variables) to construct a representative landing touch-down posture, a landing profile shape (LPS).

4.6.1 Group 1 (Parallel Bars) Results

All landing performances on parallel bars represent the last part of double back somersaults piked dismount with a backward horizontal velocity. Brüggemann (1990) indicated that dismounts on parallel bars are classified as movements with rotation in the vertical plane with fixed horizontal axes of rotation. "The force of gravity acts in the plane of movement which during the down swing is the main generator of the kinetic energy needed for the subsequent dismount" (p. 81). The biomechanically necessary generation of maximum energy during the downswing, energy is also generated through internal forces. These together provide the energy transfer for successful dismounts. The mechanics a gymnast can use to generate or increase energy, are those muscle groups which flex and extend the hip and shoulder joints in the sagittal plane (Brüggemann, 1994 a).

Table 4.6.1 Group 1 (Parallel Bars) Individual Apparatus Finalists Details

Subject No.	Competitor No.	Country	Routine Duration (sec)	Routine Score (points)	Rank	Landing Score (%)
1	249	RUS	29	9.550	4	79.63
2	253	RUS	36	9.575	3	87.04
3	118	BLR	33	9.525	6	81.48
4	232	CHN	35	9.775	1	90.74
5	133	BUL	32	9.550	4	77.78
6	274	UKR	33	9.612	2	77.78
7	203	KOR	38	9.450	8	79.63
8	204	KOR	33	9.487	7	74.08

The video recordings of the individual landing performances were carefully viewed to qualitatively analyse the release position of the body and its segments, the body position of the double back somersault during flight, and the body position before the landing and at landing touch-down. The best performances showed a dish shaped position of the body at release, a controlled body position during the flight, an extension of the body before the landing, and the landing was actively anticipated through proper feet placement. All dismounts and landing performances were executed in a controlled manner thus receiving good landing scores.

The results of the qualitative evaluation of the parallel bars landing performances were as follows: subject 1 scored 79.63%, good landing, knees buckled, small step backwards with right leg; subject 2 scored 87.04%, good landing, small hop backwards; subject 3 scored 81.48%, under-rotated, small hop forwards; subject 4 scored 90.74%, stuck landing, almost perfect landing; subject 5 scored 77.78%, stuck landing but showed poor body position, excessive arm movements and arm circle forwards; subject 6 scored 77.78%, over-rotated, small hop backwards; subject 7 scored 79.63%, over-rotated slightly, small hop backwards and to outside; and subject 8 scored 74.08%, stuck landing, feet slightly apart.

4.6.1.1 Linear Kinematic Data

In this section, the results from the CM positions and displacements (Table 4.6.1.1), and, the horizontal and vertical velocities (Table 4.6.1.2) will be presented and discussed.

Table 4.6.1.1 Mean values and standard deviations for the CM position during the release, flight phase and landing phase on parallel bars (m)

Subject	Release	Flight Phase		Landing Phase	
	cmhr	mcmhf	cmhdrt/d	cmht/d	cmhm
1	2.38	2.47	0.40	0.73	0.66
2	2.49	2.65	0.44	0.72	0.60
3	2.23	2.45	0.55	0.74	0.56
4	2.42	2.69	0.43	0.78	0.47
5	2.30	2.37	0.39	0.69	0.57
6	1.75	2.51	0.22	0.85	0.70
7	2.32	2.56	0.73	0.68	0.54
8	2.26	2.51	0.49	0.71	0.46
Mean (SD)	2.27(0.23)	2.53 (0.11)	0.46 (0.15)	0.74 (0.05)	0.57 (0.08)

The mean value for the ***CM height at release*** (cmhr) was 2.27 ± 0.23m, with the highest value of 2.49m, and the lowest value of 1.75m (Figure 4.6.1.1).

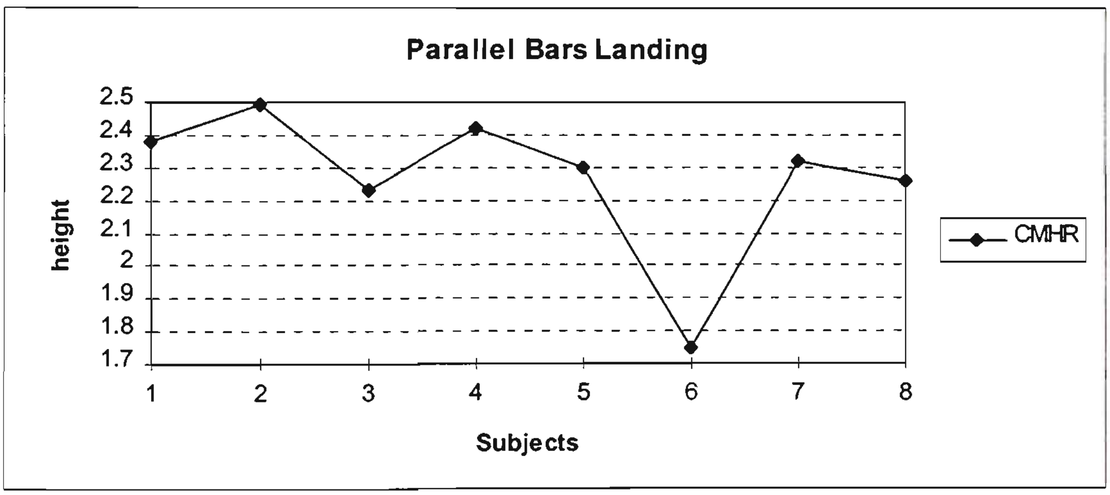


Figure 4.6.1.1 CM height at release for the subjects in group 1

The mean values for the ***maximum CM height during flight*** (mcmhf) was 2.53 ± 0.11 m, with the highest value of 2.69m and the lowest value of 2.37m (Figure 4.6.1.2). The mean value of the displacement from the CM height from release(2.27 ± 0.23m) to the maximum CM height (2.53 ± 0.11 m) was 0.26m.

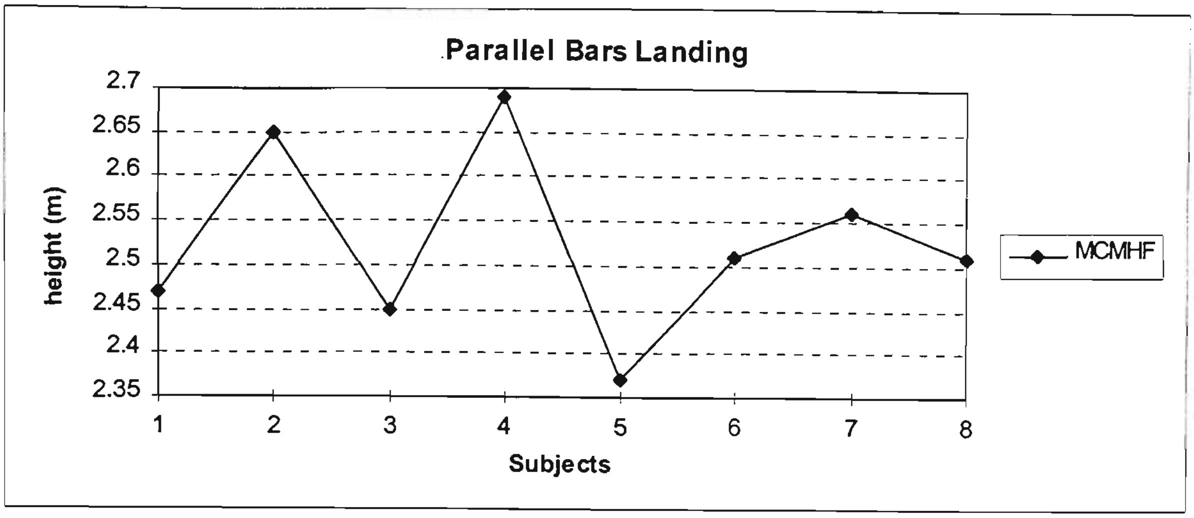


Figure 4.6.1.2 Maximum CM height in flight

Significant correlations were found between the variables mcmhf & ftrt/d (r = 0.928, p<.001).

The mean ***CM horizontal displacement from release to landing touch-down*** (cmhdrt/d) was 0.46 ± 0.15m, with the highest value of 0.73m and the lowest value of 0.22m (Figure 4.6.1.3).

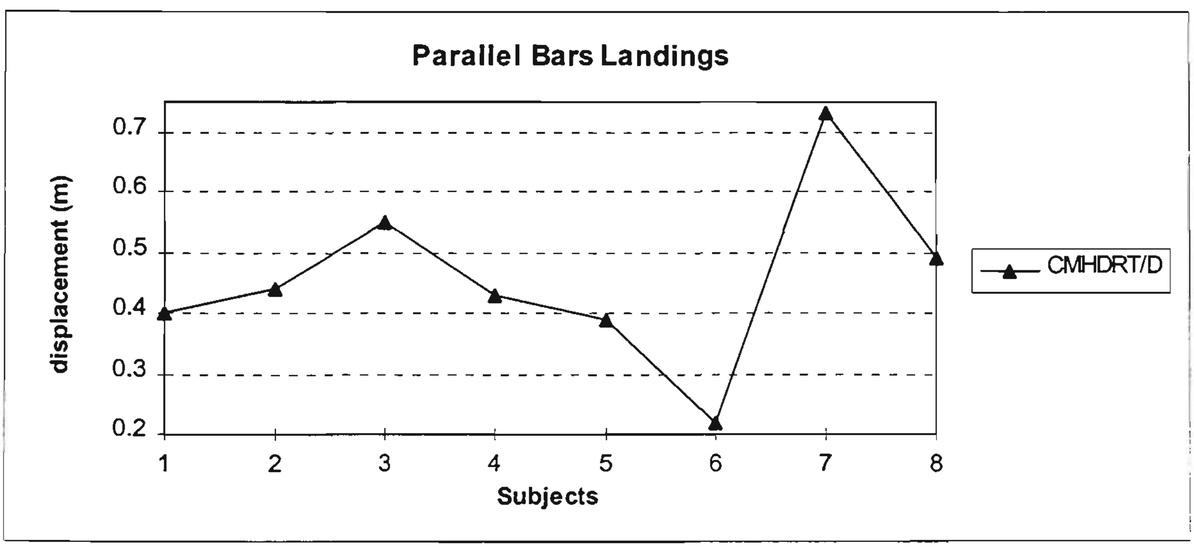


Figure 4.6.1.3 CM horizontal displacement from release to landing touch-down

Significant correlations were found between the variables cmhdrt/d & cmdt/dm (r = 0.720, p<.05), and cmhdrt/d & cmhvt/d (r = 0.693, p<.06).

The mean ***CM height at landing touch-down*** (cmht/d) was 0.74 ± 0.05m, with the highest value of 0.85m and the lowest value of 0.68m (Figure 4.6.1.4).

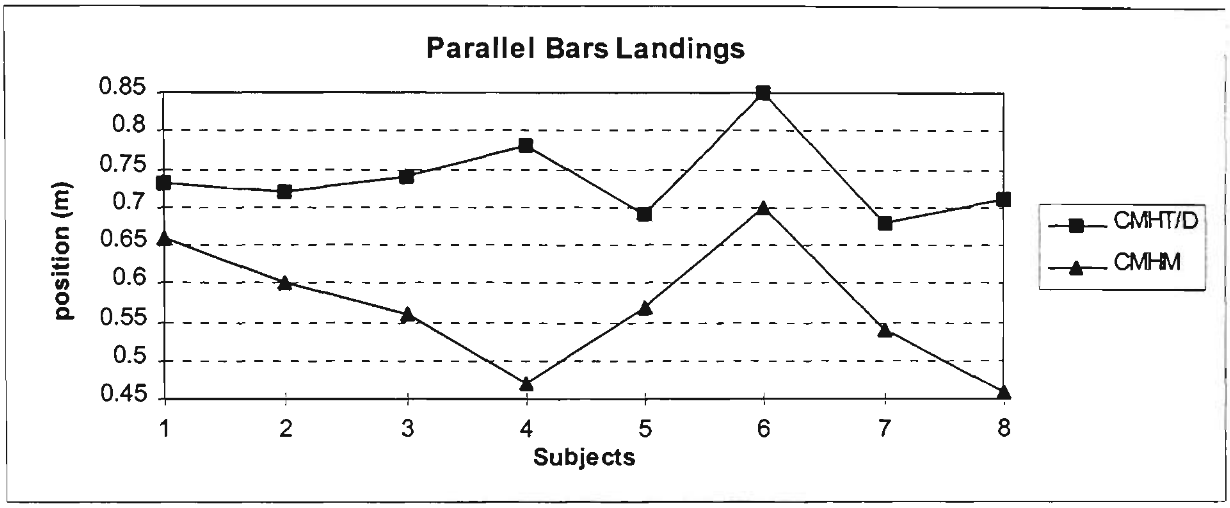


Figure 4.6.1.4 CM height at touch-down and minimum position

The displacement from the maximum CM height (2.53 ± 0.11 m) to the CM height at landing (0.74 ± 0.05m) was 1.79m. Significant correlations were found between the variables cmht/d & cmhm ($r = 0.926$, $p<.001$), cmht/d & acmght/d ($r = 0.71$, $p<.05$), cmht/d & aatt/d ($r = 0.825$, $p<.02$), cmht/d & aat/d ($r = 0.72$, $p<.05$), and between the variables cmhm & aatt/d ($r = 0.804$, $p<.02$).

The mean ***CM height minimum*** (cmhm) value was 0.57 ± 0.08m, with the highest value of 0.70m and the lowest value of 0.47m (see Figure 4.6.1.4). The landing phase displacement (lpdispl) from the CM height at landing (0.74 ± 0.05m) to CM height minimum (0.57 ± 0.08 m) was 0.17m.

Table 4.6.1.2 Mean values and standard deviations for the CM horizontal and vertical velocities during the release/take-off-, flight phase and landing phase on parallel bars (m/s)

Subject	Release			Landing Phase		
	cmhvr	cmhvm/lr	cmvvr	cmhvt/d	cmhvm/lt/d	cmvvt/d
1	-0.83	0.76	1.61	-0.21	0.68	-5.49
2	-1.22	0.96	2.27	-0.50	0.48	-5.76
3	-0.84	0.87	2.36	-0.60	0.72	-5.38
4	-1.14	0.92	2.77	-0.22	0.65	-5.59
5	-1.13	1.22	1.65	-0.77	0.87	-5.30
6	-1.16	0.92	1.57	-0.23	0.64	-5.56
7	-1.15	0.75	2.40	-0.89	0.98	-5.81
8	-0.70	0.96	2.30	-0.51	0.51	-4.46
Mean (SD)	1.02 (0.20)	0.92 (0.15)	2.12 (0.45)	0.69 (0.17)	0.49 (0.26)	-5.42 (0.42)

The mean value for the ***CM horizontal velocity at release*** (cmhvr) was -1.02 ± 0.20 m/s, with the highest value of -1.22m/s and the lowest value of 0.70m/s (Figure 4.6.1.5).

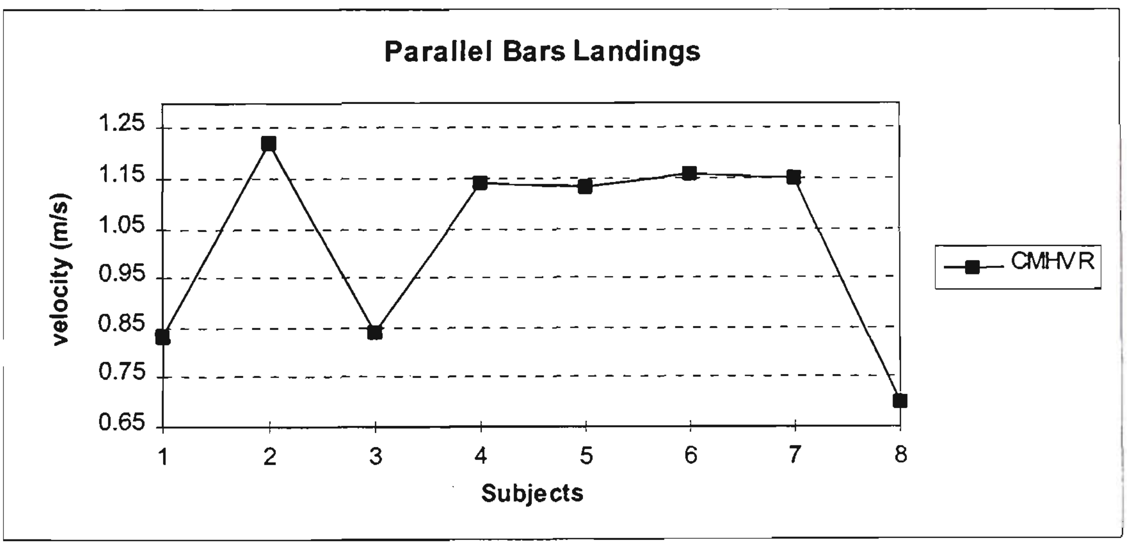


Figure 4.6.1.5 CM horizontal velocity at release

Significant correlations were found between the variables cmhvr & cmvvt/d ($r = -0.761$, $p<.03$).

The mean value for the ***CM horizontal velocity sidewards at release*** (cmhvr) was 0.92 ± 0.17 m/s, with the highest value of 1.22m/s and the lowest value of 0.75m/s (Figure 4.6.1.6).

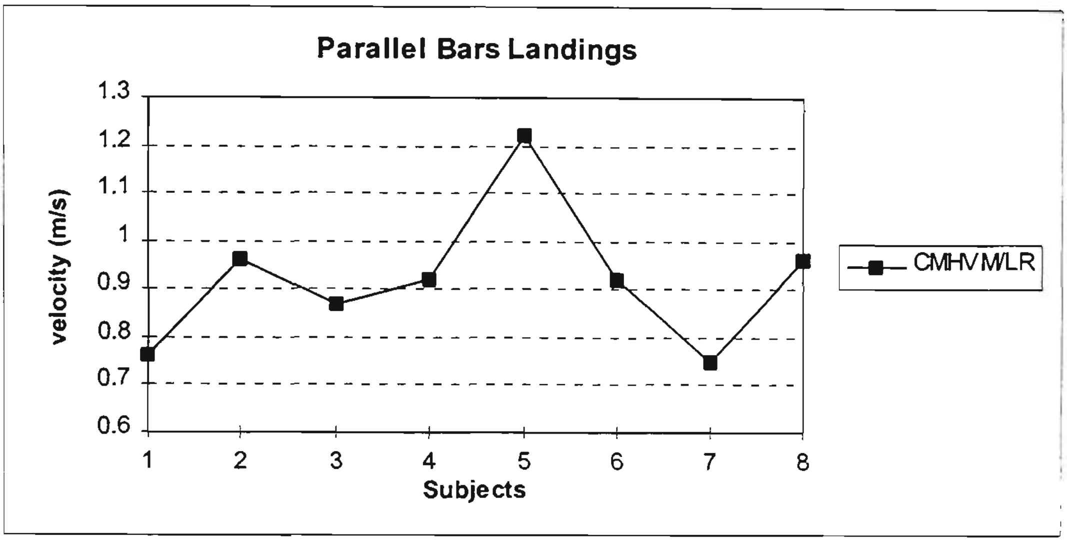


Figure 4.6.1.6 CM horizontal velocity sidewards at release

The values for the ***CM vertical velocity at release*** (cmvvr) were 2.12 ± 0.45m/s, with the highest value of 2.77m/s and the lowest value of 1.57m/s (Figure 4.6.1.7).

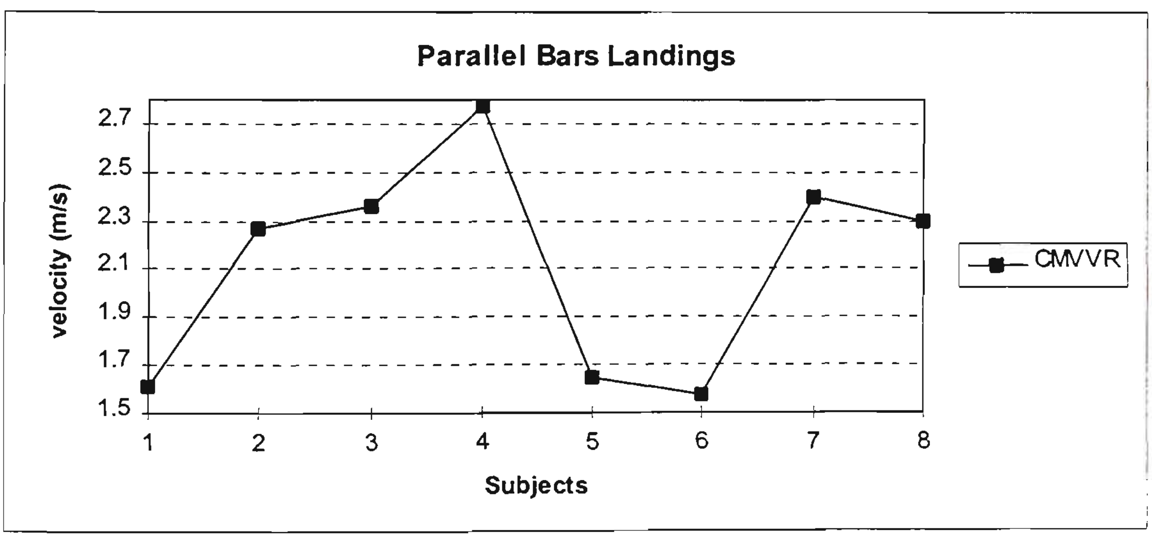


Figure 4.6.1.7 CM vertical velocity release

Significant correlations were found between the variables cmvvr & cmdt/dm (r = 0.736, p<.04), cmvvr & lpdispl (r = 0.729, p<.04), cmvvr & cmhm (r = -0.797, p<.02), cmvvr & akm (r = -0.715, p<.05).

The mean ***CM horizontal velocity at touch-down*** (cmhvt/d) was -0.49 ± 0.26m/s, with the highest value of -0.89m/s and the lowest value of -0.21m/s (see Figure 4.6.1.8).

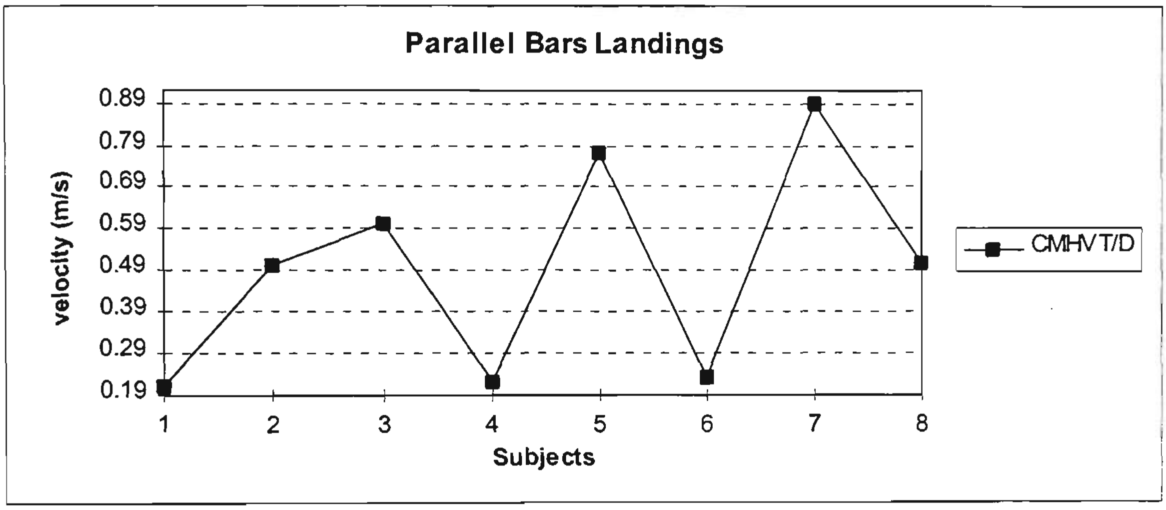


Figure 4.6.1.8 CM horizontal velocity at landing touch-down

Significant correlations were found between the variables cmhvt/d & cmht/d (r = -0.756, p<.03), cmhvt/d & lansco (r = 0.773, p<.03), and to the cmhvt/d & cmhdrt/d (r = 0.693, p<.06).

The mean ***CM horizontal velocity sidewards at touch-down*** (cmhvm/lt/d) was 0.69 ± 0.17m/s, with the highest value of 0.98m/s and the lowest value of 0.48m/s (Figure 4.6.1.9).

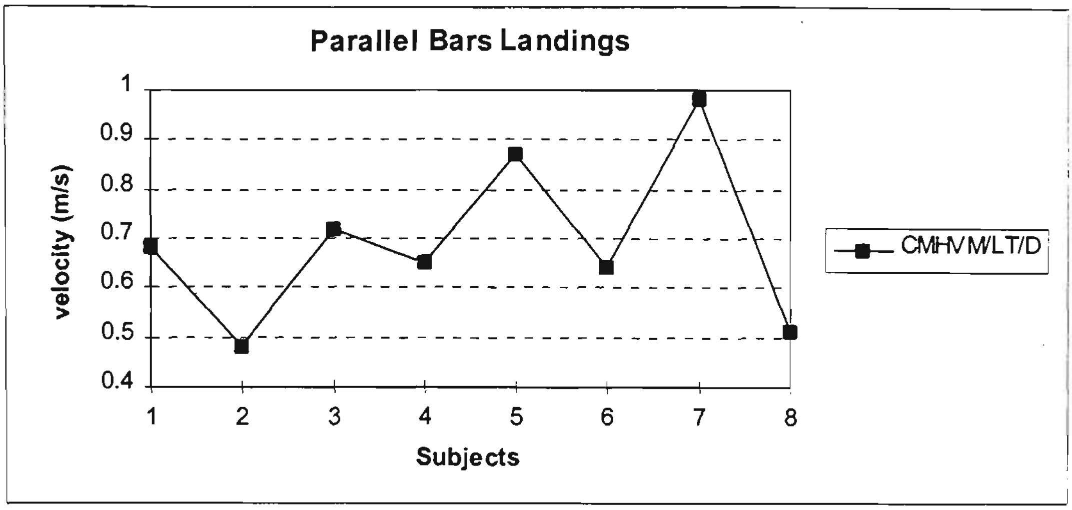


Figure 4.6.1.9 CM horizontal velocity sidewards at landing touch-down

The mean ***vertical impact velocitiy*** (cmvvt/d) was -5.42 ± 0.42m/s, with the highest value of -5.81m/s and the lowest value of -4.46m/s (Figure 4.6.1.10).

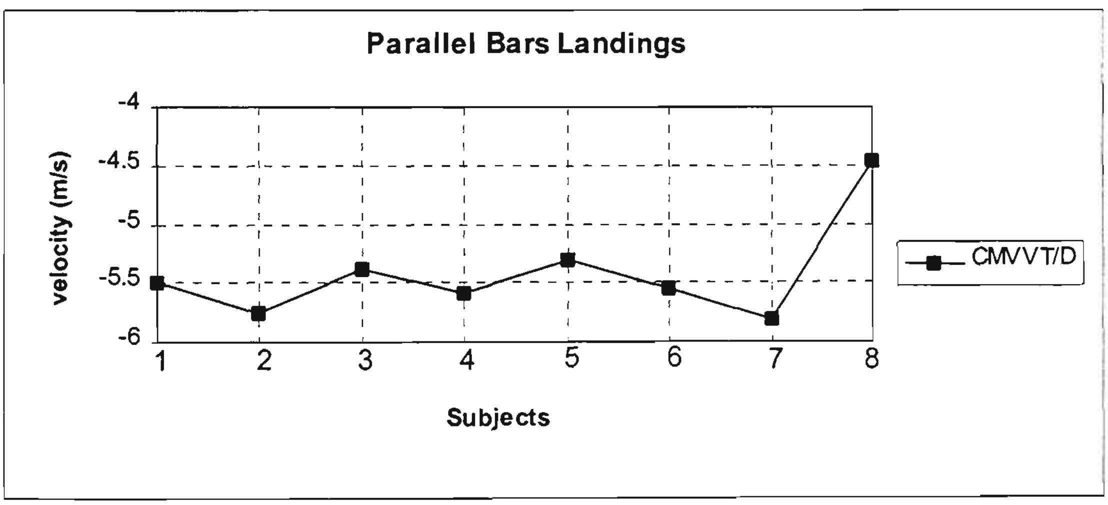


Figure 4.6.1.10 CM vertical velocity at landing touch-down

Significant correlations were found between the variables cmvvt/d & cmhvr (r = -0.761, p<.03).

4.6.1.2 Angular Kinematic Data

In this section, the results from the angular positions (joint angles) and displacements (Table 4.6.1.2), angular velocities (Table 4.6.1.3), angle-angle diagrams, and angular velocity-angular displacement diagrams will be presented and discussed.

Table 4.6.1.2 Mean values and standard deviations for the joint angles during the landing phase on parallel bars (degrees)

	Subject									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Mean**	**SD**
acmght/d	89	82	79	88	84	98	87	83	86.25	5.80
aatt/d	85	40	74	-41	78	30	39	56	45.13	40.24
aatm	53	59	64	70	70	84	58	74	66.50	10.03
aht/d	102	91	98	116	102	95	100	99	100.38	7.31
ahm	86	60	57	66	69	73	83	62	69.50	10.57
akt/d	166	161	153	154	160	167	138	168	158.38	9.98
akm	137	114	94	85	107	126	53	103	102.38	25.98
aat/d	101	96	81	96	89	112	89	97	95.12	9.25
aam	97	83	90	88	90	98	89	83	89.75	5.55
atht/d	27	14	12	43	19	27	36	14	24	11.29
athm	33	13	14	37	20	23	63	27	28.75	16.20

The values for the ***angles CM to ground contact (toes) and the horizontal at landing touch-down*** for the subjects in group 1 were 86.25 ± 5.80°, with the highest value of 98° and the lowest value of 79° (Figure 4.6.1.2.1).

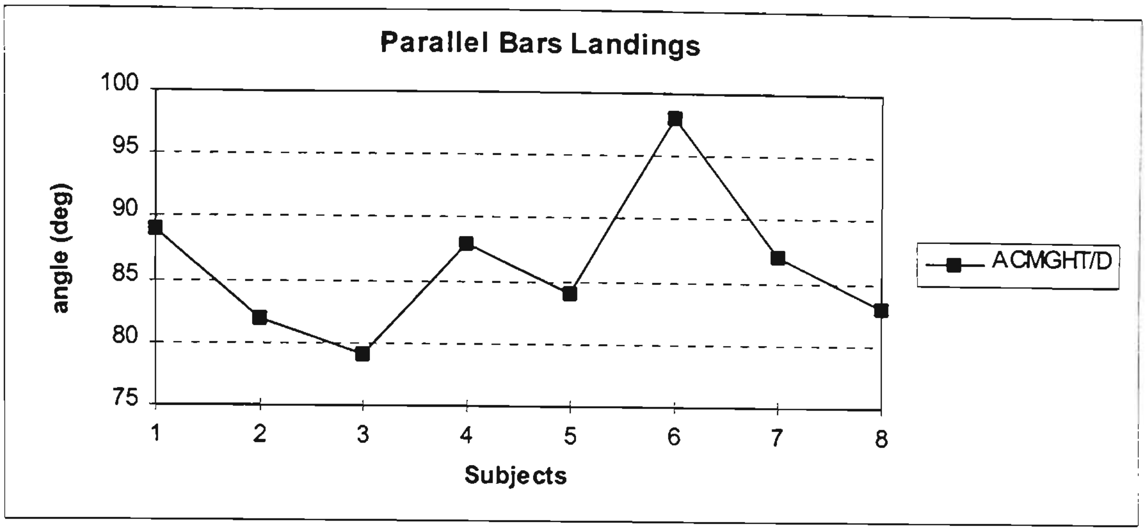


Figure 4.6.1.2.1 Angles CM to ground contact and the horizontal at landing touch-down

Significant correlations were found between the variables acmght/d & aat/d (r = 0.846, p<.0.1), acmght/d & aat/d (r = 0.846, p<.0.1), acmght/d & aam (r = 0.717, p<.0.5), and acmght/d & cmht/d (r = 0.71, p<.0.5).

The mean ***shoulder joint angles at landing touch-down*** (aatt/d) were 45.13 ± 40.24°, with the highest value of 85° and the lowest value of -45° (Figure 4.6.1.2.2).

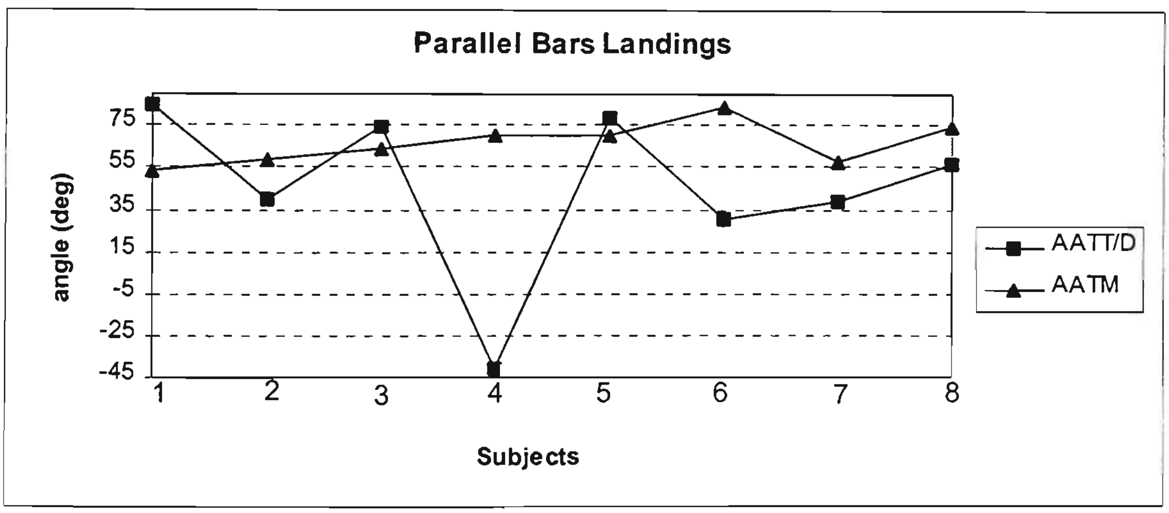


Figure 4.6.1.2.2 Shoulder joint angles at landing touch-down and minimum

A very interesting finding here is that subject 4, who was judged with the highest landing score (90.74%), recorded a large negative value for aatt/d (-41°). The negative value was due to hyperextension of the shoulder joint at landing touch-down. This extraordinary value effected the mean value (45.13°) and subsequently the high within group variability (S. D. = 40.24°).

The ***minimum angles at the shoulder joint*** (aatm) were 66.50 ± 10.03°, with the highest value of 84° and the lowest value of 53° (Figure 4.6.3.2). Significant correlations were found between the variables aatt/d & cmht/d ($r = 0.825$, $p<.02$), aatt/d & cmhm ($r = 0.804$, $p<.02$), and aatt/d & aht/d ($r = 0.723$, $p<.05$). There was a great variability (S.D.= 40.24°) among subjects with respect to the angular displacement profiles of the shoulder at landing touch-down.

The mean ***hip joint angles at landing touch-down*** (aht/d) were 100.38 ± 7.31°, with the highest value of 116° and the lowest value of 91° (Figure 4.6.1.2.3).

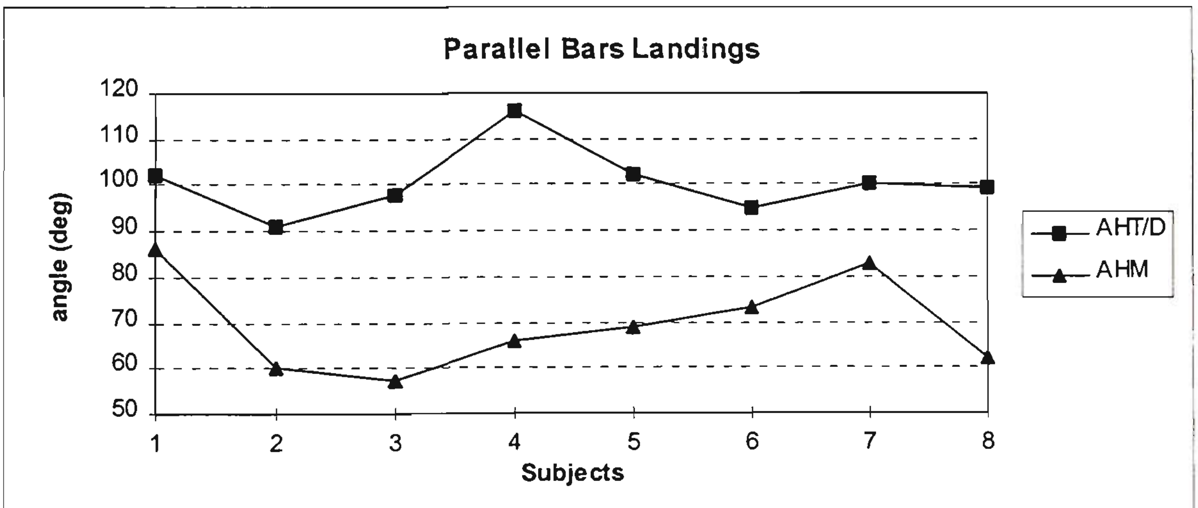


Figure 4.6.1.2.3 Hip joint angles at landing touch-down and minimum

Significant correlations were found between the variables aht/d & atht/d ($r = 0.708$, $p<.0.5$), aht/d & avht/d ($r = 0.733$, $p<.0.5$).

The ***minimum hip joint angles*** (ahm) were 69.50 ± 10.57°, with the highest value of 86° and the lowest value of 57° (see Figure 4.6.1.2.3). Significant correlations were found between the variables aht/d & ahm (r = 0.88, p<.01),and aht/d & aatt/d (r = 0.723, p<.05).

The mean ***knee joint angles at landing touch-down*** (akt/d) were 158.38 ± 9.98°, with the highest value of 168° and the lowest value of 138° (Figure 4.6.1.2.4).

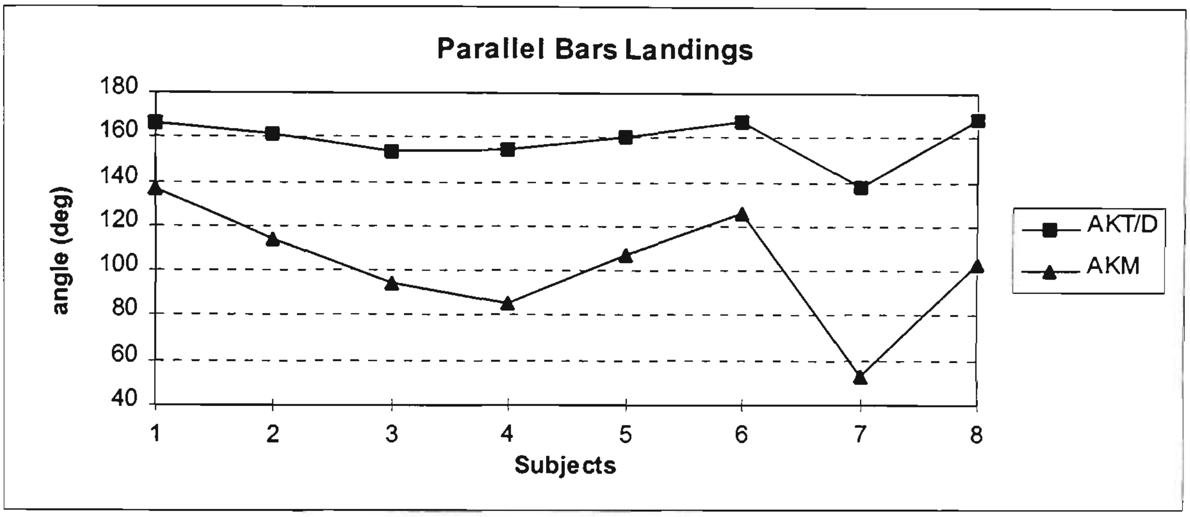


Figure 4.6.1.2.4 Knee joint angles at landing touch-down and minimum

Significant correlations were found between the variables akt/d & akm (r = 0.903, p<.01), akt/d & avkt/d (r = 0.892, p<.01), akt/d & cmdt/dm (r = -0.787, p<.03), akt/d & cmhdrt/d (r = -0.748, p<.04).

The ***minimum knee joint angles*** (akm) were 102.38 ± 25.98°, with the highest value of 137° and the lowest value of 53° (Figure 4.6.1.2.4). The mean angular displacement between the akt/d and akm was 56° with a landing duration of 0.11 seconds. Significant correlations were found between the variables akt/d & aat/d (r = 0.719, p<.05), akt/d & avkt/d (r = 0.69, p<.06), and akt/d & avht/d (r = 0.857, p<.01).

The mean ***ankle joint angles at landing touch-down*** (aat/d) were 95.12 ± 9.25°, with the highest value of 112° and the lowest value of 81° (Figure 4.6.1.2.5); and the

minimum ankle joint angles (aam) were 89.75 ± 5.55°, with the highest value of 98° and the lowest value of 83° (Figure 4.6.1.2.5).

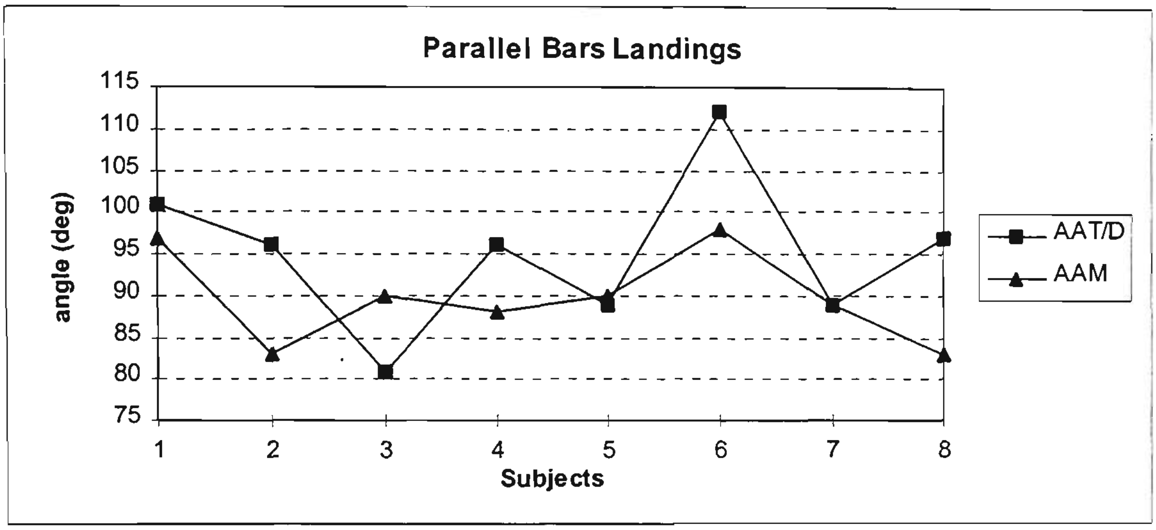


Figure 4.6.1.2.5 Ankle joint angles at landing touch-down and minimum

Significant correlations were found between the variables aat/d & cmhdrt/d (r = -0.76, p<.05), aat/d & cmhvt/d (r = -0.712, p<.05), aat/d & acmght/d (r = 0.846, p<.01).

The mean ***angles between the trunk and the horizontal at touch-down*** (atht/d) were 24 ± 11.29°, with the highest value of 43° and the lowest value of 12° (Figure 4.6.1.2.6); and the a***ngles between trunk and the horizontal at CM minimum*** (athm) were 28.75 ± 16.20°, with the highest value of 63° and the lowest value of 14° (Figure 4.6.1.2.6).

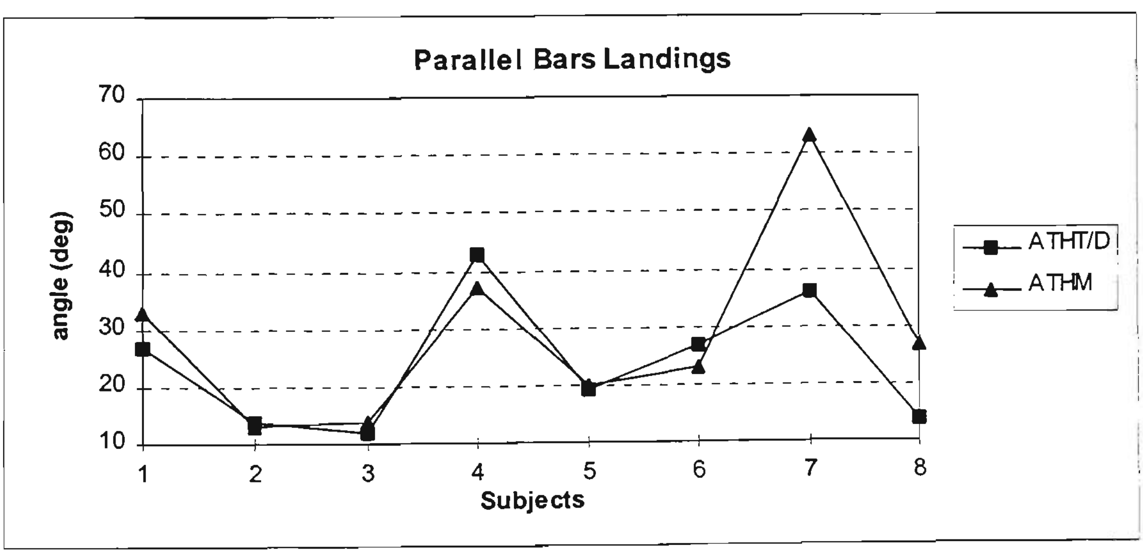


Figure 4.6.1.2.6 Angles trunk to horizontal at landing touch-down and minimum

Significant correlations were found between the variables atht/d & athm ($r = 0.924$, $p<.001$), atht/d & aht/d ($r = 0.914$, $p<.001$), and atht/d & ahm ($r = 0.785$, $p<.03$).

Table 4.6.1.3 Hip, knee, and ankle joint angular velocities at landing phase on parallel bars (deg/sec)

Subject		**Landing Phase**	
	avht/d	**avkt/d**	**avat/d**
1	-277	-537	-133
2	-123	-608	-387
3	-196	-718	-358
4	-313	-1005	-369
5	-223	-689	-239
6	-85	-478	-210
7	-247	-1021	-185
8	-306	-480	-111
Mean (SD)	-221 (83.01)	-692 (216.7)	-249 (109.25)

The mean value for the ***hip angular velocity*** (avht/d) at landing touch-down was -221 ± 83.01 deg/sec, with the highest value of -313 deg/sec and the lowest value of -85 deg/sec; for ***knee angular velocity*** -692 ± 246.7 deg/sec, with the highest value of -1005 deg/sec and the lowest value of -478 deg/sec.

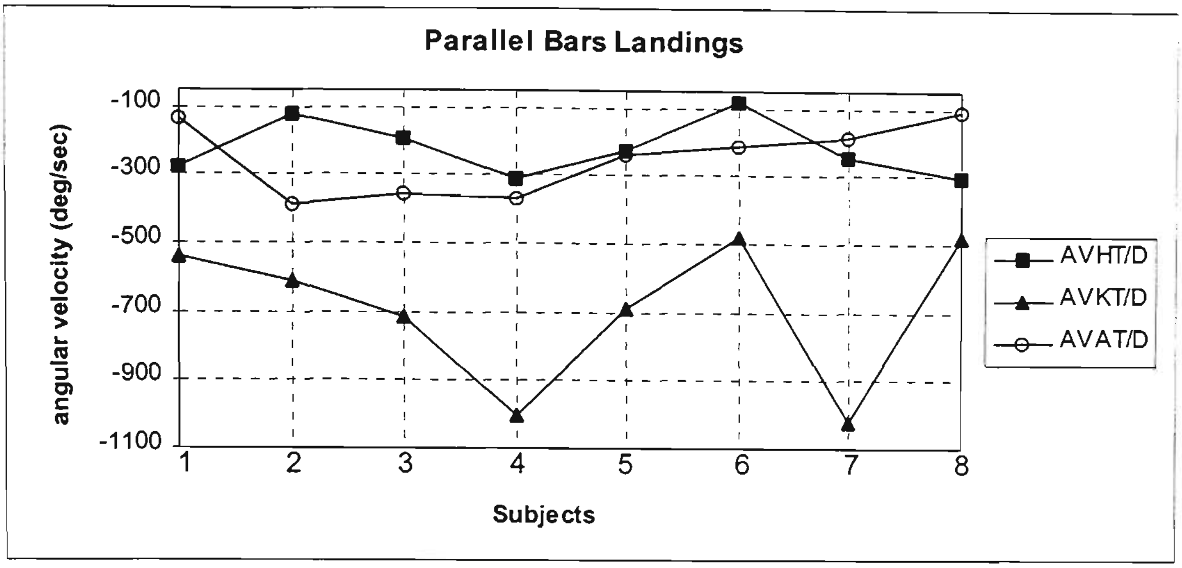


Figure 4.6.1.2.7 Angular velocities of the hip, knee and ankle joints

The mean ***ankle angular velocity*** was -249 ± 109.25 deg/sec, with the highest value of -387 deg/sec and the lowest value of -111 deg/sec (Figure 4.6.1.2.7). Significant correlations were found between the variables avht/d & aht/d ($r = -0.733$, $p<.05$), avht/d & akt/d ($r = 0.857$, $p<.01$), avkt/d & akt/d ($r = 0.892$, $p<.01$), avkt/d & akm ($r = 0.849$, $p<.01$), and avkt/d & cmdt/dm ($r = -0.804$, $p<.02$). There was a great variability among subjects with respect to the angular velocity profiles of the knee and hip.

Angle-angle diagrams were produced of the best landing performances to investigate the relationship between ankle and knee angles, knee and hip angles, and hip and shoulder angles over the period of the landing phase. Changes in these relationships indicate a change in angular kinematics and sequencing among joints. Subjects' 4 ankle angle-knee angle is illustrated in Figure 4.6.1.2.8.

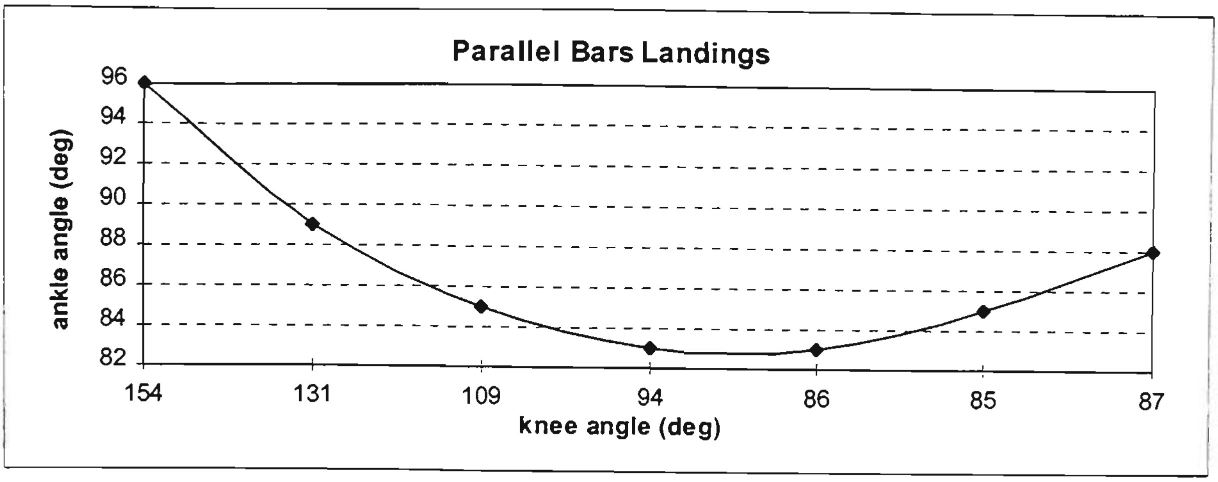


Figure 4.6.1.2.8 Ankle joint angle-knee joint angle diagram for subject 4

Significant correlations were found between the variables akt/d & aat/d ($r = 0.719$, $p<.05$). Subject's 4 angular displacement between the aat/d and aam was 14°, and between akt/d and akm was 69°, over a landing phase duration of 0.14 seconds. Through qualitative analysis from the video, subject's 4 landing phase appeared to be smooth. However, the angle-angle diagram reveals a change of vertical downward motion to a horizontal backward and upward motion from frame 4 (0.08sec) for the ankle angle, and frame 6 (0.12sec) for the knee angle. This backward shift of the CM, which causes the opening of the ankle joint and, subsequently, the knee joint, can be attributed mainly to the parameters cmhvr or cmht/d, and the acmght/d.

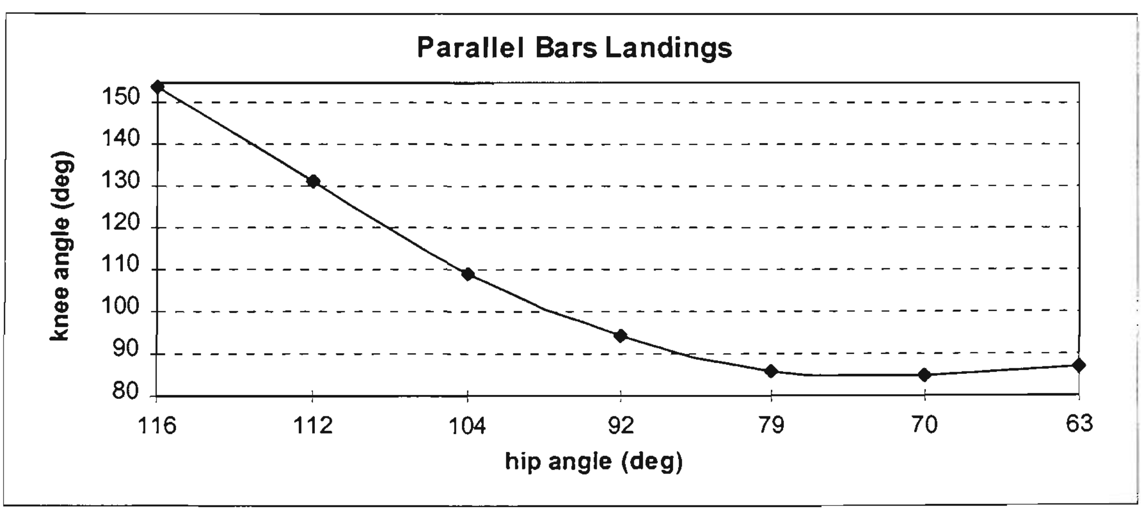


Figure 4.6.1.2.9 Knee joint angle-hip angle diagram for subject 4

Significant correlations were found between the variables akt/d & akm (r = 0.903, p<.01), akt/d & avkt/d (r = 0.892, p<.01), and akt/d & avht/d (r = 0.857, p<.01). Subject's 4 angular displacement between the akt/d and akm was 69°, and between aht/d and ahm was 53°. The trend line indicates that the knee angle was reduced quickly before it levelled out and then increased slightly at the end of the landing phase. However, the hip angle was reduced steadily throughout the landing phase.

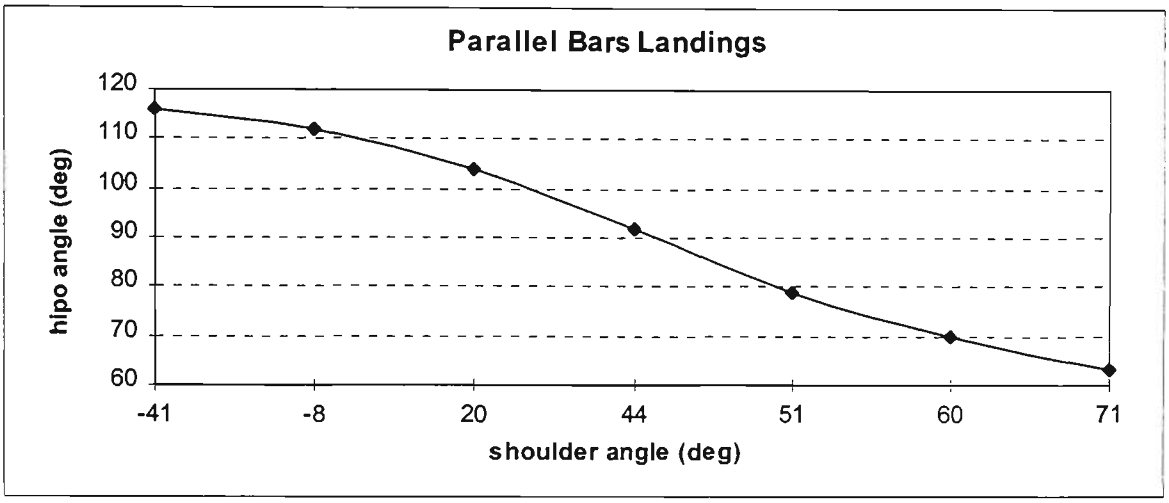


Figure 4.6.1.2.10 Hip angle-shoulder angle diagram for subject 4

Significant correlations were found between the variables aatt/d & aht/d (r = 0.723, p<.05). The subject made spontaneous changes to the range of shoulder joint motion during the landing process, ranging from -41° (shoulder joint hyperextension) to 70° (shoulder joint flexion). This indicates, that the arms act as powerful stabilising factors during the landing phase.

Angular velocity-joint angle diagrams for the ankle, knee, hip, and shoulder angles were also produced to provide a description of the respective angular velocity-angular displacement relationship during the landing process. The ankle angular velocity-angular displacement relationship for subject 4 is illustrated in Figure 4.6.1.2.11.

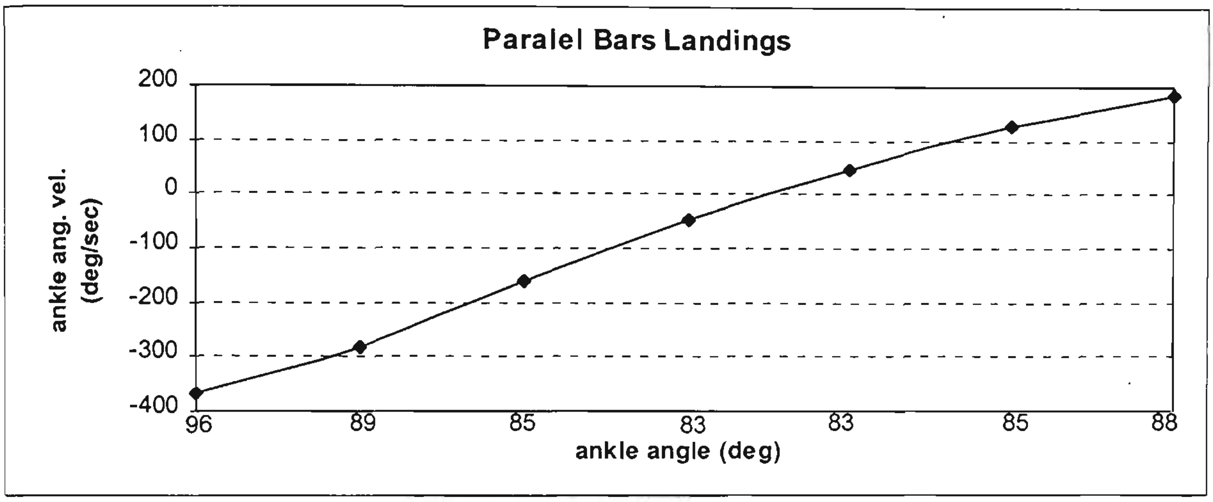


Figure 4.6.1.2.11 Ankle joint angular velocity-ankle joint angle diagram for subject 4

The values of the negative (flexion) ankle angular velocities showed very consistent reduction during the first part of the landing process, thus decreasing at a relative constant angular velocity. Subsequently, they showed positive values at the same rate until ankle angle minimum.

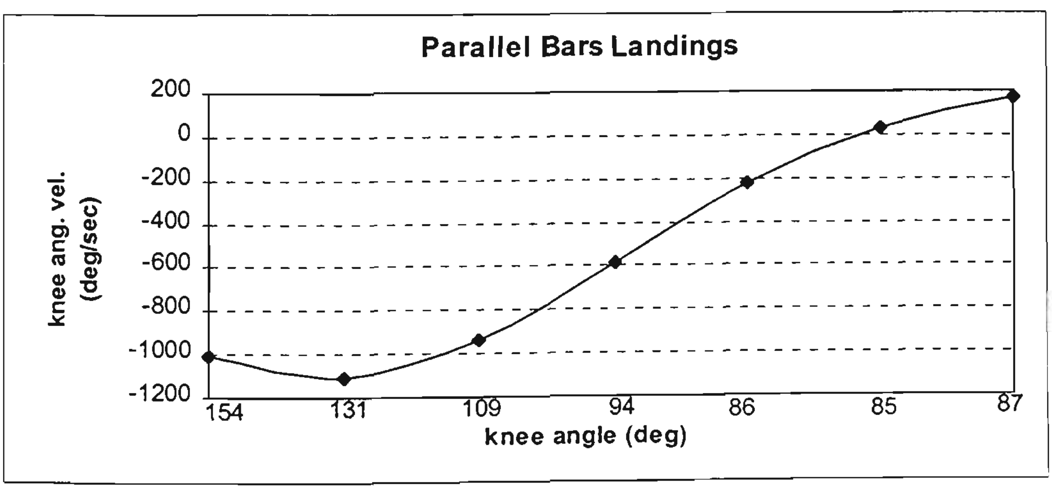


Figure 4.6.1.2.12 Knee joint angular velocity-knee joint angle diagram for subject 4

Significant correlations were found between the akt/d & avkt/d ($r = 0.69$, $p<.06$), and akt/d & avht/d ($r = 0.857$, $p<.01$). The trend line indicates a momentary increase in the value of the negative knee angular velocity, that is, the subject went quickly into a more flexed position of the knee joint. There was a subsequent reduction of the negative knee angular velocity followed by a positive value of the knee angular velocity until knee angle minimum.

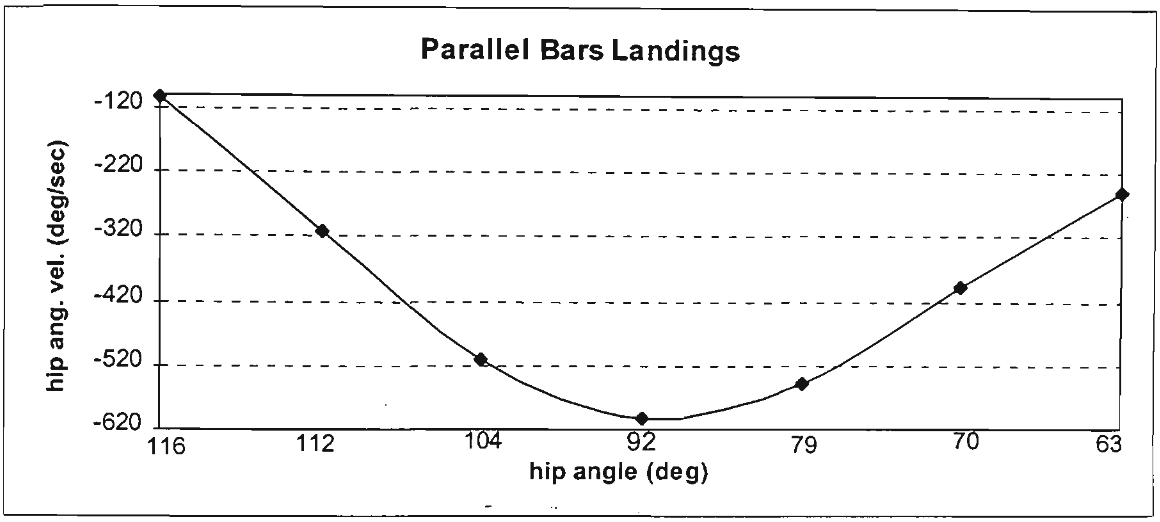


Figure 4.6.1.2.13 Hip joint angular velocity-hip joint angle diagram for subject 4

Significant correlations were found between the variables avht/d & aht/d ($r = -0.733$, $p<.05$), avht/d & akt/d ($r = 0.857$, $p<.01$). There was a consistent increase of the negative hip angular velocity during the first part of the landing process, followed by a subsequent decrease of negative angular velocity until hip angle minimum.

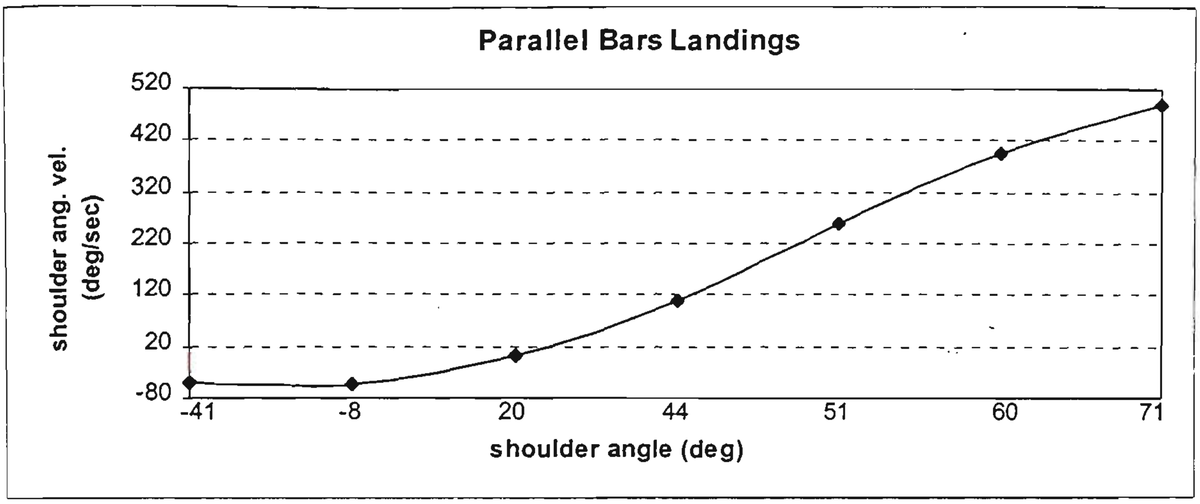


Figure 4.6.1.2.14 Shoulder joint angular velocity-shoulder joint angle diagram for subject 4

Figure 4.6.1.2.14 illustrates changes of the shoulder joint angles which indicates that the subject corrected an imbalance in the forward direction.

4.6.1.3 Temporal Characteristics Of The Flight- And Landing Phase

The flight time constitutes the duration from release (first frame non-contact), to landing touch-down (first frame contact with landing surface), and represents the angular distance through which a gymnast's body rotates while in the air. The only external forces acting during flight are gravity, which acts vertically and cannot be manipulated during flight, and air resistance, which is so small it can be disregarded completely. This means that horizontal velocity determined at release, remains constant throughout the flight and the vertical velocity at take-off is only changed by gravity.

Table 4.6.1.3.1 Temporal characteristics of the flight and landing phase on parallel bars (seconds)

Subject	Flight Phase ftrt/d (sec)	Landing Phase cmdt/dm (sec)
1	0.86	0.06
2	0.90	0.10
3	0.84	0.12
4	0.92	0.14
5	0.76	0.12
6	0.86	0.08
7	0.88	0.16
8	0.86	0.12
Mean (SD)	0.86 (0.05)	0.11 (0.03)

The mean value for the ***flight time from release to touch-down*** (ftrt/d) was 0.86 ± 0.05 sec, with the highest value of 0.92sec and the lowest value of 0.76sec.

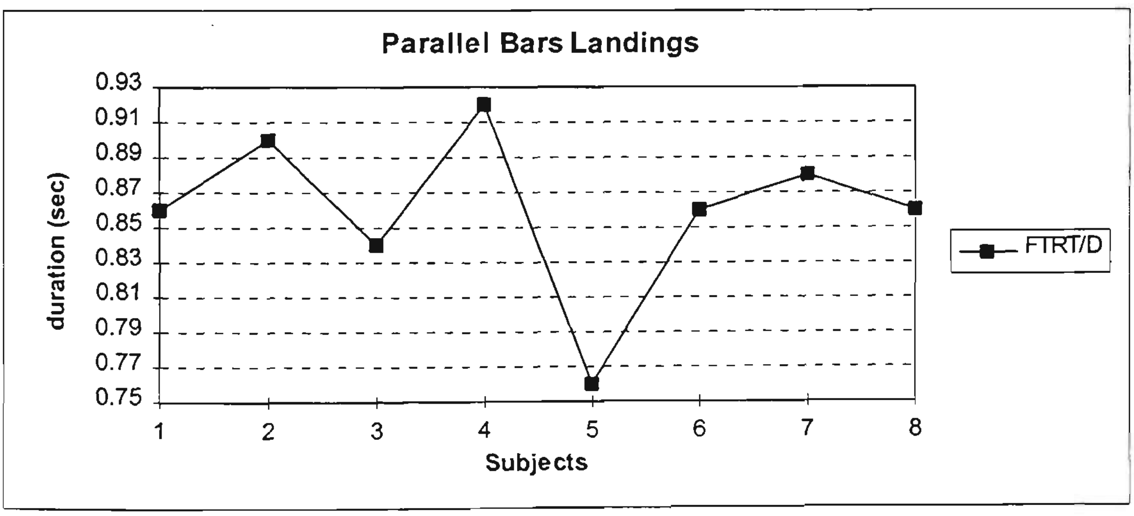


Figure 4.6.1.3.1 Flight time from release to landing touch-down

Significant correlations were found between the variables ftrt/d & mcmhf ($r = 0.928$, $p<.001$), and ftrt/d & aatt/d ($r = 0.695$, $p<.06$).

The ***CM duration touch-down to minimum*** (cmdt/dm) was 0.11 ± 0.03 sec, with the highest value of 0.16sec and the lowest value of 0.06sec (Figure 4.6.1.3.1).

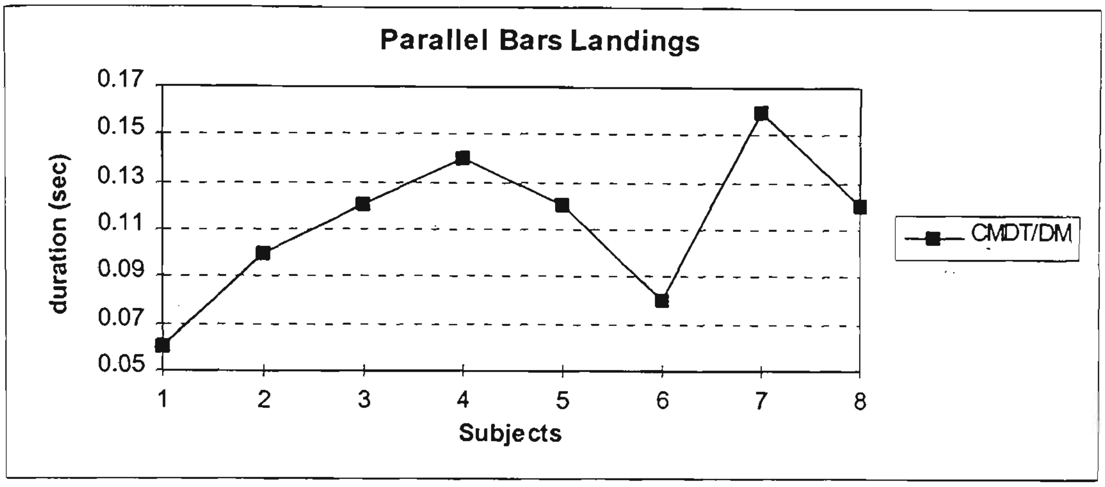


Figure 4.6.1.3.2 CM duration from landing touch-down to landing minimum

Significant correlations were found between the variables cmdt/dm & akt/d ($r = -0.787$, $p<.03$), cmdt/dm & akm ($r = -0.96$, $p<.001$), cmdt/dm & avkt/d ($r = -0.804$, $p<.02$), cmdt/dm & cmhdrt/d ($r = 0.72$, $p<.05$), cmdt/dm & cmvvr ($r = 0.736$, $p<.05$), cmdt/dm & cmhm ($r = -0.769$, $p<.03$). The rate of absorption of the landing impact velocities varied greatly (almost 300%) within the group

4.6.1.4 Kinematic Parameter Interaction Related To The Landing Score of the Parallel Bars Landing Model

To provide an optimal landing, all landing performances, with particular emphasis on the best landing performance on parallel bar, will be discussed in relation to the group mean. The best landing performance was recorded by subject 4 (90.74). Subject 4 recorded very high (92%) within group values on all variables. He recorded a cmhvr of -1.14m/s, and a cmhvm/lr of 0.92m/s, compared to the mean value of -1.02 ± 0.20 and 0.92 ± 0.15m/s, respectively. These variables were identified in the 14th level of the deterministic model and indicate a strong relationship between the horizontal distance of the CM travelled to the horizontal distance at landing impact. He also obtained a cmhvt/d of -0.22m/s compared to the mean value of 0.49 ± 0.26m/s, and also recorded a significant horizontal velocity sidewards (cmhvm/lt/d) of 0.65m/s (level 10), compared to the mean value of 0.69 ± 0.17m/s. Significant correlation were found between cmhvt/d & cmhdrt/d (r = 0.789, p<.02). His cmvvr was recorded at 2.77m/s and his cmvvt/d was calculated at -5.59m/s compared to the mean value of 2.12 ± 0.45 and -5.42 ± 0.42m/s, respectively. Liu, Nelson and Jiang (1992) analysed stable and unstable landings after backward tuck and pike somersault dismounts on parallel bars. Stable landings had a minimum CM horizontal velocity backwards at landing touch-down (between 0 - 0.65m/s) and a mean angle CM to ground contact and the horizontal of 67°. The results of this study for the mean value of the cmhvt/d was -0.49m/s (-0.22m/s for subject 4), and a mean angle acmght/d of 86.25 ± 5.80° (88° for subject 4), a difference of 19 or approximately 25% compared to the study of Liu et al. These findings indicate that the landing performances in this study were of higher quality. Subject 4 recorded a hip angle of 116° at landing touch-down, compared to the mean value of 100.38 ± 7.31° and a minimum hip angle of 66° (level 4), compared to the mean value of 69.50 ± 10.57°. His hip joint angle was 104° (0.02sec), 92° (0.04sec), and 79° (0.06sec) after landing touch-down. Subject 4 also recorded a knee joint angle of 154° at landing touch-down, compared to the mean value of 158.38 ± 9.98°, and a minimum knee joint angle of 85° compared to the mean value of 102.38 ± 25.98. His knee joint angle was 131° (0.02sec), 109° (0.04sec), and 94° (0.06sec) after landing touch-down. The respective knee joint angular velocity was -1109, -935 and

-585deg/sec. The availability of the large range of knee joint motion (69°) provided the subject with the opportunity of using various knee joint flexion temporal options, e.g. from fast to slow absorption of the landing forces (levels 4-10). This result indicates that the large range in knee joint motion plays a great role during the landing process. The extended position of the hip and knee joints at landing touch-down provided the subject with the option of using a large range of joint motion for reducing the impact velocities during the landing phase. The notion of having an extended body position prior to landing is well documented in the research in landings by McNitt-Gray (1989, 1991 and 1993b), Liu et al. (1992) and Takei et al. (1992). Subject 4's ankle angle was 96° at landing touch-down, compared to the mean value of 95.12 ± 9.25°, and a minimum ankle joint angle of 88° compared to the mean value of 89.75 ± 5.55°. His ankle joint angle was 92° (0.02sec), 88° (0.04sec), and 79° (0.06sec) after landing touch-down. Subject's 4 angle-angle diagrams and angular velocity-angular displacement diagrams provided an excellent visual perspective of their relationship during the landing process.

Subject 4 also exhibited a longer CM duration from landing touch-down to landing minimum 0.14 sec compared to the mean value of 0.11 seconds. Overall, the rate of absorption of the landing impact velocities varied greatly (<300%) within the group. In order to bring the body momenta to zero during landings, the gymnast must effectively dissipate the large forces encountered at landing impact during the landing phase. This result suggests that subject 4 adjusted to the landing impact by absorbing the landing forces over a longer period of time. There were also significant correlations within the group between the variables cmht/d & cmhm ($r = 0.926$, $p<.001$).

Poor landing performances were typified by inadequate technique and subsequently unstable landings occurred when the gymnasts were still somersaulting, coming out of the piked somersault position slowly by extending the hip and knee joints downward into the landing surface (levels 11-13). Unstable landings occurred also when the gymnasts did not have enough landing preparation time due to poor release properties, and subsequently, were unable to complete the skill before the landing, and when the gymnasts did not have enough or had too much somersault rotation (over or under rotation). Subject 3 for example under rotated, landing with his trunk leaning too much forward and downwards, thus shifting his CM too far in front of his feet causing him to take a hop forwards. This piked position at landing touch-down on parallel bars (or floor) is typical in somersaults with under rotation at landings. The lack of rotation requires the gymnast to flex at the hips prior to landing touch-down so that the gymnast can place his feet in a favourable position to still enable him to "save" the landing. However this reduction in available hip flexion is expected to reduce the landing phase time considerably and if the gymnast is unable to extend the hip joint prior to landing touch-down (contact with the landing surface), the knee joint is expected to play a greater role in absorbing the landing forces. Also the ankle joint has the minimum angle, thus no additional range of motion is available in under rotated landings.

The need to control the rotational factors during landings of somersaults may prohibit the use of extensive trunk motion. The magnitude of the landing velocities of the CM were critical parameters for controlled landings. Gymnast's should land in a position which allows for a greater angular displacement before the line of gravity has moved backward beyond the base of support and thus increases the gymnast's chance of "sticking" the landing. Biomechanical parameters influencing the controlled landing on parallel bars are, the CM horizontal velocities at landing touch-down, the sidewards and backwards CM horizontal velocities (level 10), which are determined at release (levels 14-15). This indicates that the release and flight properties should be optimised in order to ensure good landing conditions. Also, to ensure controlled landing performances, the horizontal velocity (forward/backward) should be zero and the sideward velocity should be very small. Therefore, "sticking" the landing depends on the ability of the gymnast to absorb the angular momentum when the axis of rotation shifts from the gymnast's CM to the feet (floor contact).

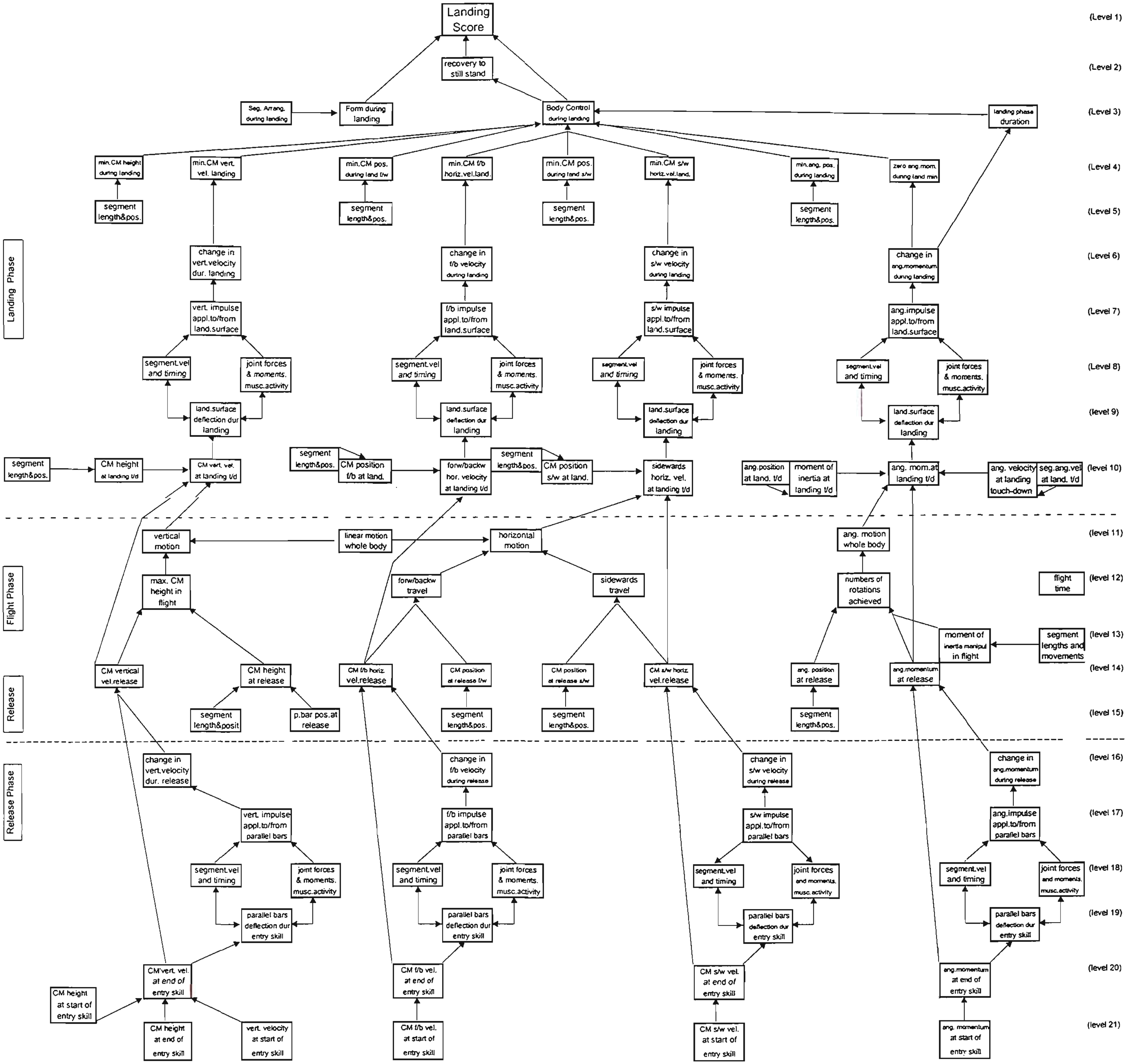


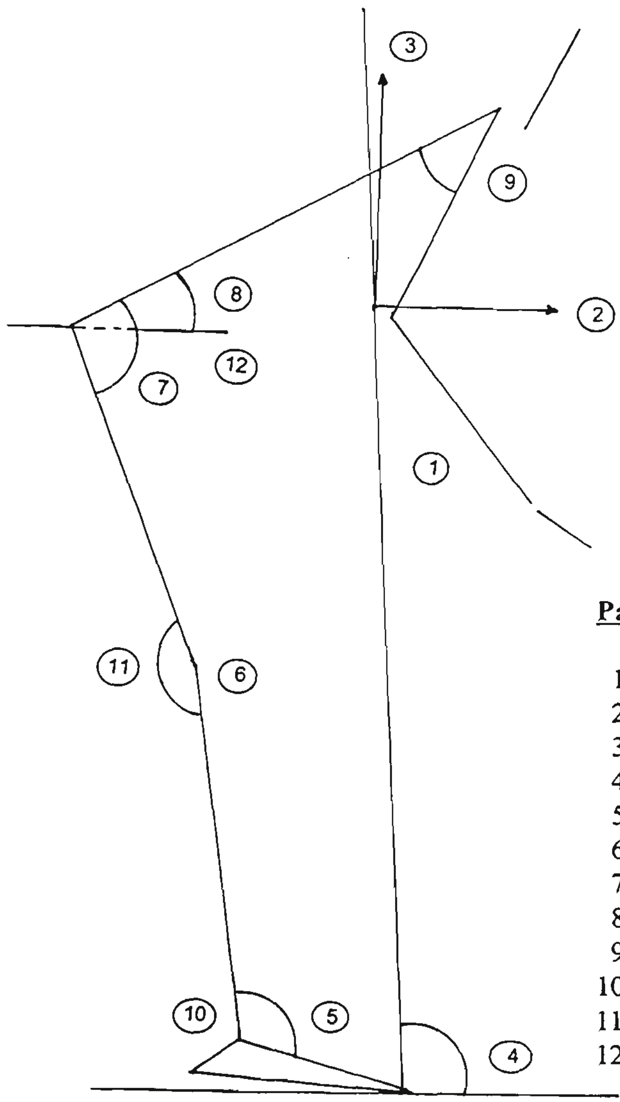
Figure 4.6.1.4.1 Deterministic model showing the release, flight and landing phases, and the biomechanical factors related to controlled landing performances on parallel bars

However, there are other factors which are crucial for the achievement of a controlled landing, such as;- the maximum CM height during flight, and the angle between CM to ground contact and the horizontal at landing touch-down. Controlled landings on parallel bars are likely when gymnasts achieve (a) a high vertical velocity at release; (b) a low horizontal velocity at release; (c) a tight pike position (hip joint angle 40°-50°) in the double back somersault near the peak of the flight to accommodate the rotational requirements of the flight phase; (d) an early preparation for the landing, and (e) good body segment coordination and timing during the landing phase.

4.6.1.5 Development Of The Parallel Bars Landing Model

Biomechanical factors crucial for controlled landings are identified in the parallel bars landings model. To achieve successful, controlled landings on parallel bars, the gymnast must first fulfil the biomechanical requirements at release. Controlled landings are likely when the release and landing impact mechanics are optimised, and ideal segment coordination and timing are achieved during the landing process.

To achieve good release conditions on parallel bars, the mean value of the best three values of the analysed release phase parameters cmhr (2.43m), cmhvr (-0.79m/s) and cmvvr (2.51m/s) on parallel bars, were considered. For the construction of a landing model and the subsequent development of the landing profile shape (LPS), the mean value of the best three values of the landing touch-down parameters were taken into consideration. These parameters were: cmht/d (normalised height percentage value 90.29%), cmhvt/d (-0.22m/s), cmvvt/d (-5.72m/s), acmght/d (92°), aatt/d (36°), aht/d (107°), akt/d (167°), aat/d (103°), atht/d (35°), avht/d (-299°/sec), avkt/d (-915°/sec), and avat/d (-371°/sec). The best three values for the landing parameters represent the lowest values for cmhvt/d and aatt/d, and the highest values for cmvvt/d, cmht/d, acmght/d, aht/d, akt/d, aat/d, atht/d, avht/d, avkt/d and avat/d.



Parallel Bars

1. cmht/d = 0.79m (90.29%)
2. cmhvt/d = -0.22m/s
3. cmvvt/d = -5.72m/s
4. acmght/d = 92°
5. aat/d = 103°
6. akt/d = 167°
7. aht/d = 107°
8. atht/d = 35°
9. aatt/d = 36°
10. avat/d = -371 deg/sec
11. avkt/d = -915 deg/sec
12. avht/d = -299 deg/sec

Figure 4.6.1.5.1 Landing profile shape (LPS) for parallel bars landings

4.6.2 Group 2 (Horizontal Bar) Results

Landing performances on horizontal bar represented the last phase of dismounts consisting of different types of double back somersaults with one or two twists (rotations along the longitudinal axis), and triple somersaults tucked, with a forward horizontal velocity. The personal descriptive data of the gymnasts performing horizontal bar dismounts is presented in Table 4.6.2.1.

Table 4.6.2.1 Descriptive data of group 2 (horizontal bar) subjects

Skill	Subject No.	Competitor No.	Age(years)	Height (m)	Weight (kg)
double layout 2/1 twist	1	283	20	1.71	x
double layout 2/1 twist	2	119	20	1.60	60
double layout 1/1 twist	3	118	21	1.68	65
triple back tucked	4	184	17	x	x
double back tucked 2/1 twist	5	161	20	1.73	64
triple back tucked	6	204	x	x	x
double layout 2/1 twist	7	200	20	1.70	60
triple back tucked	8	174	22	1.63	55

The recordings of the individual dismounts and subsequent landing performances were qualitatively reviewed to investigate the completion of the last salto of the double and triple back somersaults before the landing. The double back layout dismounts showed a back arched shape for most of the flight phase before re-piking in preparation for the landing. The better performances showed a reasonable extension of the body or a kick out before the landing, and the landing was actively anticipated through proper feet placement. Poor landing performances were typified by inadequate technique and subsequently unstable landings occurred when the gymnasts were still somersaulting, coming out of the somersault position slowly by extending the hip and knee joints downward into the landing surface. Unstable landings occurred also when the gymnasts did not have enough landing preparation time due to poor release properties/qualities, and subsequently, were unable to complete the skill before the landing.

Table 4.6.2.2 Group 2 (horizontal bar) competitors details

Subject No.	Competitor No.	Country	Routine Duration (sec)	Routine Score (points)	Rank	Landing Score (%)
1	283	USA	34	9.487	4	62.96
2	119	BLR	35	9.500	3	64.82
3	118	BLR	36	9.687	1	83.34
4	184	HUN	46	9.537	2	75.93
5	161	FIN	46	8.950	8	66.67
6	204	KOR	41	7.850	x	70.37
7	200	KZK	40	8.050	x	75.93
8	174	GER	38	8.725	x	72.22

The results of the qualitative evaluation of the horizontal bar landing performances were as follows: subject 1 scored 62.96%, under-rotated, big jump step forward; subject 2 scored 64.82%, one jump forward, poor body position and excessive arm movements; subject 3 scored 83.34%, stuck landing, excessive arm movements, armcircle forward, lack of landing rhythm; subject 4 scored 75.93%, small hop forward, excessive trunk movement forward and excessive arm movements; subject 5 scored 66.67%, over-rotated, jump backward, poor body position; subject 6 scored 70.37%, good landing position, excessive trunk movement forwards; subject 7 scored 75.93, good landing touch-down position, small hop forward, armcircle backward, excessive knee flexion; subject 8 scored 72.22%, good landing touch-down position, excessive trunk motion forward.

4.6.2.1 Linear Kinematic Data

In this section, the results from the CM positions and displacements (Table 4.6.2.1.1), and the horizontal and vertical velocities (Table 4.6.2.1.2) will be presented and discussed.

Table 4.6.2.1.1 Mean values and standard deviations for the CM positions and displacements during the release, flight phase and landing phase on horizontal bar (m)

Subject	Release	Flight Phase		Landing Phase	
	cmhr	mcmhf	cmhdrt/d	cmht/d	cmhm
1	2.44	3.65	2.21	0.83	0.66
2	2.61	3.81	1.72	0.82	0.49
3	2.77	3.78	1.05	0.96	0.73
4	2.54	3.87	0.61	0.87	0.69
5	2.79	4.01	0.66	0.90	0.45
6	2.81	3.84	0.51	0.74	0.56
7	2.83	3.80	1.28	0.82	0.50
8	2.71	3.86	1.13	0.77	0.63
Mean (SD)	2.69 (0.14)	3.83 (0.10)	1.13 (0.55)	0.84 (0.07)	0.59 (0.10)

The mean value for the ***CM height at release*** (cmhr) was 2.69 ± 0.14m, with the highest value of 2.83m, and the lowest value of 2.44m (Figure 4.6.2.1.1).

The mean CM horizontal velocity (cmhvr) at release was 0.93 ± 0.62 m/s and the CM vertical velocity (cmvvr) at release was 4.74 ± 0.33m/s. The mean horizontal impact velocity (cmhvt/d) was 0.93 ± 0.49m/s and the mean vertical impact velocity (cmvvt/d) was -7.02 ± 0.37m/s.

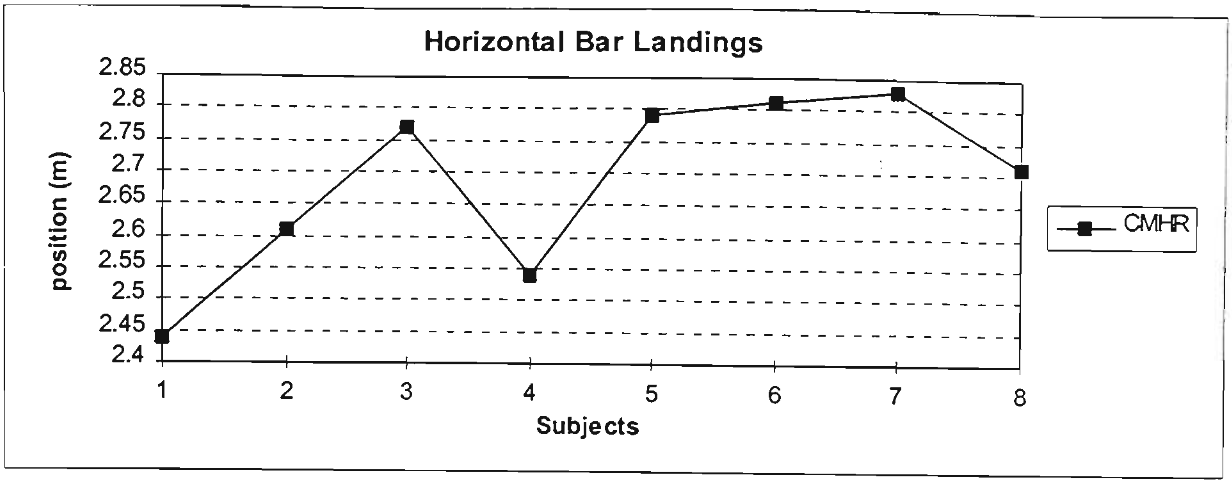


Figure 4.6.2.1.1 CM height at release

Significant correlations were found between the variables cmhr & cmdt/dm ($r = 0.804$, $p<.02$), and cmhr & cmvvr ($r = 0.838$, $p<.001$).

The mean values for the ***maximum CM height during flight*** (mcmhf) was 3.83 ± 0.10 m, with the highest value of 4.01m and the lowest value of 3.65m (Figure 4.6.2.1.2). The mean value of the displacement from the CM height from release to the maximum CM height was 1.14m. The displacement from the maximum CM height to the CM height at landing was 2.99m; and the landing phase vertical displacement (lpdispl) from the CM height at landing (0.84 ± 0.07m) to CM height minimum (0.59 ± 0.10 m) was 0.25m.

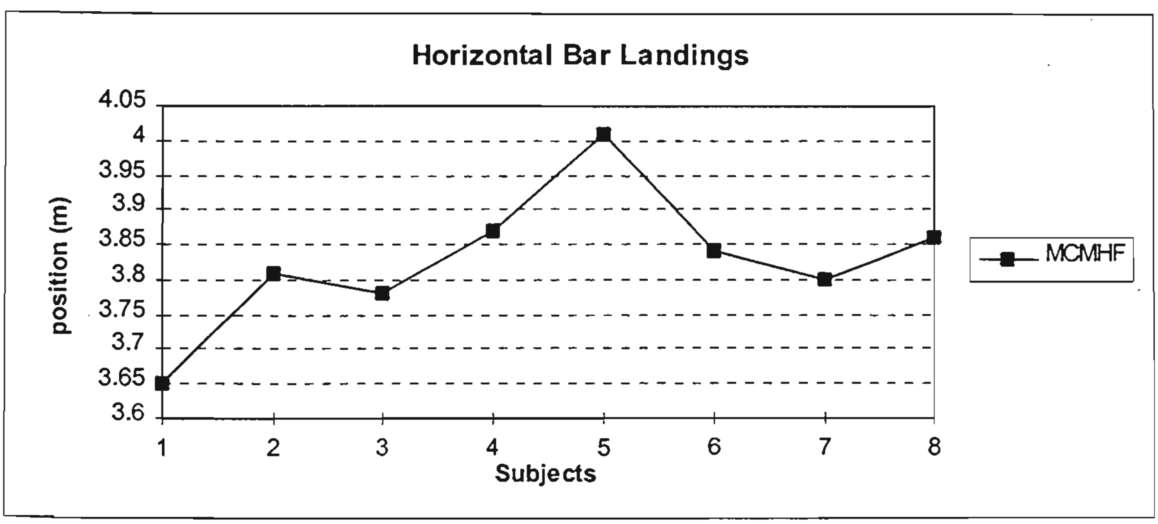


Figure 4.6.2.1.2 Maximum CM height in flight

Significant correlations were found between the variables mcmhf & cmhdrt/d

(r = -0.748, p<.05), and mcmhf & cmhvt/d (r = -0.806, p<.02).

The mean ***CM horizontal displacement from release to landing touch-down*** (cmhdrt/d) was 1.13 ± 0.55m, with a range of 2.21m to 0.51m (Figure 4.6.2.1.3). Significant correlations were found between the variables

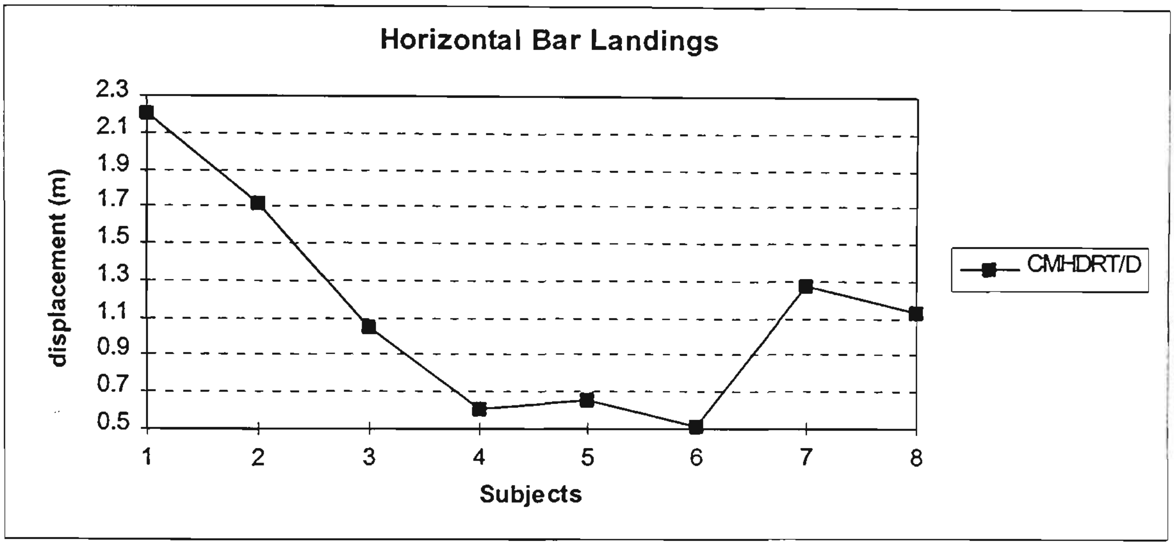


Figure 4.6.2.1.3 CM horizontal displacement from release to landing touch-down

Significant correlations were found between the variables cmhdrt/d & cmhvt/d

(r = 0.893, p<.001), cmhdrt/d & cmhvr (r = 0.831, p<.02), and cmhdrt/d & mcmhf (r = -0.748, p<.05).

The mean ***CM height at landing touch-down*** was 0.84 ± 0.07m, with a range of 0.96m to 0.74m (Figure 4.6.2.1.4).

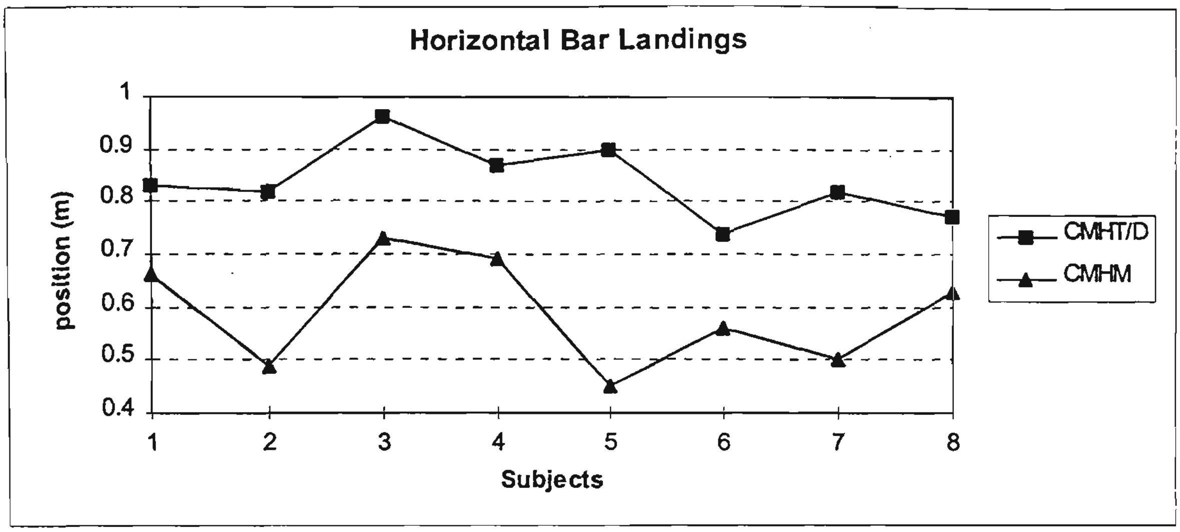


Figure 4.6.2.1.4 CM height at touch-down and minimum position

The mean ***CM height minimum*** (cmhm) value was 0.59 ± 0.10m, with the highest value of 0.73m and the lowest value of 0.45m (see Figure 4.6.2.1.4). Significant correlations were found between the variables cmhm & akm ($r = 0.816$, $p<.02$), cmhm & ahm ($r = 0.777$, $p<.05$), cmhm & cmdt/dm ($r = -0.776$, $p<.05$), and cmhm & lpdispl ($r = -0.776$, $p<.05$).

Table 4.6.2.1.2 Mean values and standard deviations for the CM horizontal and vertical velocities during the release, flight and landing phase on horizontal bar (m/s)

Subject	Release Phase		Landing Phase	
	cmhvr	cmvvr	cmhvt/d	cmvvt/d
1	2.12	4.99	1.77	-7.07
2	1.01	4.88	1.17	-6.24
3	0.54	4.53	0.67	-6.85
4	0.40	5.28	0.40	-7.28
5	0.90	4.57	0.37	-7.23
6	0.22	4.62	0.72	-7.36
7	1.49	4.21	1.36	-6.83
8	0.73	4.86	1.02	-7.29
Mean (SD)	0.93 (0.62)	4.74 (0.33)	0.93 (0.49)	-7.02 (0.37)

The mean value for the ***CM horizontal velocity at release*** (cmhvr) was 0.93 ± 0.62 m/s, with the highest value of 1.49m/s and the lowest value of 0.22m/s (Figure 4.6.2.1.5).

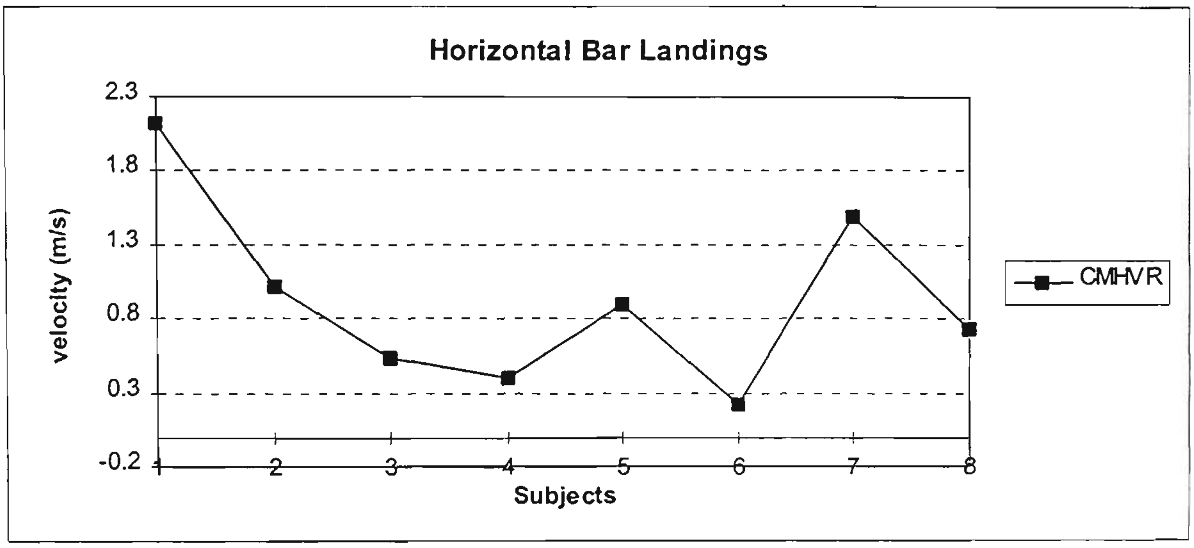


Figure 4.6.2.1.5 CM horizontal velocity at release

Significant correlations were found between the variables cmhvr & cmhdrt/d ($r = 0.831$, $p<.02$), and cmhvr & cmhvt/d ($r = 0.843$, $p<.01$).

The values for the ***CM vertical velocity at release*** (cmvvr) were 4.74 ± 0.33m/s, with the highest value of 5.28m/s and the lowest value of 4.21m/s (Figure 4.6.2.1.6).

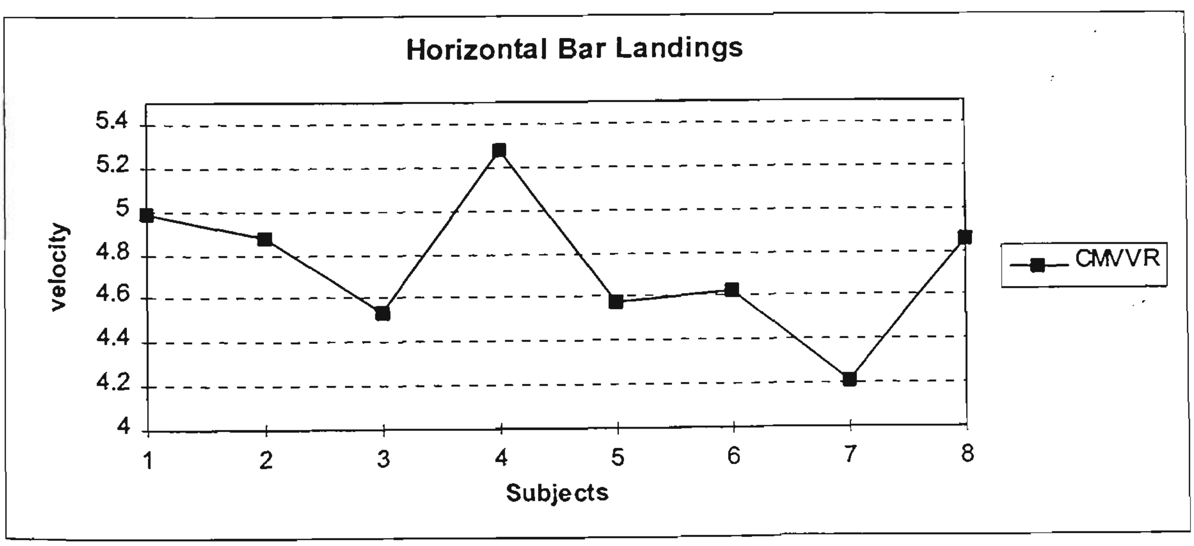


Figure 4.6.2.1.6 CM vertical velocity release

Significant correlations were found between the cmvvr & akt/d (r = 0.753, p<.05), cmvvr & akm (r = 0.765, p<.05), cmvvr & avkt/d (r = 0.769, p<.05), cmvvr & avat/d (r = 0.747, p<.05), and cmvvr & cmhr (r = -0.838, p<.001).

The mean ***CM horizontal impact velocity*** (cmhvt/d) was 0.93 ± 0.49m/s, with the highest value of 1.77m/s and the lowest value of 0.37m/s (Figure 4.6.1.7).

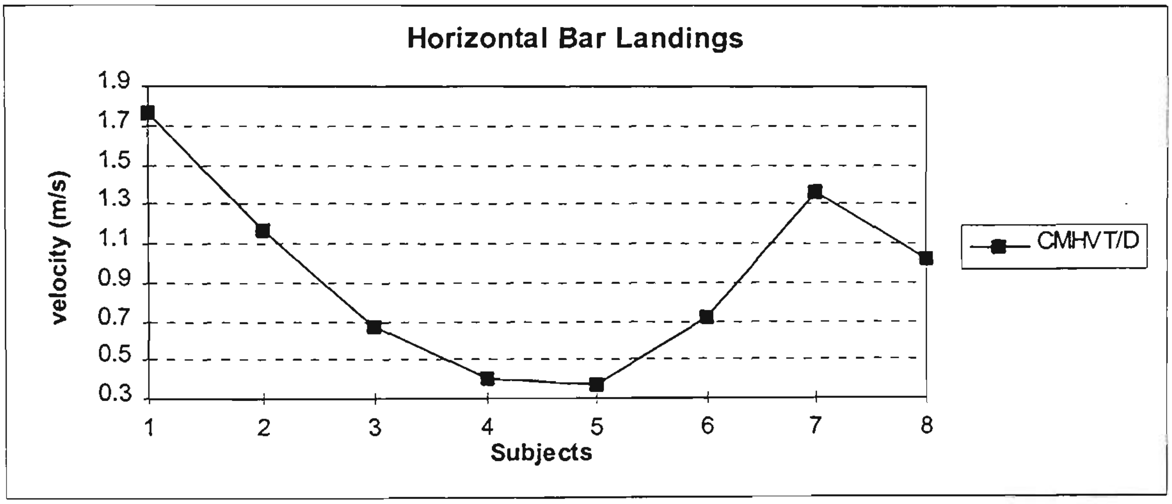


Figure 4.6.2.7 CM horizontal velocity at landing touch-down

Significant correlations were found between the variables cmhvt/d & cmhvr (r = 0.843, p<.01), cmhvt/d & aht/d (r = -0.803, p<.02), cmhvt/d & cmhdrt/d (r = 0.893, p<.01), and cmhvt/d & mcmhf (r = -0.806, p<.02).

The mean ***vertical impact velocity*** (cmvvt/d) was -7.02 ± 0.37m/s, with the highest value of -7.36m/s and the lowest value of -6.24m/s (Figure 4.6.1.8).

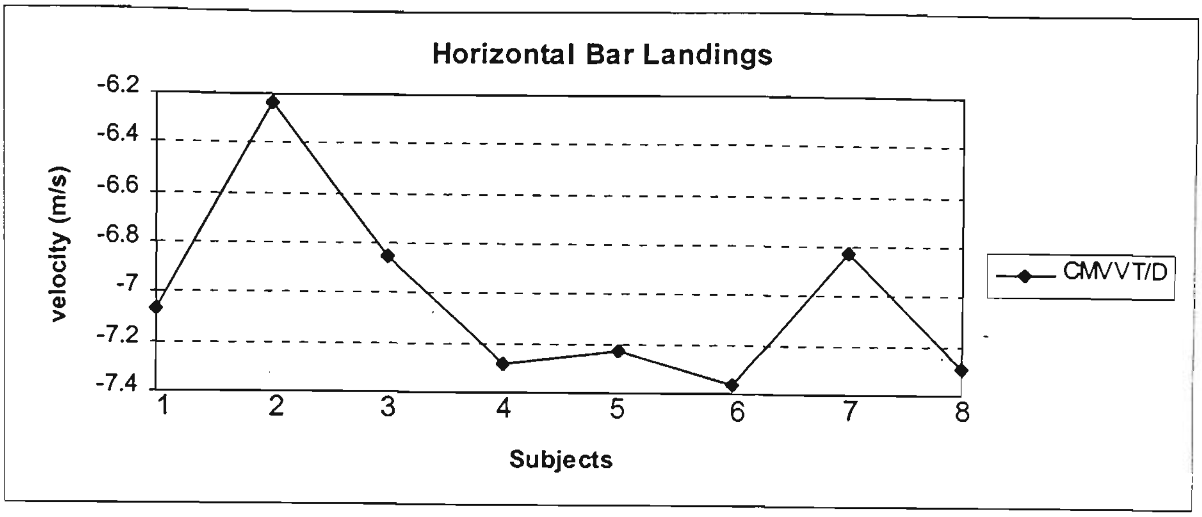


Figure 4.6.2.8 CM vertical velocity at landing touch-down

4.6.2.2 Angular Kinematic Data

In this section, the results from the angular positions and displacements (Table 4.6.2.2.1), angular velocities (Table 4.6.2.2.2), angle-angle diagrams, and angular velocity-angular displacement diagrams will be presented and discussed.

Table 4.6.2.2.1 Mean values and standard deviations for joint, segmental and CM to ground contact and the horizontal, during the landing phase on horizontal bar (degrees)

	Subject									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Mean**	**SD**
acmght/d	91	95	93	91	96	95	97	94	94	2.2
aatt/d	44	103	139	98	73	61	102	48	83.5	32.62
aatm	38	106	89	62	103	58	111	40	75.88	29.96
aht/d	108	113	130	123	124	115	101	112	115.75	9.44
ahm	87	56	81	82	58	44	60	66	66.75	15.13
akt/d	162	145	160	169	141	157	133	159	153.25	12.22
akm	103	85	101	123	42	98	42	98	86.50	29.38
aat/d	107	106	106	104	88	83	91	82	95.88	10.95
aam	76	86	96	103	68	67	76	72	80.5	13.24
atht/d	29	44	55	39	51	45	48	36	43.38	8.43
athm	32	30	42	25	56	7	59	26	34.63	17.17

The values for the ***angles CM to ground contact (toes) and the horizontal at landing touch-down*** for the subjects in group 2 were 94 ± 2.20°, with the highest value of 97° and the lowest value of 91° (Figure 4.6.2.2.1).

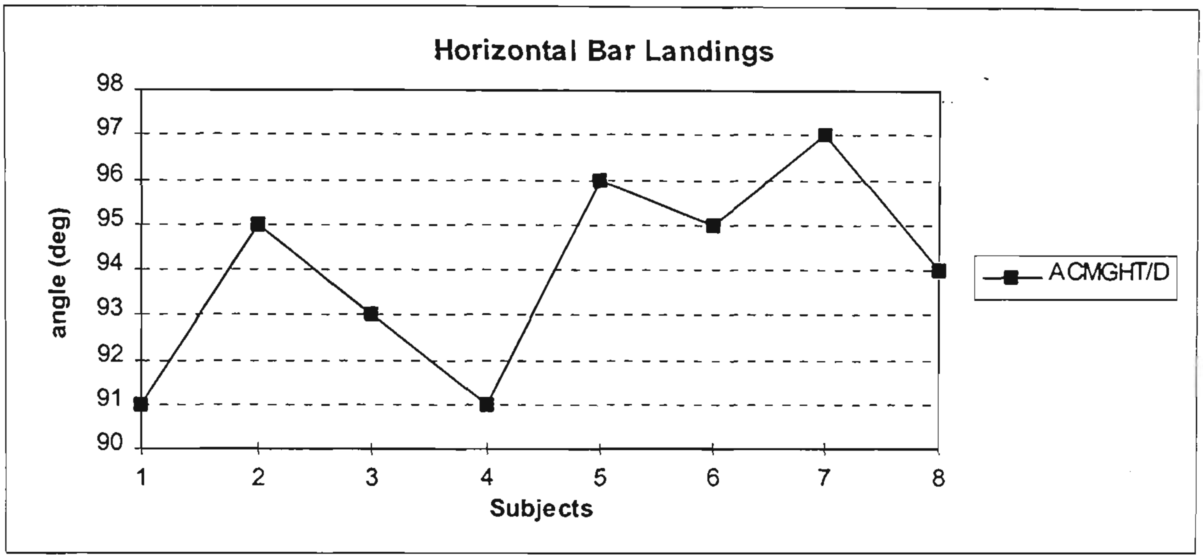


Figure 4.6.2.2.1 Angles CM to ground contact (toes) and the horizontal at landing touch-down

Significant correlations were found between the variables acmght/d & akt/d (r = -0.902, p<.01), acmght/d & akm (r = -0.852, p<.01), acmght/d & ahm (r = -0.823, p<.02) acmght/d & cmhr (r = 0.81, p<.02), acmght/d & cmhm (r = -0.835, p<.01), acmght/d & cmdt/dm (r = 0.926, p<.001), acmght/d & avht/d (r = -0.863, p<.01), acmght/d & avkt/d (r = -0.918, p<.001), acmght/d & avat/d (r = -0.757, p<.03), and acmght/d & cmvvr (r = -0.803, p<.02).

The mean ***shoulder joint angles at landing touch-down*** (aatt/d) were 83.5± 32.62°, with the highest value of 139° and the lowest value of 44° (Figure 4.6.2.2.2).

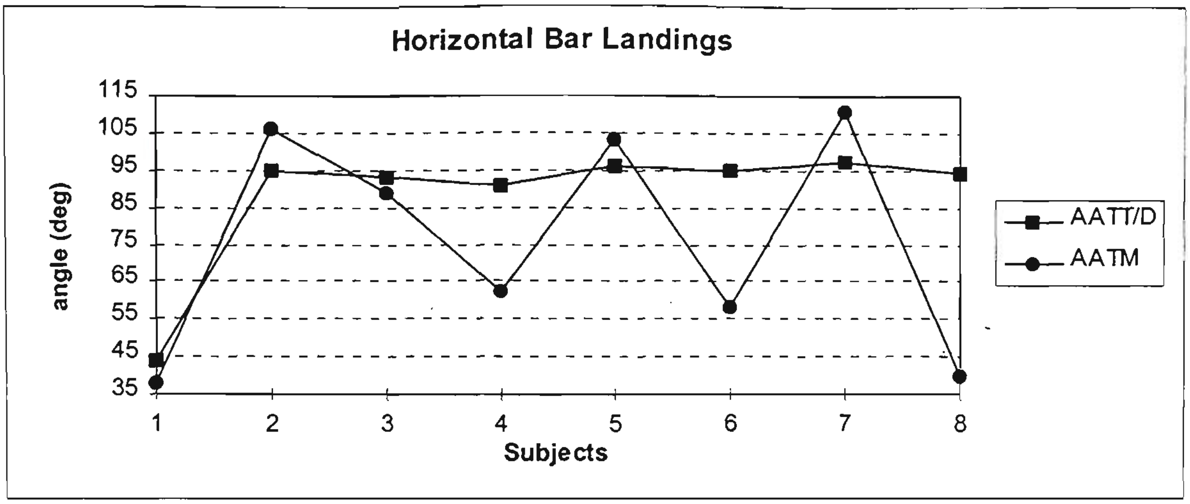


Figure 4.6.2.2.2 Shoulder joint angles at landing touch-down and minimum

Significant correlations were found between the variables aatt/d & atht/d (r = 0.723, p<.05).

The ***minimum shoulder joint angles*** (aatm) were 75.88 ± 29.96°, with the highest value of 111° and the lowest value of 40° (Figure 4.6.2.2). Significant correlations were found between the variables aatm & akm (r = -0.71, p<.05), and aatm & lpdispl (r = 0.858, p<.01).

The mean ***hip joint angles at landing touch-down*** (aht/d) were 115.75 ± 9.44°, with the highest value of 130° and the lowest value of 101° (Figure 4.6.2.2.3).

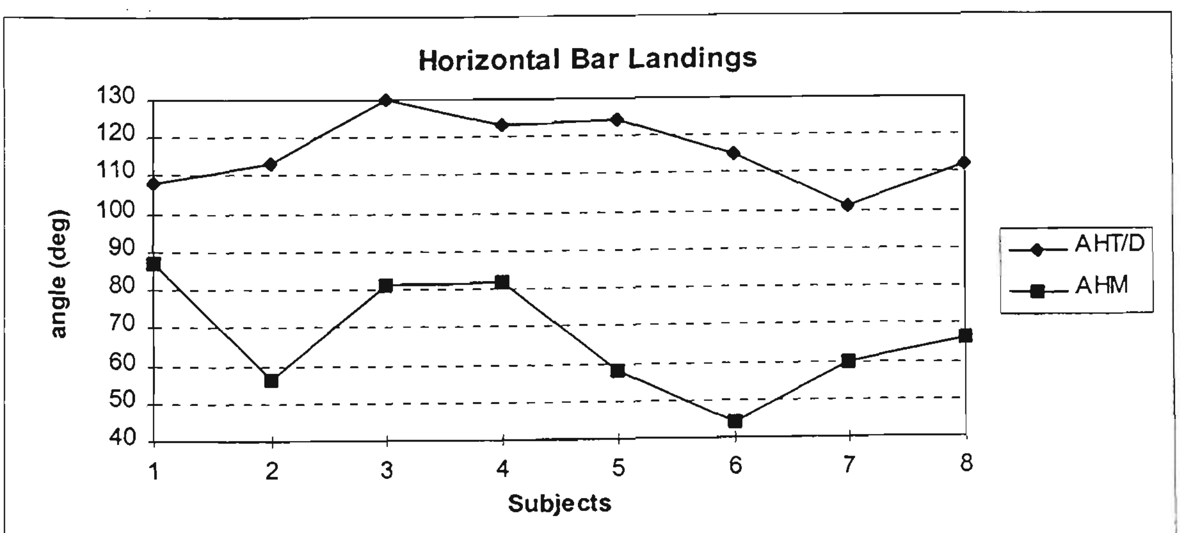


Figure 4.6.2.2.3 Hip joint angles at landing touch-down and minimum

Significant correlations were found between the variables aht/d & cmhvt/d (r = -.803, p<.02), and aht/d & cmhvt/d (r = -.803, p<.02).

The ***minimum hip joint angles*** (ahm) were 66.75 ± 15.13°, with the highest value of 87° and the lowest value of 44° (Figure 4.6.2.3). Significant correlations were found between the variables ahm & acmght/d (r = -.823, p<.02), ahm & avht/d (r = 0.849, p<.01), ahm & avkt/d (r = 0.763, p<.05), ahm & cmdt/dm (r = -0.834, p<.01), and ahm & cmhm (r = 0.777, p<.05),

The mean ***knee joint angles at landing touch-down*** (akt/d) were 153.25 ± 12.22°, with the highest value of 169° and the lowest value of 133° (Figure 4.6.2.2.4).

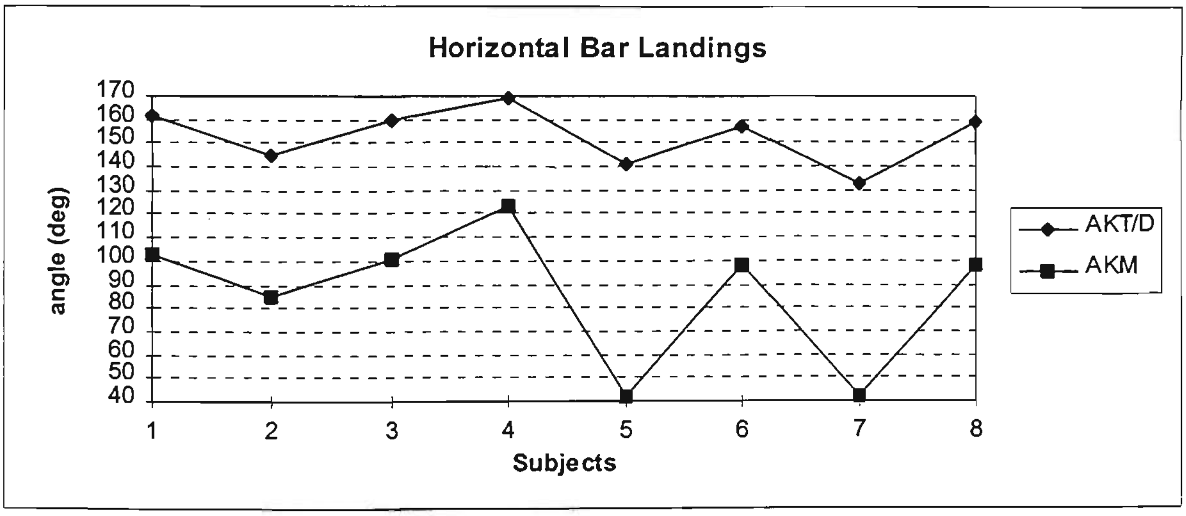


Figure 4.6.2.2.4 Knee joint angles at landing touch-down and minimum

Significant correlations were found between the variables akt/d & akm (r = 0.949, p<.001), akt/d & acmght/d (r = -0.902, p<.01), akt/d & cmvvr (r = 0.753, p<.05), akt/d & avkt/d (r = 0.809, p<.02), akt/d & avht/d (r = 0.809, p<.02),akt/d & avat/d (r = 0.721, p<.05), akt/d & cmdt/dm (r = -0.813, p<.02), akt/d & aatm (r = -0.791, p<.02), akt/d & cmhm (r = 0.862, p<.01), and akt/d & lpdispl (r = -0.805, p<.02).

The ***minimum knee joint angles*** (akm) were 86.50 ± 29.38°, with the highest value of 123° and the lowest value of 42° (Figure 4.6.2.4.). Significant correlations were found between the variables akm & akt/d (r = -0.949, p<.001), akm & acmght/d (r = -0.852, p<.01), akmd & aatm (r = -0.71, p<.05), akm & athm (r = -0.774, p<.05), akm & athm (r = -0.774, p<.05), akm & avkt/d (r = 0.831, p<.02), akm & avat/d (r = 0.861, p<.01), akm & cmdt/dm (r = -0.771, p<.05), akm & cmhm (r = 0.816, p<.02), and akm & lpdispl (r = -0.836, p<.01).

The mean ***ankle joint angles at landing touch-down*** (aat/d) were 95.88 ± 10.95°, with the highest value of 107° and the lowest value of 82° (Figure 4.6.2.5). Significant correlations were found between the variables aat/d & aam (r = 0.746, p<.05).

The ***minimum ankle joint angles*** (aam) were 80.50 ± 13.24°, with the highest value of 103° and the lowest value of 68° (Figure 4.6.2.2.5).

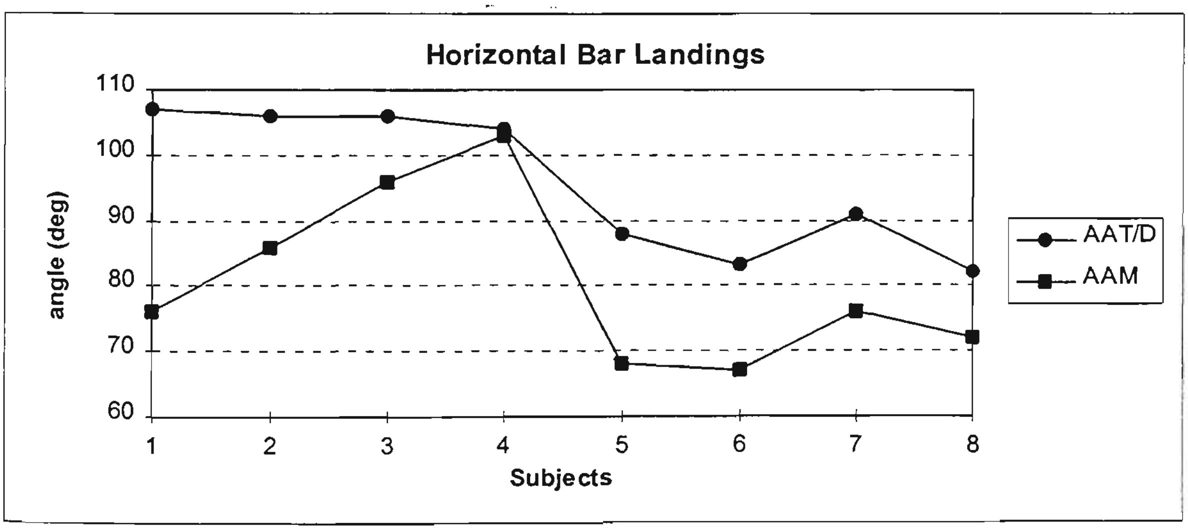


Figure 4.6.2.2.5 Ankle joint angles at landing touch-down and minimum

Significant correlations were found between the variables aam & aatt/d (r = 0.703, p<.05).

The mean ***angles between the trunk and the horizontal at touch-down*** (atht/d) were 43.38 ± 8.43°, with the highest value of 55° and the lowest value of 29° (Figure 4.6.2.2.6). Significant correlations were found between the variables atht/d & aatt/d ($r = 0.723$, $p<.05$), and atht/d & aatm ($r = 0.781$, $p<.05$).

The ***minimum angles trunk to horizontal*** were (athm) were 34.63 ± 17.17°, with the highest value of 59° and the lowest value of 7° (Figure 4.6.2.2.6).

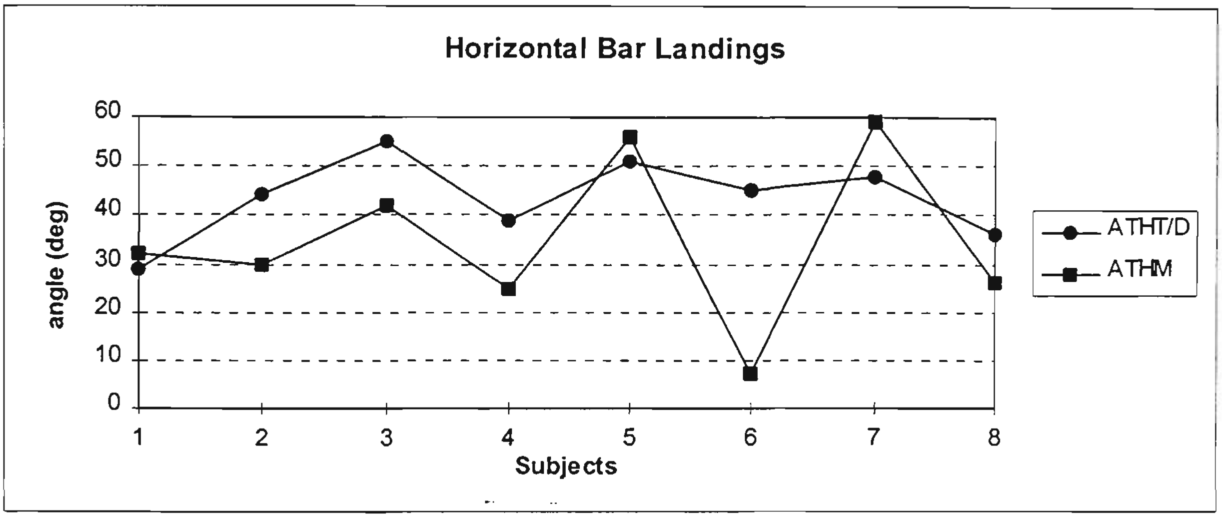


Figure 4.6.2.2.6 Angles trunk to horizontal at landing touch-down and minimum

Significant correlations were found between the variables athm & akm ($r = -0.774$, $p<.05$), and athm & lpdispl ($r = 0.718$, $p<.05$).

Table 4.6.2.2.2 Hip, knee and ankle joint angular velocities at landing phase on horizontal bar (deg/sec)

Subject	Landing Phase		
	avht/d	**avkt/d**	**avat/d**
1	-518	-650	-68
2	-734	-883	-66
3	-543	-811	-128
4	-445	-532	-93
5	-634	-1104	-286
6	-690	-926	-144
7	-706	-963	-290
8	-549	-870	-166
Mean (SD)	-602.38 (103.51)	-842.38 (179.97)	-155.13 (89.2)

The mean value for the ***hip joint angular velocity*** (avht/d) at landing touch-down was -602.38 ± 103.51 deg/sec, with the highest value of -734 deg/sec and the lowest value of -445 deg/sec. Significant correlations were found between the variables avht/d & acmght/d (r = -0.863, p<.01), avht/d & ahm (r = 0.849, p<.01), avht/d & akt/d (r = 0.809, p<.02), avht/d & cmdt/dm (r = -0.896, p<.01), and avht/d & cmhm (r = 0.824, p<.02).

The mean value for ***knee joint angular velocity*** -842.38 ± 179.97 deg/sec, with the highest value of -1104 deg/sec and the lowest value of -532 deg/sec.

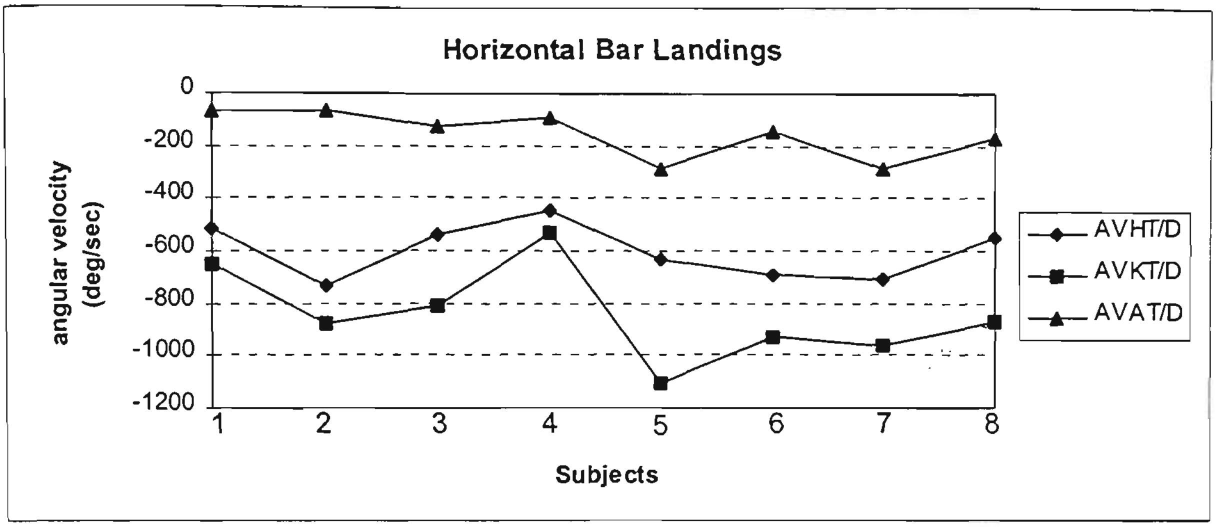


Figure 4.6.2.2.7 Angular velocities of the hip, knee and ankle joints

Significant correlations were found between the variables avkt/d & acmght/d (r = -0.918, p<.001), avkt/d & ahm (r = 0.763, p<.05), avkt/d & akt/d (r = 0.799, p<.02), avkt/d & akm (r = 0.831, p<.02), and avkt/d & cmhm (r = 0.783, p<.05).

The mean ***ankle joint angular velocity*** was -155.13 ± 89.20 deg/sec, with the highest value of -290 deg/sec and the lowest value of -66 deg/sec (Figure 4.6.2.2.7). Significant correlations were found between the variables avat/d & acmght/d (r = -0.757, p<.05), avat/d & akt/d (r = 0.721, p<.05), and avat/d & akm (r = 0.861, p<.01).

Angle-angle diagrams were produced of the best landing performance (subject 3), to investigate the relationship between ankle and knee angles, knee and hip angles, and hip and shoulder angles over the period of the landing phase. These diagrams provide a very good visual picture as was described in the qualitative analysis for subject 3 (Figures 4.6.2.2.8-4.6.2.2.10).

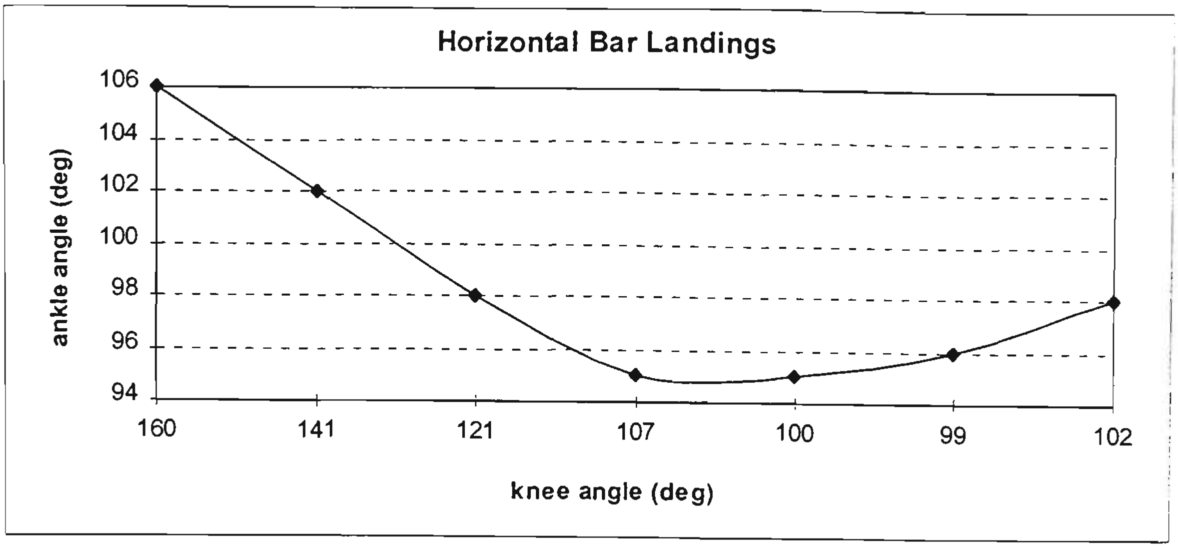


Figure 4.6.2.2.8 Ankle joint angle-knee joint angle diagram for subject 3

Significant correlations were found between the variables akt/d & avat/d (r = 0.721, p<.05), and akm & avat/d (r = 0.861, p<.01). The trend line indicates that subject 3's ankle angle and knee angle is reduced very quickly immediately after landing impact (0.02-0.04sec).

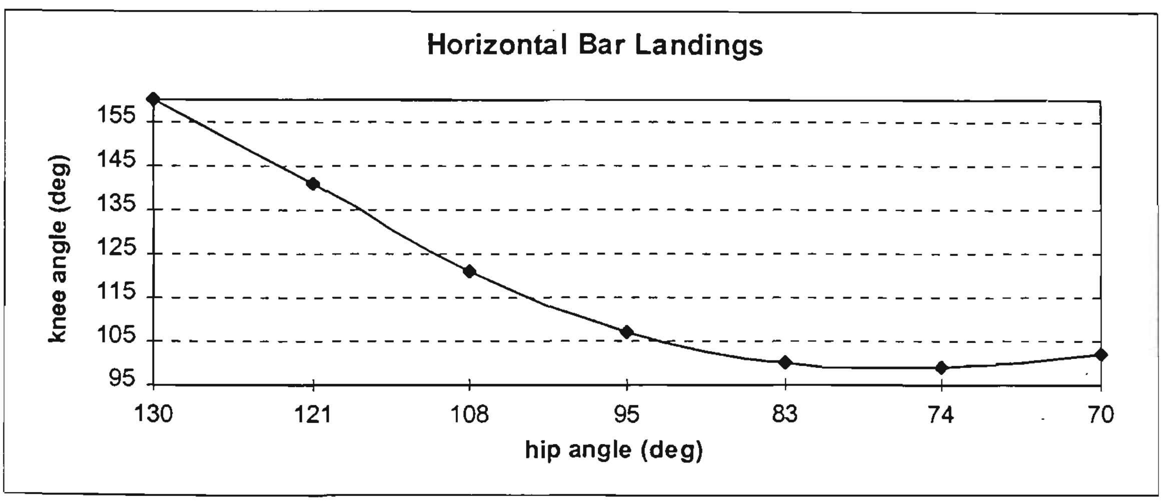


Figure 4.6.2.2.9 Knee joint angle-hip joint angle diagram for subject 3

Significant correlations were found between the akt/d & avht/d (r = 0.809, p<.02). The trend line indicates that the knee angular displacement was reduced by approximately 90% of the total knee displacement within 0.06sec.

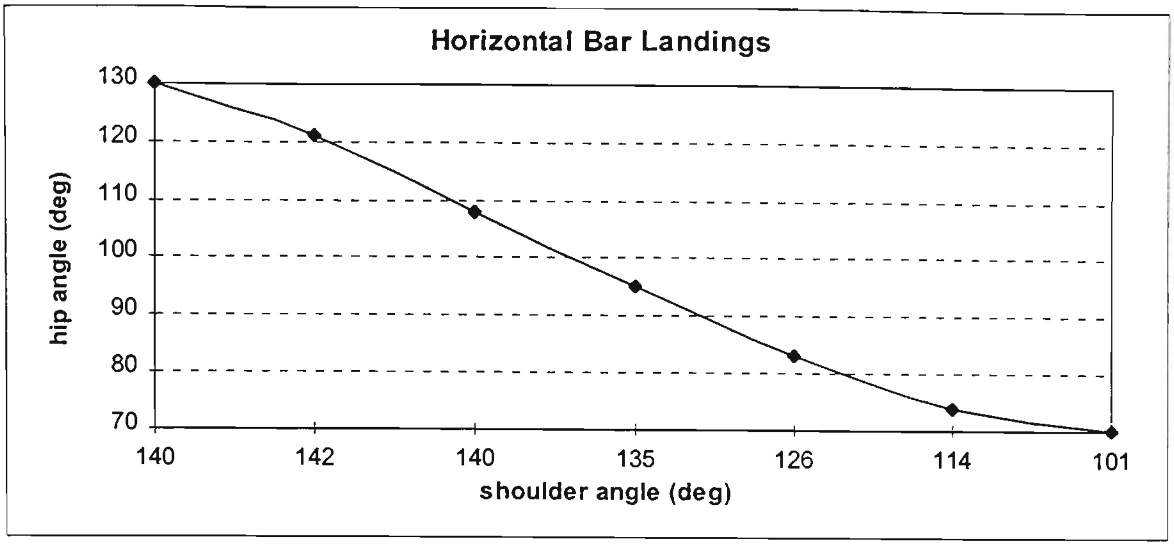


Figure 4.6.2.2.10 Hip joint angle-shoulder joint angle diagram for subject 3

Significant correlations were found between the variables aatt/d & atht/d ($r = 0.723$, $p<.05$).

Angular velocity-angular displacement diagrams for the hip, knee and ankle angles were also produced to provide a description of the respective angular velocity-angular displacement relationship during the landing process. The ankle angular velocity-angular displacement relationship for subject 3 is illustrated in Figure 4.6.2.2.11.

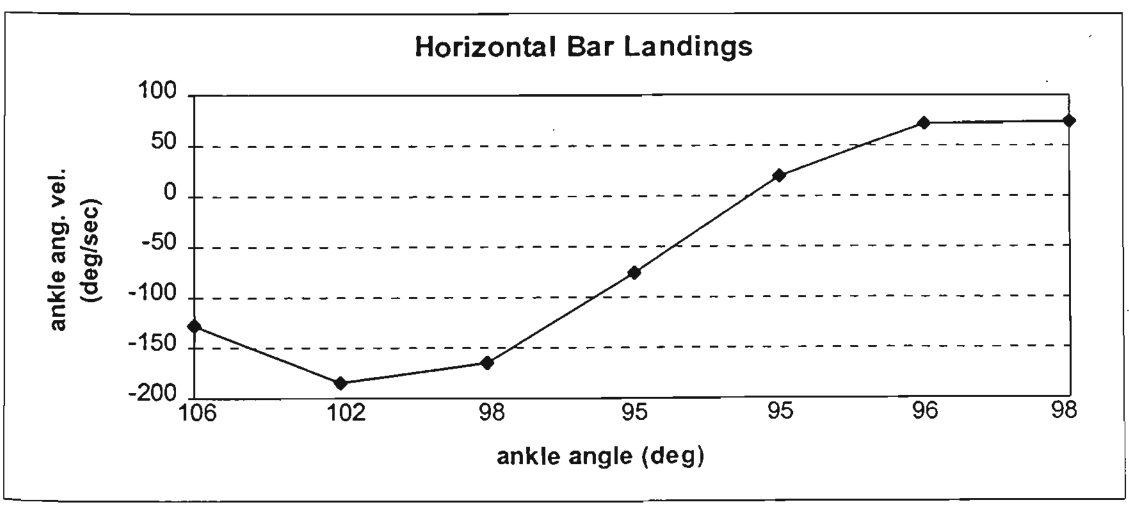


Figure 4.6.2.2.11 Ankle joint angular velocity-ankle joint angle diagram for subject 3

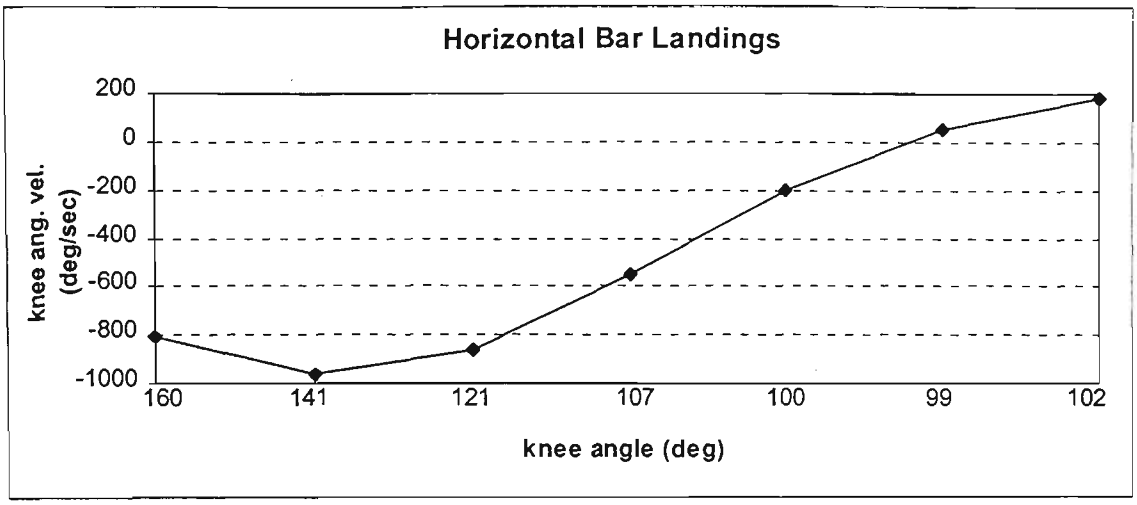


Figure 4.6.2.2.12 Knee joint angular velocity-knee joint angle diagram for subject 3

Significant correlations were found between the variables akt/d & avkt/d ($r = 0.809$, $p<.02$).

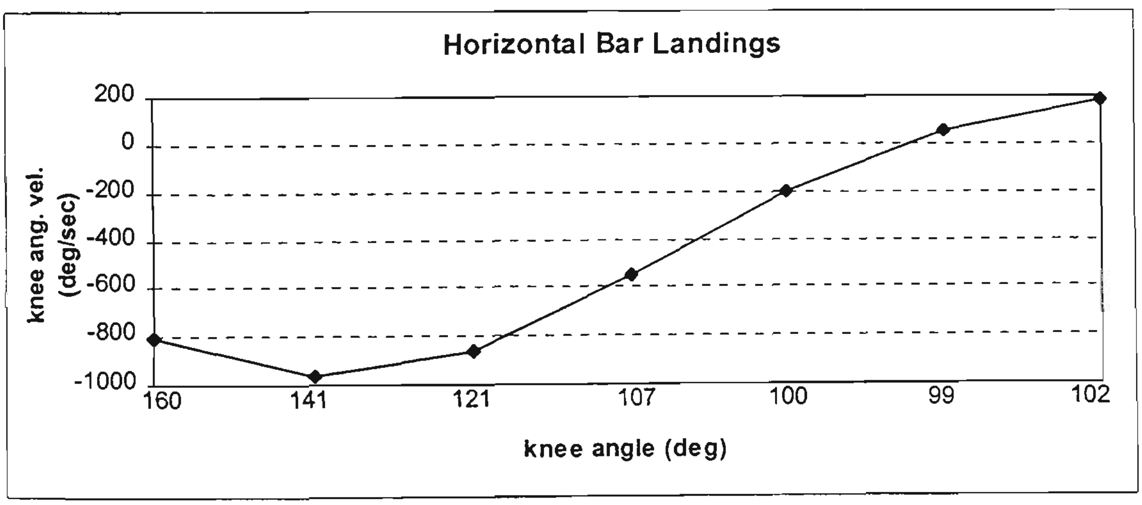


Figure 4.6.2.2.13 Hip joint angular velocity-hip joint angle diagram for subject 3

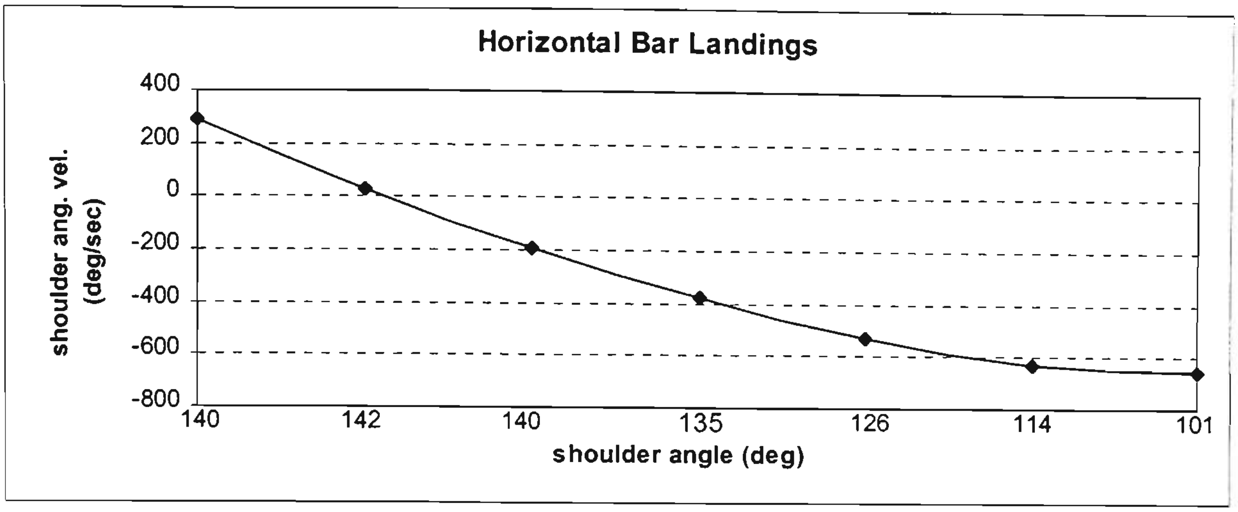


Figure 4.6.2.2.14 Shoulder joint angular velocity-shoulder joint angle diagram for subject 3

4.6.2.3 Temporal Characteristics Of The Flight Phase And Landing Phase

The flight time from release to landing touch-down (ftrt/d), represents the duration through which the gymnast's body rotates while in the air. The flight phase includes parameters such as the vertical height reached by the CM, forward horizontal distance travelled by the CM, and the number of angular rotations achieved; e.g. number of somersaults and twists. The CM duration from landing touch-down to the CM minimum position (cmdt/dm) constitutes the time taken from first contact with the landing surface to CM minimum position.

Table 4.6.2.3.1 Temporal characteristics of the flight phase and landing phase on horizontal bar (seconds)

Subject	Flight Phase ftrt/d	Landing Phase cmdt/dm
1	1.24	0.10
2	1.32	0.16
3	1.24	0.14
4	1.03	0.08
5	1.32	0.18
6	1.28	0.18
7	1.26	0.18
8	1.30	0.12
Mean (SD)	1.25 (0.09)	0.14 (0.04)

The mean value for the ***flight time from release to touch-down*** (ftrt/d) was 1.25 ± 0.09 sec, with the highest value of 1.32sec and the lowest value of 1.03sec (Figure 4.6.2.3.1).

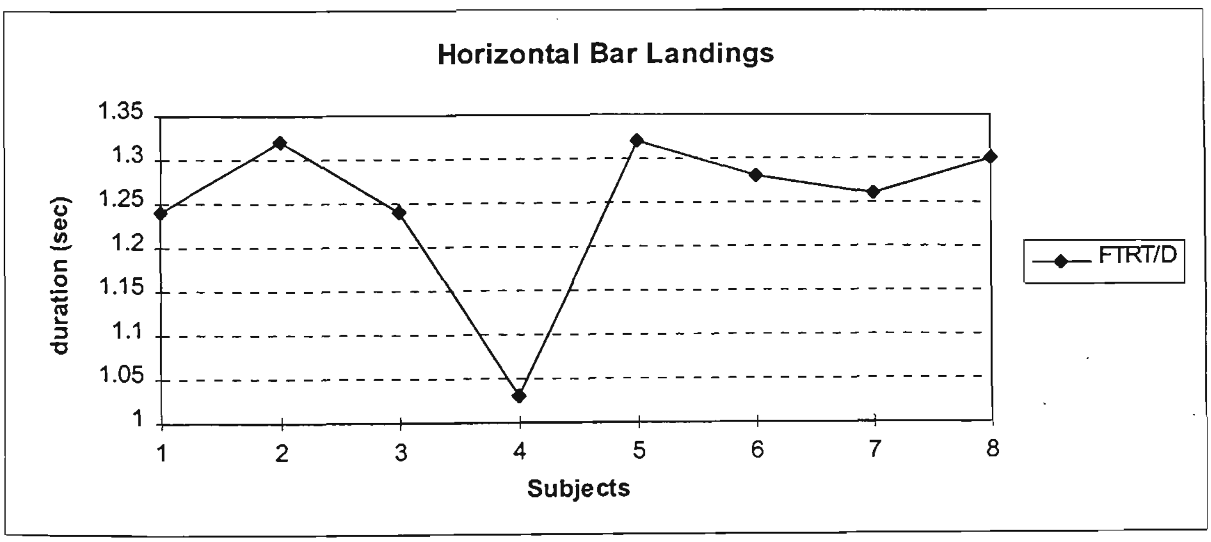


Figure 4.6.2.3.1 Flight time from release to landing touch-down

Significant correlations were found between the variables ftrt/d & aam ($r = -0.737$, $p<.05$), ftrt/d & avht/d ($r = -0.712$, $p<.05$), ftrt/d & avkt/d ($r = -0.817$, $p<.02$), and ftrt/d & cmdt/dm ($r = 0.714$, $p<.05$).

The mean values for the ***CM duration touch-down to minimum*** (cmdt/dm) was 0.14 ± 0.04 sec, with the highest value of 0.18sec and the lowest value of 0.08sec (Figure 4.6.2.3.2).

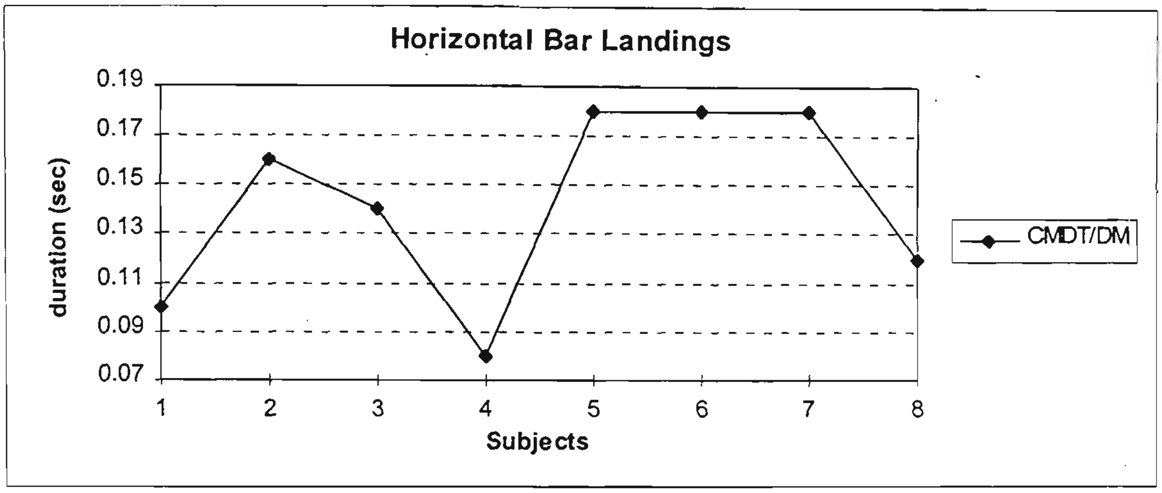


Figure 4.6.2.3.2 CM duration from landing touch-down to CM minimum position

Significant correlations were found between the variables cmdt/dm & acmght/d ($r = 0.926$, $p<.001$), cmdt/dm & ahm ($r = -0.833$, $p<.01$), cmdt/dm & akt/d ($r = -0.813$, $p<.02$), cmdt/dm & akm ($r = -0.77$, $p<.05$), cmdt/dm & avkt/d ($r = -0.916$, $p<.001$), cmdt/dm & avht/d ($r = -0.896$, $p<.01$), cmdt/dm & cmhr ($r = 0.805$, $p<.02$), cmdt/dm & cmhm ($r = -0.776$, $p<.05$), cmdt/dm & cmvvr ($r = -0.83$, $p<.02$), and cmdt/dm & ftrt/d ($r = 0.714$, $p<.05$).

4.6.2.4 Kinematic Parameter Interaction Related To The Landing Score of the Horizontal Bar Landing Model

To provide an optimal landing representation, all landing performances on horizontal bar were discussed in relation to the group mean. The best landing performance was recorded by subject 3 (83.34%), who performed a double layout backward somersault with full twist dismount. Subject 3 recorded a cmhvt/d of (0.67m/s) compared to the mean value of 0.93± 0.49m/s. His cmvvr was measured at 4.53m/s compared to the mean value of 4.74 ± 0.33 m/s, and his cmvvt/d was -6.85m/s compared to the mean value of -7.02 ± 0.37m/s. Significant correlation were found between cmhvr and cmvvr (0.768, p<.03). These variables were identified in levels 10 & 14 of the deterministic model. The result of this relationship is portrayed in the mcmhf and the cmhdrt/d, the height-distance trade-off, from double layout backward somersault dismounts to triple backward somersault dismounts. Brüggemann et al. (1994b), reported mean release vertical velocities of 4.79 ± 0.33 m/s for double tucked back somersault, 4.04 ± 0.1 m/s for double layout back somersault, and 5.08 ± 0.31 m/s for triple tucked back somersault dismounts. Takei et al. (1992) reported vertical velocities at bar release of 4.79m/s. Both studies' results compare to the vertical release velocities of this study. The magnitudes of the landing velocities of the CM were critical factors for stable landings. As a result of the force of gravity, the vertical velocity, and subsequently, the vertical momentum, is decreased from the point of release to the maximum CM height where it will become zero, and than increases continuously up to the moment of landing touch-down (impact). Subject 3's mcmhf was 3.78m compared to the mean value of 3.83 ± 0.10m. These values are consistent with the findings from Kerwin et al. (1990). Because of the forward horizontal impact velocity the gymnast possessed, coupled with the large vertical impact velocity, the ground reaction forces acting in the opposite direction, thus causing his trunk to move forward very quickly. Subsequently, the subject was rotating his arms in the same direction of the trunk to counteract his trunk movement forward. The subject finally maintained his balance, after having resourced to using excessive arm and body movements. His value for acmght/d was 93° compared to the mean value of 94°. He recorded a hip angle of 130° at landing touch-down, compared to the mean value of 115.75°, and a minimum hip angle of 81° compared to the mean value of 66.75°. His hip angle was 131° (0.02sec), 134° (0.04sec) and 136° (0.06 sec), before the landing touch-down. The respective hip angular velocity was recorded as -339, 154 and 27 deg/sec. His hip angle was 121° (0.02sec), 108° (0.04sec), and 95° (0.06sec) after landing touch-down. The respective hip angular velocity was -532, -653 and -640 deg/sec. Subject 3 also recorded a knee angle of 160° at landing touch-down, compared to the mean value of 153°, and a minimum knee angle of 101° compared to the mean value of 86.50°. His knee angle was 174° (0.02sec), 178° (0.04sec), and 176° (0.06sec), almost completely extended legs, before the landing touch-down. The knee angular velocity was recorded as -443, -59 and 41deg/sec, respectively. His knee angle was 141° (0.02sec), 121° (0.04sec), and 107° (0.06sec) after landing touch-down. The respective knee angular velocity was -964, -859 and -549deg/sec. Significant correlations were obtained for the variables in level 10 of the model akt/d & avkt/d ($r = 0.809$, $p<.02$). These correlations indicated that the angular position at landing touch-down is significantly correlated to the duration at which the knee angle closes during the landing process. There was also a significant relationship among the variables acmght/d & akt/d (r = -0.902, p<.01), acmght/d & avht/d (r = -0.863, p<.01), acmght/d & avkt/d (r = -0.918, p<.001), and acmght/d & avat/d (r = -0.757, p<.03). These correlations indicate that the degree of knee flexion and the magnitude of the hip, knee and ankle angular velocity is strongly related to the impact lean angle. The extended position of the hip and knee joints at landing touch-down provided the subject with the option of using a large range of joint motion for reducing the impact velocities during the landing phase. This difference may create a large margin in case the subject needs to modify his landing technique to increase his chances for a controlled landing. If the hip joint is too flexed prior to landing touch-down due to lack of somersault rotation, less hip joint motion is available during the landing phase. The importance of having an extended body position prior to landing is well documented in the research of horizontal bar dismounts by Takei et al. (1992). The availability of a large hip and knee joint range of motion (49 and 59°) provided the subject with the opportunity of choosing an optimal landing technique and suggests that the knee and hip play a large role in increasing the landing phase duration on this event.

Subject 3's ankle angle was 106° at landing touch-down, compared to the mean value of 95.88°, and a minimum ankle angle of 96° compared to the mean value of 80.50°. His ankle angle was 107° (0.02sec), 107° (0.04sec), and 106° (0.06sec), before the landing touch-down. The respective ankle angular velocity was recorded as -44, 19, and 27deg/sec. His ankle angle was 102° (0.02sec), 98° (0.04sec), and 95° (0.06sec) after landing touch-down. The respective ankle angular velocity was -184, -165 and -75deg/sec.

Subject 8 performed a triple backward somersault dismount. He recorded a cmhvt/d of 1.02m/s compared to the mean value of 0.93m/s. His cmvvr was measured at 4.86m/s compared to the mean value of 4.74 ± 0.33 m/s, and his cmvvt/d was measured at -7.29m/s compared to the mean value of -7.02 ± 0.37m/s. His mcmhf was 3.86m compared to the mean value of 3.83 ± 0.10m. These values are consistent with the findings from Kerwin et al. (1990) who reported mean values of 3.63± 0.13m for double backward somersault dismounts, and 3.99± 0.08m for triple backward somersault dismounts. Subject 8 recorded a hip angle of 112° at landing touch-down, compared to the mean value of 115.75°, and a minimum hip angle of 66° compared to the mean value of 66.75°. His hip angle was 119° (0.02sec), 121° (0.04sec) and 118° (0.06 sec), before the landing touch-down. The respective hip angular velocity was recorded as -491, 402 and 292deg/sec. His hip angle was 103° (0.02sec), 91° (0.04sec), and 80° (0.06sec) after landing touch-down. The respective hip angular velocity was -548, -465 and -320deg/sec. Subject 8 also recorded a knee angle of 159° at landing touch-down, compared to the mean value of 153°, and a minimum knee angle of 98° compared to the mean value of 86.50°. His knee angle was 173° (0.02sec), 179° (0.04sec), and 177° (0.06sec), almost completely extended legs, before the landing touch-down. The knee angular velocity was recorded as -501, -103 and 113deg/sec, respectively. His knee angle was 139° (0.02sec), 118° (0.04sec), and 104° (0.06sec) after landing touch-down. The respective knee angular velocity was -1018, -866 and -510deg/sec. Subject 8's ankle angle was 82° at landing touch-down, compared to the mean value of 95.88°, and a minimum ankle angle of 72° compared to the mean value of 80.50°. His ankle angle was 84° (0.02sec), 85° (0.04sec), and 86° (0.06sec), before the landing touch-down. The respective ankle angular velocity was recorded as -95, 49, and 9deg/sec. His ankle angle was 78° (0.02sec), 73° (0.04sec), and 72° (0.06sec) after landing touch-down. The respective ankle angular velocity was -206, -138 and -23deg/sec.

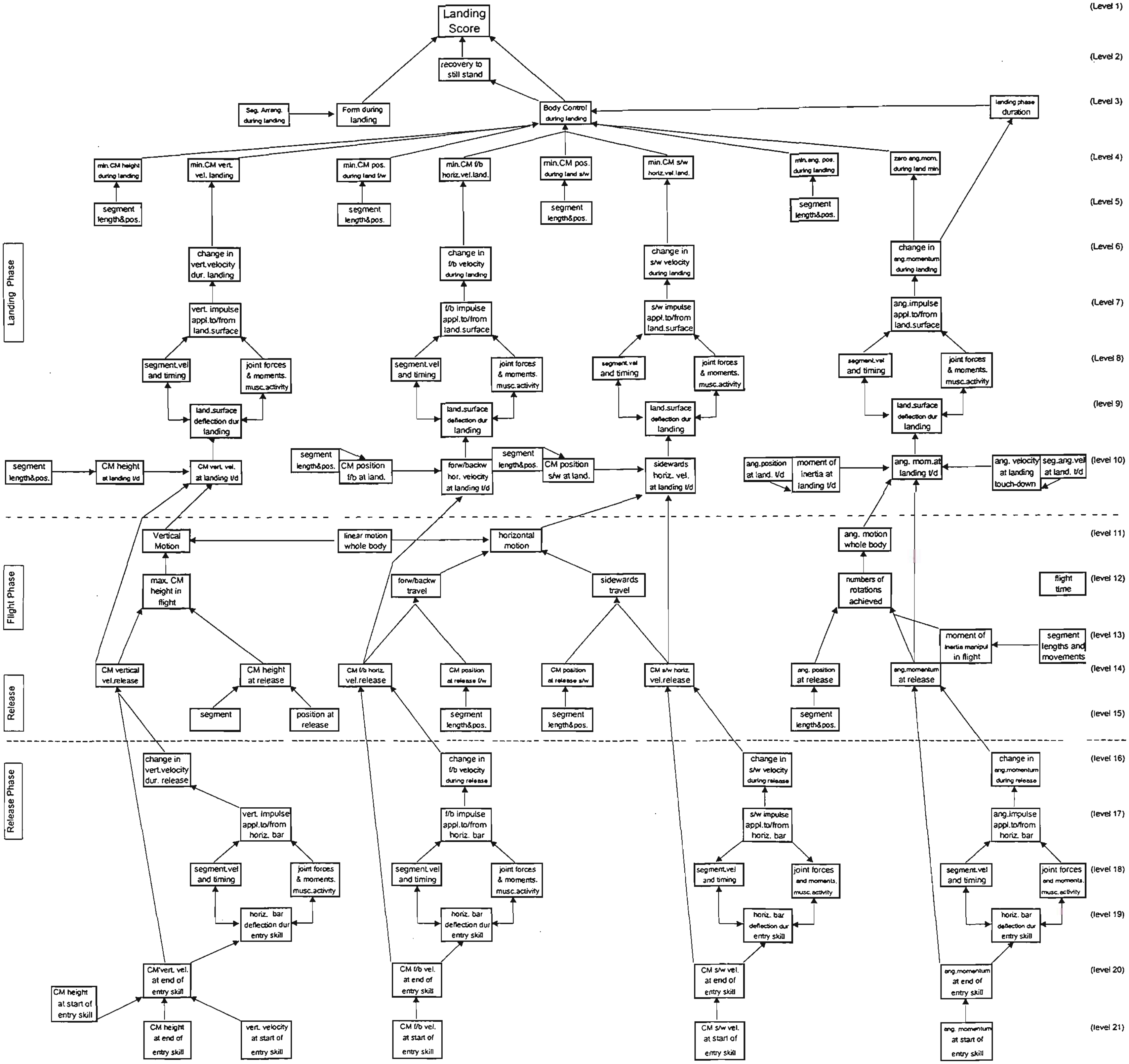


Figure 4.6.2.4.1 Deterministic model showing the release, flight and landing phases, and the biomechanical factors related to controlled landing performances on horizontal bar

Stable landings on this event were typified by a small CM horizontal velocity forwards at landing touch-down (between 0.37 - 1.02m/s) and a mean angle CM to ground contact and the horizontal of 94°.

Poor landing performances were typified by inadequate technique and when the gymnasts did not have enough landing preparation time due to poor release properties. Subsequently, the gymnasts were unable to complete the skill before the landing, or when the gymnasts did not have enough or had too much somersault rotation (over or under rotation). This was most evident in triple back somersault dismounts. Unstable landings also occurred, when the gymnasts did not complete the twisting or somersault rotations before the landing, which was most evident in full and double twisting tucked and layout backward somersault dismounts. The most stable landings were achieved by gymnasts who performed the dismount with good technique and body control. The need to control the angular momentum during landings of somersaults may prohibit the use of extensive trunk motion. A crucial biomechanical parameter influencing a controlled landing is the CM horizontal velocity at landing touch-down, which is a direct consequence of the CM horizontal velocity at release. However, there are other factors which are crucial for the achievement of a controlled landing, such as;- the maximum CM height during flight, and the angle between CM to ground contact and the horizontal at landing touch-down.

It is concluded that successful landings are likely when efforts are made to achieve (a) a high vertical velocity at release; (b) optimal rotational requirements of the flight phase; e.g. a tight tucked position in the triple backward somersault during the flight in order to complete the last somersault as early as possible; (c) an early preparation for the landing, and (d) optimal body segment coordination and timing during the landing phase.

4.6.2.5 Development Of The Horizontal Bar Landing Model

Biomechanical factors crucial for controlled landings are identified in the "horizontal bar landings model". To achieve successful, controlled landings on horizontal bar, the gymnast must first fulfil the biomechanical requirements in the release phase. Subsequent landings are likely to be successful when the landing impact kinematics are optimised, and optimal segment coordination and timing are achieved during the landing process.

The mean values of the landing phase parameters cmhr, cmhvr and cmvvr, from the best three horizontal bar landing performances were considered for the development of the landing profile.

To achieve optimal release conditions on horizontal bar, the mean value of the best three values of the analysed release phase parameters cmhr (2.81m), cmhvr (0.39m/s) and cmvvr (5.05m/s), were considered. The mean value of the best three values of the landing touch-down parameters cmht/d (0.91m), cmhvt/d (0.48m/s), cmvvt/d (-7.31m/s), acmght/d (96°), aht/d (126°), akt/d (164°), atht/d (51°), avht/d (-710°/sec), and avkt/d (-998°/sec), were taken into consideration for the development of the landing profile shape (LPS). The best three values for the landing parameters represent the lowest values for cmhvt/d and aatt/d, and the highest values for cmvvt/d, cmht/d, acmght/d, aht/d, akt/d, aat/d, atht/d, avht/d, avkt/d and avat/d.

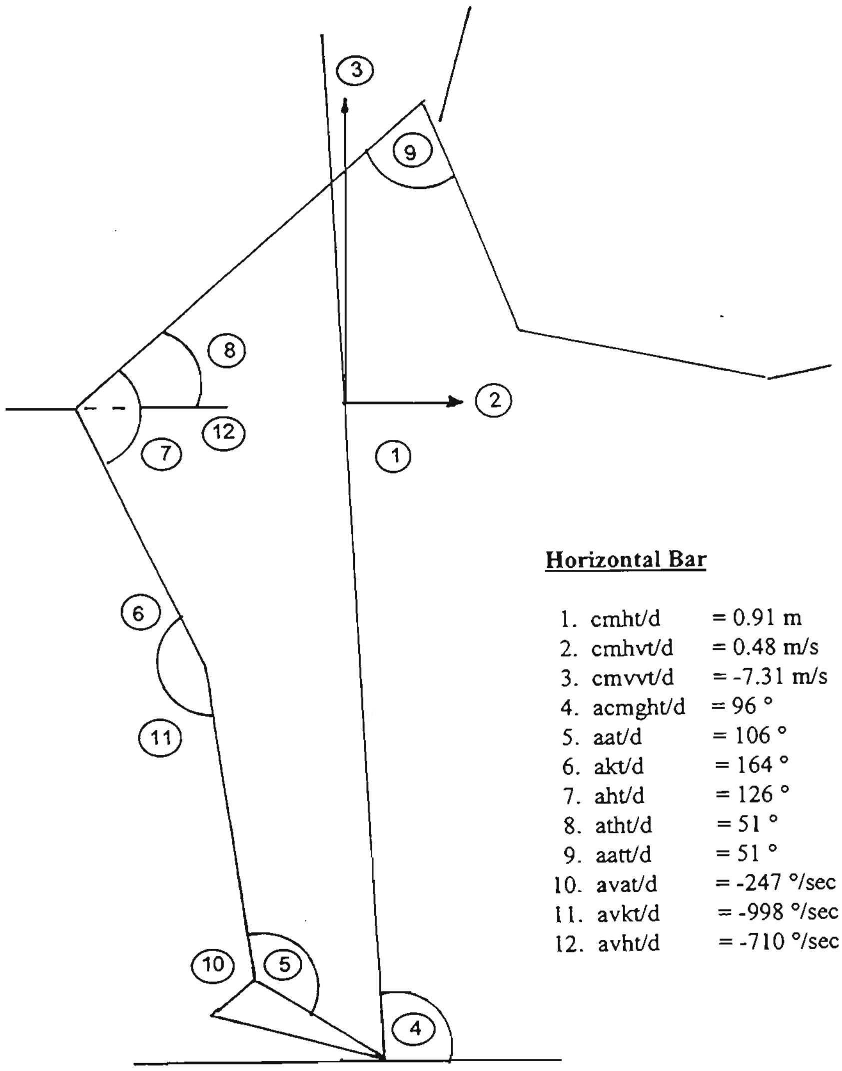


Figure 4.6.2.5.1 Landing profile shape (LPS) for horizontal bar landings

4.6.3 Group 3 (Floor) Results

One of the most frequently used components of a floor exercise are the landings which occur anywhere after an acrobatic tumbling skill during the exercise.

The personal descriptive data of the gymnasts performing the floor landings are presented in Table 4.6.3.1.

Table 4.6.3.1 Descriptive data of group 3 (floor) subjects (n=8)

Skill	Subject No.	Competitor No.	Age(years)	Height (m)	Weight (kg)
*** full-in back out	1	264	20	1.71	76
*** full-in back out	2	132	21	1.62	57
*** full-in back out	3	250	21	1.64	68
** double back tucked	4	243	17	x	x
** double back tucked	5	235	22	1.63	55
* double layout 1/1 twist	6	192	20	x	61
double back layout	7	238	22	x	x
*** full-in back out	8	246	18	1.70	63

* opening ** middle/during *** finishing

All performances represented different types of double back somersaults with backward horizontal velocity, performed as either the last skill of an opening, during, or finishing acrobatic series, of a floor routine. Double back somersaults, which have linear and angular momentum before take-off, are very difficult to control during landings.

Table 4.6.3.2 Group 3 (floor) subjects details

Subject No.	Country	Routine Duration (sec)	Routine Score (points)	Landing Score (%)
1	SWE	53	8.925	80.25
2	BUL	59	9.200	84.08
3	RUS	58	9.175	83.34
4	FRA	65	8.450	90.74
5	CHN	69	7.650	75.93
6	ITA	63	8.900	88.89
7	PUR	58	8.525	59.26
8	ROM	69	8.425	57.21

Examination of the video recordings indicate that landing techniques employed by the gymnasts differ within the group. The video recordings of the individual landing performances were carefully viewed in order to qualitatively analyse the take-off position of the body and its segmental positions, the tightness of the tuck/pike position during the double backward somersault, the body position before the landing, and at landing touch-down. The better performances showed a good extension of the body at take-off, a controlled position during the flight, and the landing was actively anticipated through proper feet placement. Poor performances showed an incorrect body position at take-off which resulted in either an under- or over-rotation of the saltos and subsequently these gymnasts were extending the hip and knee joints hurriedly into the landing surface.

The results of the qualitative evaluation of the floor landing performances were as follows: subject 1 performed a full in back out double back somersault and scored 80.25% for the landing, good landing, one step backwards with left leg (bandage on left knee), fair body position during landing; subject 2 performed a full in back out double back somersault and scored 84.08%, good controlled landing, one step backwards with left leg, trunk too low; subject 3 performed a full in back out double back somersault and scored 83.34%, very good landing, little hop forwards; subject 4 performed a double back somersault tucked and scored 90.74%, perfectly stuck landing; subject 5 performed a double back somersault tucked and scored 75.93%, small hop backwards, slightly over-rotated; subject 6 performed a double layout full twist somersault and scored 88.89%, stuck landing, almost perfect landing, minor body movement; subject 7 performed a double layout back somersault and scored 57.21%, poor body position during landing, uncontrolled stiff legged landing, three steps backwards, over-rotated; and subject 8 performed a full-in back-out double backward somersault and scored 59.26%, poor body position during landing, under-rotatated and fell forwards onto hands.

4.6.3.1 Linear Kinematic Data

In this section, the results from the CM positions and displacements (Table 4.6.3.1.1), and, the horizontal and vertical velocities (Table 4.6.3.1.2) will be presented and discussed.

Table 4.6.3.1.1 Mean values and standard deviations for the CM position during the take-off, flight phase and landing phase on floor (m)

Subject	Take-off	Flight Phase		Landing Phase	
	cmht/o	mcmhf	cmhdt/ot/d	cmht/d	cmhm
1	1.16	2.29	2.16	0.83	0.75
2	1.09	2.07	2.57	0.68	0.60
3	1.19	2.42	1.76	0.74	0.66
4	1.11	2.20	2.21	0.81	0.68
5	1.00	2.01	2.31	0.73	0.67
6	1.07	2.14	2.28	0.63	0.58
7	1.15	2.07	2.23	0.63	0.57
8	1.15	2.21	2.47	0.71	0.59
Mean (SD)	1.12 (0.06)	2.18 (0.13)	2.25 (0.24)	0.72 (0.07)	0.64 (0.06)

The mean value for the ***CM height at take-off*** (cmht/o) was recorded at 1.12 ± 0.06m, within a range of 1.00m to 1.19m (Figure 4.6.3.1.1).

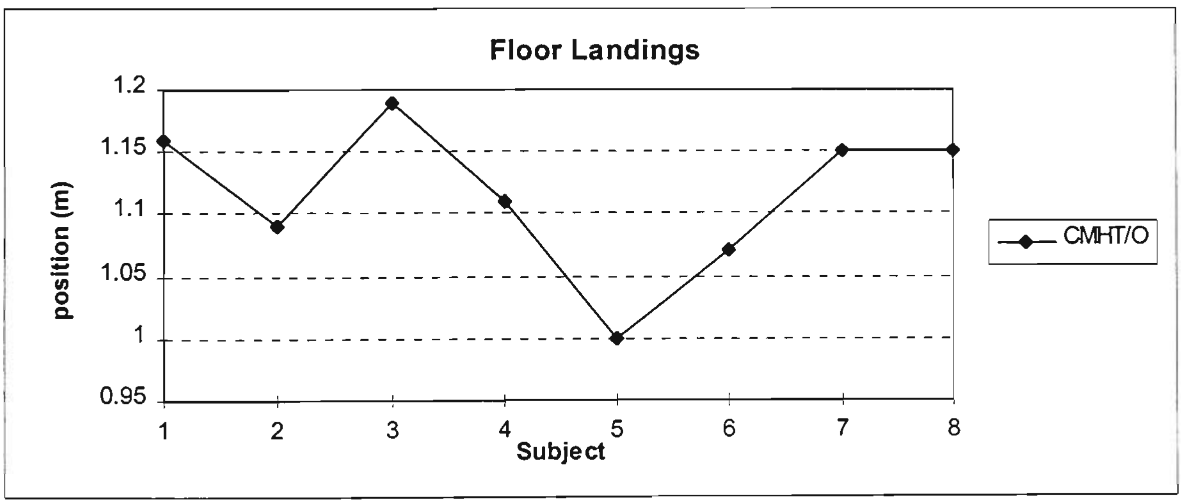


Figure 4.6.3.1.1 CM height at take-off

The mean values for the ***maximum CM height during flight*** (mcmhf) was 2.18 ± 0.13 m, with the highest value of 2.42m and the lowest value of 2.01m (Figure 4.6.3.1.2). The mean displacement value from CM height at t/o to the max. CM height in flight was 1.06m. Significant correlations (r = 0.773, p<.03) were found between the variables (cmht/o & mcmhf).

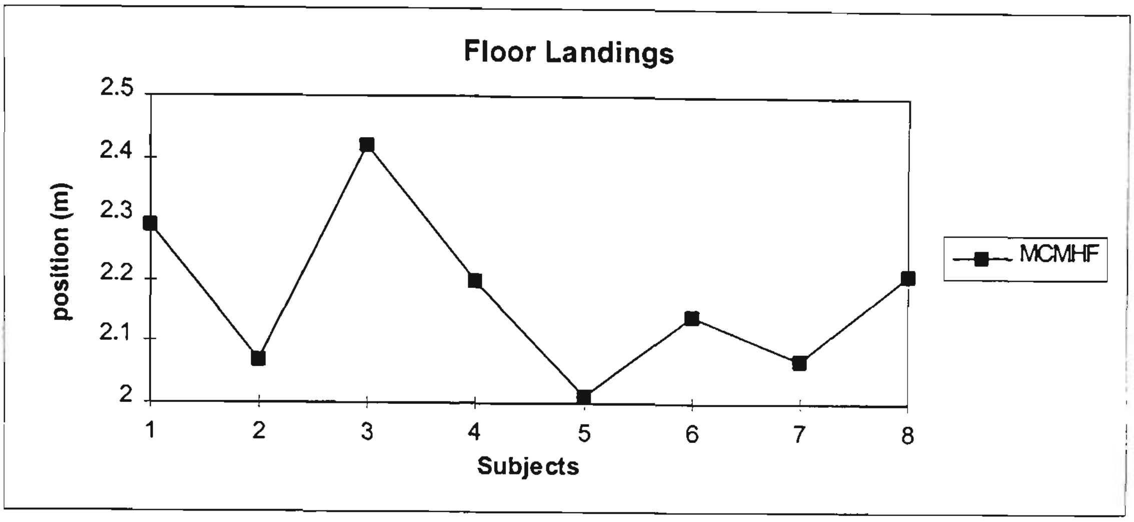


Figure 4.6.3.1.2 Maximum CM height in flight

The mean ***CM horizontal displacement from take-off to landing touch-down*** (cmhdt/ot/d) was 2.25 ± 0.24m, with the highest value of 2.57m and the lowest value of 1.76m (see Figure 4.6.3.1.3). Significant correlations were found between the variables mcmhf & cmhdt/ot/d (r = 0.736, p<.05), and between the variables cmhdt/ot/d & cmhvt/d (r = 0.789, p<.02).

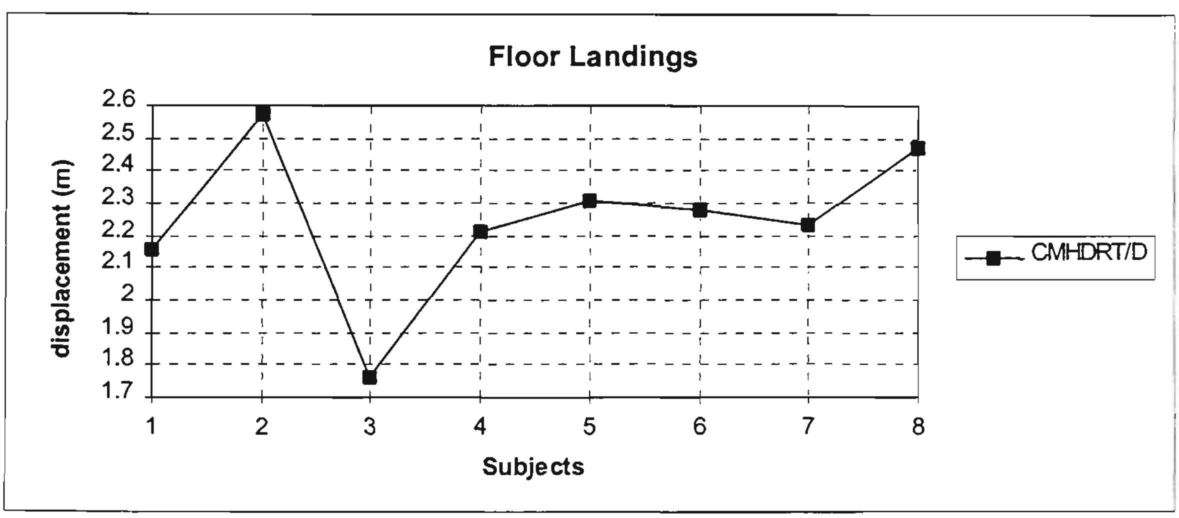


Figure4.6.3.1.3 CM horizontal displacement from take-off to landing touch-down

The mean ***CM height at landing touch-down*** was 0.72 ± 0.07m, with the highest value of 0.83m and the lowest value of 0.63m (Figure 4.6.3.1.4).

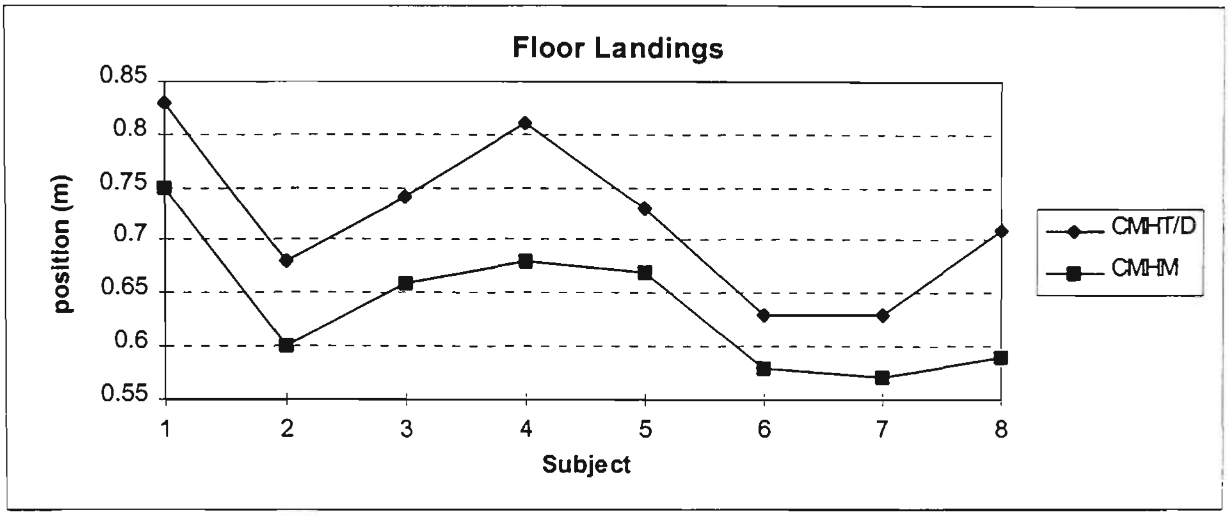


Figure 4.6.3.1.4 CM height at touch-down and minimum position

The mean ***CM height minimum*** (cmhm) value was 0.642 ± 0.06m, with the highest value of 0.75m and the lowest value of 0.57m (see Figure 4.6.3.1.4). Significant correlations were found between the variables cmht/d & cmhm ($r = 0.926$, $p<.001$), cmht/d & aat/d ($r = 0.72$, $p<.05$), cmht/d & aatt/d ($r = 0.825$, $p<.02$), and between the variables cmhm & aatt/d ($r = 0.804$, $p<.02$).

Table 4.6.3.1.2 Group 3 subjects individual data, mean values and standard deviations for the CM horizontal and vertical velocities during take-off, and landing touch-down on floor (m/s)

Subject	Take-off		Landing Phase	
	cmhvt/o	cmvvt/o	cmhvt/d	cmvvt/d
1	-3.38	4.31	-1.94	-4.19
2	-3.28	4.13	-2.59	-4.71
3	-3.00	4.74	-1.80	-5.49
4	-2.82	4.58	-1.95	-4.34
5	-2.33	4.90	-1.98	-5.28
6	-3.82	3.38	-2.07	-4.68
7	-2.46	4.23	-1.74	-5.00
8	-2.73	4.47	-2.38	-5.43
Mean (SD)	-2.98 (0.50)	4.34 (0.47)	-2.06 (0.29)	-4.89 (0.49)

The mean value for the ***CM horizontal velocity at take-off*** (cmhvt/o) was -2.98 ± 0.50 m/s, with the highest value of 3.82m/s and the lowest value of 2.46m/s (Figure 4.6.3.1.5).

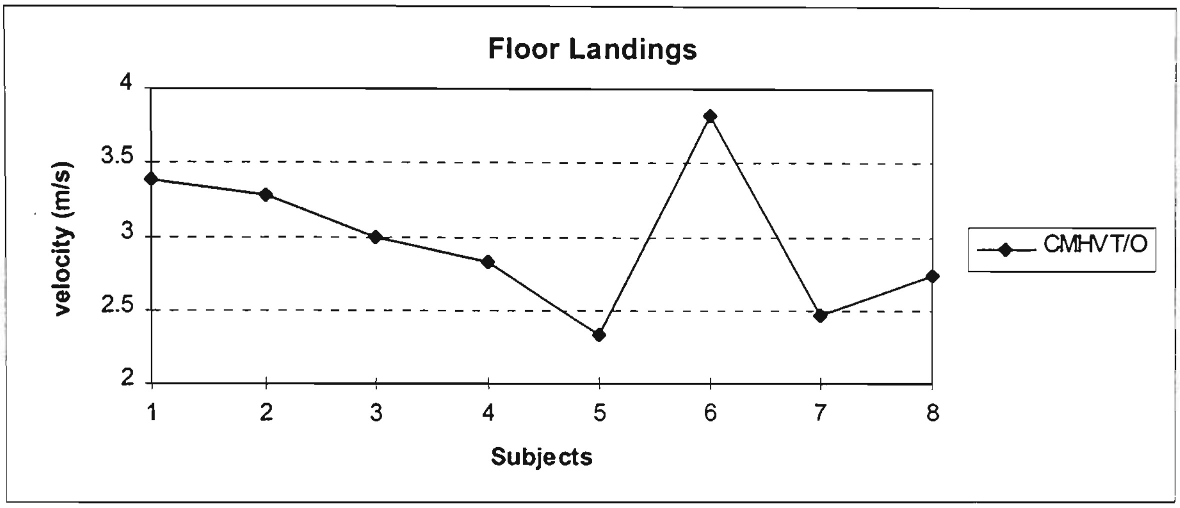


Figure 4.6.3.1.5 CM horizontal velocity at take-off

The values for the ***CM vertical velocity at take-off*** (cmvvt/o) were 4.34 ± 0.47m/s, with the highest value of 4.90m/s and the lowest value of 3.38m/s (Figure 4.6.3.1.6). Significant correlations were found between the variables cmhvt/o & cmvvt/o (r = 0.768, p<.03).

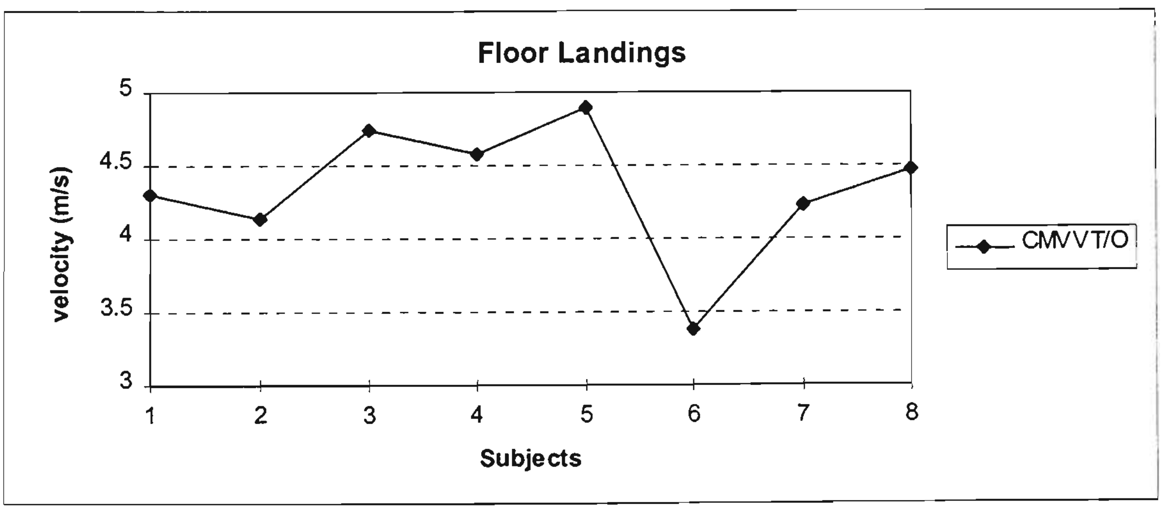


Figure 4.6.3.1.6 CM vertical velocity at take-off

The mean ***CM horizontal impact velocity*** (cmhvt/d) was 2.06 ± 0.29m/s, with the highest value of 2.59m/s and the lowest value of 1.74m/s (Figure 4.6.3.1.7). Significant correlations were found between the variables cmhvt/d & cmhdt/ot/d (r = 0.789, p<.02).

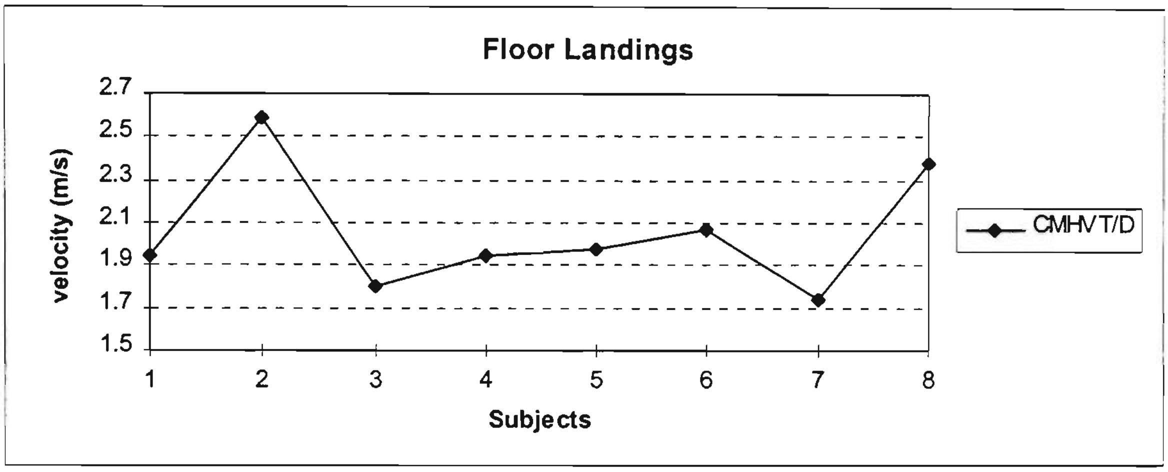


Figure 4.6.3.1.7 CM horizontal velocity at landing touch-down

The mean ***vertical impact velocitiy*** (cmvvt/d) was -4.89 ± 0.49m/s, with the highest value of -5.49m/s and the lowest value of -4.19m/s (Figure 4.6.3.1.8).

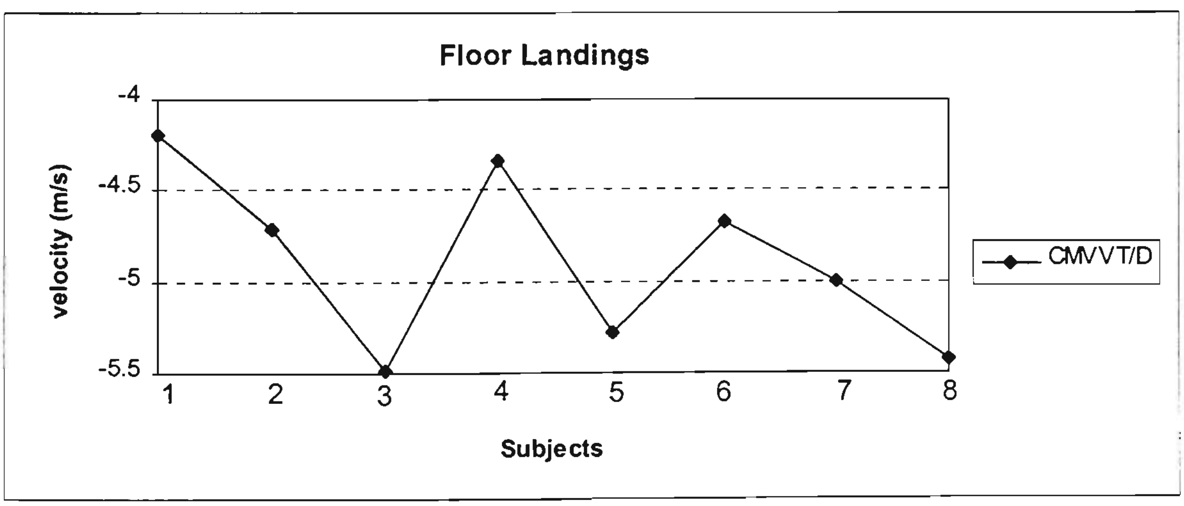


Figure 4.6.3.1.8 CM vertical velocity at landing touch-down

There were no significant correlations found between the variable cmvvt/d and other variables.

4.6.3.2 Angular Kinematic Data

In this section, the results from the angular positions and displacements (Table 4.6.3.2.1), angular velocities (Table 4.6.3.2.2), and angle-angle diagrams will be presented and discussed.

Table 4.6.3.2.1 Mean values and standard deviations for joint, segmental and CM to ground contact and the horizontal during the landing phase on floor (degrees)

				Subject						
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Mean**	**SD**
acmght/d	63	63	65	56	71	54	75	58	63.13	7.24
aatt/d	68	44	51	75	65	52	44	50	56.13	11.66
aatm	97	49	61	92	57	92	66	72	73.25	18.22
aht/d	115	80	108	127	139	117	91	123	112.5	19.23
ahm	86	34	80	80	90	81	57	101	76.13	21.05
akt/d	154	154	153	162	146	143	152	163	153.38	6.89
akm	107	106	87	79	104	71	109	90	94.13	14.43
aat/d	99	89	81	97	89	78	86	96	89.38	7.61
aam	90	87	91	95	80	77	96	73	86.12	8.53
atht/d	20	-9	20	23	40	28	6	15	17.88	14.63
athm	30	-16	16	41	43	31	11	23	22.38	19.08

The values for the ***angles between CM to ground contact (toes) and the horizontal at landing touch-down*** for the subjects in group 3 were 63.13 ± 7.24°, with the highest value of 75° and the lowest value of 54° (Figure 4.6.3.2.1).

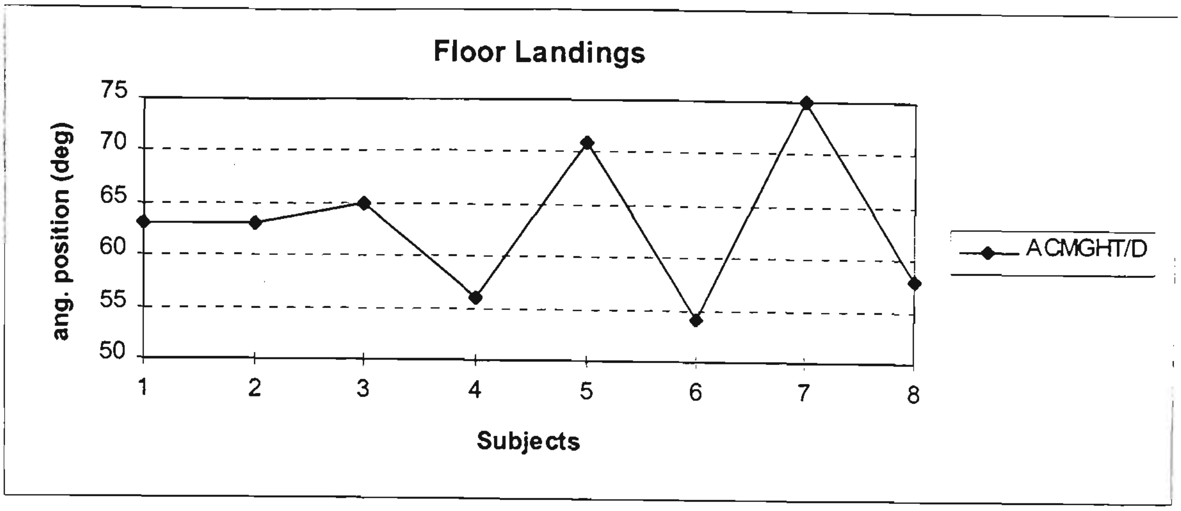


Figure 4.6.3.2.1 Angles CM to ground contact (toes) and the horizontal at landing touch-down

Significant correlations were found between the variables acmght/d & cmdt/dm (r = -0.779, p<.03), and between acmght/d & akm (r = 0.79, p<.02).

The mean ***shoulder joint angles at landing touch-down*** (aatt/d) were 56.13 ± 11.66°, with the highest value of 75° and the lowest value of 44° (Figure 4.6.3.2.2).

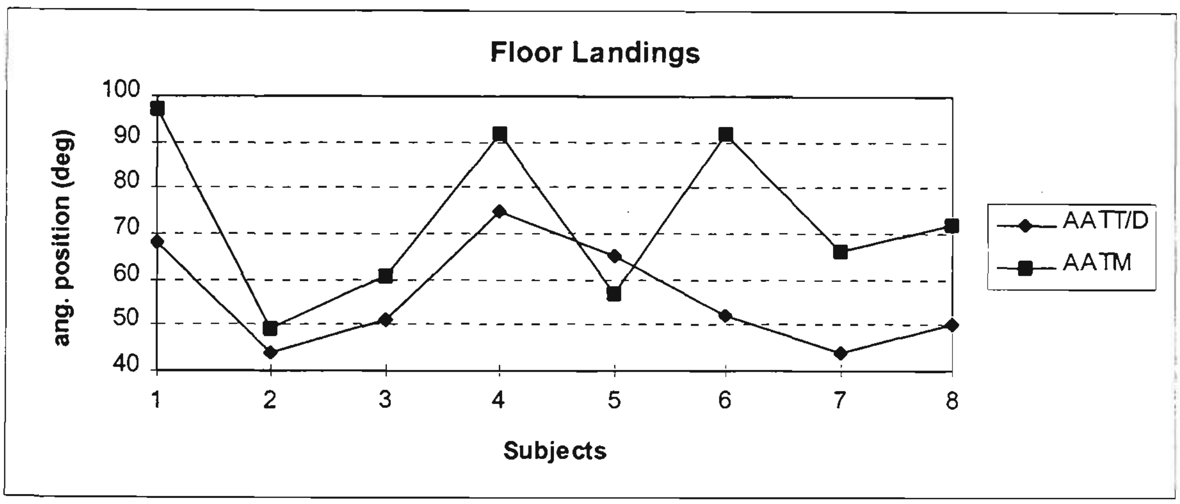


Figure 4.6.3.2.2 Shoulder joint angles at landing touch-down and minimum

The ***minimum shoulder joint angles*** (aatm) were 73.25 ± 18.22°, with the highest value of 97° and the lowest value of 49° (see Figure 4.6.3.2.2). Significant correlations were found between the variables aatt/d & cmht/d ($r = 0.825$, $p<.02$), and aatt/d & cmhm ($r = 0.804$, $p<.02$).

The mean ***hip joint angles at landing touch-down*** (aht/d) were 112.50 ± 19.23°, with the highest value of 139° and the lowest value of 80° (Figure 4.6.3.2.3).

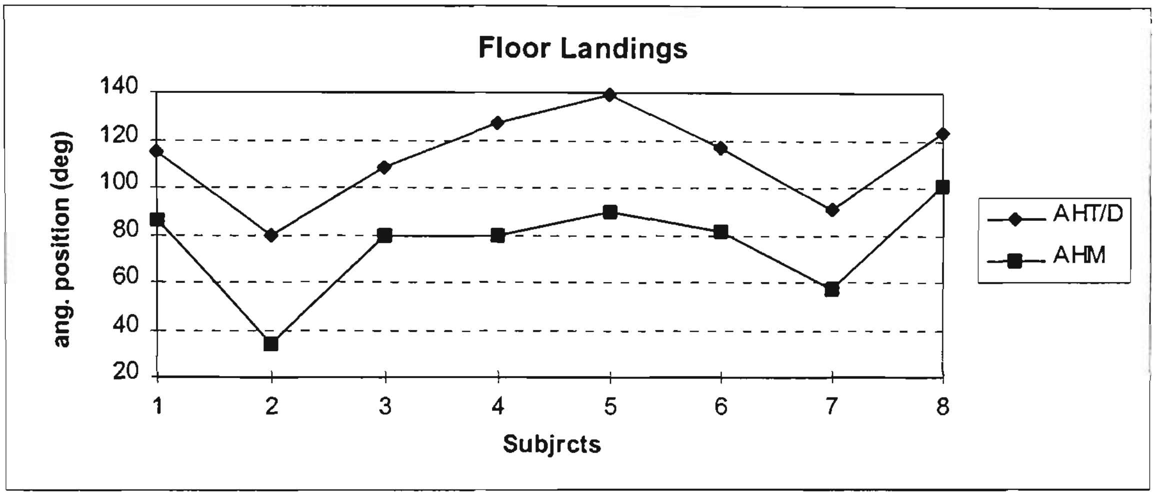


Figure 4.6.3.2.3 Hip joint angles at landing touch-down and minimum

The ***minimum hip joint angles*** (ahm) were 76.13 ± 21.05°, with the highest value of 101° and the lowest value of 34° (see Figure 4.6.3.2.3). Significant correlations were found between the variables aht/d & ahm ($r = 0.88$, $p<.01$),and aht/d & aatt/d ($r = 0.723$, $p<.05$).

The mean ***knee joint angles at landing touch-down*** (akt/d) were 153.38 ± 6.89°, with the highest value of 163° and the lowest value of 143° (Figure 4.6.3.2.4).

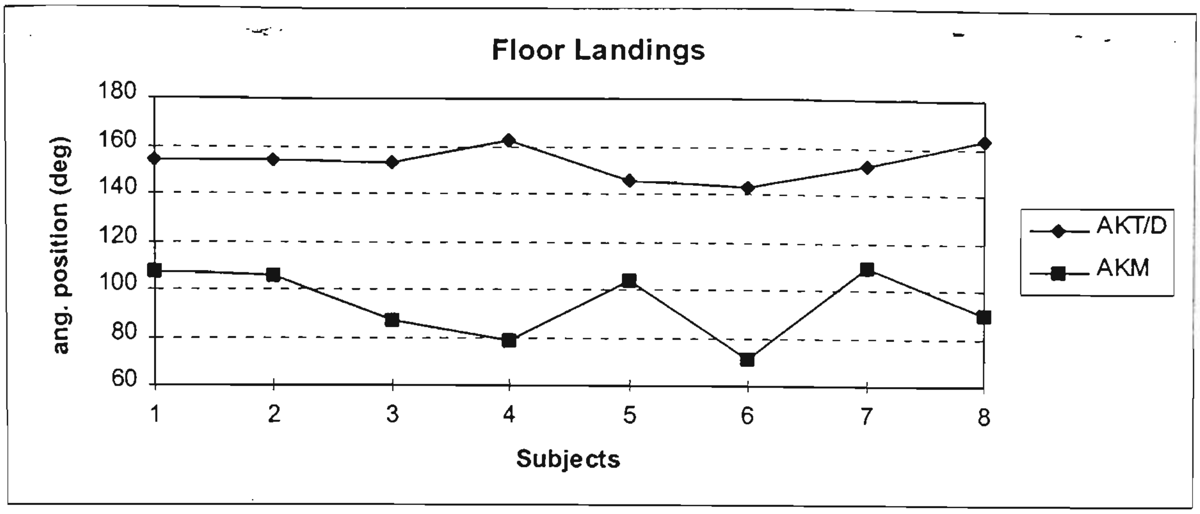


Figure 4.6.3.2.4 Knee joint angles at landing touch-down and minimum

The ***minimum knee joint angles*** (akm) were 94.13 .± 14.43°, with a range of 109° and to 71° (see Figure 4.6.3.2.4). Significant correlations were found between the variables akt/d & aat/d (r = 0.719, p<.05), akt/d & avkt/d (r = 0.69, p<.06), and akt/d & avht/d (r = 0.857, p<.01). The mean angular displacement between the akt/d and akm was 59° with a mean landing duration of 0.0975 seconds.

For the technically well executed double back somersaults, the extended position of the joints at touch-down provided the subject with the option of using a large range of joint motion during the landing phase. For example, the best landing performance was recorded by subject 4 with 90.74%. He recorded a knee angle of 162° at landing touch-down, compared to the mean value of 153°, and a minimum knee angle of 79° compared to the mean value of 94°. His knee angle was 144° after 0.02sec, 133° after 0.04sec, and 124° after 0.06sec. The availability of that large knee joint range of motion (68°) provided the gymnast with the opportunity of using various joint flexion timing strategies (e.g. from fast to slow absorption of the landing forces).

The mean ***ankle joint angles at landing touch-down*** (aat/d) were 89.38 ± 7.61°, with the highest value of 99° and the lowest value of 78° (Figure 4.6.3.2.5).

The ***minimum ankle joint angles*** (aam) were 86.12 ± 8.53°, with the highest value of 96° and the lowest value of 73° (Figure 4.6.3.2.5).

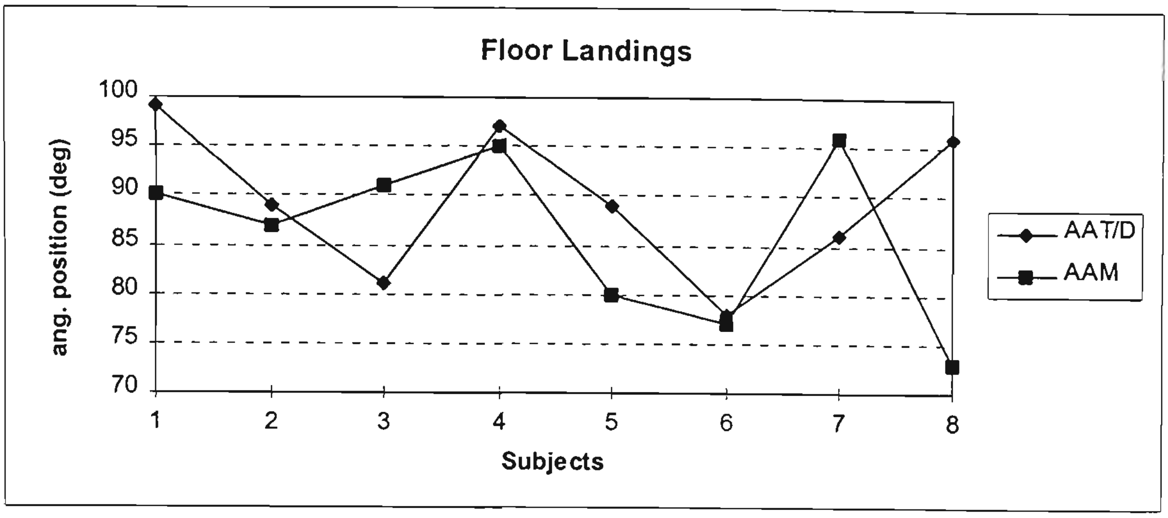


Figure 4.6.3.2.5 Ankle joint angles at landing touch-down and minimum

Significant correlations were found between the variables aat/d & avkt/d (r = 0.91, p<.01), and aat/d & lpdispl (r = 0.716, p<.05).

The mean ***angles between the trunk and the horizontal*** (atht/d) were 17.88 ± 14.63°, with the highest value of 40° and the lowest value of -9° (Figure 4.6.3.2.6); and the ***angles trunk to horizontal at CM minimum*** (athm) were 22.38 ± 19.08°, with the highest value of 43° and the lowest value of -16° (Figure 4.6.3.2.6).

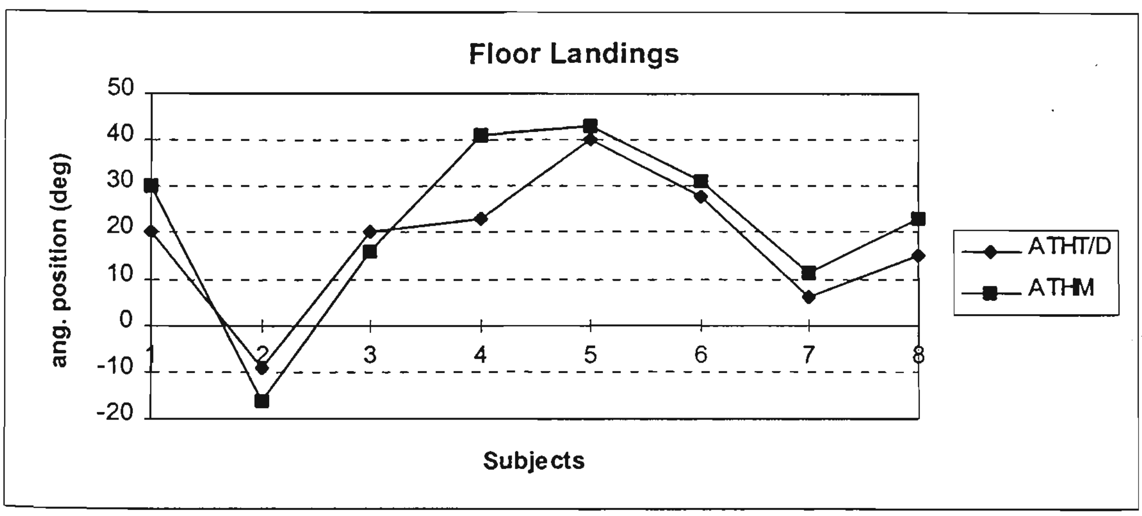


Figure 4.6.3.2.6 Angles trunk to horizontal at landing touch-down and minimum

Significant correlations were found between the variables atht/d & athm (r = 0.924, p<.001), atht/d & aht/d (r = 0.914, p<.001), and atht/d & ahm (r = 0.785, p<.03).

Table 4.6.3.2.2 Hip, knee, and ankle joint angular velocities at landing touch-down on floor (degrees/sec)

Subject		**Landing Phase**	
	avht/d	**avkt/d**	**avat/d**
1	-295	-281	-303
2	-219	-522	-37
3	-379	-947	-431
4	-344	-475	-553
5	-645	-637	-379
6	-914	-1185	-146
7	-326	-492	-95
8	-65	-509	-801
Mean (SD)	-398 (264)	-597 (328)	-343 (256)

The mean value for the ***hip joint angular velocity*** (avht/d) at landing touch-down was -398 ± 264 deg/sec, with the highest value of -914 deg/sec and the lowest value of -65 deg/sec; for ***knee joint angular velocity*** -597 ± 328 deg/sec, with the highest value of -1185 deg/sec and the lowest value of -200 deg/sec.

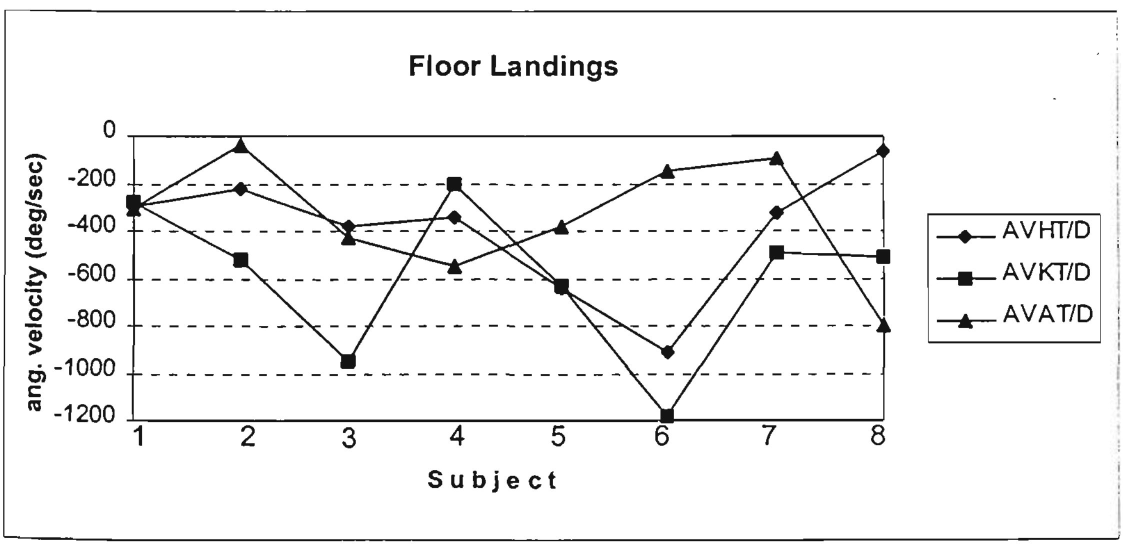


Figure 4.6.3.2.7 Angular velocities of the hip, knee and ankle joints at landing

The ***ankle joint angular velocity*** was -343 ± 256 deg/sec, with the highest value of -801 deg/sec and the lowest value of -37 deg/sec (Figure 4.6.3.2.7). Significant correlations were found between the variables atht/d & athm ($r = 0.924$, $p<.001$), atht/d & aht/d ($r = 0.914$, $p<.001$), and atht/d & ahm ($r = 0.785$, $p<.03$).

Angle-angle diagrams were produced of the best landing performances to investigate the relationship between hip and knee angles, and knee and ankle angles over the period of the landing phase. Changes in these relationships indicate a change in angular kinematics and sequencing among joints. Subjects' 4 ankle angle-knee angle, knee angle-hip angle, and hip angle-shoulder angle relationship is illustrated in Figure 4.6.3.2.8.

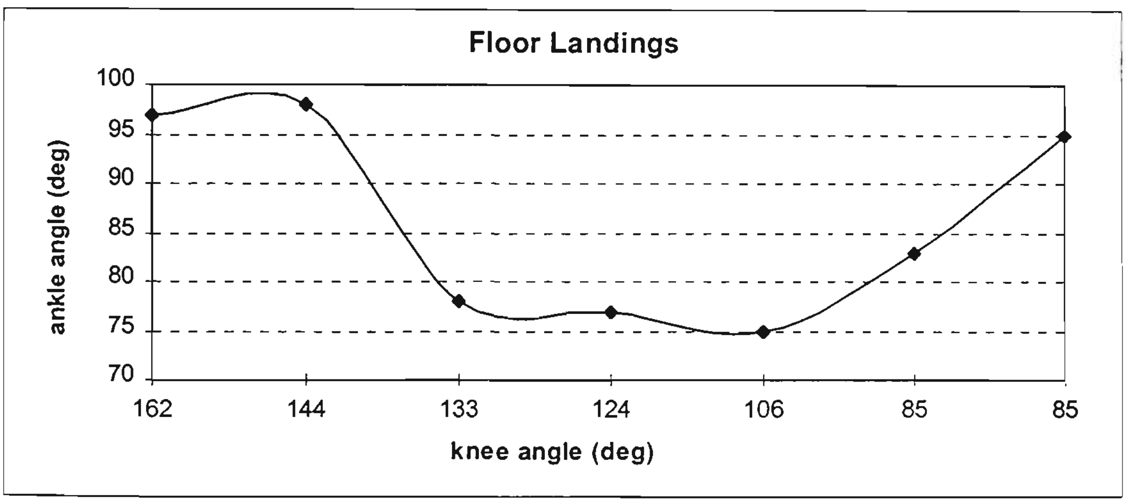


Figure 4.6.3.2.8 Ankle joint angle-knee joint angle diagram for subject 4

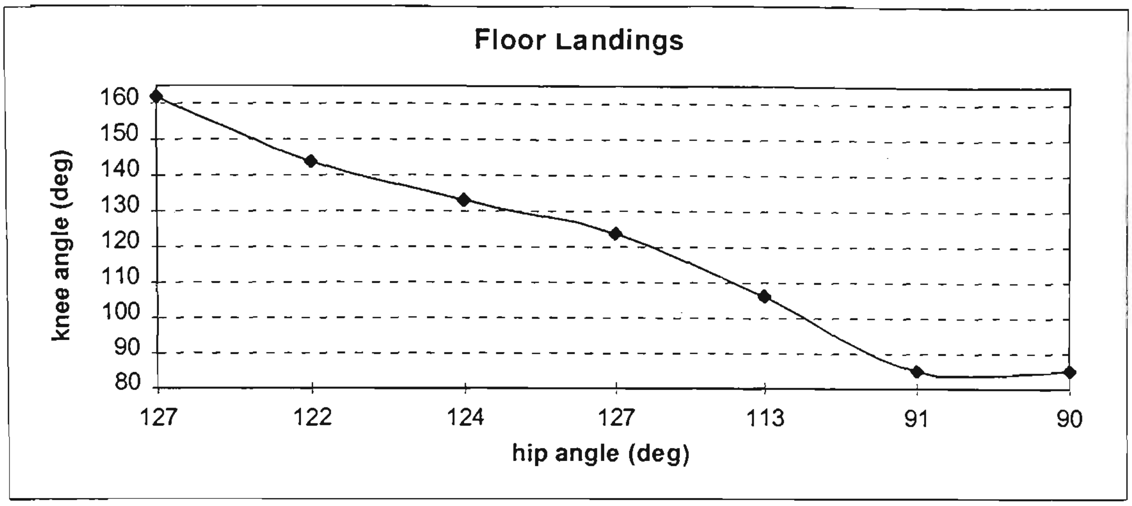


Figure 4.6.3.2.9 Knee joint angle-hip joint angle diagram for subject 4

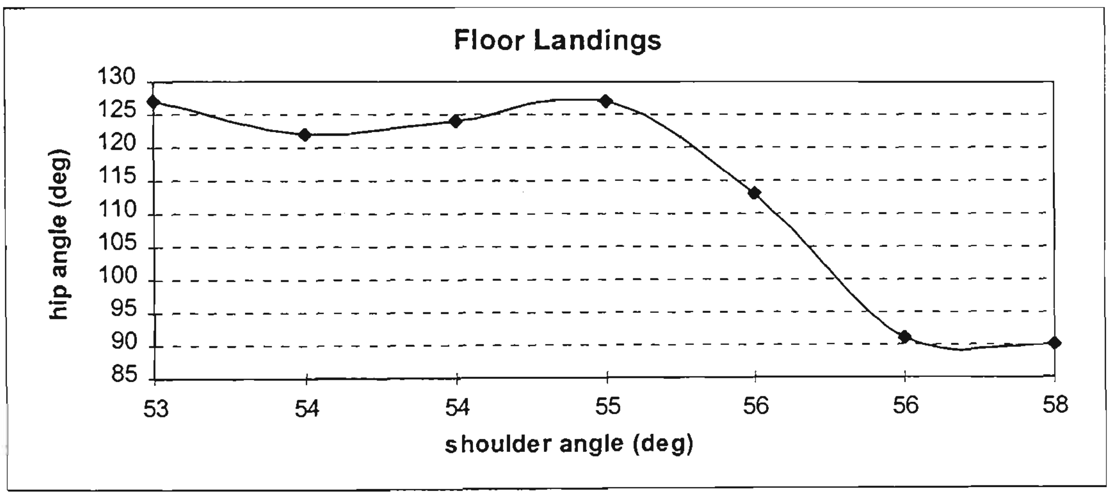


Figure 4.6.3.2.10 Hip joint angle-shoulder joint angle diagram for subject 4

Angular velocity-joint angle diagrams for the hip, knee and ankle angles were also produced to provide a description of the respective angular velocity-angular displacement relationship during the landing process. The ankle, knee and hip angular velocity-angular displacement relationship for subject 4 are illustrated in Figure 4.6.3.2.11.

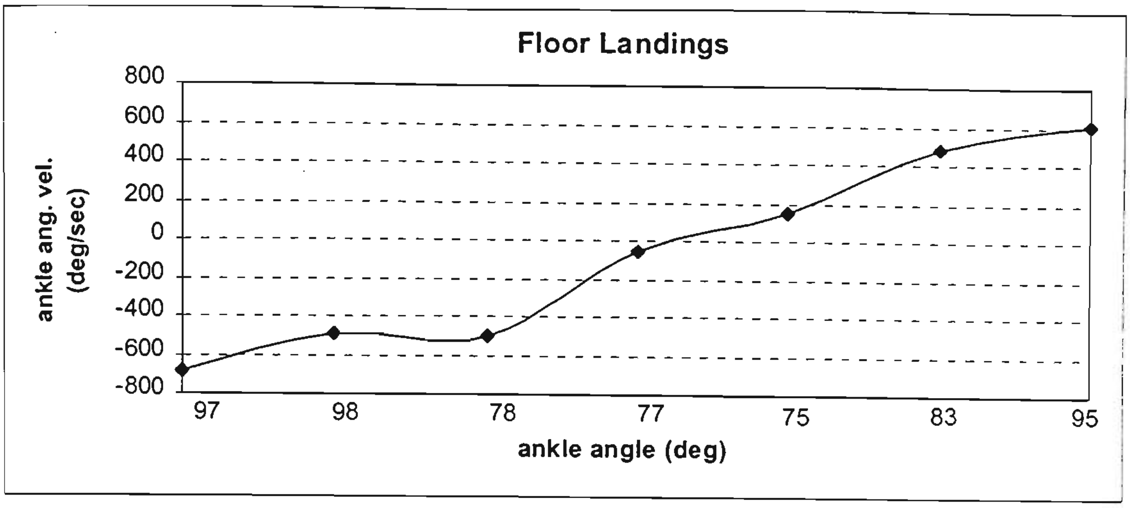


Figure 4.6.3.2.11 Ankle joint angular velocity-ankle joint diagram for subject 4

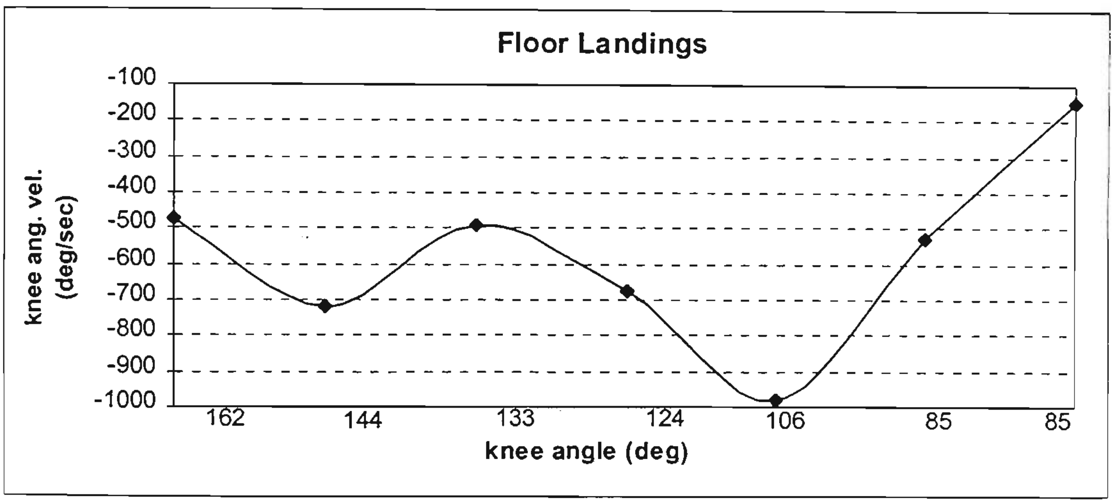


Figure 4.6.3.2.12 Knee joint angular velocity-knee joint angle diagram for subject 4

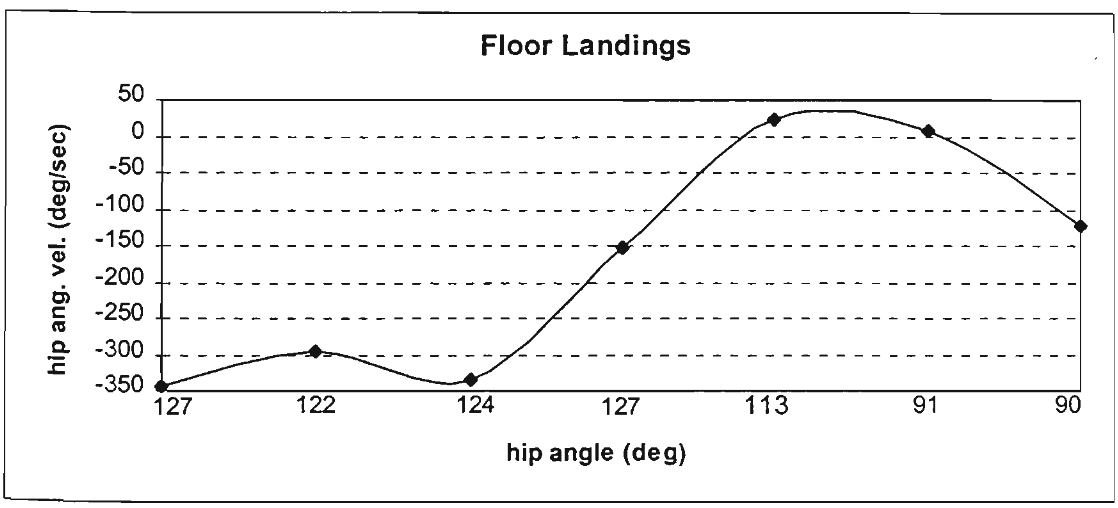


Figure 4.6.3.2.13 Hip joint angular velocity-hip joint angle diagram for subject 4

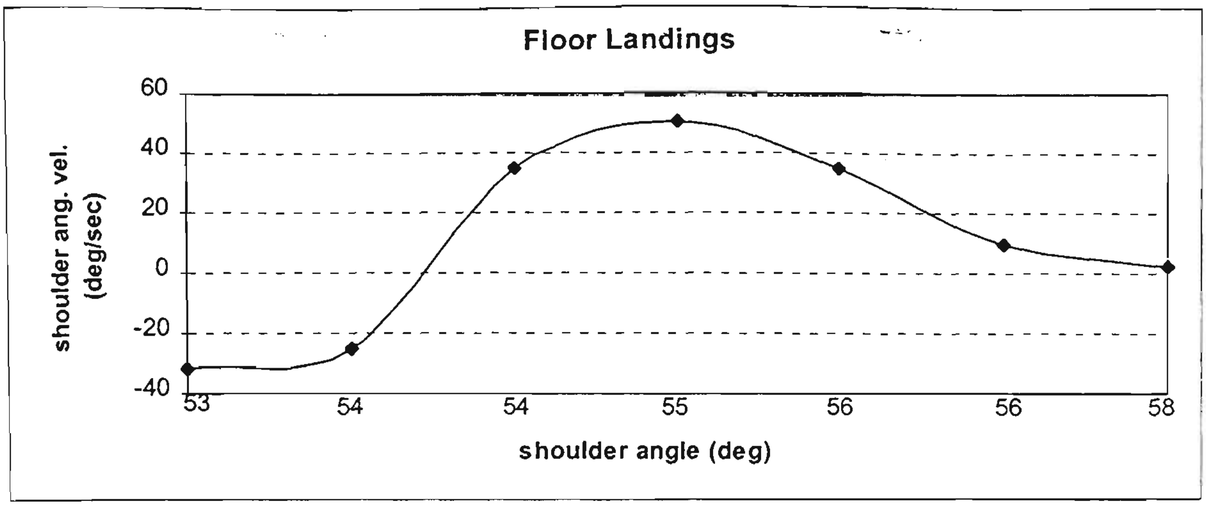


Figure 4.6.3.2.14 Shoulder joint angular velocity-shoulder joint angle diagram for subject 4

4.6.3.3 Temporal Characteristics Of The Flight- And Landing Phase

The flight time from take-off to the landing touch-down represents the time through which a gymnast's body rotates while in the air. The only external forces acting during flight are gravity, which acts vertically and cannot be manipulated during flight, and air resistance, which is so small it can be disregarded completely. However, unlike mass, moment of inertia can be changed during flight (e.g. changing from a layout position to a tucked position). The flight phase includes parameters such as the vertical height reached by the CM, backwards horizontal distance travelled by the CM, and the number of angular rotations achieved (e.g. number of somersaults and twists).

Table 4.6 3.3 1 Temporal characteristics of the flight time from take-off to landing touch-down and CM duration from landing touch-down to minimum on floor (seconds)

Subject	Flight Phase ftt/ot/d	Landing Phase cmdt/dm
1	0.96	0.10
2	0.96	0.10
3	1.08	0.08
4	0.96	0.14
5	0.96	0.08
6	1.02	0.10
7	0.98	0.10
8	1.00	0.08
Mean (SD)	0.99 (0.04)	0.0975 (0.02)

The mean value for the ***flight time from take-off to landing touch-down*** (ftt/ot/d) was 0.99 ± 0.04 sec, with the highest value of 1.08sec and the lowest value of 0.96sec (Figure 4.6.3.3.1).

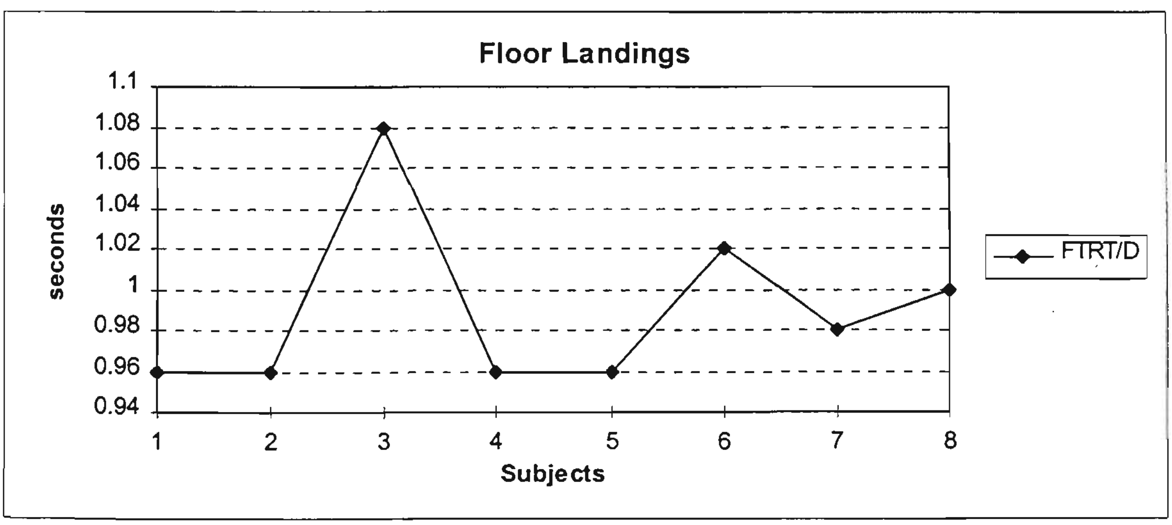


Figure 4.6.3.3.1 Flight times from take-off to landing touch-down

The temporal characteristics illustrated similarities across subjects, except for subject 3 who showed a longer flight time from take-off to landing touch-down (1.08sec) compared to the mean value of 0.99 seconds. Significant correlations were found between the variables ftt/ot/d & avkt/d (r = 0.732 p<.05).

The mean value for the ***CM duration from landing touch-down to minimum*** (cmdt/dm) was 0.098 ± 0.02 sec, with the highest value of 0.14sec and the lowest value of 0.08sec (Figure 4.6.3.3.2).

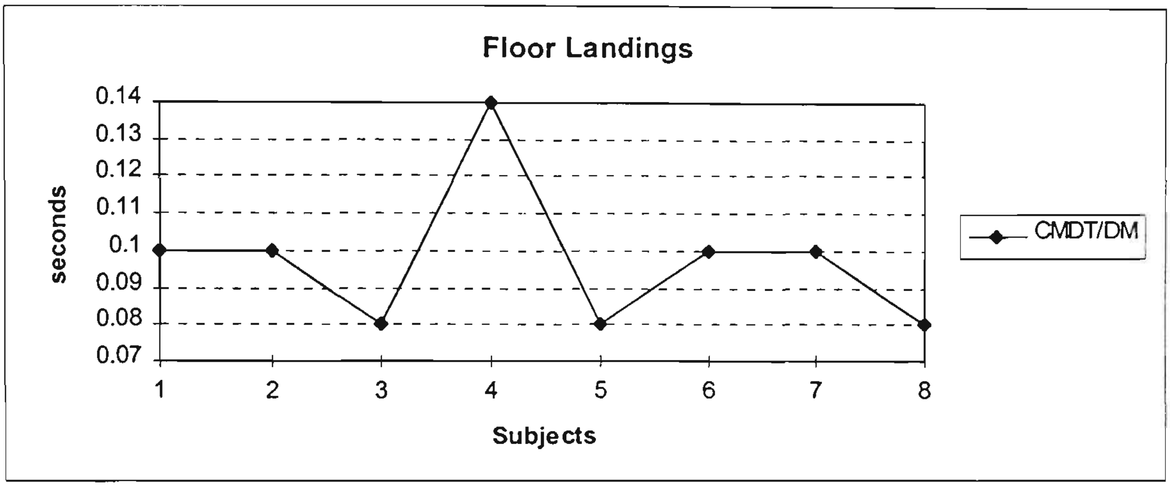


Figure 4.6.3.3.2 CM duration from landing touch-down to landing minimum

Significant correlations were found between the variables cmdt/dm & acmght/d (r = -0.78, p<.03). The temporal patterns showed a distal to proximal sequence, where those joints closest to the initial contact (toes) were brought to rest prior to the more proximal joints (e.g. ankle knee and hip).

Subject 4 also exhibited a longer CM duration from landing touch-down to landing minimum 0.14 sec compared to the mean value of 0.1 seconds. The increase in landing phase time was most likely due to the choice of landing strategy before the landing.

4.6.3.4 Kinematic Parameter Interaction Related To The Landing Score of the Floor Landing Model

To provide an optimal landing representation, all landing performances, with particular emphasis on the best landing performance on floor, were discussed in relation to the group mean. The best performance was recorded by subject 4 (90.74%), which constituted an exemplary landing performance from a double backward somersault tucked performed in the middle of his routine. Subject 4 recorded high within group values on most variables. He recorded a cmhvt/o of -2.82m/s, compared to the mean value of -2.98 ± 0.50m/s. He also obtained a cmhvt/d of -1.95m/s, compared to the mean value of 2.06 ± 0.29m/s. His cmvvt/o was recorded at 4.58m/s and his cmvvt/d was calculated at -4.34m/s compared to the mean value of 4.34 ± 0.47m/s and -4.89 ± 0.49m/s, respectively. Significant correlation were found between cmhvt/o & cmvvt/o ($r = 0.768$, $p<.03$). These variables were identified in the 14th level of the deterministic model, the take-off properties, and indicate the strong relationship between the horizontal and vertical velocity, the height-distance trade-off, observed in double backward somersaults on the floor.

Subject 4 recorded a hip angle of 127° at landing touch-down (level 10), compared to the mean value of 112.50 ± 19.23° and a minimum hip angle of 80° (level 4), compared to the mean value of 76.13 ± 21.05°. His hip angle was 125° (0.02sec), 122° (0.04sec) and 136° (0.06 sec), before the landing touch-down. The respective hip angular velocities were 326, 252 and 673deg/sec. His hip angle was 122° (0.02sec), 124° (0.04sec), and 127° (0.06sec) after landing touch-down. The respective hip angular velocities were -344, -295 and -335deg/sec. Subject 4 recorded a knee angle of

162° at landing touch-down, compared to the mean value of 153.38 ± 6.89°, and a minimum knee angle of 79° compared to the mean value of 94.13 ± 14.43°. His knee angle was 163° (0.02sec), 147° (0.04sec) and 134°, before the landing touch-down. The knee angular velocities were recorded as -372, -716 and 823deg/sec, respectively. His knee angle was 144° (0.02sec), 133° (0.04sec), and 124° (0.06sec) after landing touch-down. The respective knee angular velocities were -720, -492 and -675deg/sec. The large knee joint range of motion (83°) provided the gymnast with the opportunity of using various joint flexion techniques. Subject 4's ankle angle was 97° at landing touch-down, compared to the mean value of 89.38 ± 7.61°, and a minimum ankle angle of 95° compared to the mean value of 86.12 ± 8.53°. His ankle angle was 125° (0.02sec), 126° (0.04sec), and 120° before the landing touch-down. His ankle angle was 98° (0.02sec), 78° (0.04sec), and 77° (0.06sec) after landing touch-down.

Subject 4 also exhibited a longer CM duration from landing touch-down to landing minimum 0.14 sec, compared to the mean value of 0.1 seconds.

The flexible landing surface of the floor mats and sprung floor sections made it an increased challenge and subsequently more difficult for the gymnasts to "stick" the landing. Also, many unstable landings occurred due to "soft and stiff spots" on the floor area (landing surface), because the whole floor area was inconsistent in springiness and stability. This was physically tested and identified by the author and two of his assistants. Unstable landings occurred when the gymnasts were still twisting and/or somersaulting, coming out of the somersault position slowly by extending the hip and knee joints downward into the landing surface.

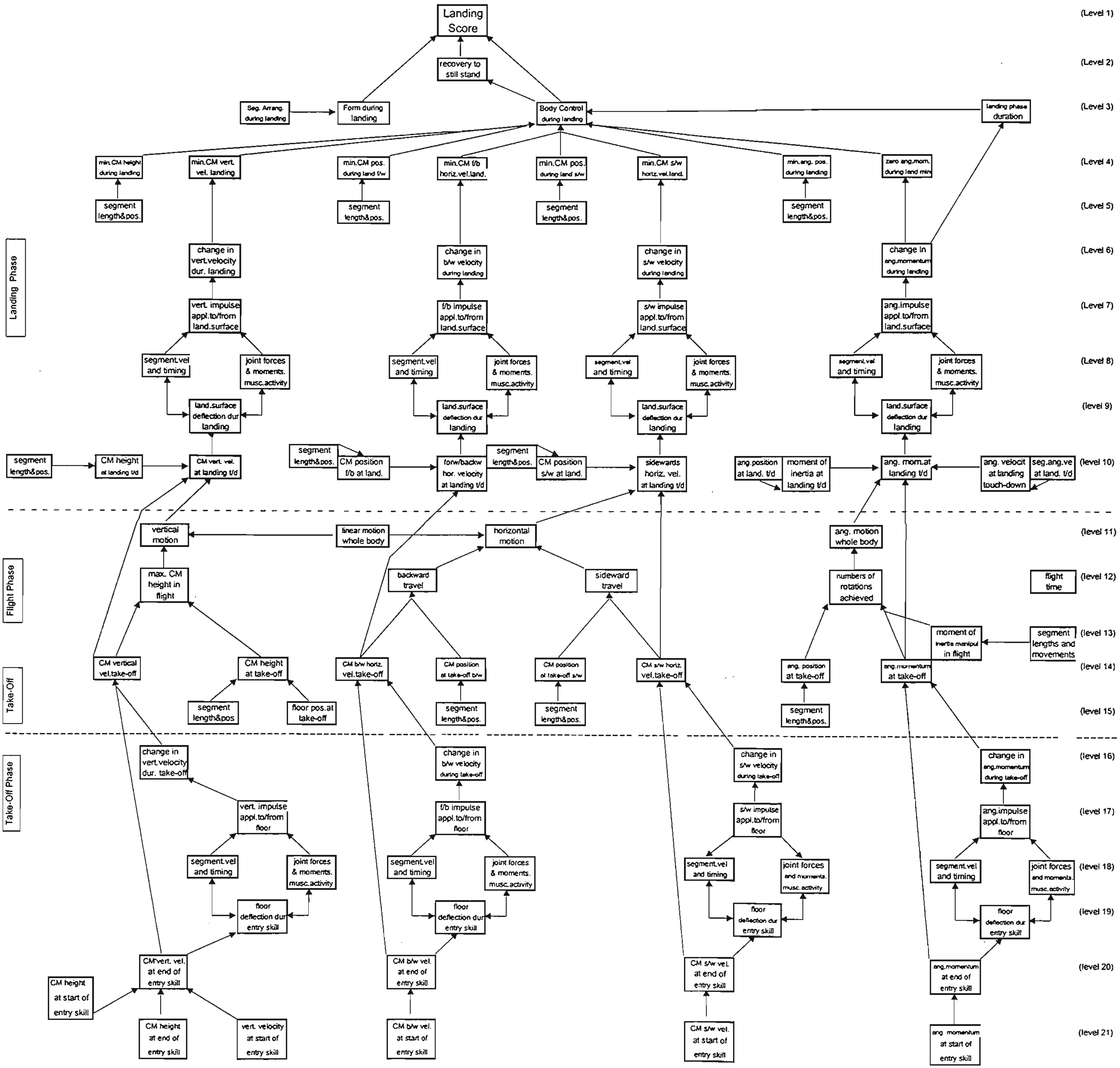


Figure 4.6.3.4.1 Deterministic model showing the release, flight phase, landing phase, and the biomechanical factors related to controlled landing performances on floor

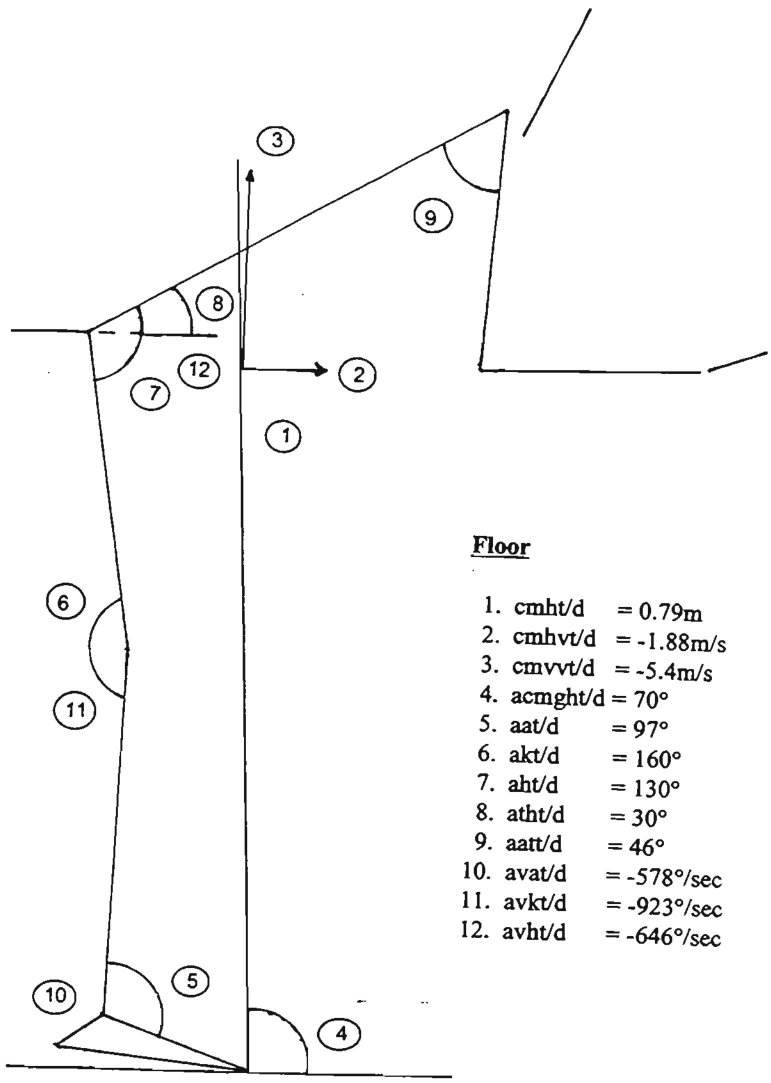
Unstable landings also occurred when the gymnasts did not have enough landing preparation time due to poor dismount technique or were unable to complete the skill before the landing, or, when the gymnasts over or under rotated. The need to control the angular momentum during landings of somersaults may prohibit the use of extensive trunk motion. It is very difficult to control the landing if the trunk and hips approach full flexion during touch-down of the landing. The magnitude of the landing velocities of the CM were critical parameters for controlled landings. An important biomechanical parameter influencing a controlled landing is the CM horizontal velocity backwards at landing touch-down. However, there are other factors which are important for the achievement of a controlled landing, such as the cmvvt/d and the angle CM to ground contact and the horizontal at landing touch-down.

It is concluded that controlled landings on floor are likely when gymnast's achieve (a) a high maximal vertical velocity at take-off; (b) a relatively low horizontal velocity at take-off; (c) optimal rotational flight phase properties; (d) an early preparation for the landing, and (e) optimal body segment coordination and timing during the landing phase.

4.6.3.5 Development Of The Floor Landing Model

Biomechanical factors crucial for controlled landings are identified in the "floor landings model". To achieve successful, controlled landings on floor after acrobatic tumbling skills, the gymnast must first fulfil the biomechanical requirements in the release phase. From the analysis of the data, it can be concluded that controlled landings are likely when the take-off properties and the landing impact kinematics are optimised, and optimal segment coordination and timing are achieved during the landing process.

To achieve optimal take-off conditions on floor, the mean value of the best three values of the analysed take-off phase parameters cmht/o (1.17m), cmhvt/o (-2.51m/s) and cmvvt/o (4.74m/s), were considered. The mean value of the best three values of the landing touch-down parameters cmht/d (0.79m), cmhvt/d (-1.88m/s), cmvvt/d (-5.4m/s), acmght/d (70°), aatt/d (46°), aht/d (130°), akt/d (160°), aat/d (97°), atht/d (30°), avht/d (-646°/sec), avkt/d (-923°/sec), and avat/d (-578°/sec), were taken into consideration for the development of the floor landing profile shape (LPS). The best three values for the landing parameters represent the lowest values for cmhvt/d and aatt/d, and the highest values for cmvvt/d, cmht/d, acmght/d, aht/d, akt/d, aat/d, atht/d, avht/d, avkt/d and avat/d.



Floor

1. cmht/d = 0.79m
2. cmhvt/d = -1.88m/s
3. cmvvt/d = -5.4m/s
4. acmght/d = 70°
5. aat/d = 97°
6. akt/d = 160°
7. aht/d = 130°
8. atht/d = 30°
9. aatt/d = 46°
10. avat/d = -578°/sec
11. avkt/d = -923°/sec
12. avht/d = -646°/sec

Figure 4.6.3.5.1 Landing profile shape (LPS) for floor landings

4.6.4 Rings Landings

Rings dismounts are initiated by generating rotational kinetic energy during the downswing phase from a momentary handstand position. Thus the angular velocity of the body in the sagittal plane is relative to the body's centre of gravity. The main emphasis here is to generate high vertical velocity simultaneously with high angular momentum about the transverse axis. In the upward swing, before the hand release from the rings, a reduction in the moment of inertia occurs through accelerated and muscle controlled flexion at the hip and shoulder joints, thus producing an increase of rotation for the following dismount (Brüggemann, 1990). The analysis of the joint angle movements provides an insight into the mechanism for increasing rotation. If high angular momentum about the transverse axis in the forward upward swing is required then an increase in rotation generated through a rapid hip flexion does not appear to suffice for the angular momentum required. The powerful shoulder joint extension is the most important technical component for increasing rotation in preparation for the dismount.

Five dismounts were double backward somersault layout with full twist, and three dismounts were double backward somersault layout without twist. Seven dismounts had a backward horizontal velocity and one dismount a forward horizontal velocity at landing.

Table 4.6.4.1 Group 4 (Rings) Individual Apparatus Finalists Details

Subject No.	Competitor No.	Country	Routine Duration (sec)	Routine Score (points)	Rank	Landing Score (%)
1	247	ROM	44	9.700	3	74.07
2	185	HUN	52	9.587	7	88.89
3	175	GER	53	9.637	5	83.34
4	132	BUL	50	9.400	8	64.82
5	280	USA	39	9.725	2	79.63
6	170	GER	46	9.700	3	83.34
7	274	UKR	49	9.600	6	81.48
8	191	ITA	52	9.787	1	83.34

The video recordings of the individual landing performances were carefully viewed to qualitatively analyse the release position of the body and its segments, the body position of the double back somersault during flight, and the body position before the landing and at landing touch-down. The best performances showed a convex position of the body at release, a controlled body position during the flight, an extension of the body before the landing, and the landing was actively anticipated through correct placement of the feet. All dismounts and landing performances were executed in a controlled manner thus receiving good landing scores.

The results of the qualitative evaluation of the rings landing performances were as follows: subject 1 performed a double layout full twist dismount and scored 74.07% for the landing, stuck landing, feet slightly apart, excessive arm movements (armcircle forward); subject 2 performed a double layout full twist dismount and scored 88.89% for the landing, stuck an excellent landing; subject 3 performed a double layout dismount and scored 83.34% for the landing, stuck landing, fast landing, feet slightly apart; subject 4 performed a double layout full twist dismount and scored 64.82% for the landing, under-rotated, big jump forward; subject 5 performed a double layout

6 performed a double layout full twist dismount and scored 83.34% for the landing, stuck landing, little untidy; subject 7 performed a double layout full twist dismount and scored 81.48%, slightly over-rotated, small jump backward; subject 8 performed a double layout dismount and scored 83.34%, stuck landing, little untidy, excessive arm and trunk movements.

4.6.4.1 Linear Kinematic Data

In this section, the results from the CM positions and displacements (Table 4.6.4.1.1) and, the horizontal and vertical velocities (Table 4.6.4.1.2) will be presented and discussed.

Table 4.6.4.1.1 Mean values and standard deviations for the CM positions, and displacements during the release, flight phase and landing phase on the rings (m)

Subject	Release Phase	Flight Phase		Landing Phase	
	cmhr	mcmhf	cmhdrt/d	cmht/d	cmhm
1	2.41	2.84	0.26	0.70	0.49
2	2.16	2.68	0.20	0.77	0.55
3	2.33	2.77	0.21	0.84	0.64
4	2.54	2.74	0.14	0.67	0.49
5	2.54	2.76	0.11	0.81	0.62
6	2.59	2.75	0.20	0.76	0.57
7	2.34	2.75	0.12	0.77	0.66
8	2.64	2.83	0.03	0.76	0.59
Mean (SD)	2.44 (0.16)	2.77 (0.05)	0.16 (0.07)	0.76 (0.05)	0.58 (0.06)

The mean value for the ***CM height at release*** (cmhr) was 2.44 ± 0.16m, with the highest value of 2.64m and the lowest value of 2.16m (Figure 4.6.4.1.1).

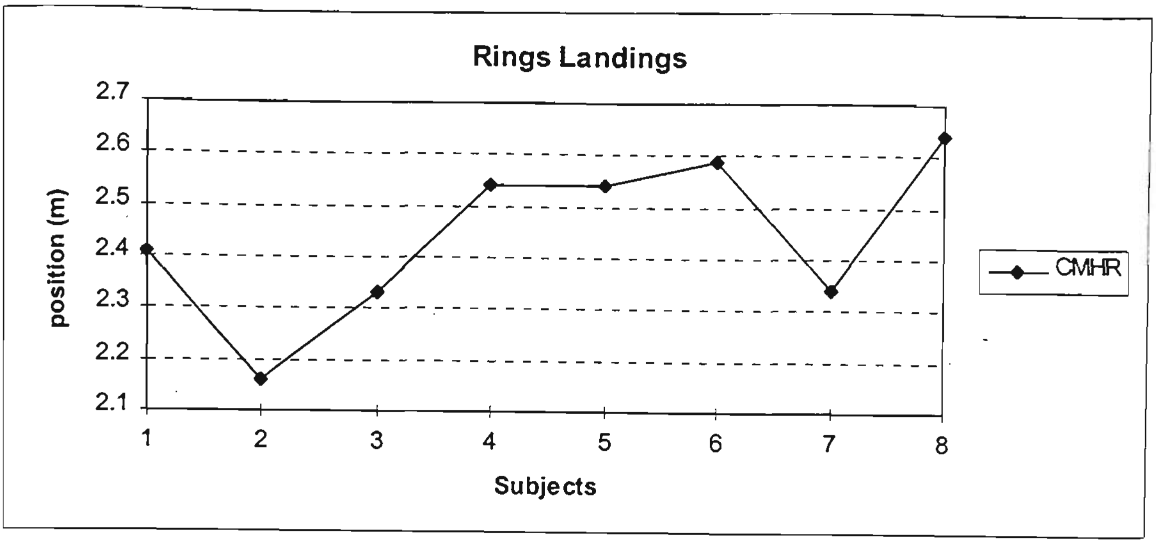


Figure 4.6.4.1.1 CM height at release

Significant correlations were found between the variables cmhr & cmvvr ($r = -.814$, $p<.02$), cmhr & ftrt/d ($r = -.805$, $p<.02$).

The mean value for the ***maximum CM height during flight*** (mcmhf) was 2.77 ± 0.05 m, with the highest value of 2.84m and the lowest value of 2.68m (Figure 4.6.4.1.1).

The mean displacement value from CM height at release (2.44 ± 0.16) to the max. CM height in flight (2.77 ± 0.05) was 0.33m and the displacement from the maximum CM height to the mean CM height at landing (0.76 ± 0.05) was 2.01m.

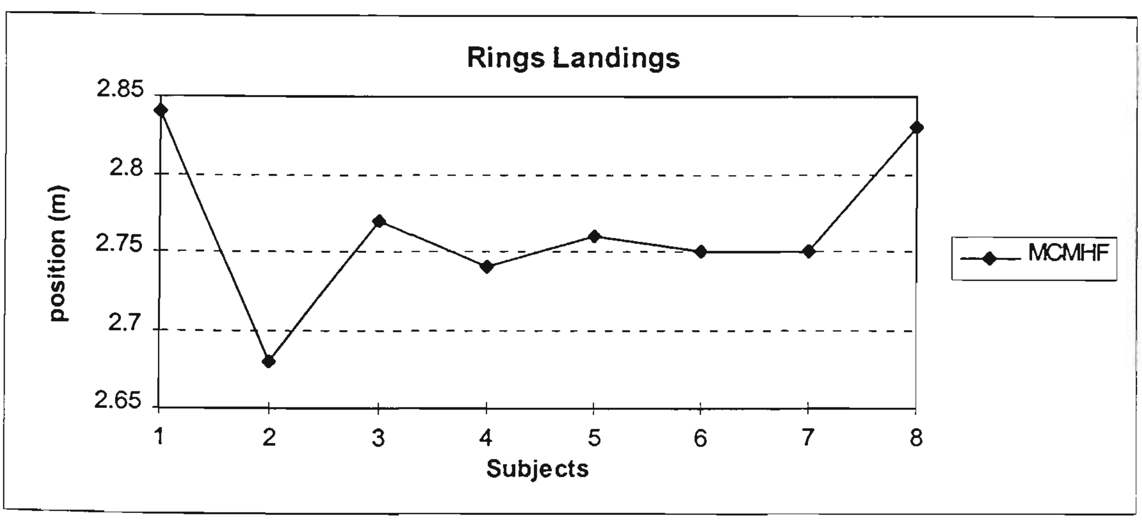


Figure 4.6.4.1.2 Maximum CM height in flight

Significant correlations were found between the variables mcmhf & aatm (r = 0.739, p<.05), mcmhf & cmvvt/d (r = -0.785, p<.05).

The mean ***CM horizontal displacement from release to landing touch-down*** (cmhdrt/d) was 0.16 ± 0.07m, with the highest value of 0.26m and the lowest value of 0.03m (Figure 4.6.4.1.3).

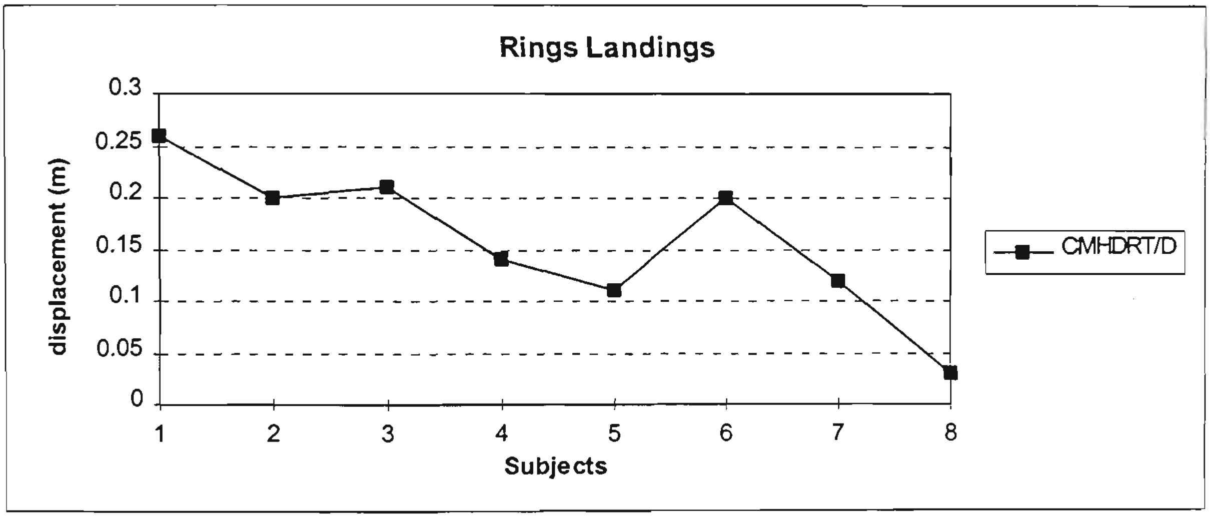


Figure 4.6.4.1.3 CM horizontal displacement from release to landing touch-down

Significant correlations were found between the variables cmhdrt/d & cmhvt/d (r = 0.762, p<.05), cmhdrt/d & avkt/d (r = 0.7318 p<.05).

The mean ***CM height at landing touch-down*** was 0.76 ± 0.05m, with the highest value of 0.84m and the lowest value of 0.67m (Figure 4.6.4.1.4).

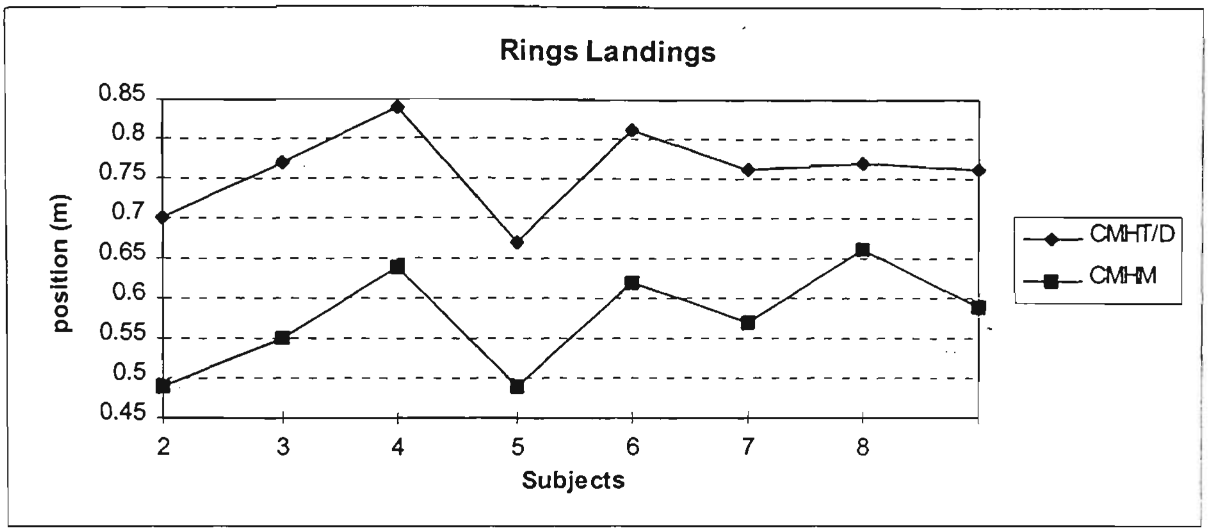


Figure 4.6.4.1.4 CM height at touch-down and minimum position

Significant correlations were found between the variables cmht/d & aht/d (r = 0.71, p<.05), cmht/d & akm (r = 0.793, p<.02), cmht/d & avht/d (r = 0.755, p<.05), cmht/d & cmhm (r = 0.85, p<.01), cmht/d & lansco (r = 0.738, p<.05).

The mean ***CM height minimum*** (cmhm) value was 0.58 ± 0.06m, with the highest value of 0.66m and the lowest value of 0.49m (Figure 4.6.4.1.4). Significant correlations were found between the variables cmhm & akm (r = 0.84, p<.01), cmhm & athm (r = 0.731, p<.05), cmhm & avht/d (r = 0.705, p<.05), cmhm & cmht/d (r = 0.85, p<.01). The landing phase displacement (lpdispl) from the CM height at landing to CM height minimum was 0.18 ± 0.03m.

Table 4.6.4.1.2 Mean values and standard deviations for the CM horizontal and vertical velocities during the release, flight and landing phase on rings (m/s)

Subject	Release		Landing Phase	
	cmhvr	cmvvr	cmhvt/d	cmvvt/d
1	-0.24	2.81	-0.15	-6.03
2	-0.05	3.19	-0.10	-5.90
3	-0.12	3.42	-0.13	-6.00
4	-0.02	2.17	-0.11	-5.92
5	-0.34	2.87	-0.16	-6.02
6	-0.35	2.03	-0.16	-5.92
7	-0.12	3.07	-0.04	-6.02
8	-0.02	2.34	0.11	-6.18
Mean (SD)	-0.16 (0.14)	2.74 (0.50)	-0.09 (0.09)	-6.00 (0.09)

The mean value for the ***CM horizontal velocity at release*** (cmhvr) was -0.16 ± 0.14 m/s, with the highest value of 0.35m/s and the lowest value of 0.02m/s (Figure 4.6.4.1.5).

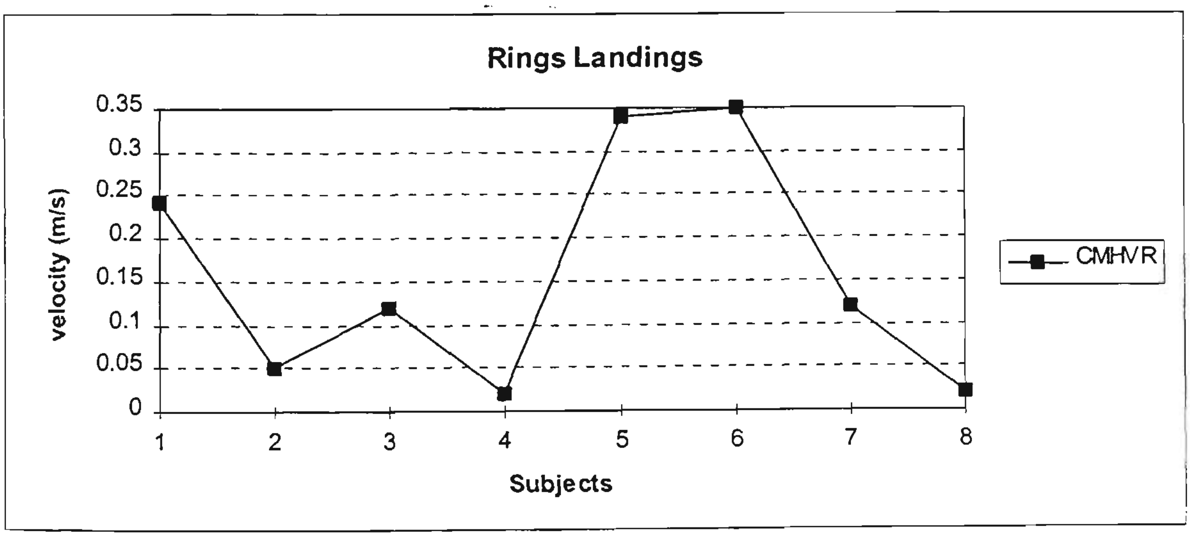


Figure 4.6.4.1.5 CM horizontal velocity at release

The values for the ***CM vertical velocity at release*** (cmvvr) were 2.74 ± 0.50m/s, with the highest value of 3.42m/s and the lowest value of 2.03m/s (Figure 4.6.4.1.6).

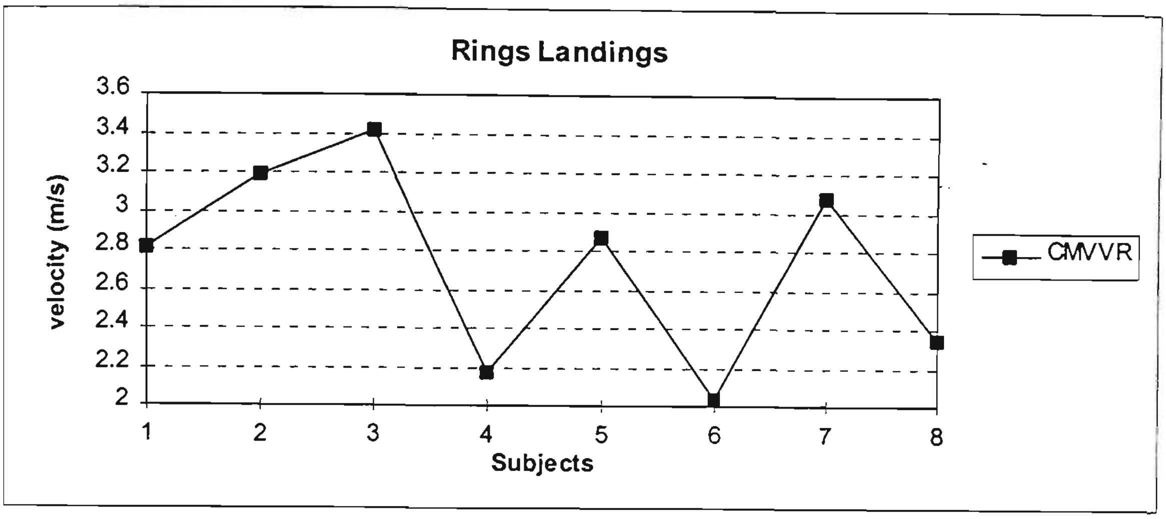


Figure 4.6.4.1.6 CM vertical velocity release

Significant correlations were found between the variables cmvvr & akm (r = 0.736, p<.05), cmvvr & cmhr (r = -0.814, p<.02), cmvvr & ftrt/d (r = 0.808, p<.02).

The mean ***CM horizontal impact velocity*** (cmhvt/d) was 0.09 ± 0.09m/s, with the highest value of 0.16m/s and the lowest value of 0.04m/s (Figure 4.6.4.1.7).

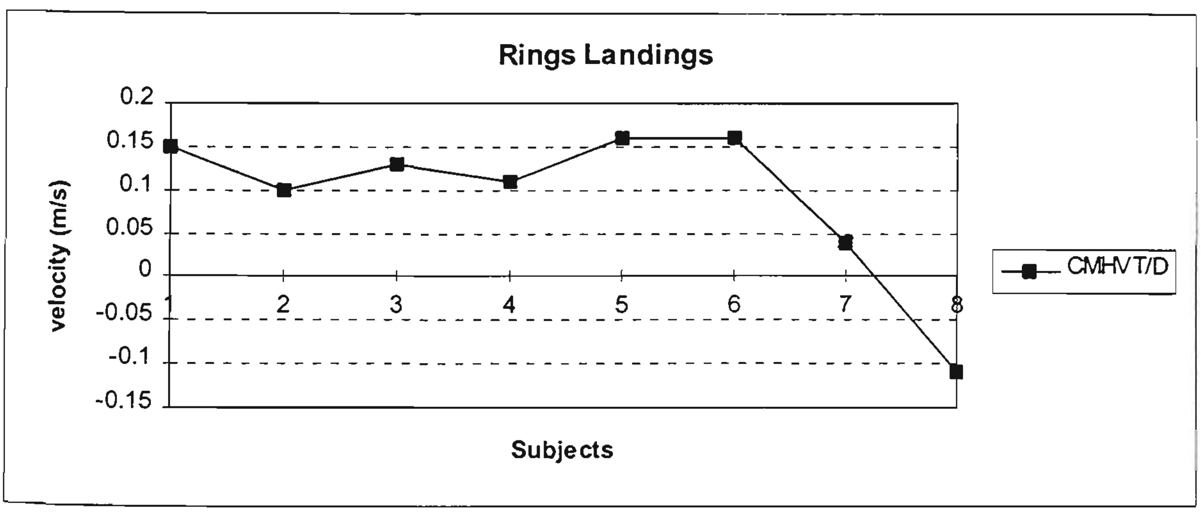


Figure 4.6.4.1.7 CM horizontal velocity at landing touch-down

Significant correlations were found between the variables cmhvt/d & cmhdrt/d (r = 0.762, p<.05), cmhvt/d & cmvvt/d (r = 0.731, p<.05).

The mean ***vertical impact velocity*** (cmvvt/d) was -6.0 ± 0.09m/s, with the highest value of -6.18m/s and the lowest value of -5.90m/s (see Figure 4.6.4.1.8).

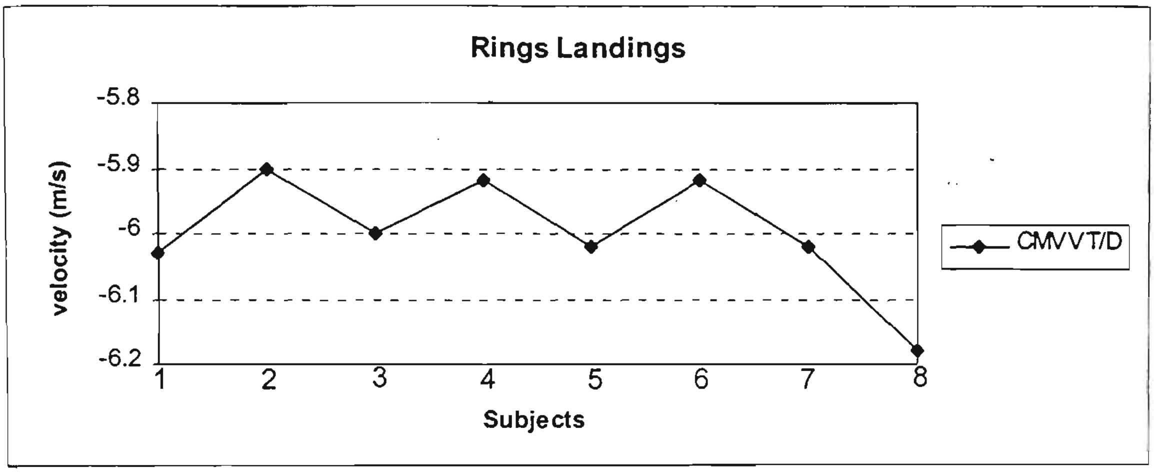


Figure 4.6.4.1.8 CM vertical velocity at landing touch-down

Significant correlations were found between the variables cmvvt/d & aatm ($r = -0.803$, $p<.02$), cmvvt/d & cmhvt/d ($r = 0.731$, $p<.05$), cmvvt/d & mcmhf ($r = -0.785$, $p<.05$).

4.6.4.2 Angular Kinematic Data

In this section, the results from the angular positions and displacements (Table 4.6.4.2.1), angular velocities (Table 4.6.4.2.2), angle-angle diagrams, and angular velocity-joint angle diagrams will be presented and discussed.

Table 4.6.4.2.1 Mean values and standard deviations for joint, segmental and CM to ground contact and the horizontal during the landing phase on the rings (degrees)

	Subjects									
	1	2	3	4	5	6	7	8	Mean	SD
acmght/d	83	84	84	85	88	88	96	88	87	4.17
aatt/d	73	66	102	68	74	42	62	93	73.13	18.18
aatm	111	71	106	86	130	85	93	124	100.88	20.44
aht/d	103	109	118	102	121	122	105	118	112.25	8.38
ahm	59	56	84	64	67	86	75	66	69.63	11.04
akt/d	142	156	165	158	150	152	153	147	153.75	6.61
akm	77	87	113	73	86	81	103	86	88.25	13.38
aat/d	90	88	96	86	86	85	89	91	88.88	3.56
aam	73	77	84	76	80	73	76	81	77.50	3.89
atht/d	22	18	26	13	40	37	33	37	28.25	9.97
athm	29	24	39	27	38	44	45	31	34.63	7.95

The values for the ***angles CM to ground contact (toes) and the horizontal at landing touch-down*** for the subjects in group 4 were 87 ± 4.17°, with the highest value of 96° and the lowest value of 83° (Figure 4.6.4.2.1).

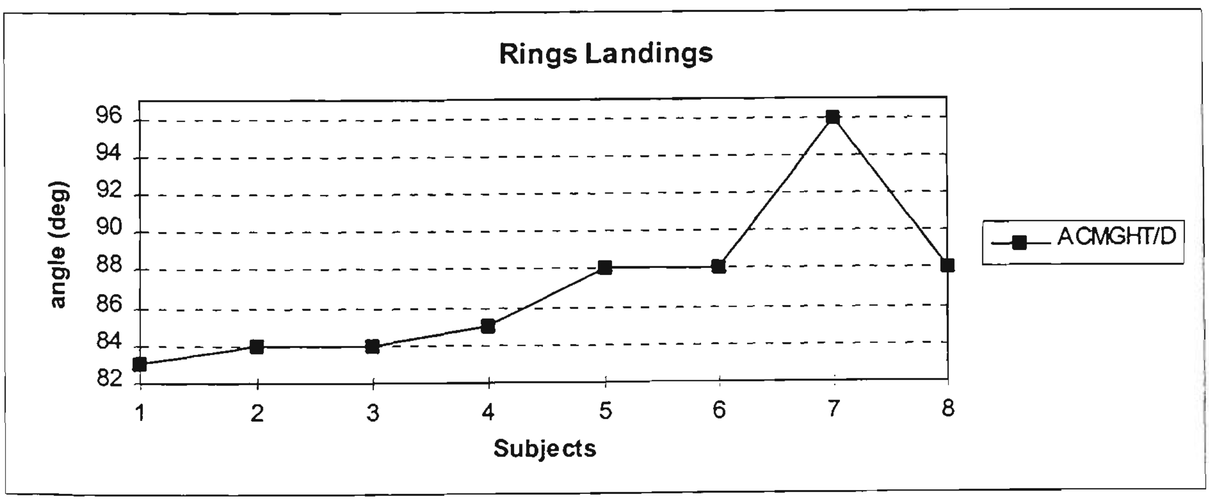


Figure 4.6.4.2.1 Angles CM to ground contact (toes) and the horizontal at landing touch-down

Significant correlations were found between the variables acmght/d & lpdispl (r = 0.932, p<.001).

The mean ***arm trunk angle at landing touch-down*** (aatt/d) was 73.13 ± 18.18°, with the highest value of 102° and the lowest value of 42° (Figure 4.6.4.2.2).

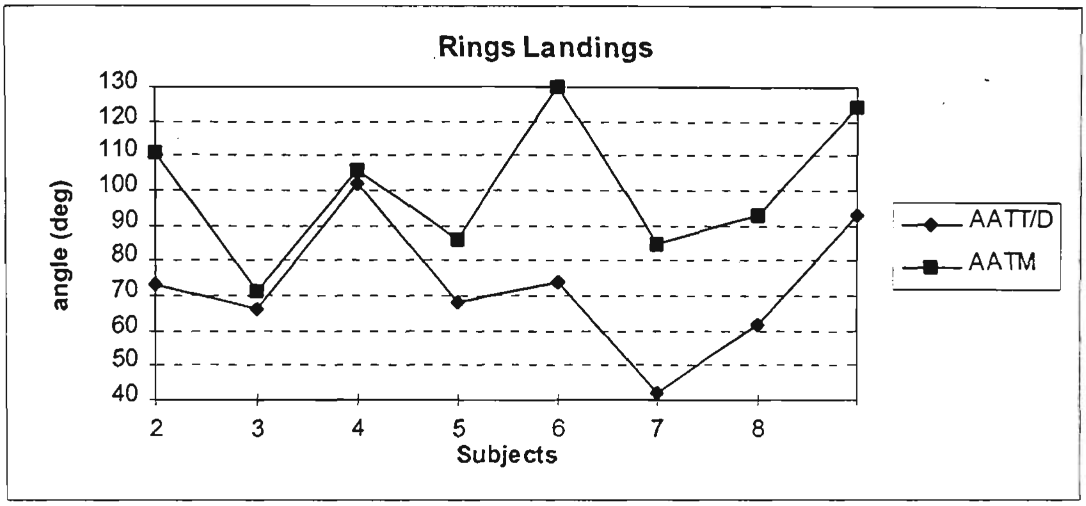


Figure 4.6.4.2.2 Angles arm-trunk at landing touch-down and minimum

Significant correlations were found between the variables aatt/d & aat/d (r = 0.852, p<.01), aatt/d & aam (r = 0.849, p<.01), and att/d & avht/d (r = 0.754, p<.05).

The mean ***minimum arm trunk angle*** (aatm) was 100.88 ± 20.44°, with the highest value of 124° and the lowest value of 71° (Figure 4.6.4.4.2). Significant correlations were found between the variables aatm & aatt/d (r = 0.849, p<.01), and aatm & avht/d (r = 0.717, p<.05).

The mean ***hip joint angles at landing touch-down*** (aht/d) were 112.25 ± 8.38°, with the highest value of 122° and the lowest value of 103° (Figure 4.6.4.2.3).

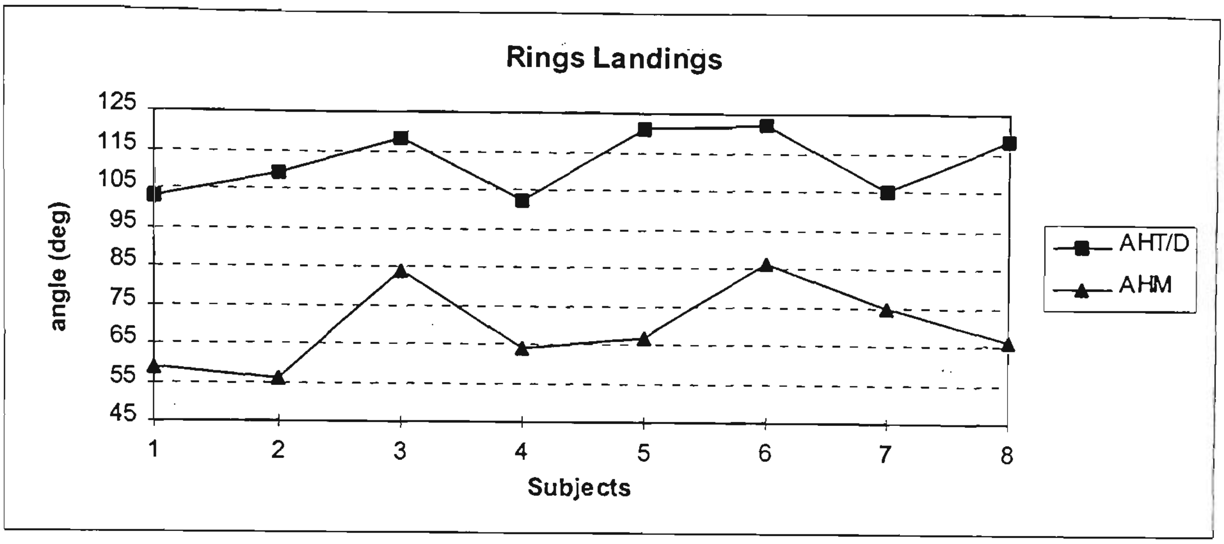


Figure 4.6.4.2.3 Hip joint angles at landing touch-down and minimum

Significant correlations were found between the variables aht/d & atht/d (r = 0.75, p<.05), aht/d & cmht/d (r = 0.71, p<.05).

The mean ***minimum hip joint angles*** (ahm) were 69.63 ± 11.04°, with the highest value of 86° and the lowest value of 56° (Figure 4.6.4.2.3). Significant correlations were found between the variables ahm & athm (r = 0.853, p<.01).

The mean ***knee joint angles at landing touch-down*** (akt/d) were 153.785 ± 6.61°, with the highest value of 165° and the lowest value of 142° (Figure 4.6.4.2.4).

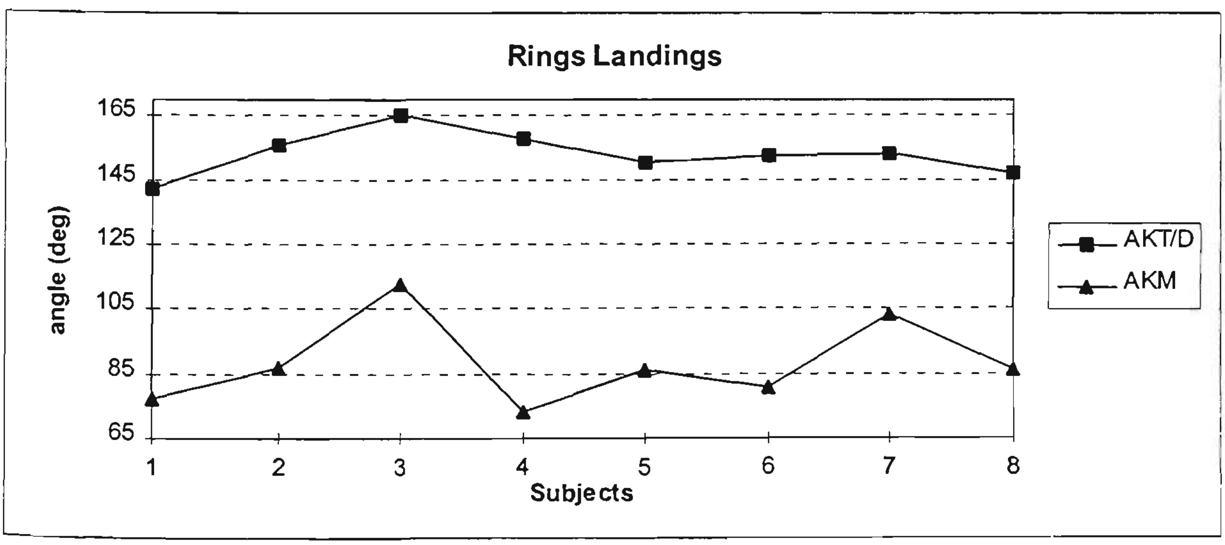


Figure 4.6.4.2.4 Knee joint angles at landing touch-down and minimum

The mean ***minimum knee joint angles*** (akm) were 88.25 .± 13.38°, with the highest value of 103° and the lowest value of 73° (Figure 4.6.4.2.4). Significant correlations were found between the variables akm & cmhm ($r = 0.840$, $p<.01$), and akm & avht/d ($r = 0.851$, $p<.01$). The angular displacement between the akt/d and akm was 66° with a landing duration of 0.13 seconds.

The mean ***ankle joint angles at landing touch-down*** (aat/d) were 88.89 ± 3.56°, with the highest value of 96° and the lowest value of 73° (Figure 4.6.4.2.5).

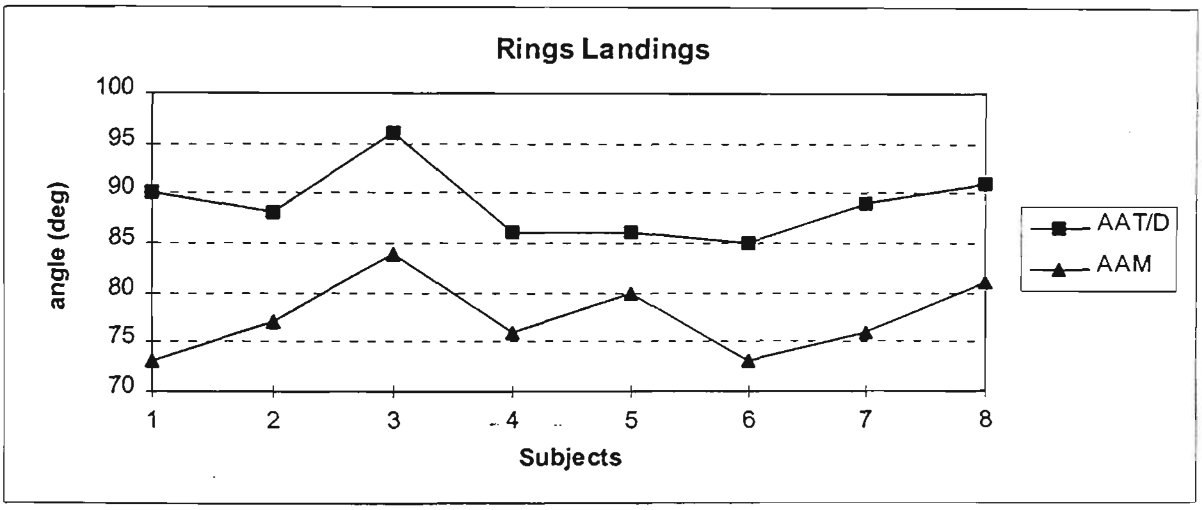


Figure 4.6.4.2.5 Ankle joint angles at landing touch-down and minimum

Significant correlations were found between the variables aat/d & aatt/d (r = 0.852, p<.01), aat/d & akm (r = 0.72, p<.05), and aat/d & avht/d (r = 0.754, p<.05).

The mean values for the ***minimum ankle joint angles*** (aam) were 77.50 ± 3.89°, with the highest value of 84° and the lowest value of 73° (Figure 4.6.4.2.5).

The mean ***angles between the trunk and the horizontal at landing touch-down*** (atht/d) were 28.25 ± 9.97°, with the highest value of 40° and the lowest value of 13° (Figure 4.6.4.2.6).

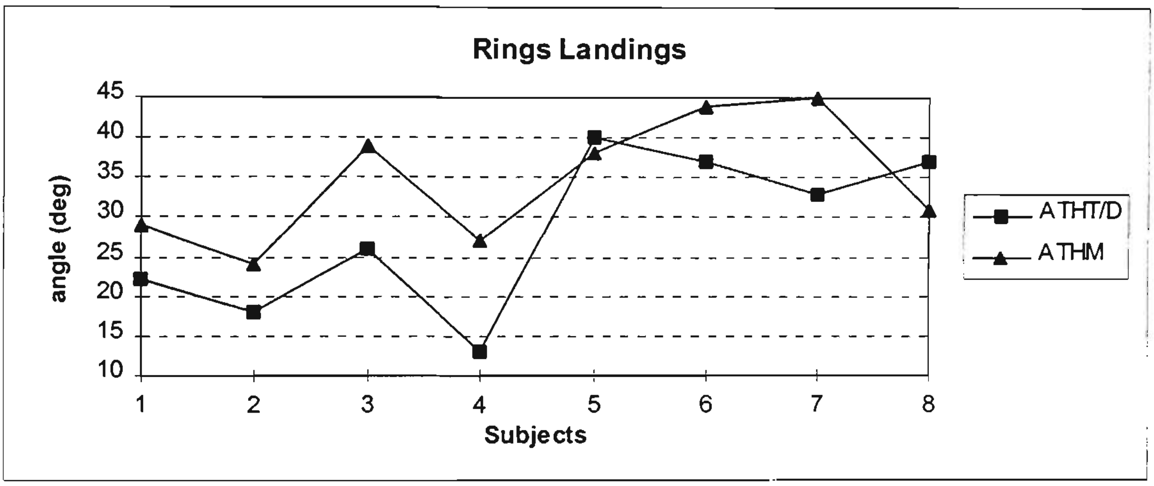


Figure 4.6.4.2.6 Angles trunk to horizontal at landing touch-down and minimum

Significant correlations were found between the variables atht/d & aht/d (r = 0.75, p<.05), atht/d & athm (r = 0.703, p<.05).

The mean values for the ***minimum angles trunk to horizontal*** (athm) were 34.63 ± 7.95°, with the highest value of 45° and the lowest value of 24° (Figure 4.6.4.2.6). Significant correlations were found between the variables athm & ahm (r = 0.853, p<.01), athm & atht/d (r = 0.703, p<.05),and athm & cmhm (r = 0.731, p<.05).

Table 4.6.4.2.2 Hip, knee and ankle joint angular velocities during the landing phase on the rings (deg/sec)

Subject		Landing Phase	
	avht/d	avkt/d	avat/d
1	-399	-163	-624
2	-161	-640	-292
3	-21	-371	-381
4	-462	-815	-232
5	-330	-803	-371
6	-348	-658	-198
7	-177	-804	-255
8	-131	-692	-268
Mean (SD)	-253.63 (152.55)	-618.25 (233.98)	-327.63 (135.55)

The mean value for the ***hip joint angular velocity*** (avht/d) at landing touch-down was -253.65 ± 152.55 deg/sec, with the highest value of -462 deg/sec and the lowest value of -21 deg/sec. Significant correlations were found between the variables avht/d & aat/d ($r = 0.754$, $p<.05$), and avht/d & cmht/d ($r = 0.755$, $p<.05$).

The mean value for the ***knee joint angular velocity*** was -618.25 ± 233.98 deg/sec, with the highest value of -804 deg/sec and the lowest value of -163 deg/sec.

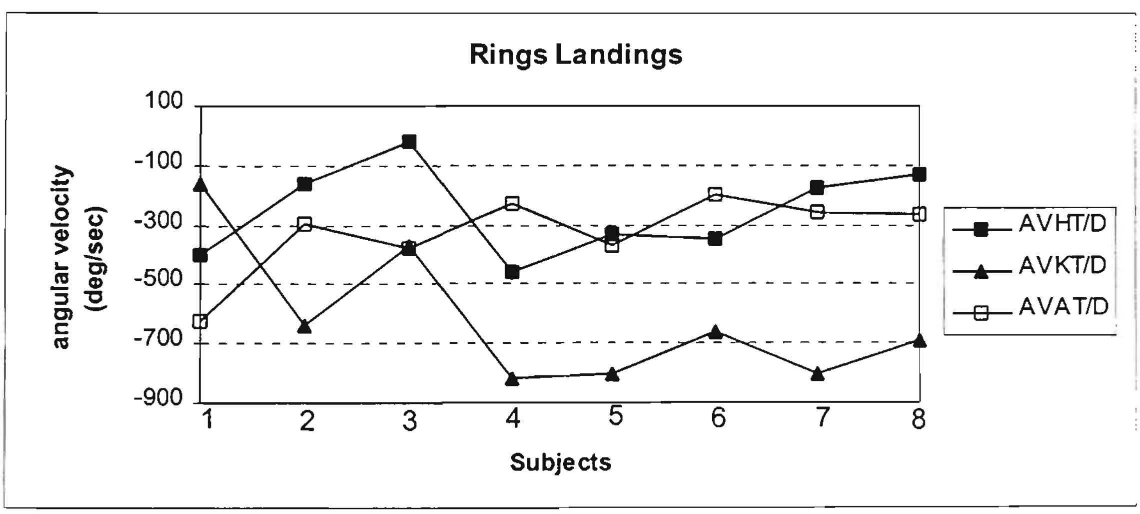


Figure 4.6.4.2.7 Angular velocities of the hip, knee and ankle joints

Significant correlations were found between the variables avkt/d & avat/d (r = -0.823, p<.02).

The mean ***ankle joint angular velocity*** was -327.63 ± 135.55 deg/sec, with the highest value of -624 deg/sec and the lowest value of -198 deg/sec (Figure 4.6.4.2.8). Significant correlations were found between the variables avat/d & avkt/d (r = -0.823, p<.02).

Angle-angle diagrams were produced of the best landing performances to investigate the relationship between ankle and knee angles, knee and hip angles, and hip and shoulder angles over the period of the landing phase. Subject 2 ankle angle-knee angle is illustrated in Figure 4.6.4.2.8.

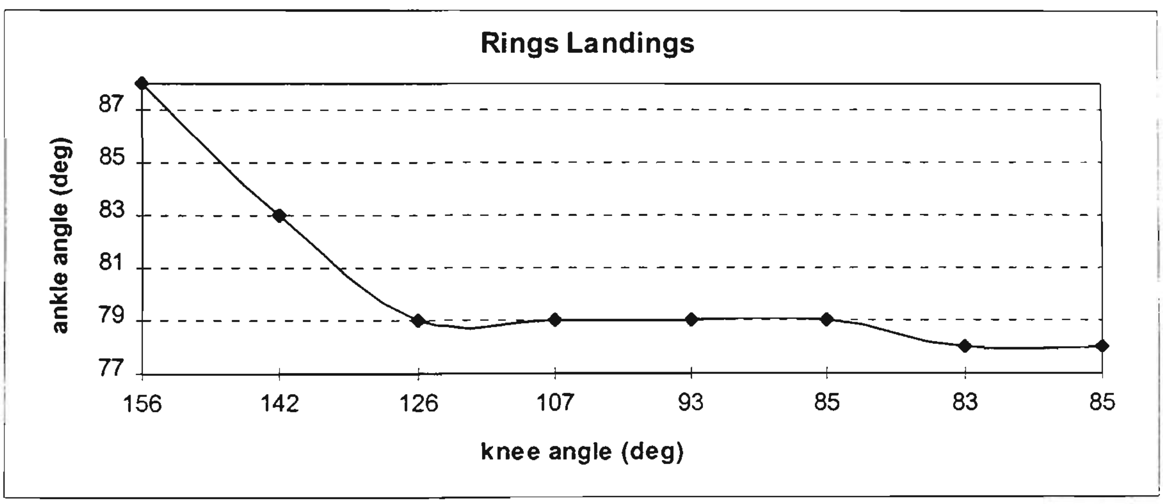


Figure 4.6.4.2.8 Ankle joint angle-knee joint angle diagram for subject 2

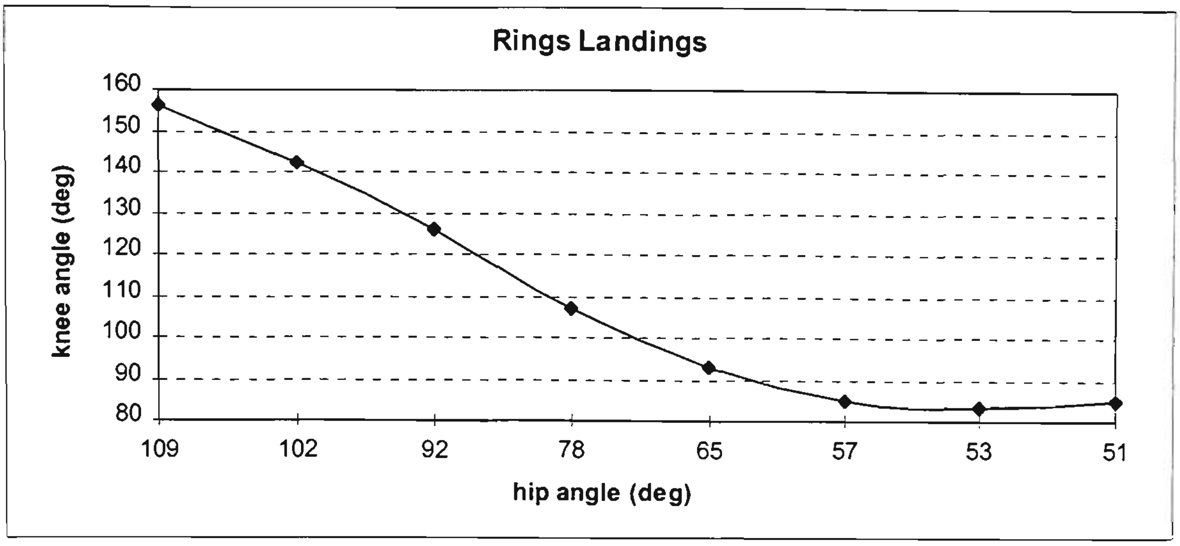


Figure 4.6.4.2.9 Knee joint angle-hip joint angle diagram for subject 2

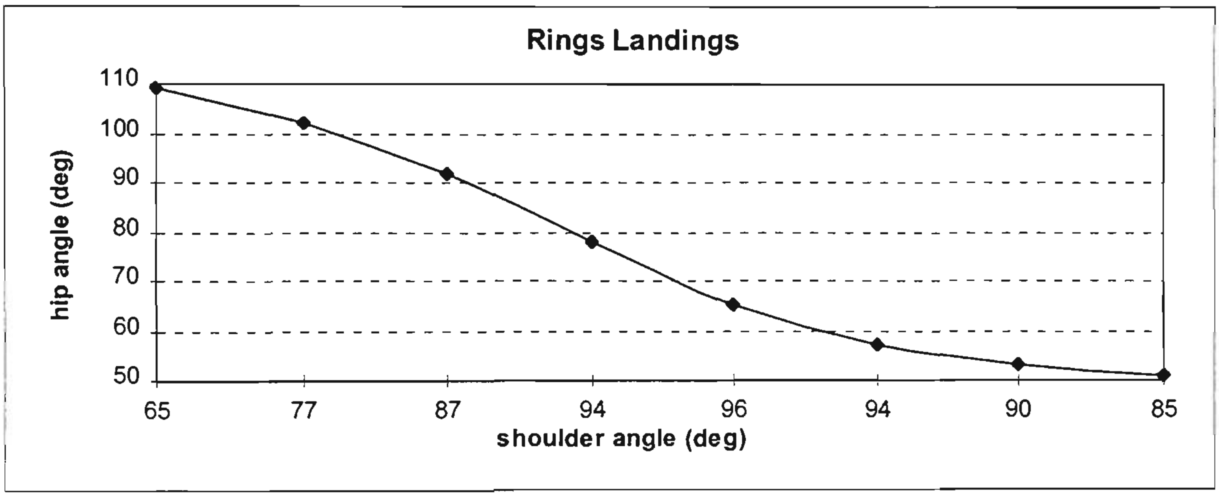


Figure 4.6.4.2.10 Hip joint angle-shoulder angle diagram for subject 2

Angular velocity-joint angle diagrams for ankle, knee, hip and shoulder angles were also produced to provide a description of the respective angular velocity-angular displacement relationship during the landing process. The ankle angular velocity-ankle joint angle relationship of subject 2 is illustrated in Figure 4.6.4.2.12.

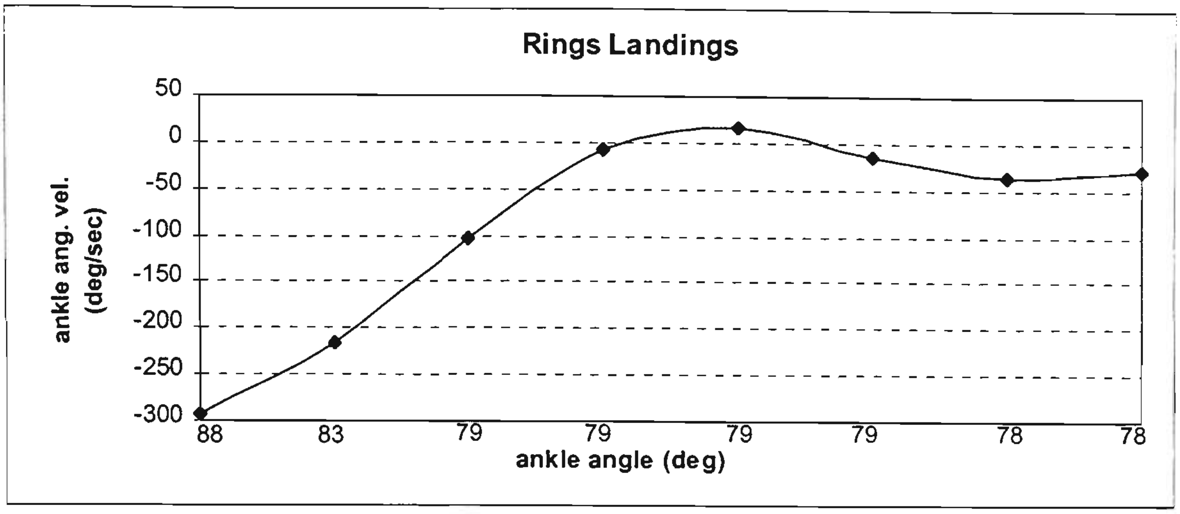


Figure 4.6.4.2.11 Ankle joint angular velocity-ankle joint angle diagram for subject 2

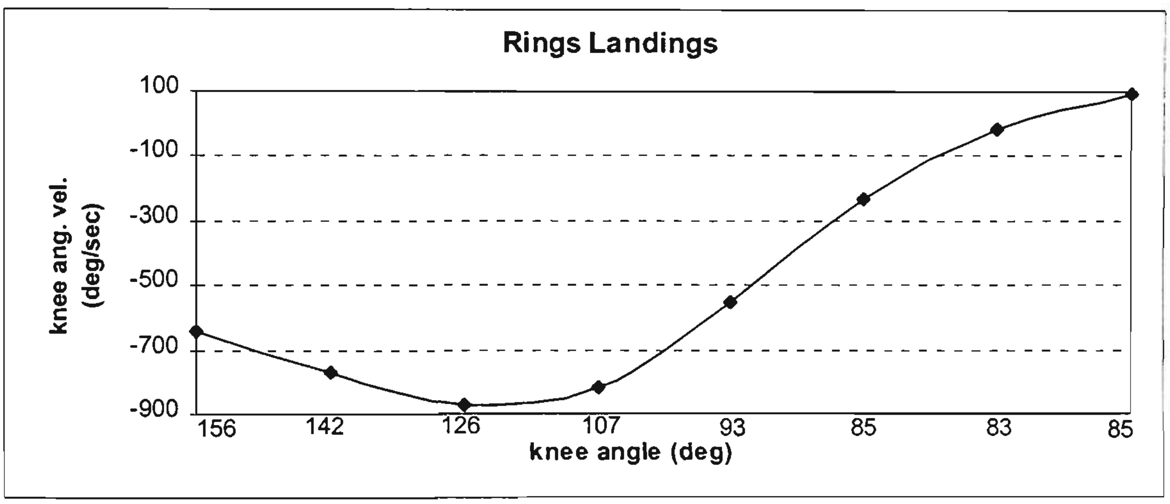


Figure 4.6.4.2.12 Knee joint angular velocity-knee joint angle diagram for subject 2

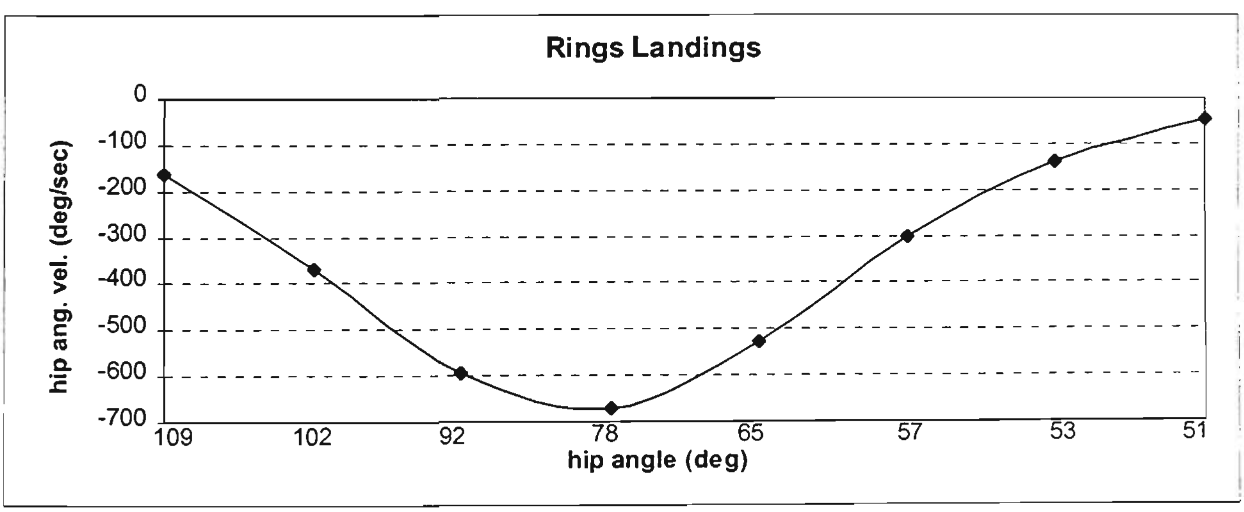


Figure 4.6.4.2.13 Hip joint angular velocity-hip joint angle diagram for subject 2

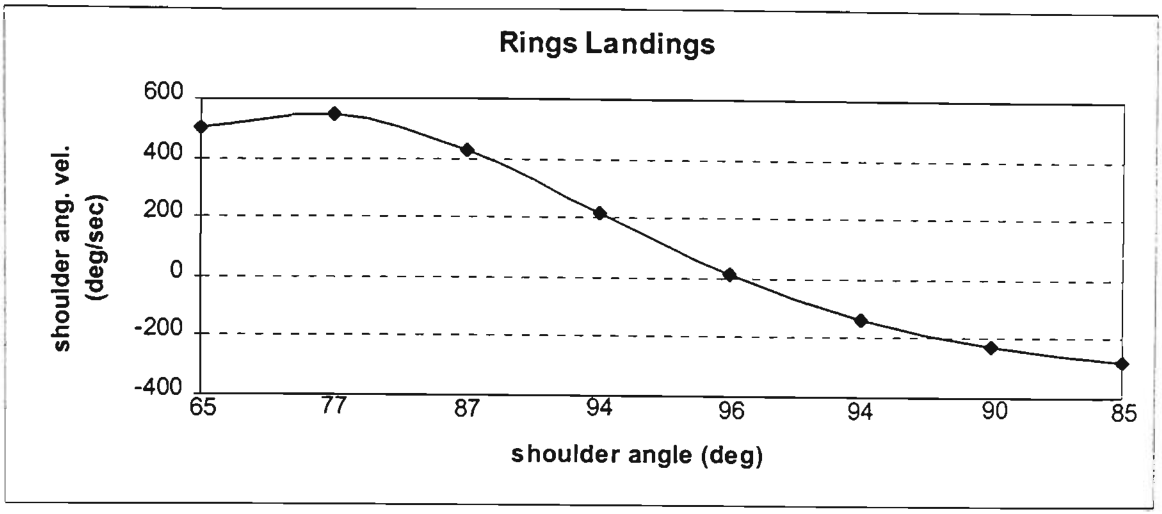


Figure 4.6.4.2.14 Shoulder joint angular velocity-shoulder joint angle diagram for subject 2

4.6.4.3 Temporal Characteristics Of The Flight- And Landing Phase

The flight phase covers parameters such as the vertical height reached by the CM, backwards horizontal distance travelled by the CM, and the number of angular rotations achieved; e.g. number of somersaults and twists (Table 4.6.4.3.1).

Table 4.6.4.3.1 Temporal characteristics of the landing performances on the rings (seconds)

Subject	Flight Phase ftrt/d	Landing Phase cmdt/dm
1	0.96	0.14
2	0.96	0.16
3	0.92	0.10
4	0.86	0.12
5	0.90	0.14
6	0.84	0.14
7	0.92	0.10
8	0.88	0.12
Mean (SD)	0.91 (0.04)	0.13 (0.02)

The mean value for the ***flight time from release to touch-down*** (ftrt/d) was 0.91 ± 0.04 sec, with the highest value of 0.96sec and the lowest value of 0.84seconds (Figure 4.6.4.3.1).

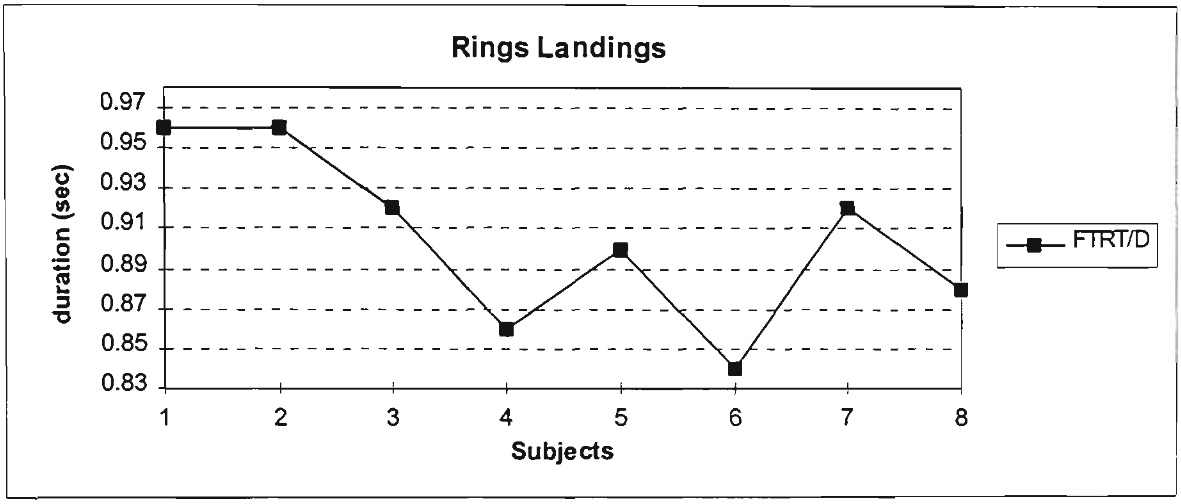


Figure 4.6.4.3.1 Flight time from release to landing touch-down

Significant correlations were found between the variables ftrt/d & cmhr ($r = -0.805$ $p<.02$), ftrt/d & cmvvr ($r = 0.808$ $p<.02$).

The mean values for the ***CM duration touch-down to minimum*** (cmdt/dm) was 0.13 ± 0.02 sec, with the highest value of 0.16sec and the lowest value of 0.10sec (Figure 4.6.4.3.2).

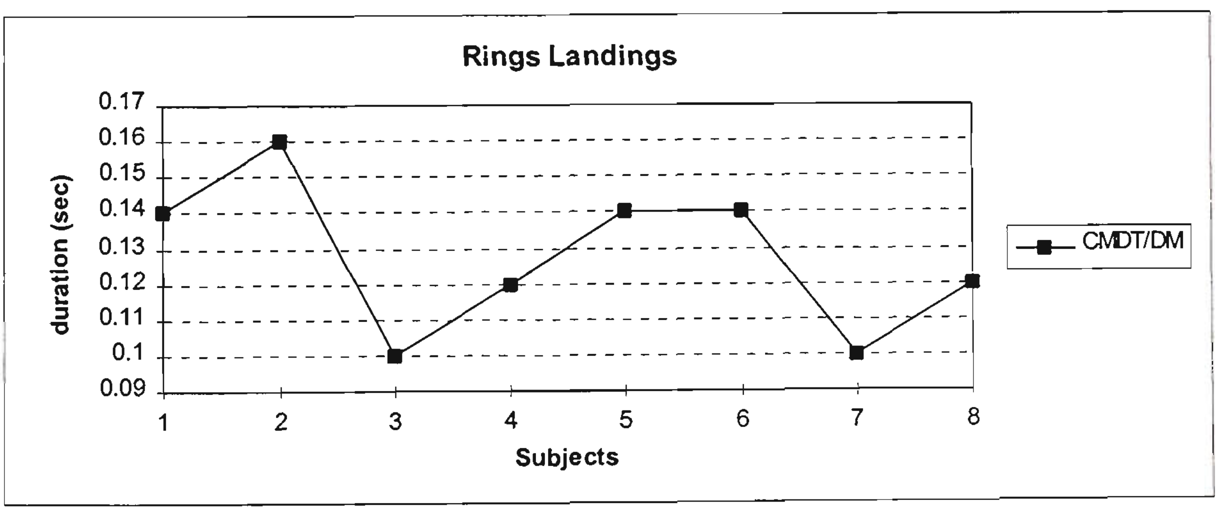


Figure 4.6.4.3.2 CM duration from landing touch-down to landing minimum

4.6.4.4 Kinematic Parameter Interaction Related To The Landing Score of the Rings Landing Model

To provide an optimal landing representation, all landing performances, with particular emphasis on the best landing performance on the rings, were discussed in relation to the group mean. The best performance was recorded by subject 2 (88.89%), from a double layout full twist dismount. Subject 2 recorded high within group values on all variables. He recorded a cmhvr of -0.05m/s (level 10), compared to the mean value of -0.16 ± 0.14 m/s, respectively. He also obtained a cmhvt/d of -0.10m/s, compared to the mean value of -0.09 ± 0.09m/s. Significant correlations were found between the variables cmhvt/d & cmhdrt/d ($r = 0.762$, $p<.05$), cmhvt/d & cmvvt/d ($r = 0.731$, $p<.05$).

These variables were identified in level 10 of the deterministic model and indicate a significant relationship between the CM horizontal velocity at touch-down and the CM horizontal distance travelled from release to touch-down and with the CM vertical velocity at touch-down. His cmvvr was recorded at 3.19m/s and his cmvvt/d was calculated at -5.90m/s compared to the mean value of 2.74 ± 0.50 and -6.00 ± 0.09m/s, respectively.

Subject 2 recorded a hip angle of 109° at landing touch-down, compared to the mean value of 112.25 ± 8.38° and a minimum hip angle of 56° compared to the mean value of 69.63 ± 11.04°. His hip angle was 109° (0.02sec), 108° (0.04sec) and 110° (0.06 sec), before the landing touch-down. The respective hip angular velocities were 48, 43 and 146deg/sec. His hip angle was 102° (0.02sec), 92° (0.04sec), and 78° (0.06sec) after landing touch-down. The respective hip angular velocities were -367, -593 and

-669deg/sec. Subject 2 recorded a knee angle of 156° at landing touch-down, compared to the mean value of 153.75 ± 6.61°, and a minimum knee angle of 87° compared to the mean value of 88.25 ± 13.38°. His knee angle was 168° (0.02sec), 176° (0.04sec) and 173°, before the landing touch-down. The knee angular velocities were recorded as -490 and -141 and 221deg/sec, respectively. His knee angle was 142° (0.02sec), 126° (0.04sec), and 107° (0.06sec) after landing touch-down. The respective knee angular velocities were -771, -873 and -821deg/sec.

Subject 2's ankle angle was 88° at landing touch-down, compared to the mean value of 88.88 ± 3.56°, and a minimum ankle angle of 77° compared to the mean value of 77.50 ± 3.89°. His ankle angle was 94° (0.02sec), 101° (0.04sec), and 107° before the landing touch-down. The respective ankle angular velocities were -323, -322 and -260deg/sec. His ankle angle 83° (0.02sec), 79° (0.04sec), and 79° (0.06sec) after landing touch-down. The respective ankle angular velocities were -216, -104 and -8deg/sec. Subject 2's angle-angle diagrams and angular velocity-joint angle diagrams provided an excellent visual perception of their relationship during the landing process. Subject 2 also exhibited a longer CM duration from landing touch-down to landing minimum 0.16 sec, compared to the mean value of 0.13 ± 0.02seconds.

All landing performances were executed with good technique, except for subject 4 who under-rotated during somersaulting, coming out of the tucked somersault position too slow.

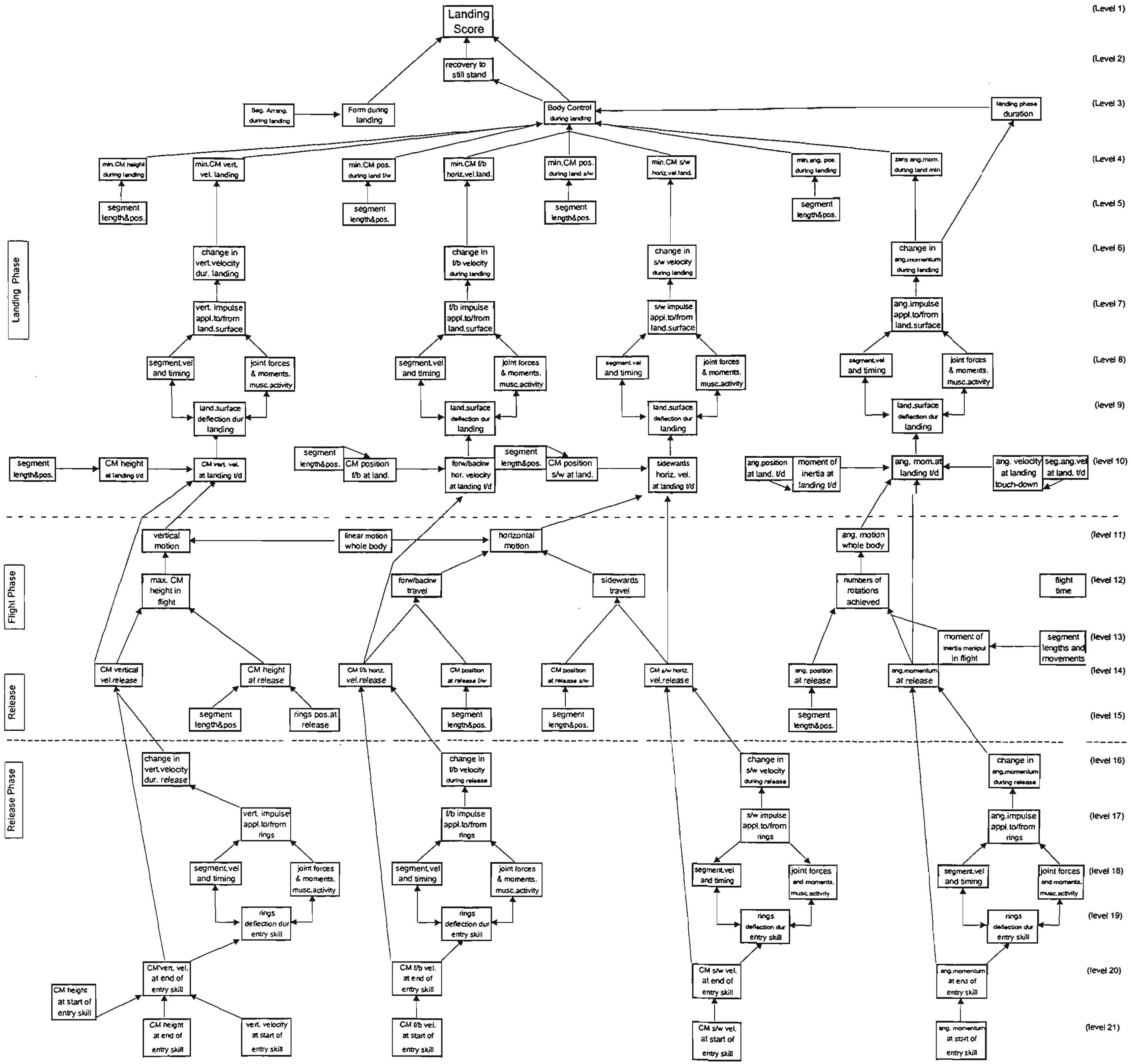


Figure 4.6.4.4.1 Deterministic model showing the release, flight phase, landing phase, and the biomechanical factors related to controlled landing performances on rings

Slightly unstable landings also occurred when the gymnasts did not have enough landing preparation time due to technique insufficiencies, unable to complete the skill before the landing.

It is concluded that controlled landings on the rings are likely when gymnast's achieve (a) a very low horizontal velocity at release (no swinging of the rings);

(b) optimal rotational requirements of the flight phase; (c) an early preparation for the landing, and (d) optimal body segment coordination and timing during the landing phase.

4.6.4.5 Development Of The Rings Landing Model

Biomechanical factors crucial for controlled landings are identified in the "rings landings model". To achieve successful, controlled landings on the rings, the gymnast must first fulfil the biomechanical requirements in the release phase. Successful landings are likely when the release and the landing mechanics are optimised, and optimal segment coordination and timing are achieved during the landing process.

To achieve optimal release conditions for the rings, the mean value of the best three values of the analysed release parameters cmhr (2.59m), cmhvr (0.03m/s) and cmvvr (3.23m/s), were considered. The mean value of the best three values of the landing touch-down parameters cmht/d (0.81m), cmhvt/d (-0.22m/s), cmvvt/d

(-6.08m/s), acmght/d (91°), aatt/d (57°), aht/d (120°), akt/d (160°), aat/d (92°), atht/d (38°), avht/d (-403°/sec), avkt/d (-807°/sec), and avat/d (-459°/sec), were taken into consideration for the development of the landing profile shape (LPS). The best three values for the landing parameters represent the lowest values for cmhvt/d and aatt/d, and the highest values for cmvvt/d, cmht/d, acmght/d, aht/d, akt/d, aat/d, atht/d, avht/d, avkt/d and avat/d.

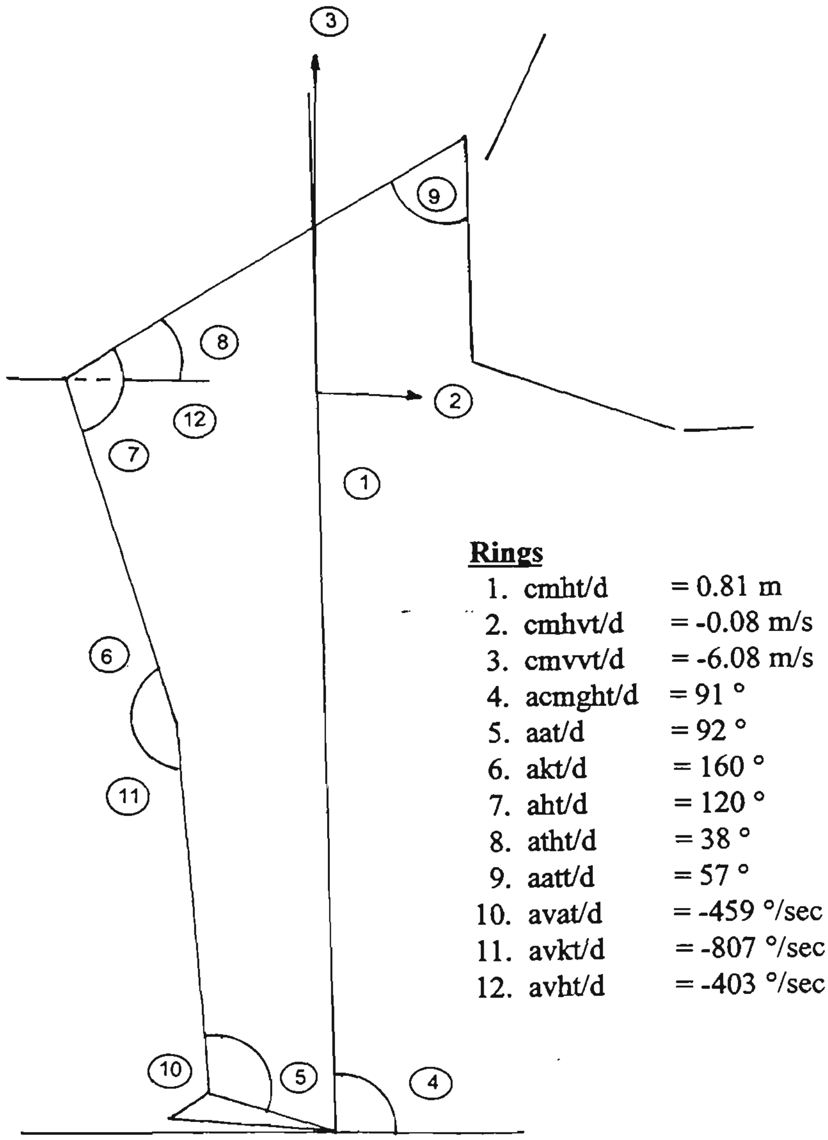


Figure 4.6.4.5.1 Landing profile shape (LPS) for rings landings

4.7 *Overview and Implications Of The Results*

This study consisted of an investigation into the linear and angular kinematics, the temporal characteristics involved in the execution of competition landings, and the quantification and identification of kinematic parameters crucial for controlled competition landings. Also, an effort was made to identify and describe the interaction of the kinematic parameters necessary to achieve controlled landings. Subsequently, landing profile shapes (LPS) for each group on four events (floor, rings, parallel bars and horizontal bar), which constitute a typical landing posture on the respective events, were developed.

From thirty two subjects over the four events, seventeen performed double backward somersaults without twist, and fifteen performed double backward somersaults with twist(s). All dismounts had backward rotations with either backwards horizontal velocity (parallel bars, floor and rings), and backward rotations with forward horizontal velocity (horizontal bar). Qualitative analysis revealed that the gymnasts arrangement of body segments at landing touch-down (first contact with the landing surface) differed on all events and differed within groups. This was due to the different types of dismounts performed on three events (horizontal bar, floor and rings). On parallel bars all subjects performed the same dismount (double backward somersault piked).

The results from the ANOVA and post-hoc tests showed that there were relationships and differences in the variables from the release, flight and landing phase across the four groups. Results from the release phase showed that the magnitudes of the variables CM height, CM horizontal velocity, and the CM vertical velocity, were found to be significant at the $p<.01$ level. The CM horizontal velocity at release/take-off, which is determined by the precision and correct timing of the entry skill represents a very important kinematic parameter relative to the whole landing process, specifically on the floor. The CM vertical velocity at release is also determined by the precision and correct timing of the entry skill and determines the maximum CM height during flight, the vertical displacement, and, in conjunction with flight time, the vertical impact velocity. There were very little difference in the amount of within group variability among all groups. There is an indication, that floor landings are influenced significantly due to the relatively large horizontal velocity at take-off and the subsequent horizontal impact velocity.

Results from the flight phase indicated that the means of the variables CM horizontal displacement release to touch-down, flight time release to touch-down, and max CM height in flight were found to be significant at the $p<.001$ level. These biomechanical parameters have significantly different mean values for each event, thus requiring specific flight technique properties to ensure adequate preparation for the landing.

Results from the landing phase indicated that the means for the variables CM height at touch-down, CM horizontal velocity at touch-down, CM vertical velocity at landing touch-down (the vertical impact velocity), angle CM to ground contact and the horizontal, hip angular velocity at touch-down, and the landing phase displacement, were found to be significant at the $p<.001$ level. The segmental coordination and timing of the body joint actions during the landing process in relation to these parameters differed for the four events and, thus constitute crucial variables for successful landing performance. These results indicated that the null hypotheses 'that there are no significant differences in landing techniques between the four events (parallel bars, horizontal bar, floor and rings)', and, 'that there are no significant differences in landing techniques between the four events due to the horizontal and vertical impact velocities during the landing process', is therefore rejected.

The results from the factor analysis demonstrated that 70% of the total variance was attributed to the first three factors, with more than half of that variation (35.9 %) being associated with the first factor. Thus, a model with three factors was adequate to represent the data. This was also displayed by the scree plot.

A very interesting observation was obtained from the rotated factor matrix. Factor 1 included all variables from the release phase and two variables from the landing phase, and the first three variables (cmhvr, cmhdrt/d, and cmhvt/d) were directly related to one another. The CM height at release (cmhr) and the CM vertical velocity at release (cmvvr) were also deemed to be important release properties. The angle CM to ground contact and the horizontal at landing touch-down (acmght/d) constitutes the most crucial angle for controlled landings.

The gymnasts' landing performances on floor and horizontal bar represent separate distinct groupings, and the gymnasts' landing performances on rings and parallel bars are grouped together. These results suggested that the gymnasts landing performances on horizontal bar were quite different to those on the other events. This can be explained by the fact that horizontal bar landings demonstrated a <u>forward</u> horizontal velocity of (0.93m/s), and a large vertical impact velocity (-7.02m/s). The gymnasts landing performances on floor demonstrated a high <u>backward</u> horizontal velocity (2.06m/s), and a vertical impact velocity of -4.89m/s. In the third group, the gymnasts landing performances from parallel bars and rings had a relatively small <u>backward</u> horizontal velocity of 0.49 and 0.09m/s, and a vertical impact velocity of -5.42 and -6.0m/s, respectively.

The results from the cluster analysis indicate that all landing performances are partitioned into three distinct different subgroups of landing techniques. It is highly interesting that all cases (subjects landing performances) from group 2 (horizontal bar) and group 3 (floor), made up two distinct different clusters (cluster 1 & 2), and all cases from groups 1 and 4 made up the third cluster. This translates to that landing techniques adopted by gymnasts on horizontal bar differed to those performed on floor, and that landing techniques on parallel bars and rings are similar but different from those on horizontal bar and floor. These results are consistent with the results obtained from the factor analysis performed previously. These results are also consistent with observation from qualitative analysis and practical experience by the author, that horizontal bar landings, were gymnasts experience backward rotations with forward horizontal velocity (0.93± 0.49m/s) require different landing techniques to those on floor, were gymnasts experience backward rotations with backward horizontal velocity (-2.06± 0.29m/s). The indication that landing techniques on parallel bars and rings are similar, thus forming the biggest cluster, is due to minimal horizontal velocity backwards (parallel bars 0.49 ± 0.26m/s, and for rings 0.09 ± 0.09m/s) experienced by the gymnasts at landing touch-down.

The results from the cluster analysis for variables suggests that the variables formed first in the analysis process are important indicators for successful landing techniques. The results obtained using this cluster procedure shows three cluster formations. It is suggested that the variables from the first cluster formation relating to the landing phase touch-down: cmhvt/d, cmht/d, cmvvt/d, and the atht/d, constitute the most important linear kinematic variables.

The variables from the second cluster formation: aat/d, acmght/d, athht/d, aht/d, aatt/d and the akt/d, constitute the most important angular kinematic variables. These variables were included in the landing profile shapes (LPS) because of their importance in developing controlled landings. Prior to landing touch-down, the variables from the release phase: cmhdrt/d, cmhvr, cmhr, cmvvr; and the variables from the flight phase: ftrt/d and mcmhf, are important indicators for successful landings.

Because of the differences in the variety and difficulty of dismounts on each event, the individual group results indicated the need for the development of separate landing profile shapes (LPS) for each of the four events. Thus the landing profile shapes, which constitute a typical or classical landing posture, can be considered as a representative biomechanical landing profile for competition landings in artistic gymnastics.

It was interesting to observe a strong association between the landing impact velocities and the landing phase duration. This trend was apparent for each group as demonstrated by the groups data mean values. On parallel bars, the group mean values were for the vertical impact velocity (cmvvt/d) -5.42m/s, the horizontal backward velocity (cmhvt/d) -0.49m/s, the horizontal sideward velocity (cmhvm/lt/d) 0.69m/s, and for the landing phase, the duration was 0.11sec. For horizontal bar, the group mean values for the vertical impact velocity (cmvvt/d) were -7.02m/s, the horizontal forward velocity (cmhvt/d) 0.93m/s, and for the landing phase, the duration was 0.14sec. For floor, the group mean value for the vertical impact velocity (cmvvt/d) were -4.89m/s, the horizontal backward velocity (cmhvt/d) -2.06m/s, and for the landing phase, the duration was 0.10sec. For rings, the group mean value for the vertical impact velocity (cmvvt/d) were -6.00m/s, the horizontal backward velocity (cmhvt/d) -0.09m/s, and for the landing phase, the duration was 0.13sec. This data suggests that an increase in impact velocities result in an increase in landing phase duration as shown across the four groups. These findings are consistent with those reported by McNitt-Gray (1989) and other published data.

The strong association between the landing impact velocities and their respective landing phase duration was apparent for each group as demonstrated by the groups data mean values (Table 4.7.1).

Table 4.7.1 Association between landing impact velocities and landing phase duration for parallel bars, horizontal bar, floor and rings

Events	cmvvt/d (m/s)	cmhvt/d (m/s)	cmdt/dm (sec)
Parallel Bars	-5.42	-0.49	0.11
Horizontal Bar	-7.02	0.93	0.14
Floor	-4.89	-2.06	0.10
Rings	-6.00	-0.09	0.13

The strong association between the landing impact velocities and their respective landing phase duration are a causative result of the cmvvr and cmhvr. The temporal patterns between groups on each event, and within groups varied greatly when encountering higher vertical impact velocities. The rate of absorption of the landing impact velocities varied within the group on each event (Appendix 1), depending on the landing technique employed, that is, the manipulation of and interplay with the variables by the individual subject. McNitt-Gray (1989) reported that "the human has the opportunity to modify the characteristics of the impact force in anticipating the increase in loading rate by selectively activating muscles to control the segment motion during the contact with the surface" (p. 1).

An interesting finding was that the mean knee angles at landing touch-down (akt/d) were simular for all groups (153°), except for a marginal higher value on parallel bars (158°), despite the variations in horizontal and vertical impact velocities.

The large knee and hip joint motion in landing suggests that the knee and hip play a substantial role in the absorption of the landing impacts by increasing the duration of the landing phase (cmdt/dm). In dismounts performed from greater heights, i.e. horizontal bar and rings, the landing duration increases.

The interplay of the angular velocities between the ankle, knee, hip and shoulder joints, (the temporal patterns of the kinematic chain), which enables the subject to shift the CM at will in order to maintain balance and stability during the landing process, is an important indicator of the characteristics of the landing technique employed by the subject to produce a controlled landing performance.

The variety of landing techniques adopted by subjects within groups on all events suggests that there is no one superior technique for competition landings. However, the results suggested that there were similarities in biomechanical landing parameters across the four groups which can be viewed as performance indicator variables for controlled landings.

Also, there were differences in parameters characterising the landing techniques for each event. For this purpose, the landing profile shape, a typical posture developed for each event, can be considered as a representative biomechanical landing profile for competition landings in artistic gymnastics.

CHAPTER 5

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The investigation consisted of a qualitative and quantitative kinematic analysis of competition landings in gymnastics and was developed on the following phases:

- Videographic data were obtained during the 1994 World Gymnastics Championships. Brisbane;
- A kinematic analysis of selected dismounts on four events was performed using the Peak 5 Motion Analysis System;
- Landing scores were established for each landing performance by a panel of qualified gymnastic judges and experts on the four events under investigation;
- A deterministic model for the dismount release, flight and landing phase was developed;
- Landing profile shapes (LPS) for each group on four events (floor, rings, parallel bars and horizontal bar) were developed.

The following conclusions were drawn based on the results of this study:

1. The subjects performed under real life conditions, at the highest level of gymnastics competition, the World Gymnastics Championships. This represented the first attempt to quantify the landing process of elite gymnasts, thus providing important data for

further scientific investigations and practical implications to the wide coaching fraternity.

2. Qualitative analysis revealed that the gymnasts arrangement of body segments at landing touch-down differed between all groups and also within groups. This was due to the different types of dismounts performed on three events (horizontal bar, floor and rings). On parallel bars all subjects performed the same dismount (double backward somersault piked), however, the arrangement of body segments at landing touch-down for all subjects differed.

3. The results from the ANOVA and post-hoc tests showed that there were 11 parameters which were most significant ($p<.01$) in distinguishing successful landing performances among the four groups under investigation. Relationships and differences in the variables from the release, flight and landing phase across the four groups were found. This result suggested that there were variables identified showing commonality across the four groups.

4. The results from the factor analysis demonstrates that almost 70% of the total variance is attributed to the first three factors, with more than half of that variation (35.9 %) being associated with the first factor. Thus, a model with three factors was adequate to represent the data which was also evident from the scree plot.

From these results it can be concluded that the CM horizontal velocity at release/take-off (cmhvr/t/o) is an important variable for controlled landings. The CM height at release (cmhr) and the CM vertical velocity at release (cmvvr) are also deemed to be important release properties. The angle CM to ground contact and the horizontal at landing touch-down (acmght/d) constitutes the most crucial angle for controlled landings.

The gymnasts landing performances on floor and horizontal bar represented separate distinct groupings, and the gymnasts landing performances on rings and parallel bars were grouped together. These results highlight the parameter interplay between the release, flight phase and landing phase, and its implication to coachs' educators.

5. The results from the cluster analysis indicated that all landing performances were clustered in three distinct different subgroups of landing strategies. It is highly interesting that all cases (subjects landing performances) from group 2 (horizontal bar) and group 3 (floor), made up two distinct different clusters (cluster 1 & 2), and all cases from groups 1 and 4 made up the third cluster. This translates to that landing strategies adopted by gymnasts on horizontal bar differed to those performed on floor, and that landing strategies on parallel bars and rings are similar but different from those on horizontal bar and floor. These results are consistent with the results obtained from the factor analysis performed previously.

The results from the cluster analysis for variables suggests that the variables formed first in the analysis process are important indicators for successful landing strategies. The results obtained using this cluster procedure showed three cluster formations. The variables from the first cluster formation relating to the landing phase touch-down, constituted the most important linear kinematics variables, and the variables from the second cluster formation constituted the most important angular kinematic variables.

These variables were considered for inclusion to the development of the landing profile shapes (LPS) because of their importance for controlled landings.

6. Because of the differences in the variety and difficulty of dismounts on each event, the individual group results indicated the need for the development of separate landing profile shapes (LPS) for each of the four events. The landing profile shapes (LPS) developed for each of the four event, can be considered as a representative biomechanical landing profile for competition landings in artistic gymnastics.

7. The data showed a strong association between landing impact velocities and landing phase duration. This was apparent for each group as demonstrated by the groups data mean values. This data suggests that an increase in impact velocities result in an increase in landing phase duration as shown across the four groups.

8. The association between landing impact velocities and landing phase duration is a causative result of the cmvvr and the cmhvr. The subsequent duration of the landing phase (cmdt/dm) is greatly related to the landing phase displacement (lpdispl).

9. The temporal patterns between groups on each event, and within groups varied greatly. The rate of absorption of the landing impact velocities varied greatly within the group on each event depending on the landing technique employed by the individual subject.

10. The knee angles at landing touch-down (akt/d) was similar for all groups (153°), except for a marginal higher value on parallel bars (158°), despite the large variations in horizontal and vertical impact velocities.

11. The available large knee and hip joint range of motion during the landing phase suggests, that the knees and hips play an important role in the absorption of the landing impact velocities by increasing the duration of the landing phase (cmdt/dm).

12. The interplay of the angular velocities between the ankle, knee, hip and shoulder joints, the temporal patterns of the kinematic chain, which enables the subject to displace the CM at will in order to maintain balance and stability during the landing process, are crucial in the production of an optimal landing performance.

13. The variety of landing techniques adopted by subjects within groups on all events suggests that there is no one superior technique for competition landings. Gymnasts have to be multi-landing-technique-wise in order to cope with the variety of situations they are confronted with before and during the landing process.

14. The successful attainment of controlled competition landings are certain when gymnast's achieve optimal release conditions, optimal rotational flight requirements, and optimal body segment coordination and timing during the landing phase.

5.2 Recommendations

Based on the findings of this study, it is recommended that further studies on competition landings should be undertaken.

1. Further studies of actual competitions landings must be done to accumulate data for future research to continue the trend to bridge the gap between sports scientists and coaches. A data bank from real life competitions (all levels) must be established to study this virtually non-researched area.

2. Investigations into symmetry of both lower extremities at landing touch-down. Kinematic and kinetic data should be collected for quantification of symmetry at landing and during the landing process to investigate potential injury sources.

3. Refinement of the landing profile shapes (LPS), future research should consider a larger sample size, more subjects performing the same dismount (e.g. compulsory dismount) under the same conditions at different competitions. A larger sample size will allow the statistical treatment to reach more concrete conclusions. Also, a higher frame rate (100-200 Hz) for data collection must be used to get more accurate results, in particular, for ankle joint data.

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APPENDICES

Appendix **Page**

APPENDIX 1

Parallel bars, horizontal bar, floor and rings data sheets

PARALLEL BARS LANDINGS

	Subjects													
	1	2	3	4	5	6	7	8	Mean	SD	Variance	Minimum	Maximum	Range
CMHT/D	0.73	0.72	0.74	0.78	0.69	0.85	0.68	0.71	0.74	0.05	0	0.68	0.85	0.17
CMHM	0.66	0.6	0.56	0.47	0.57	0.7	0.54	0.46	0.57	0.08	0.01	0.46	0.7	0.24
LPDISPL	0.07	0.12	0.18	0.31	0.12	0.15	0.14	0.25	0.17	0.08	0.01	0.07	0.31	0.24
CMDT/DM	0.06	0.1	0.12	0.14	0.12	0.08	0.16	0.12	0.11	0.03	0	0.06	0.16	0.1
CMVVT/D	-5.49	-5.76	-5.38	-5.59	-5.3	-5.56	-5.81	-4.46	-5.42	0.42	0.18	-5.81	-4.46	1.35
CMHVT/D	0.21	0.5	0.6	0.22	0.77	0.23	0.89	0.51	0.49	0.26	0.07	0.21	0.89	0.68
ACMGHT/D	89	82	79	88	84	98	87	83	86.25	5.8	33.64	79	98	19
AATT/D	85	40	74	-41	78	30	39	56	45.13	40.24	1618.98	-41	85	126
AATM	53	59	64	70	70	84	58	74	66.5	10.03	100.57	53	84	31
AHT/D	102	91	98	116	102	95	100	99	100.38	7.31	53.41	91	116	25
AHM	86	60	57	66	69	73	83	62	69.5	10.57	111.71	57	86	29
AKT/D	166	161	153	154	160	167	138	168	158.38	9.98	99.7	138	168	30
AKM	137	114	94	85	107	126	53	103	102.38	25.98	674.84	53	137	84
AAT/D	101	96	81	96	89	112	89	97	95.12	9.25	85.55	81	112	31
AAM	97	83	90	88	90	98	89	83	89.75	5.55	30.79	83	98	15
ATHT/D	27	14	12	43	19	27	36	14	24	11.29	127.43	12	43	31
ATHM	33	13	14	37	20	23	63	27	28.75	16.2	262.5	13	63	50
ATHHT/D	75	77	86	73	83	68	64	85	76.38	8	63.98	64	86	22
ATHHM	53	47	43	29	49	50	20	35	40.75	11.65	135.64	20	53	33
AVHT/D	-277	-123	-196	-313	-223	-85	-247	-306	-221	83.01	6889.93	-313	-85	228
AVKT/D	-537	-608	-718	-1005	-689	-478	-1021	-480	-692	216.7	46959.43	-1021	-478	543
AVAT/D	-133	-387	-358	-369	-239	-210	-185	-111	-249	109.25	11934.57	-387	-111	276
CMHR	2.38	2.49	2.23	2.42	2.3	1.75	2.32	2.26	2.27	0.23	0.05	1.75	2.49	0.74
CMHDRT/D	0.4	0.44	0.55	0.43	0.39	0.22	0.73	0.49	0.46	0.15	0.02	0.22	0.73	0.51
CMVVR	1.61	2.27	2.36	2.77	1.65	1.57	2.4	2.3	2.12	0.45	0.2	1.57	2.77	1.2
CMHVR	0.83	1.22	0.84	1.14	1.13	1.16	1.15	0.7	1.02	0.2	0.04	0.7	1.22	0.52
MCMHF	2.47	2.65	2.45	2.69	2.37	2.51	2.56	2.51	2.53	0.11	0.01	2.37	2.69	0.32
FTRT/D	0.86	0.9	0.84	0.92	0.76	0.86	0.88	0.86	0.86	0.05	0	0.76	0.92	0.16

HORIZONTAL BAR LANDINGS

	Subjects													
	1	2	3	4	5	6	7	8	Mean	SD	Variance	Minimum	Maximum	Range
CMHT/D	0.83	0.82	0.96	0.87	0.9	0.74	0.82	0.77	0.84	0.07	0	0.74	0.96	0.22
CMHM	0.66	0.49	0.73	0.69	0.45	0.56	0.5	0.63	0.59	0.1	0.01	0.45	0.73	0.28
LPDISPL	0.17	0.33	0.23	0.18	0.45	0.18	0.32	0.14	0.25	0.11	0.01	0.14	0.45	0.31
CMDT/DM	0.1	0.16	0.14	0.08	0.18	0.18	0.18	0.12	0.14	0.04	0	0.08	0.18	0.1
CMVVT/D	-7.07	-6.24	-6.85	-7.28	-7.23	-7.36	-6.83	-7.29	-7.02	0.37	0.14	-7.36	-6.24	1.12
CMHVT/D	1.77	1.17	0.67	0.4	0.37	0.72	1.36	1.02	0.93	0.49	0.24	0.37	1.77	1.4
ACMGHT/D	91	95	93	91	96	95	97	94	94	2.2	4.86	91	97	6
AATT/D	44	95	93	91	96	95	97	94	83.5	32.62	1064.29	44	139	95
AATM	38	106	89	62	103	58	111	40	75.88	29.96	897.55	38	111	73
AHT/D	108	113	130	123	124	115	101	112	115.75	9.44	89.07	101	130	29
AHM	87	56	81	82	58	44	60	66	66.75	15.13	228.79	44	87	43
AKT/D	162	145	160	169	141	157	133	159	153.25	12.22	149.36	133	169	36
AKM	103	85	101	123	42	98	42	98	86.5	29.38	863.14	42	123	81
AAT/D	107	106	106	104	88	83	91	82	95.88	10.95	119.84	82	107	25
AAM	76	86	96	103	68	67	76	72	80.5	13.24	175.43	67	103	36
ATHT/D	29	44	55	39	51	45	48	36	43.38	8.43	71.13	29	55	26
ATHM	32	30	42	25	56	7	59	26	34.63	17.17	294.84	7	59	52
ATHHT/D	79	69	75	84	73	70	53	76	72.38	9.2	84.55	53	84	31
ATHHM	55	26	39	57	2	37	1	40	36.25	17.54	307.64	1	57	56
AVHT/D	-518	-734	-543	-445	-634	-690	-706	-549	-602.38	103.51	10714.55	-734	-445	289
AVKT/D	-650	-883	-811	-532	-1104	-926	-963	-870	-842.38	179.97	32389.98	-1104	-532	572
AVAT/D	-68	-66	-128	-93	-286	-144	-290	-166	-155.13	89.2	7955.84	-290	-66	224
CMHR	2.44	2.61	2.77	2.54	2.79	2.81	2.83	2.71	2.69	0.14	0.02	2.44	2.83	0.39
CMHDRT/D	2.21	1.72	1.05	0.61	0.66	0.51	1.28	1.13	1.13	0.55	0.3	0.51	2.04	1.53
CMVVR	4.99	4.88	4.53	5.28	4.57	4.62	4.21	4.86	4.74	0.33	0.11	4.21	5.28	1.07
CMHVR	2.12	1.01	0.54	0.4	0.9	0.22	1.49	0.73	0.93	0.62	0.39	0.22	2.12	1.9
MCMHF	3.65	3.81	3.78	3.87	4.01	3.84	3.8	3.86	3.83	0.1	0.01	3.65	4.01	0.36
FTRT/D	1.24	1.32	1.24	1.03	1.32	1.28	1.26	1.3	1.25	0.09	0.01	1.03	1.32	0.29

FLOOR LANDINGS

	Subjects												
	1	2	3	4	5	6	7	8	Mean	SD	Variance	Minimum	Maximum	Range
CMHT/D	0.83	0.68	0.74	0.81	0.73	0.63	0.63	0.71	0.72	0.07	0.01	0.63	0.83	0.2
CMHM	0.75	0.6	0.66	0.68	0.67	0.58	0.57	0.59	0.64	0.06	0	0.57	0.75	0.18
LPDISPL	0.08	0.08	0.08	0.13	0.07	0.05	0.06	0.12	0.08375	0.027742	0	0.05	0.13	0.08
CMDT/DM	0.1	0.1	0.08	0.14	0.08	0.1	0.1	0.08	0.0975	0.019821	0	0.08	0.14	0.06
CMVVT/D	-4.19	-4.71	-5.49	-4.34	-5.28	-4.68	-5	-5.43	-4.89	0.49	0.24	-5.49	-4.19	1.3
CMHVT/D	1.94	2.59	1.8	1.95	1.98	2.07	1.74	2.38	2.06	0.29	0.08	1.74	2.59	0.85
ACMGHT/D	63	63	65	56	71	54	75	58	63.13	7.24	52.41	54	75	21
AATT/D	68	44	51	75	65	52	44	50	56.13	11.66	135.84	44	75	31
AATM	97	49	61	92	57	92	66	72	73.25	18.22	331.93	49	97	48
AHT/D	115	80	108	127	139	117	91	123	112.5	19.23	369.71	80	139	59
AHM	86	34	80	80	90	81	57	101	76.13	21.05	443.27	34	101	67
AKT/D	154	154	153	162	146	143	152	163	153.38	6.89	47.41	143	163	20
AKM	107	106	87	79	104	71	109	90	94.13	14.43	208.13	71	109	38
AAT/D	99	89	81	97	89	78	86	96	89.38	7.61	57.98	78	99	21
AAM	90	87	91	95	80	77	96	73	86.12	8.53	72.7	73	96	23
ATHT/D	20	-9	20	23	40	28	6	15	17.88	14.63	214.13	-9	40	49
ATHM	30	-16	16	41	43	31	11	23	22.38	19.08	363.98	-16	43	59
ATHHT/D	95	89	88	104	99	89	85	108	94.63	8.33	69.41	85	108	23
ATHHM	56	50	64	39	47	50	46	78	53.75	12.24	149.93	39	78	39
AVHT/D	-295	-219	-379	-344	-645	-914	-326	-65	-398.38	264.38	69894.84	-914	-65	849
AVKT/D	-281	-522	-947	-200	-637	-1185	-492	-509	-596.63	327.7	107386	-1185	-200	985
AVAT/D	-303	-37	-431	-553	-379	-146	-95	-801	-343.13	255.92	65493.27	-801	-37	764
CMHT/O	1.16	1.09	1.19	1.11	1	1.07	1.15	1.15	1.12	0.06	0	1	1.19	0.19
CMHDRT/D	2.16	2.57	1.76	2.21	2.31	2.28	2.23	2.47	2.25	0.24	0.06	1.76	2.57	0.81
CMVVT/O	4.31	4.13	4.74	4.58	4.9	3.38	4.23	4.47	4.34	0.47	0.22	3.38	4.9	1.52
CMHVT/O	3.38	3.28	3	2.82	2.33	3.82	2.46	2.73	2.98	0.5	0.25	2.33	3.82	1.49
MCMHF	2.29	2.07	2.42	2.2	2.01	2.14	2.07	2.21	2.18	0.13	0.02	2.01	2.42	0.41
FTRT/D	0.96	0.96	1.08	0.96	0.96	1.02	0.98	1	0.99	0.04	0	0.96	1.08	0.12

RINGS LANDINGS

				Subjects										
	1	2	3	4	5	6	7	8	Mean	SD	Variance	Minimum	Maximum	Range
CMHT/D	0.7	0.77	0.84	0.67	0.81	0.76	0.77	0.76	0.76	0.05	0	0.67	0.84	0.17
CMHM	0.49	0.55	0.64	0.49	0.62	0.57	0.66	0.59	0.58	0.06	0	0.49	0.66	0.17
LPDISPL	0.21	0.22	0.2	0.18	0.19	0.19	0.11	0.17	0.18	0.03	0	0.11	0.22	0.11
CMDT/DM	0.14	0.16	0.1	0.12	0.14	0.14	0.1	0.12	0.13	0.02	0	0.1	0.16	0.06
CMVVT/D	-6.03	-5.9	-6	-5.92	-6.02	-5.92	-6.02	-6.18	-5.99875	0.090149	0.01	-6.18	-5.9	0.28
CMHVT/D	0.15	0.1	0.13	0.11	0.16	0.16	0.04	-0.11	0.0925	0.090987	0.1	-0.11	0.16	0.27
ACMGHT/D	83	84	84	85	88	88	96	88	87	4.17	17.43	83	96	13
AATT/D	73	66	102	68	74	42	62	93	73.13	18.18	330.41	42	102	60
AATM	111	71	106	86	130	85	93	124	100.88	20.44	417.84	71	130	59
AHT/D	103	109	118	102	121	122	105	118	112.25	8.38	70.21	102	122	20
AHM	59	56	84	64	67	86	75	66	69.63	11.04	121.98	56	86	30
AKT/D	142	156	165	158	150	152	153	147	153.75	6.61	43.64	142	165	23
AKM	77	87	113	73	86	81	103	86	88.25	13.38	179.07	73	113	40
AAT/D	90	88	96	86	86	85	89	91	88.88	3.56	12.7	85	96	11
AAM	73	77	84	76	80	73	76	81	77.5	3.89	15.14	73	84	11
ATHT/D	22	18	26	13	40	37	33	37	28.25	9.97	99.36	13	40	27
ATHM	29	24	39	27	38	44	45	31	34.63	7.95	63.13	24	45	21
ATHHT/D	81	91	92	89	81	85	72	81	84	6.65	44.29	72	92	20
ATHHM	30	32	45	37	29	42	30	35	35	5.95	35.43	29	45	16
AVHT/D	-399	-161	-21	-462	-330	-348	-177	-131	-253.63	152.55	23270.84	-462	-21	441
AVKT/D	-163	-640	-371	-815	-803	-658	-804	-692	-618.25	233.98	54746.21	-815	-163	652
AVAT/D	-624	-292	-381	-232	-371	-198	-255	-268	-327.63	135.55	18373.41	-624	-198	426
CMHR	2.41	2.16	2.33	2.54	2.54	2.59	2.34	2.64	2.44	0.16	0.03	2.16	2.64	0.48
CMHDRT/D	0.26	0.2	0.21	0.14	0.11	0.2	0.12	0.03	0.16	0.07	0.01	0.03	0.26	0.23
CMVVR	2.81	3.19	3.42	2.17	2.87	2.03	3.07	2.34	2.74	0.5	0.25	2.03	3.42	1.39
CMHVR	0.24	0.05	0.12	0.02	0.34	0.35	0.12	0.02	0.16	0.14	0.02	0.02	0.35	0.33
MCMHF	2.84	2.68	2.77	2.74	2.76	2.75	2.75	2.83	2.77	0.05	0	2.68	2.84	0.16
FTRT/D	0.96	0.96	0.92	0.86	0.9	0.84	0.92	0.88	0.91	0.04	0	0.84	0.96	0.12

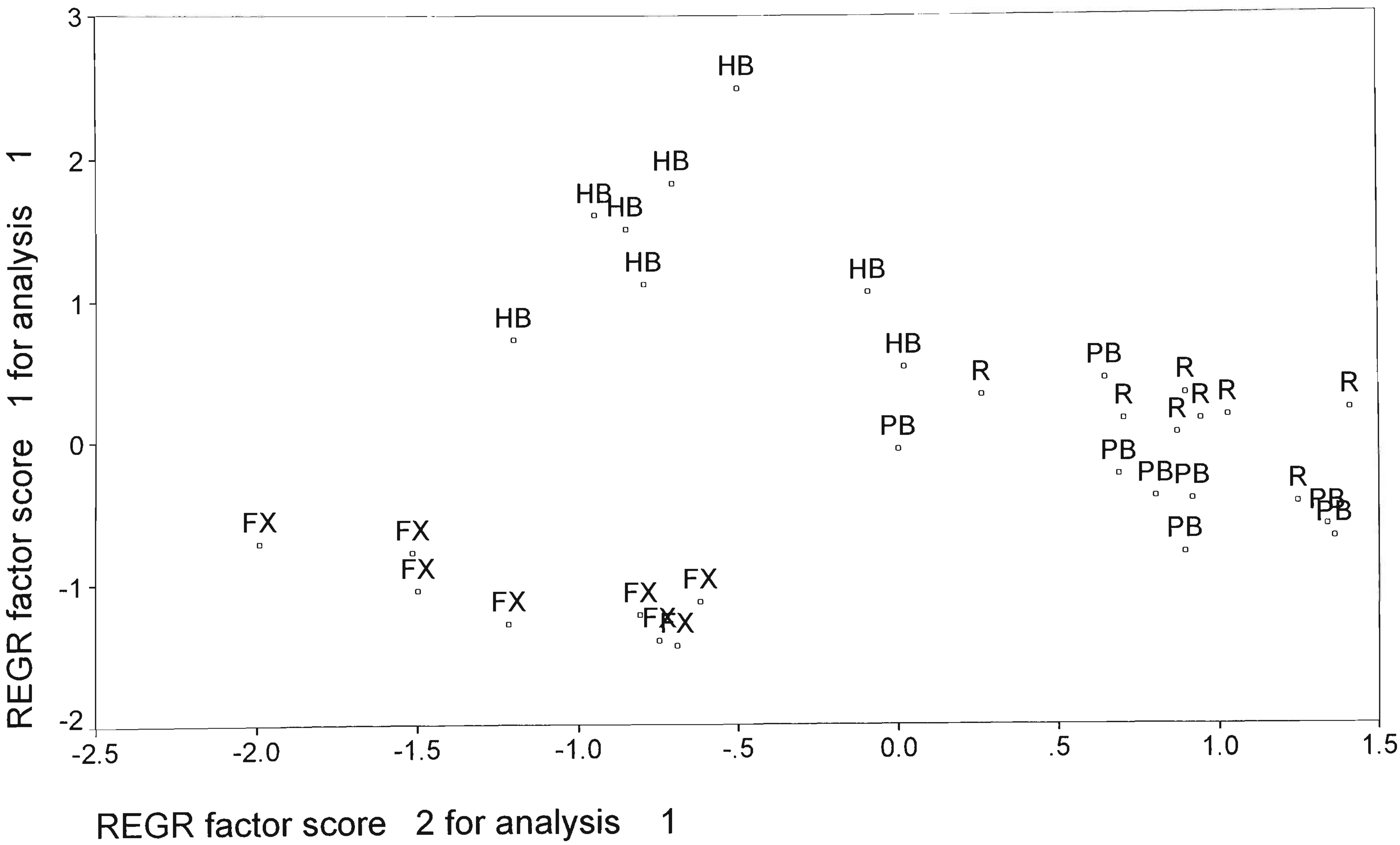
APPENDIX 2

Effect size data sheet

Variables	PB (1) Mean	HB (2) Mean	Floor (3) Mean	Rings (4) Mean	Population Std. Dev.	Effect Sizes 1 v 2	1 v 3	1 v 4	2 v 3	2 v 4	3 v 4
CMHT/D	0.74	0.84	0.72	0.76	0.08	-1.31	0.26	-0.26	1.57	1.05	-0.52
CMHM	0.57	0.59	0.64	0.58	0.08	-0.25	-0.87	-0.12	-0.62	0.12	0.74
LPDISPL	0.17	0.25	0.084	0.18	0.09	-0.89	0.96	-0.11	1.86	0.78	-1.07
CMDT/DM	0.11	0.14	0.098	0.13	0.04	-0.79	0.32	-0.53	1.11	0.26	-0.85
CMVVT/D	-5.42	-7.02	-4.89	-6	0.89	1.79	-0.59	0.65	-2.38	-1.14	1.24
CMHVT/D	-0.49	0.93	-2.06	-0.09	1.13	-1.26	1.39	-0.41	2.65	0.90	-1.74
ACMGHT/D	86.25	94	63.13	87	12.82	-0.60	1.80	-0.06	2.41	0.55	-1.86
AATT/D	45.13	83.5	56.13	73.13	30.66	-1.25	-0.36	-0.91	0.89	0.34	-0.55
AATM	66.5	75.88	73.25	100.88	23.79	-0.39	-0.28	-1.45	0.11	-1.05	-1.16
AHT/D	100.38	115.75	112.5	112.25	12.92	-1.19	-0.94	-0.92	0.25	0.27	0.02
AHM	69.5	66.75	76.13	69.63	14.72	0.19	-0.45	-0.01	-0.64	-0.20	0.44
AKT/D	158.38	153.25	153.38	153.75	9.13	0.56	0.55	0.51	-0.01	-0.05	-0.04
AKM	66.5	86.5	94.13	88.25	21.78	-0.92	-1.27	-1.00	-0.35	-0.08	0.27
AAT/D	95.12	85.95	89.38	88.88	8.54	1.07	0.67	0.73	-0.40	-0.34	0.06
AAM	89.75	80.5	86.12	77.5	9.48	0.98	0.38	1.29	-0.59	0.32	0.91
ATHT/D	24	43.38	17.88	28.25	14.39	-1.35	0.43	-0.30	1.77	1.05	-0.72
ATHM	28.75	34.63	22.38	34.63	15.77	-0.37	0.40	-0.37	0.78	0.00	-0.78
ATHHT/D	76.38	72.38	94.63	84	11.55	0.35	-1.58	-0.66	-1.93	-1.01	0.92
ATHHM	40.75	36.25	53.75	35	15.70	0.29	-0.83	0.37	-1.11	0.08	1.19
AVHT/D	-221	-602.38	-398.38	-253.63	219.91	1.73	0.81	0.15	-0.93	-1.59	-0.66
AVKT/D	-692	-842.38	-596.63	-618.25	253.16	0.59	-0.38	-0.29	-0.97	-0.89	0.09
AVAT/D	-249	-155.13	-343.13	-327.63	170.83	-0.55	0.55	0.46	1.10	1.01	-0.09
CMHR	2.27	2.69	1.12	2.44	0.63	-0.66	1.82	-0.27	2.48	0.40	-2.09
CMHDRT/D	0.46	1.13	2.25	0.16	0.87	-0.77	-2.05	0.34	-1.28	1.11	2.39
CMVVR	2.12	4.74	4.34	2.74	1.18	-2.21	-1.88	-0.52	0.34	1.69	1.35
CMHVR	1.02	0.93	2.98	0.16	1.13	0.08	-1.74	0.76	-1.82	0.68	2.50
MCMHF	2.53	3.83	2.18	2.77	0.63	-2.05	0.55	-0.38	2.60	1.67	-0.93
FTRT/D	0.86	1.25	0.99	0.91	0.16	-2.39	-0.80	-0.31	1.59	2.08	0.49
LANSCO	80.56	71.53	77.46	79.86	4.1	2.20	0.76	0.17	-1.45	-2.03	-0.59

APPENDIX 3

Regression factor analysis chart for the four events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APPENDIX 4

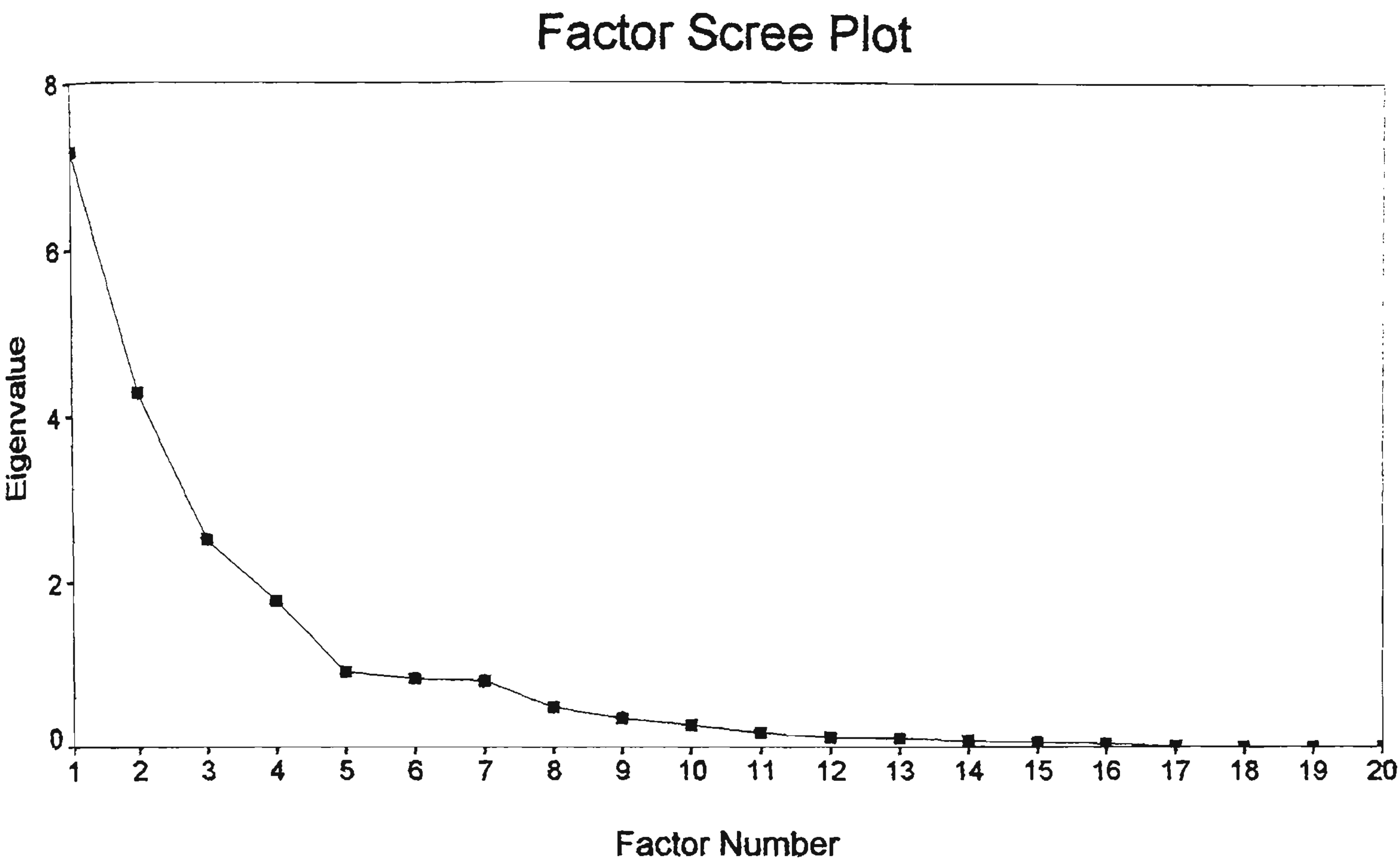
Factor analysis result sheet

VARIMAX rotation 1 for extraction 1 in analysis 1 - Kaiser Normalization.

VARIMAX converged in 8 iterations.

Rotated Factor Matrix:

	Factor 1	Factor 2	Factor 3	Factor 4
CMHDR_T_	.98172	.05436	-.01476	-.00442
CMHVA_P	.96601	-.04555	-.04304	-.03827
CMHVA_PR	.92057	-.21146	-.02758	-.08284
CMHR	-.78405	.38104	-.15734	.36247
ACMGHT_D	-.72180	.35592	-.02967	.53916
CMVVR	.65687	.63712	-.09315	.07404
CMHT_D	-.18773	.82750	.26301	.05433
MCMHF	-.27722	.76580	-.18190	.48122
AT_HT_D	-.30195	.75255	-.37932	.09369
FTR_T_D	.30636	.71937	-.31810	.41554
AHT_D	.06150	.70739	-.14853	-.53676
CMVVT_D	.34944	-.61549	.27495	-.43528
AATT_D	-.08625	.53149	.12762	-.05530
AKT_D	-.06104	-.00377	.82071	-.00001
AVKT_D	.08056	-.11078	.75916	-.34912
AAT_D	-.02533	.38938	.71560	.22596
AVHT_D	-.33413	-.44496	.59252	-.29817
CMDT_D_M	-.39215	.38830	-.54538	-.01123
AVAT_D	-.00105	-.00296	.02785	.80566
ATH_HT_D	.44494	-.14656	.30648	-.71689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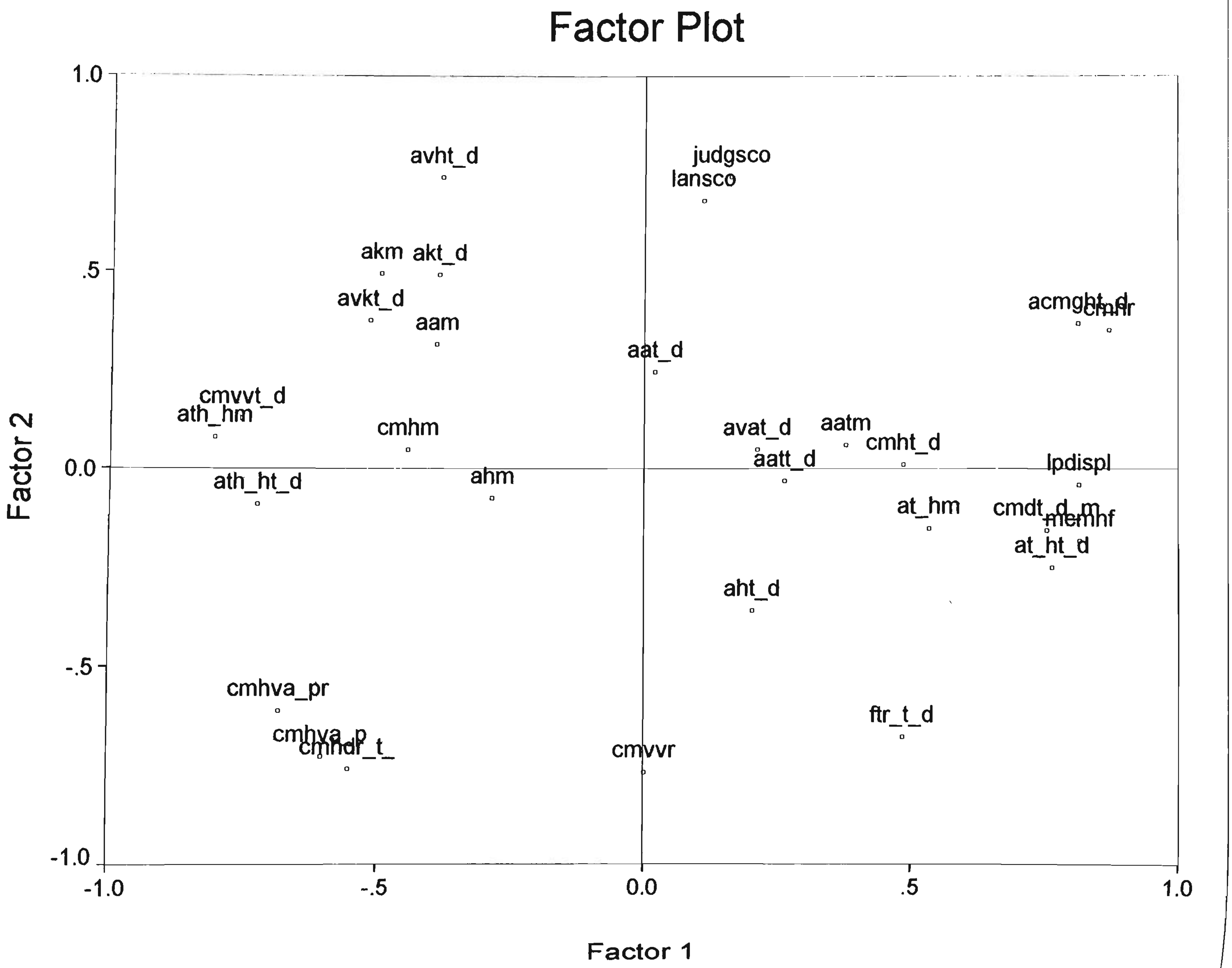
Factor Number



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ahm
at_hm
cmdt_d_m
memhf
at_ht_d
aht_d
cmhva_pr
ftr_t_d
cmvvr

APPENDIX 5

Cluster analysis result sheet

Data Information

32 unweighted cases accepted.
0 cases rejected because of missing value.

Squared Euclidean measure used.

- -

Squared Euclidean Dissimilarity Coefficient Matrix

	Case 1	Case 2	Case 3	Case 4	Case 5
Case 2	9.6928				
Case 3	17.4738	7.7492			
Case 4	40.1742	25.5423	30.6204		
Case 5	8.3234	6.4452	4.1937	32.1446	
Case 6	10.7464	12.4662	29.5092	29.7130	21.5145
Case 7	28.3492	18.8881	16.7234	20.8784	16.1529
Case 8	11.5607	10.1472	11.7917	29.8056	7.8076
Case 9	38.0434	35.6659	46.3341	42.7667	44.8578
Case 10	56.2479	57.5806	55.6160	48.9488	57.8343
Case 11	50.8517	62.4160	60.9849	60.4199	60.2366
Case 12	30.0006	39.2863	44.5357	50.4484	41.9375
Case 13	81.5073	72.3653	61.8500	42.5108	73.3355
Case 14	49.3433	44.6515	41.6274	37.7231	44.0462
Case 15	68.5606	60.6206	54.1350	51.0678	61.4841
Case 16	40.2243	34.5014	34.4035	36.1077	38.3226
Case 17	36.9495	31.8915	31.2664	56.3594	31.6951
Case 18	48.0376	33.7737	33.7728	73.6870	35.2389
Case 19	39.0580	25.5311	20.8148	42.5083	26.9626
Case 20	51.8726	42.5210	38.2430	62.7017	40.6164
Case 21	47.9719	47.1057	38.4384	53.1614	39.5331
Case 22	64.2362	58.5916	46.2676	66.1721	47.1380
Case 23	31.9156	27.3025	29.3166	64.0496	29.4605
Case 24	58.5930	40.5918	41.3818	65.5817	45.8321
Case 25	29.5880	17.5819	14.5267	36.6460	20.2741
Case 26	21.5329	11.7192	6.6135	22.3778	10.6784
Case 27	17.4237	18.4760	16.2520	40.6458	16.9076
Case 28	14.8287	10.8095	5.8006	29.4707	5.7988
Case 29	22.0785	18.9619	11.5346	19.8069	14.1537
Case 30	19.1843	17.0501	11.3839	16.6177	10.8750
Case 31	11.1089	10.2077	10.5912	23.5898	10.2847
Case 32	15.5978	16.6637	11.6340	28.1095	11.6312

	Case 6	Case 7	Case 8	Case 9	Case 10
Case 7	35.0495				

Squared Euclidean Dissimilarity Coefficient Matrix (Cont.)

	Case 6	Case 7	Case 8	Case 9	Case 10
Case 8	17.6103	28.1079			
Case 9	37.9880	43.8033	39.4372		
Case 10	60.9090	41.5340	52.0771	19.8383	
Case 11	56.3140	59.6338	58.9183	26.8531	14.4881
Case 12	36.7315	54.8901	38.0583	17.2595	28.3522
Case 13	81.0003	49.9591	72.5562	43.7947	16.3629
Case 14	60.7073	30.4609	47.9797	27.3235	19.7610
Case 15	72.7877	32.9673	67.3572	38.0478	11.2062
Case 16	50.7503	31.2854	42.0497	15.5075	23.2212
Case 17	45.8003	49.1352	31.6652	35.2130	60.6445
Case 18	61.0805	48.1133	36.0949	48.3226	83.0741
Case 19	55.0951	31.6381	37.1283	33.1380	55.3741
Case 20	62.6128	64.2040	39.7912	48.1387	70.7226
Case 21	69.6491	45.8443	48.9153	40.4096	55.6039
Case 22	94.2709	43.5078	60.2624	60.9520	71.7769
Case 23	50.8371	42.8890	32.8886	43.1738	77.5038
Case 24	69.5269	69.1911	51.7023	54.7950	91.1643
Case 25	38.2172	26.6370	25.2209	50.4359	50.2778
Case 26	27.2556	19.8404	11.9048	37.6749	43.0310
Case 27	23.9012	41.9394	15.2260	42.3631	52.4447
Case 28	30.4565	18.6995	10.4380	43.5522	50.0573
Case 29	30.5488	15.7850	22.6959	39.1150	35.5663
Case 30	27.5188	14.7298	16.3516	40.5678	43.6574
Case 31	18.5223	12.7059	18.5301	35.0894	41.0528
Case 32	26.4487	16.3519	20.8487	43.1374	40.7553

	Case 11	Case 12	Case 13	Case 14	Case 15
Case 12	13.3371				
Case 13	24.9340	42.4931			
Case 14	27.1185	27.8629	19.7848		
Case 15	31.2028	50.1488	14.4866	20.4631	
Case 16	28.6911	20.9167	27.1256	5.2274	27.2338
Case 17	63.5482	49.4111	89.9451	71.4818	77.1762
Case 18	107.5816	81.4617	120.5959	84.1302	92.6904
Case 19	65.1814	50.4955	68.0943	45.4978	57.4227
Case 20	68.5223	56.2432	92.8346	76.4096	88.6204
Case 21	59.8016	49.4555	73.7803	54.9836	67.9258
Case 22	95.2130	88.1903	92.6311	64.8192	74.4029
Case 23	96.6404	64.4168	111.3485	73.2108	87.3349
Case 24	91.7610	69.0890	108.8183	88.4828	104.8633
Case 25	58.9572	45.1645	55.2100	40.4177	45.8333
Case 26	44.3183	30.5611	44.4369	28.6542	48.8998
Case 27	38.6788	23.8587	63.4507	50.1459	67.6628

Squared Euclidean Dissimilarity Coefficient Matrix (Cont.)

	Case 11	Case 12	Case 13	Case 14	Case 15
Case 28	56.3992	37.0556	58.0335	31.6331	54.7356
Case 29	31.5241	27.0040	32.1578	22.5345	35.2573
Case 30	43.5858	31.8984	42.9250	26.3758	46.8732
Case 31	39.4418	26.2933	47.5036	26.1002	41.4934
Case 32	35.8001	27.3101	43.7056	30.5712	42.9839

	Case 16	Case 17	Case 18	Case 19	Case 20
Case 17	54.1801				
Case 18	63.5445	22.3327			
Case 19	29.3588	17.9179	23.0695		
Case 20	62.7964	6.8321	39.5664	25.2834	
Case 21	42.4168	17.5787	45.7444	15.4067	19.2978
Case 22	55.0634	38.6467	37.5970	18.3766	49.4007
Case 23	50.0724	25.4621	11.4419	18.1601	45.3297
Case 24	66.7605	19.4864	40.6914	20.7811	12.6308
Case 25	38.8075	41.8226	59.6340	38.5606	42.5670
Case 26	26.0274	36.8332	49.0159	30.5052	39.2901
Case 27	41.5293	28.2799	58.7672	38.1282	29.6833
Case 28	28.6889	45.4371	46.3354	30.7320	52.0550
Case 29	22.7317	41.1908	66.6585	30.6092	44.6273
Case 30	25.8127	41.5537	60.2874	34.2867	47.0038
Case 31	21.4727	44.0897	56.1233	31.0319	56.6156
Case 32	29.5123	44.3093	66.1053	37.9066	51.6611

	Case 21	Case 22	Case 23	Case 24	Case 25
Case 22	22.1651				
Case 23	32.8913	33.8708			
Case 24	24.9922	54.5122	39.6982		
Case 25	44.5709	69.2171	48.9699	49.5795	
Case 26	42.3518	62.0468	45.2903	47.3219	13.5820
Case 27	41.8916	79.6972	49.0804	40.4749	22.4007
Case 28	44.0929	49.6040	36.2530	55.9677	17.5113
Case 29	34.2502	55.7982	54.1320	54.8975	15.6409
Case 30	36.0572	53.1719	48.3088	58.1687	17.8707
Case 31	43.8037	61.6383	39.7599	60.9218	19.2382
Case 32	41.7029	65.0995	51.1687	59.7699	15.2584

	Case 26	Case 27	Case 28	Case 29	Case 30
Case 27	11.6619				
Case 28	7.3201	21.5742			
Case 29	7.0508	15.1684	12.2043		

* * * * * * * * * * * * * * P R O X I M I T I E S * * * * * * * * * * * * * *

Squared Euclidean Dissimilarity Coefficient Matrix (Cont.)

	Case 26	Case 27	Case 28	Case 29	Case 30
Case 30	6.7065	18.7137	9.0135	3.7697	
Case 31	9.6175	16.6625	10.3572	6.2959	8.4448
Case 32	8.0973	13.2575	11.4865	3.5279	5.7327

	Case 31
Case 32	4.8272

* * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * * * *

Agglomeration Schedule using Average Linkage (Between Groups)

	Clusters Combined			Stage Cluster 1st Appears		Next
Stage	Cluster 1	Cluster 2	Coefficient	Cluster 1	Cluster 2	Stage
1	29	32	3.527854	0	0	3
2	3	5	4.193744	0	0	5
3	29	30	4.751194	1	0	6
4	14	16	5.227433	0	0	23
5	3	28	5.799718	2	0	9
6	29	31	6.522596	3	0	8
7	17	20	6.832055	0	0	18
8	26	29	7.868028	0	6	14
9	2	3	8.334638	0	5	10
10	2	8	10.046128	9	0	14
11	1	6	10.746414	0	0	24
12	10	15	11.206157	0	0	17
13	18	23	11.441924	0	0	29
14	2	26	12.987831	10	8	19
15	11	12	13.337127	0	0	25
16	19	21	15.406748	0	0	21
17	10	13	15.424747	12	0	27
18	17	24	16.058594	7	0	28
19	2	27	16.389980	14	0	20
20	2	25	18.100517	19	0	22
21	19	22	20.270851	16	0	28
22	2	7	20.546774	20	0	24
23	9	14	21.415518	0	4	25
24	1	2	21.760057	11	22	26
25	9	11	24.783625	23	15	27
26	1	4	28.409519	24	0	30
27	9	10	28.725956	25	17	30
28	17	19	29.823421	18	21	29
29	17	18	33.701141	28	13	31
30	1	9	45.174713	26	27	31
31	1	17	54.757629	30	29	0

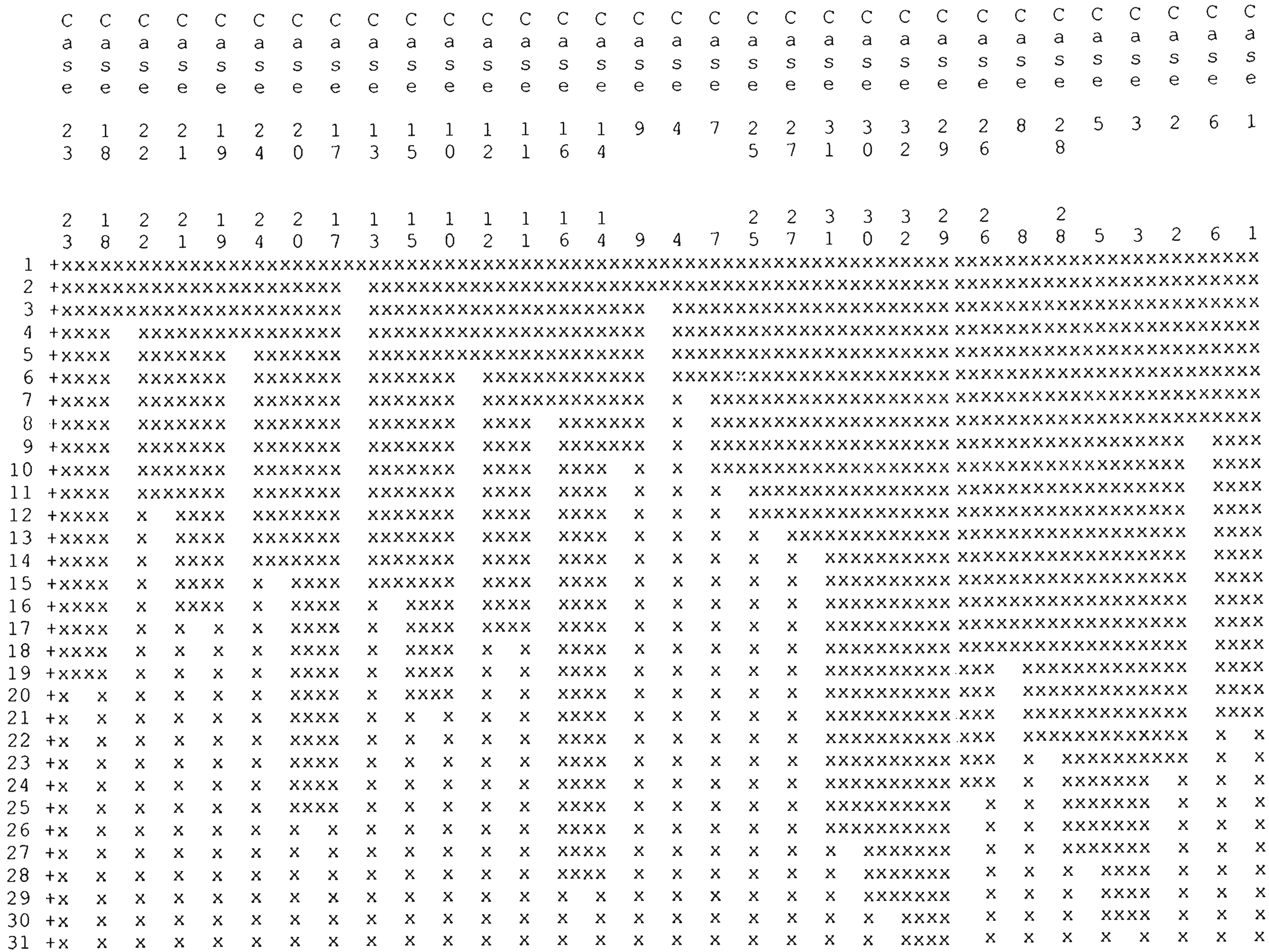
* * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * * * *

Cluster Membership of Cases using Average Linkage (Between Groups)

		Number of Clusters				
Label	Case	6	5	4	3	2
Case 1	1	1	1	1	1	1
Case 2	2	1	1	1	1	1
Case 3	3	1	1	1	1	1
Case 4	4	1	1	1	1	1
Case 5	5	1	1	1	1	1
Case 6	6	1	1	1	1	1
Case 7	7	1	1	1	1	1
Case 8	8	1	1	1	1	1
Case 9	9	2	2	2	2	1
Case 10	10	3	2	2	2	1
Case 11	11	2	2	2	2	1
Case 12	12	2	2	2	2	1
Case 13	13	3	2	2	2	1
Case 14	14	2	2	2	2	1
Case 15	15	3	2	2	2	1
Case 16	16	2	2	2	2	1
Case 17	17	4	3	3	3	2
Case 18	18	5	4	4	3	2
Case 19	19	6	5	3	3	2
Case 20	20	4	3	3	3	2
Case 21	21	6	5	3	3	2
Case 22	22	6	5	3	3	2
Case 23	23	5	4	4	3	2
Case 24	24	4	3	3	3	2
Case 25	25	1	1	1	1	1
Case 26	26	1	1	1	1	1
Case 27	27	1	1	1	1	1
Case 28	28	1	1	1	1	1
Case 29	29	1	1	1	1	1
Case 30	30	1	1	1	1	1
Case 31	31	1	1	1	1	1
Case 32	32	1	1	1	1	1

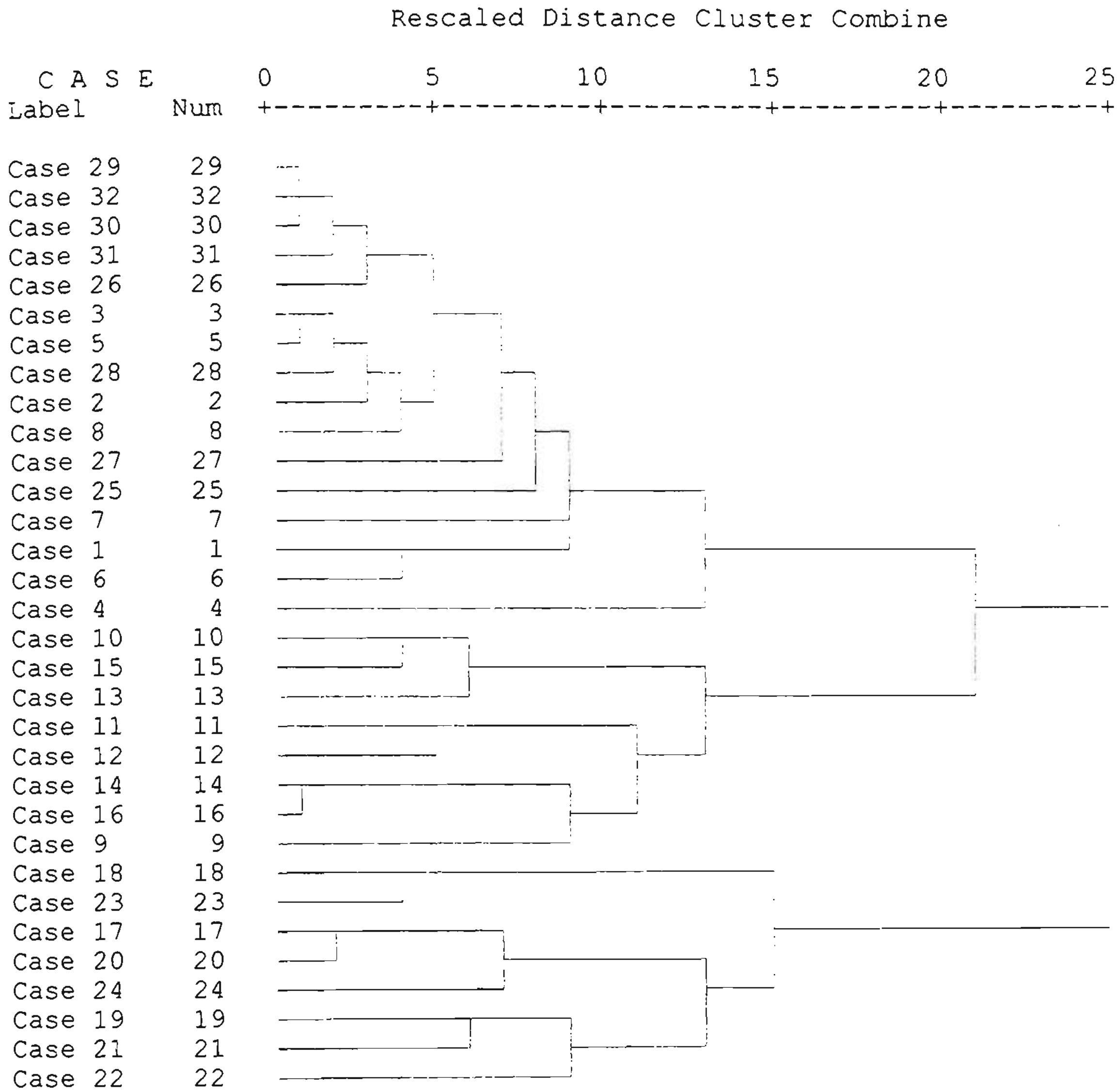
Vertical Icicle Plot using Average Linkage (Between Groups)

(Down) Number of Clusters (Across) Case Label and number



* * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * * * *

Dendrogram using Average Linkage (Between Groups)



* * * * * * * * * * * * * * P R O X I M I T I E S * * * * * * * * * * * * * *

Data Information

32 unweighted cases accepted.
0 cases rejected because of missing value.

Squared Euclidean measure used.

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Squared Euclidean Dissimilarity Coefficient Matrix

Variable	AAT_D	AATT_D	ACMGHT_D	AHT_D	AKT_D
AATT_D	53918.0000				
ACMGHT_D	8587.0000	41031.0000			
AHT_D	17275.0000	95393.0000	35336.0000		
AKT_D	126239.0000	293161.0000	173136.0000	70714.0000	
AT_HT_D	138254.0000	69290.0000	98987.0000	218485.0000	520377.0000
ATH_HT_D	10729.0000	43845.0000	16494.0000	32184.0000	173216.0000
AVAT_D	5066141.0000	4450757.0000	4804676.0000	5543230.0000	6631716.0000
AVHT_D	8287689.0000	7610817.0000	8040646.0000	8909478.0000	10211292.0000
AVKT_D	21386254.0000	20025730.0000	21018136.0000	22366674.0000	24595828.0000
CMHDR_T_	269071.2500	157029.2188	218615.8750	386831.7500	756325.8125
CMHT_D	270433.5938	157806.8750	219341.7031	388512.8750	758581.5625
CMHVA_P	269693.1250	157462.1875	219124.8594	387584.5625	757296.6875
CMHVA_PR	267567.9688	156403.7969	217479.7188	385083.1563	753722.5000
CMVVR	254756.1094	146612.8594	205576.8906	369362.7813	732168.0625
CMVVT_D	310318.0625	186259.5000	255643.9844	436041.5938	824448.0625
FTR_T_D	269064.0625	156827.0469	218095.9063	386849.7500	756283.6875
MCMHF	258463.2969	149213.7344	208369.1094	374140.9688	738507.2500
CMHR	262496.0938	152086.2031	211853.3750	379043.9063	745253.6875

Variable	AT_HT_D	ATH_HT_D	AVAT_D	AVHT_D	AVKT_D
ATH_HT_D	107425.0000				
AVAT_D	3718393.0000	4896994.0000			
AVHT_D	6656319.0000	7963990.0000	3495910.0000		
AVKT_D	18496880.0000	20830152.0000	9318697.0000	4913321.0000	
CMHDR_T_	30610.2012	213033.4063	3232986.7500	5881753.5000	17146652.0000
CMHT_D	30773.0820	214514.6406	3228518.5000	5872221.0000	17137222.0000
CMHVA_P	30821.5664	213564.7344	3231649.2500	5878247.5000	17142380.0000
CMHVA_PR	30341.1445	211589.2031	3238637.7500	5886977.5000	17158476.0000
CMVVR	26028.1523	200522.6719	3275534.2500	5944975.5000	17258688.0000
CMVVT_D	44324.6602	249572.6250	3119021.2500	5713579.5000	16843446.0000
FTR_T_D	30322.8281	213315.8125	3232278.0000	5879271.0000	17148694.0000
MCMHF	26935.6367	204228.9219	3262069.7500	5925178.5000	17231796.0000
CMHR	28161.6699	207795.6250	3250410.2500	5905455.5000	17200592.0000

Variable	CMHDR_T_	CMHT_D	CMHVA_P	CMHVA_PR	CMVVR
CMHT_D	26.2987				
CMHVA_P	1.6958	21.3615			
CMHVA_PR	10.7110	49.3343	12.4628		
CMVVR	221.6953	278.5462	241.6676	207.4285	
CMVVT_D	1512.5104	1403.8181	1464.0682	1629.4158	2844.0313
FTR_T_D	21.5013	2.4536	18.7083	41.8227	232.4500
MCMHF	150.4250	146.4983	159.8704	150.2298	50.8665
CMHR	101.6998	70.9955	103.8250	112.8310	124.9293

Variable	CMVVT_D	FTR_T_D	MCMHF
FTR_T_D	1509.6787		
MCMHF	2445.8989	114.6115	
CMHR	2072.3113	52.2639	21.4038

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* * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * * * *

Agglomeration Schedule using Ward Method

Stage	Clusters Combined Cluster 1	Cluster 2	Coefficient	Stage Cluster 1st Appears Cluster 1	Cluster 2	Next Stage
1	11	13	.847924	0	0	3
2	12	17	2.074724	0	0	5
3	11	14	9.516672	1	0	5
4	18	19	20.218571	0	0	6
5	11	12	51.971916	3	2	7
6	15	18	107.003220	0	4	7
7	11	15	343.573425	5	6	8
8	11	16	1958.924561	7	0	12
9	1	3	6252.424805	0	0	10
10	1	7	13895.591797	9	0	11
11	1	4	32110.175781	10	0	13
12	6	11	59746.179688	0	8	15
13	1	2	100553.32813	11	0	14
14	1	5	228137.93750	13	0	15
15	1	6	1294366.7500	14	12	18
16	8	9	3042321.7500	0	0	17
17	8	10	7203676.0000	16	0	18
18	1	8	27167176.000	15	17	0

* * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * * * *

Vertical Icicle Plot using Ward Method

(Down) Number of Clusters   (Across) Case Label and number

```
    A  A  A  C  C  M  C  F  C  C  C  C  A  A  A  A  A  A  A
    V  V  V  M  M  C  M  T  M  M  M  M  T  K  A  H  T  C  A
    K  H  A  V  H  M  V  R  H  H  H  H  _  T  T  T  H  M  T
    T  T  T  V  R  H  V  _  T  V  V  D  H  _  T  _  _  G  _
    _  _  _  T     F  R  T  _  A  A  R  T  D  _  D  H  H  D
    D  D  D  _              _  D  _  _  _  _     D     T  T
             D              D     P  P  T  D
                                  R     _              D  D

    1        1  1  1  1  1  1  1  1  1
    0  9  8  6  9  8  5  7  2  4  3  1  6  5  2  4  7  3  1
 1 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 2 +xxxxxxx  xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 3 +x  xxxx  xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 4 +x  x  x  xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 5 +x  x  x  xxxxxxxxxxxxxxxxxxxxxxxxxxxx  xxxxxxxxxxxxxxxx
 6 +x  x  x  xxxxxxxxxxxxxxxxxxxxxxxxxxxx  x  xxxxxxxxxxxxx
 7 +x  x  x  xxxxxxxxxxxxxxxxxxxxxxxxxxxx  x  x  xxxxxxxxxx
 8 +x  x  x  xxxxxxxxxxxxxxxxxxxxxxxxx  x  x  x  xxxxxxxxxx
 9 +x  x  x  xxxxxxxxxxxxxxxxxxxxxxxxx  x  x  x  x  xxxxxxx
10 +x  x  x  xxxxxxxxxxxxxxxxxxxxxxxxx  x  x  x  x  x  xxxx
11 +x  x  x  xxxxxxxxxxxxxxxxxxxxxxxxx  x  x  x  x  x  x  x
12 +x  x  x  x  xxxxxxxxxxxxxxxxxxxxxx  x  x  x  x  x  x  x
13 +x  x  x  x  xxxxxxx  xxxxxxxxxxxxx  x  x  x  x  x  x  x
14 +x  x  x  x  xxxx  x  xxxxxxxxxxxxx  x  x  x  x  x  x  x
15 +x  x  x  x  xxxx  x  xxxx  xxxxxxx  x  x  x  x  x  x  x
16 +x  x  x  x  x  x  x  xxxx  xxxxxxx  x  x  x  x  x  x  x
17 +x  x  x  x  x  x  x  xxxx  x  xxxx  x  x  x  x  x  x  x
18 +x  x  x  x  x  x  x  x  x  x  xxxx  x  x  x  x  x  x  x
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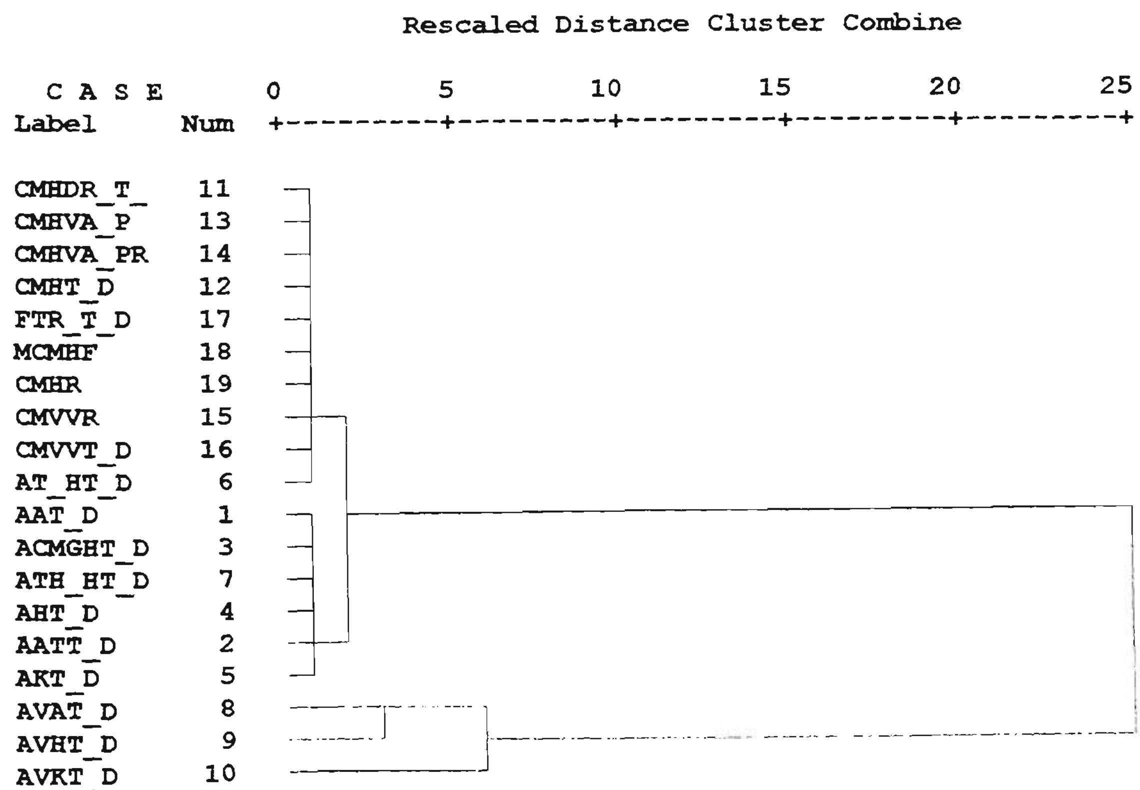
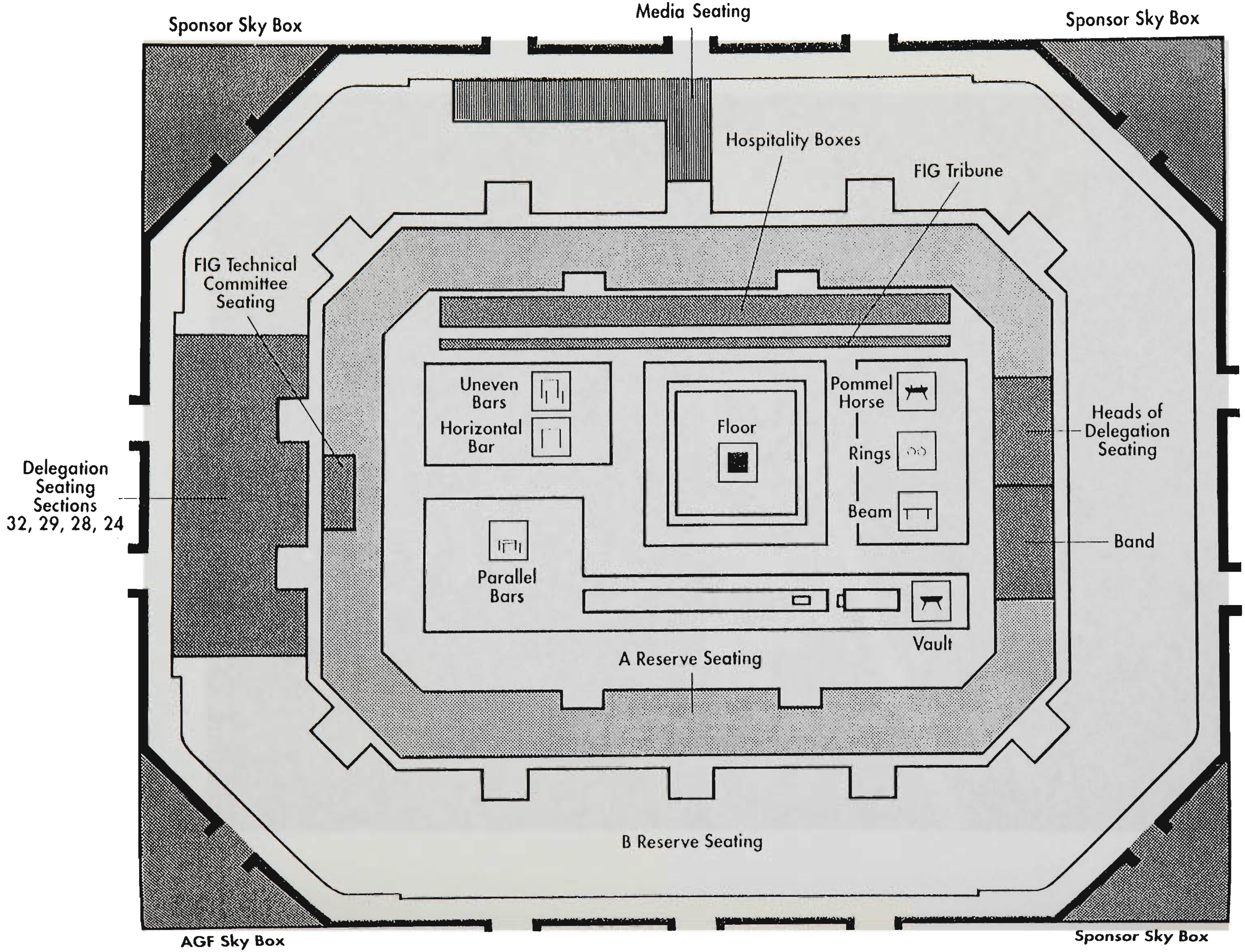
Dendrogram using Ward Method

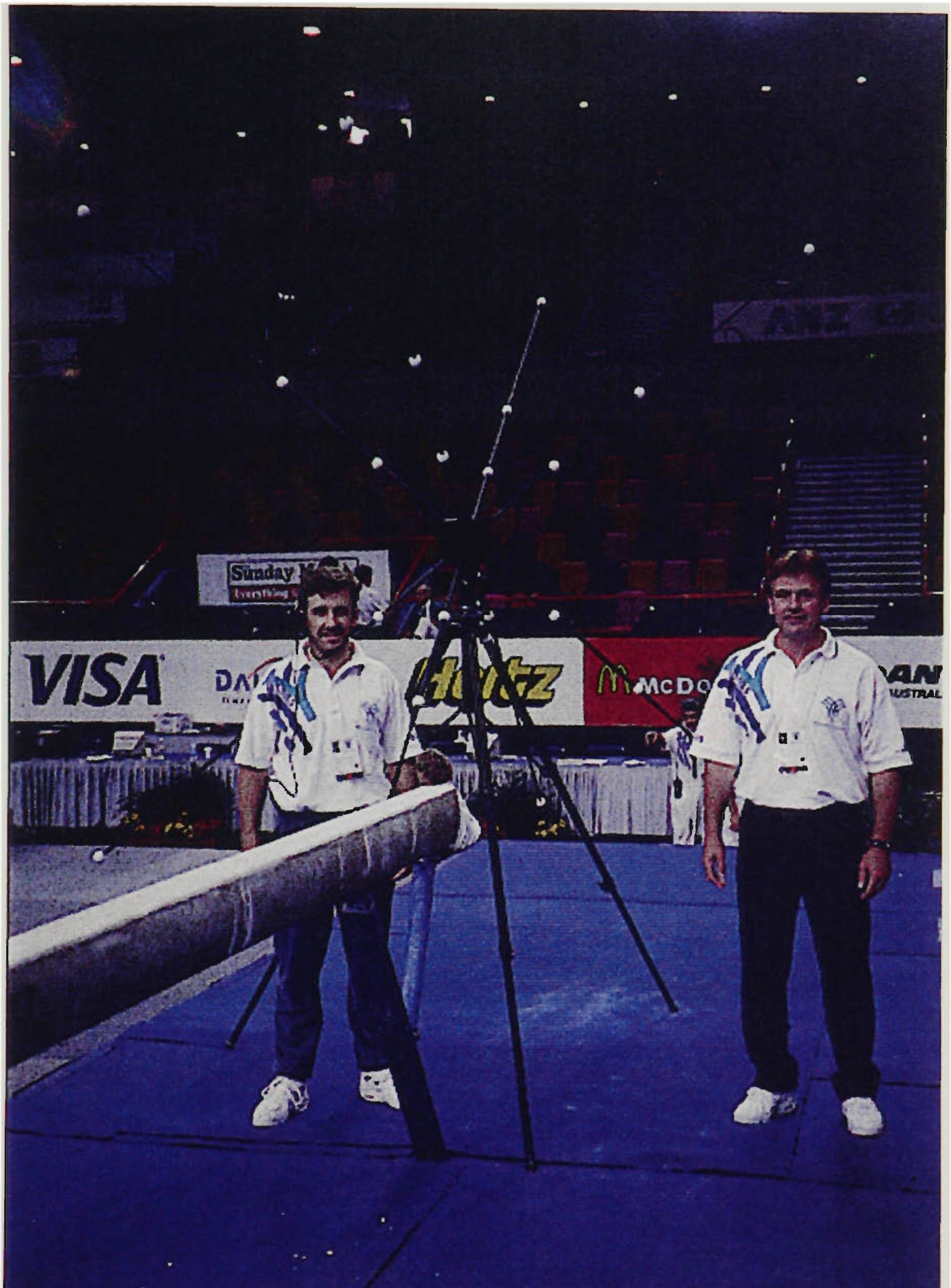


APPENDIX 6

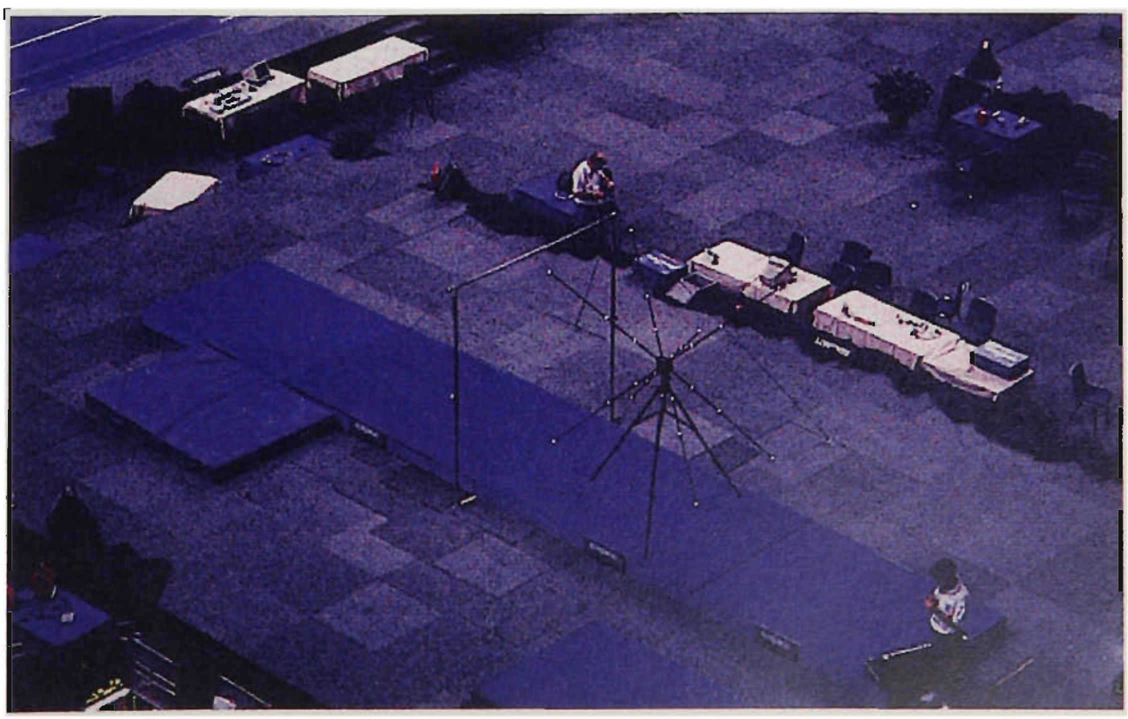
Competition floor plan and data collection set up

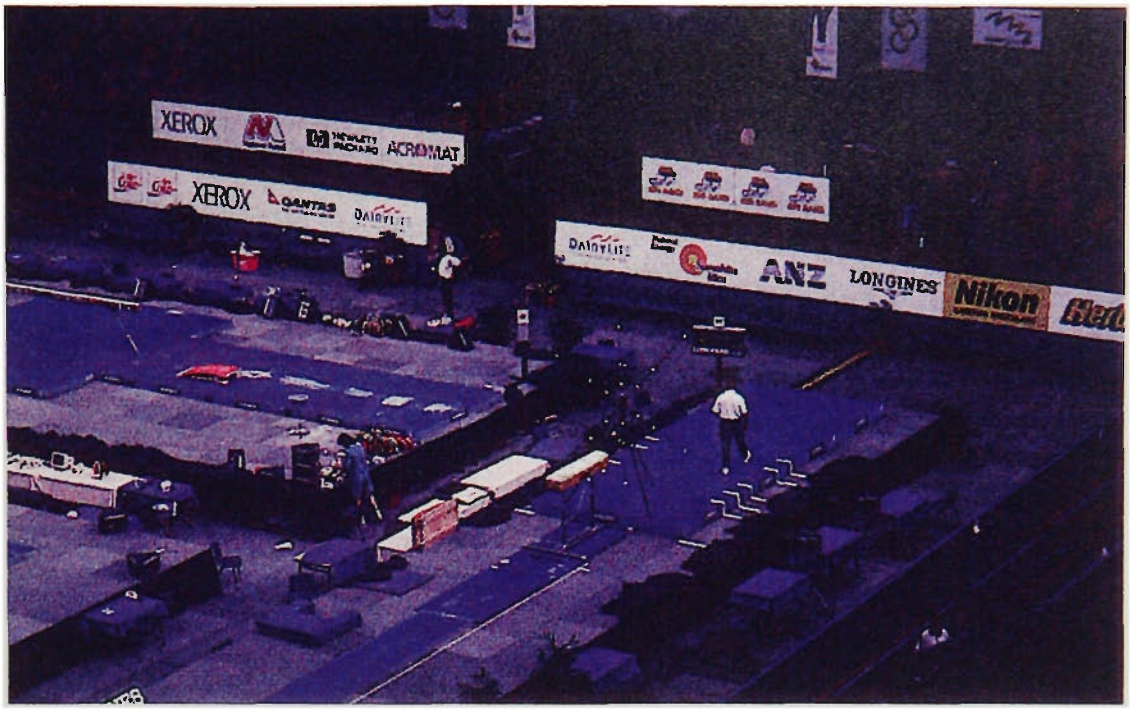
COMPETITION AREA & SEATING PLAN (Appendix 5)

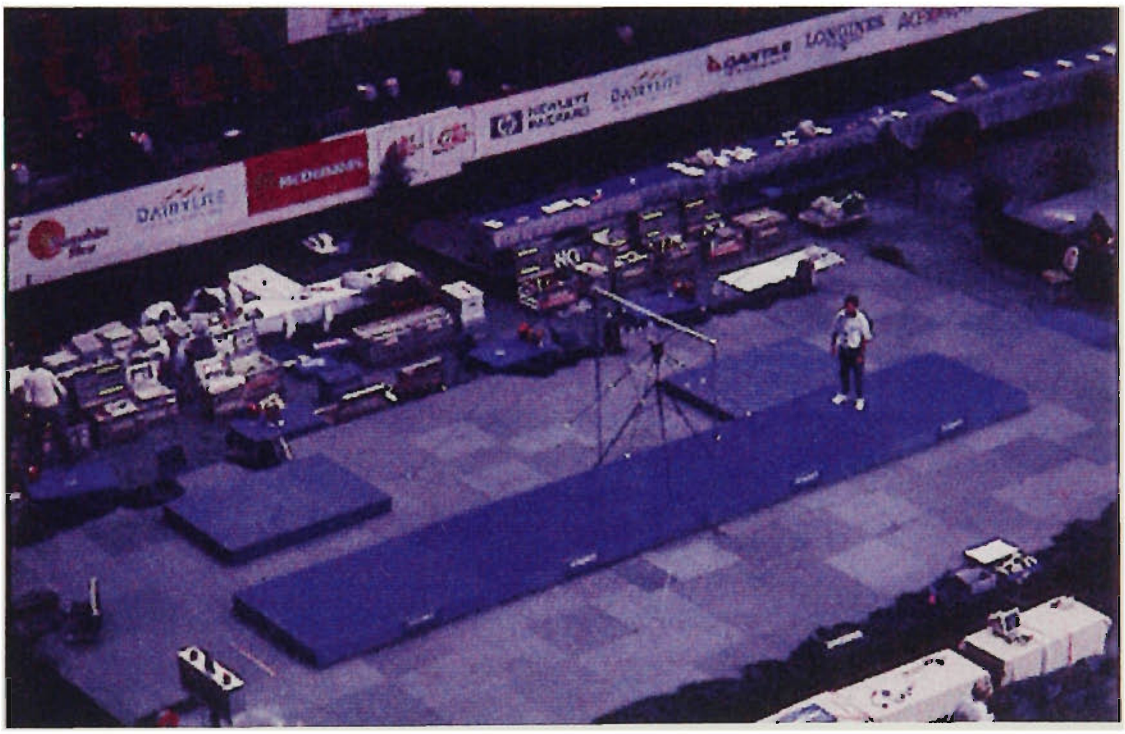



Sunday
VISA


ACROMAT
XEROX
DAIRYLITE
DAIRYLITE
ANZ
LONGINES
LONGINES




XEROX
ACROMAT
XEROX
DAIRYLITE
ANZ
LONGINES
Nikon


LONGINES
DAIRYLITE
HEWLETT PACKARD
DAIRYLITE

APPENDIX 7

Mean values for the duration of routines from all subjects

and

Apparatus Specifications of the Selected Events

Mean values for the duration of routines from all subjects groups

Event	Range (sec)	Mean (sec)
Floor:	*50-70	62
Rings:	39-53	48
Parallel Bars:	29-38	34
Horizontal Bar:	34-48	41

* The duration of the men's' floor exercise should be between 50-70 seconds according to the FIG code of points.

Apparatus Specifications of the Selected Events

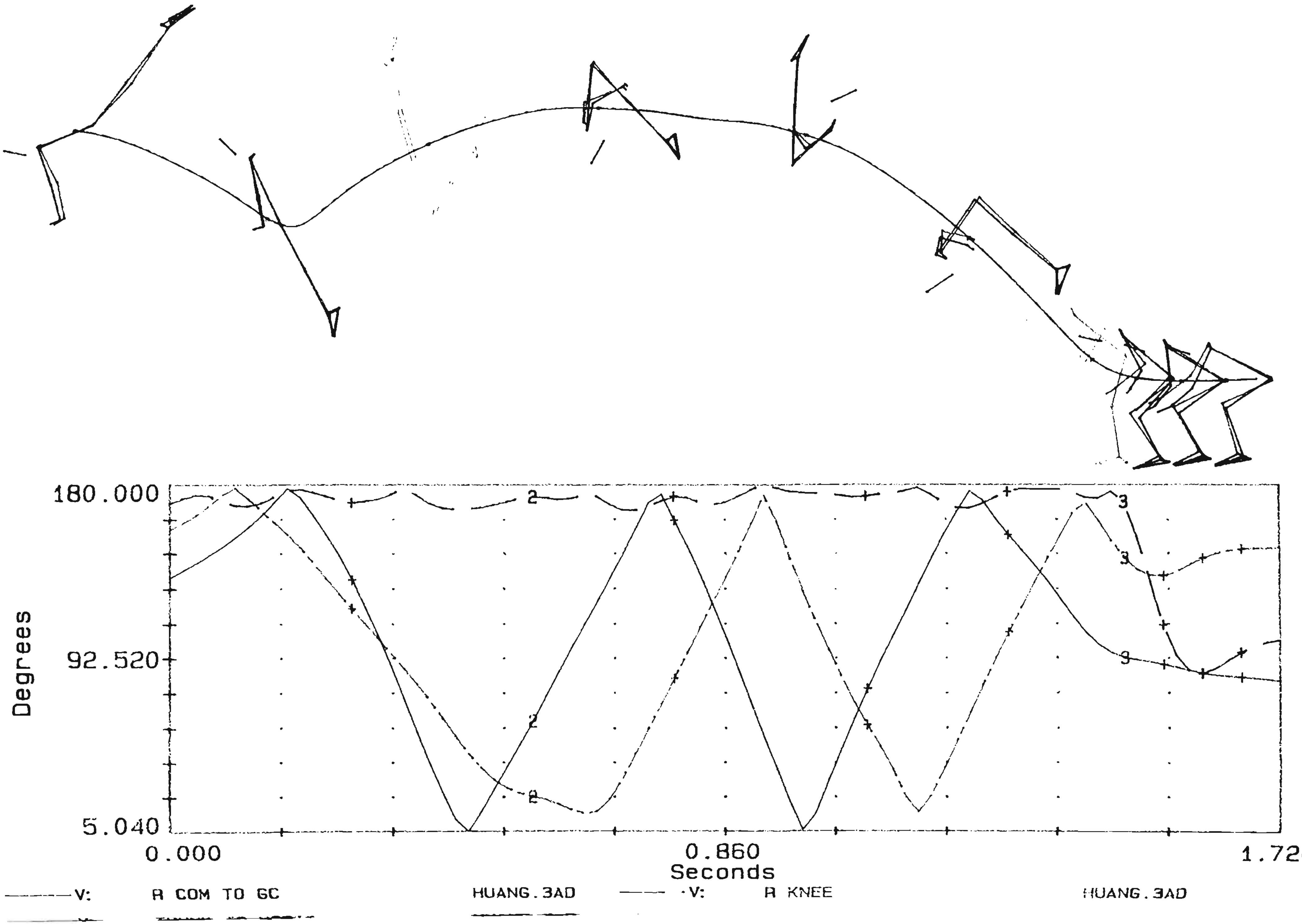
Apparatus	Height (m)	Height of landing mat (m)
Floor	12x12	sprung floor
Rings	* 2.55	0.20
Parallel Bars	* 1.75	0.20
Horizontal Bar	* 2.55	0.20

* measured from top of the mat

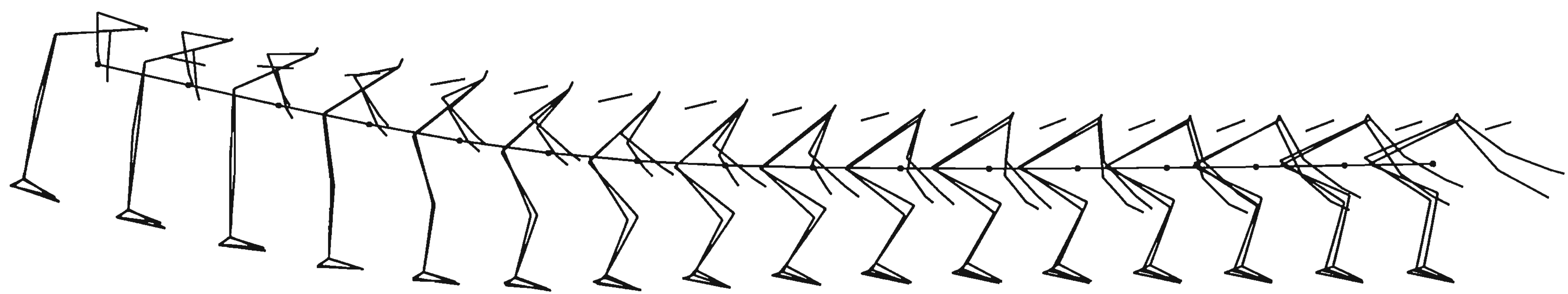
APPENDIX 8

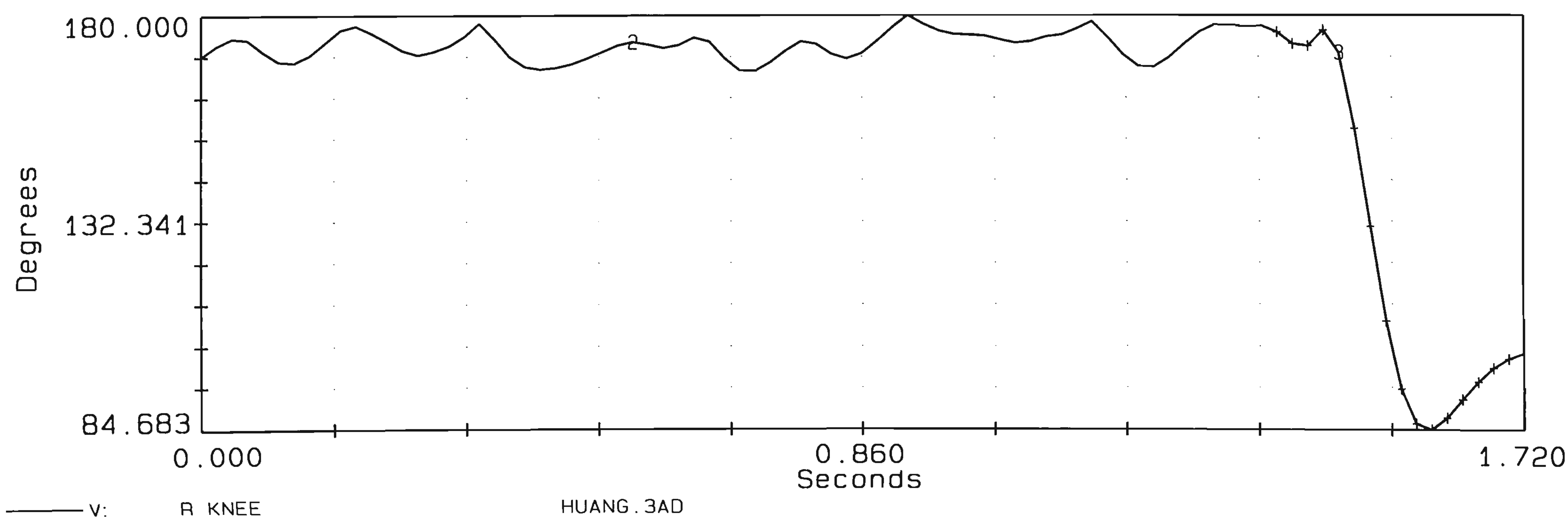
Landing performances print out from the peak motion analysis system

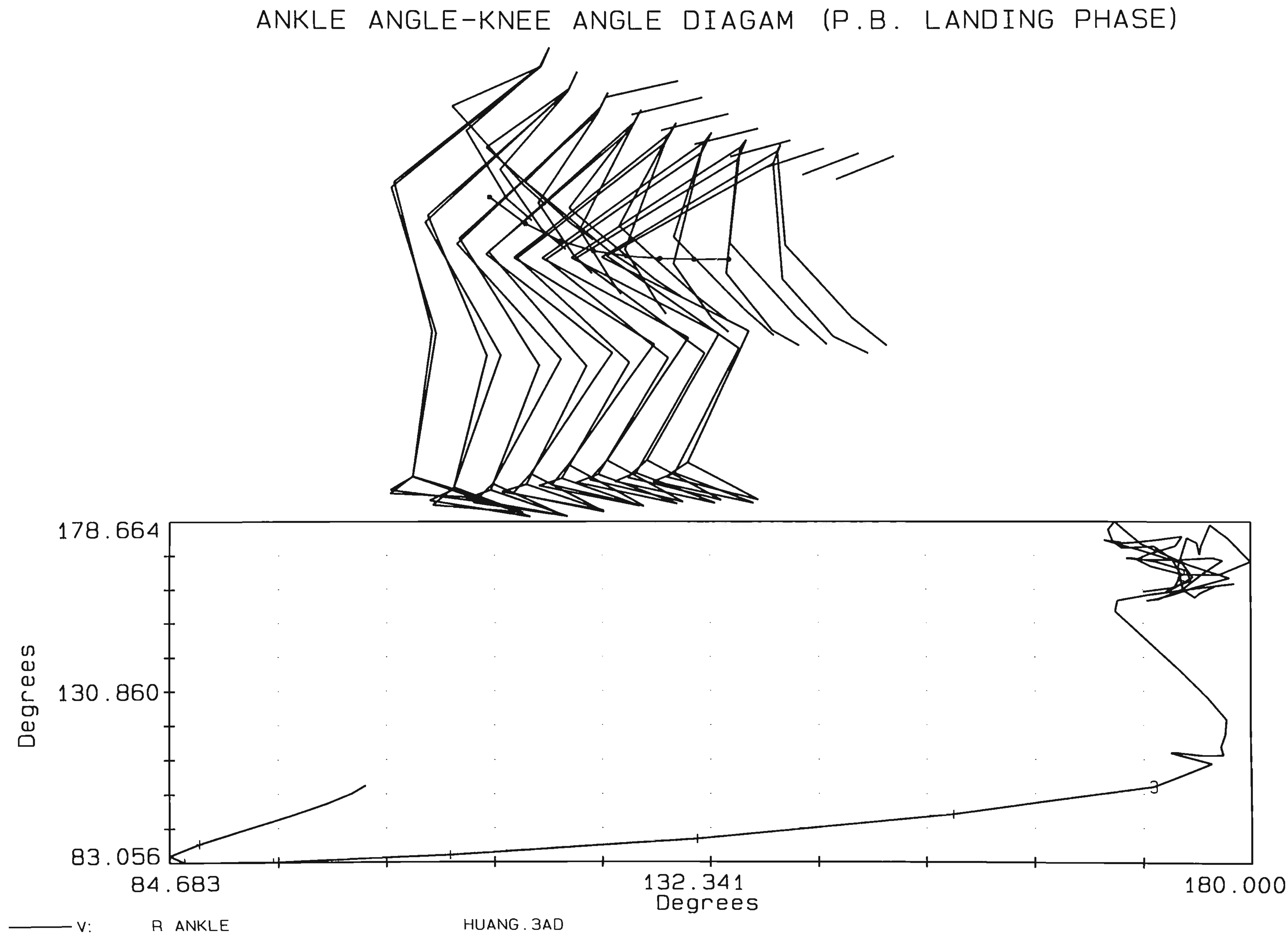
P. B. Ind. App. Finals: Gold Medailist



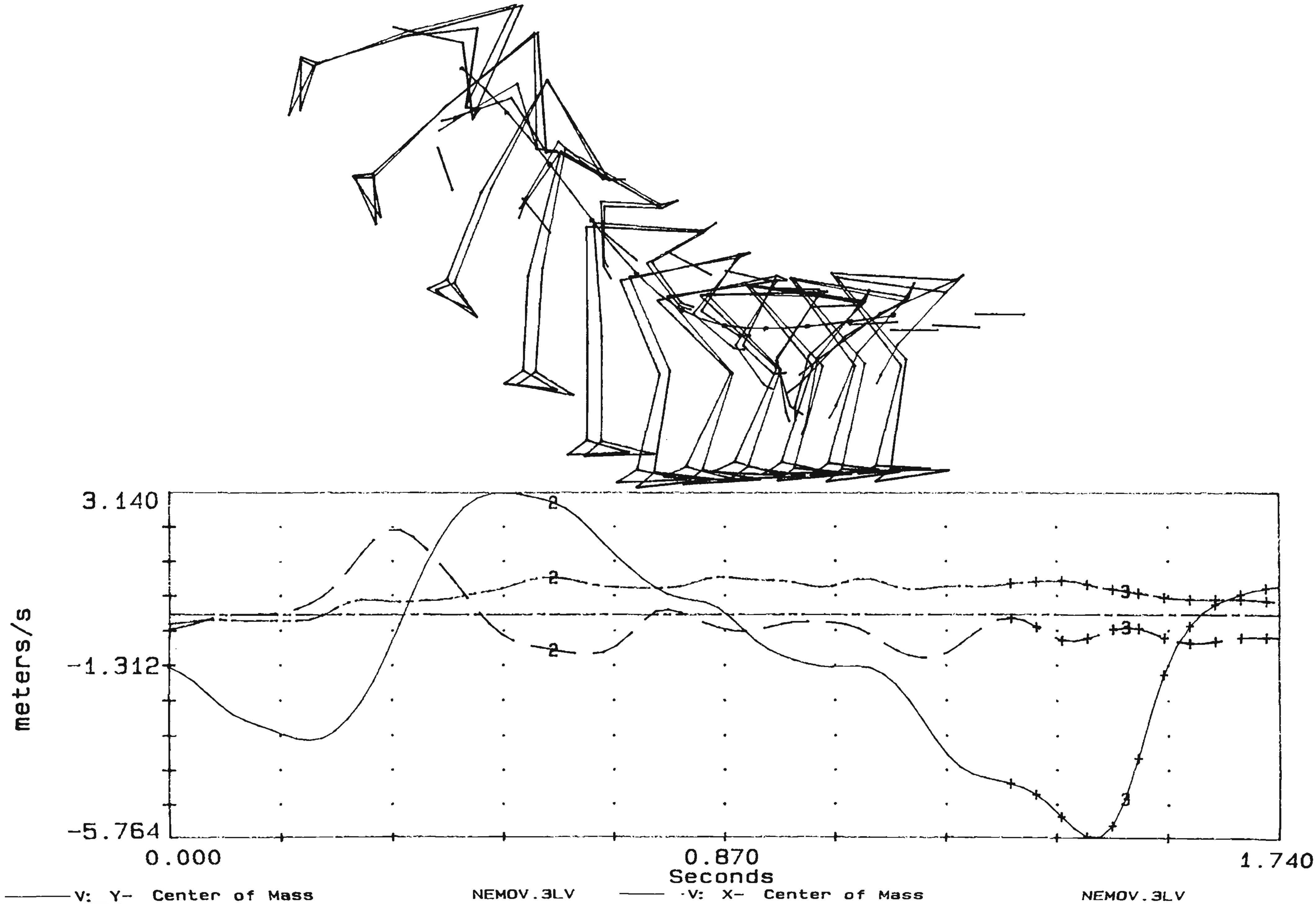
Parallel Bars Landings



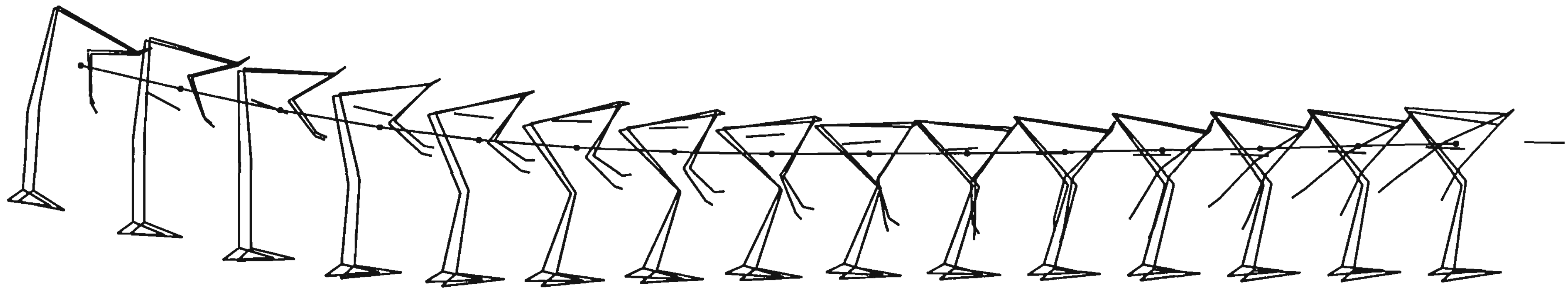


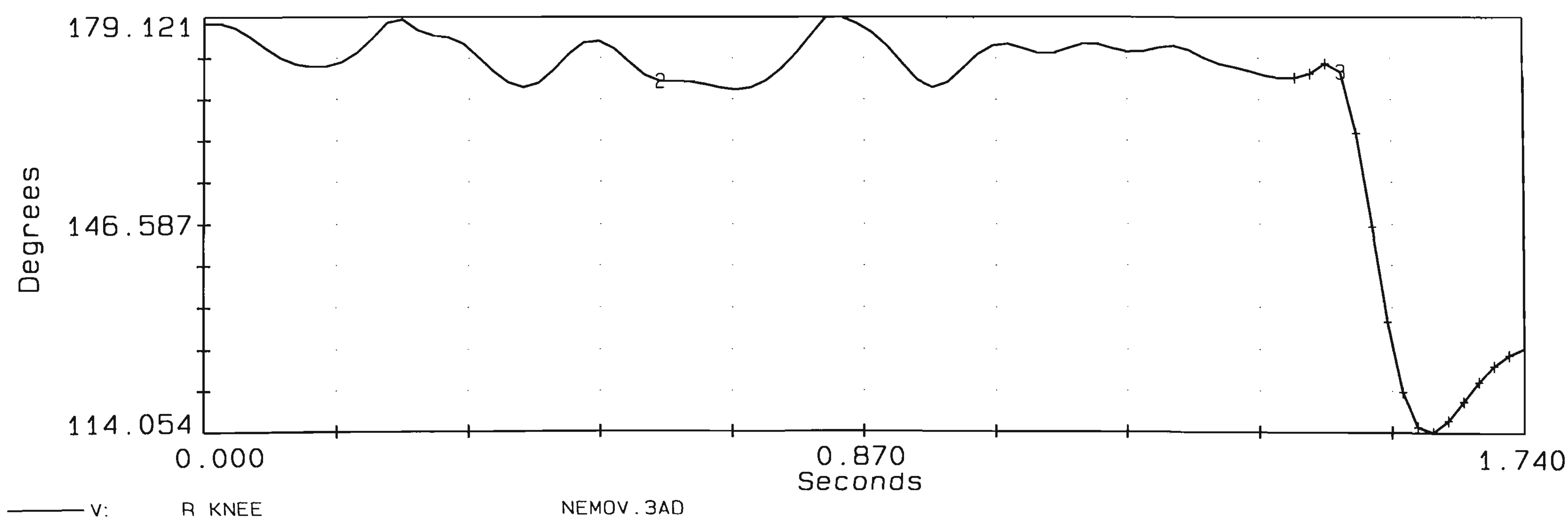

ANKLE ANGLE-KNEE ANGLE DIAGAM (P.B. LANDING PHASE)
178.664
130.860
83.056
Degrees
84.683
132.341
180.000
Degrees
3
V: R ANKLE
HUANG.3AD

Parallel Bars Landing

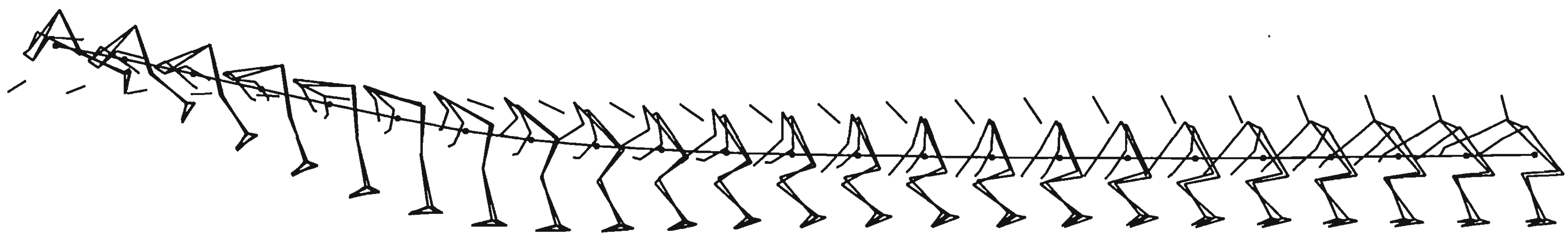


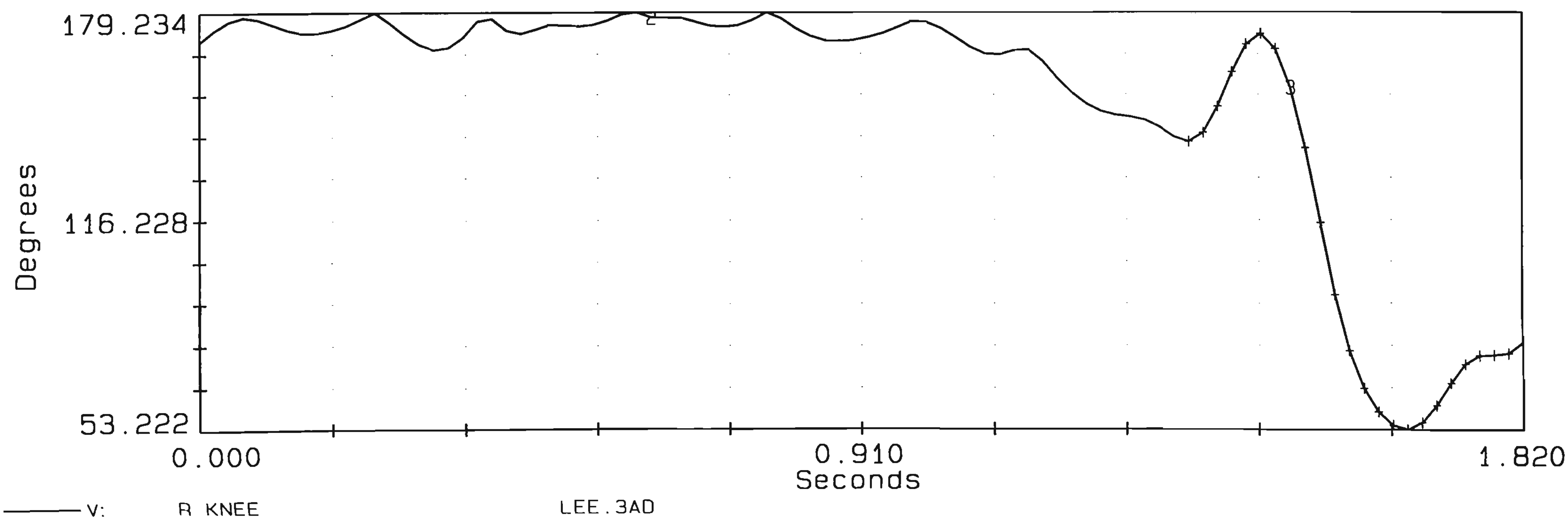
Parallel Bars Landing



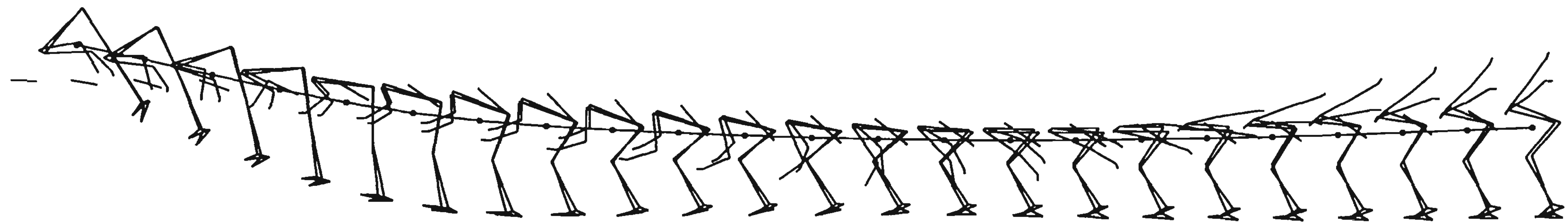


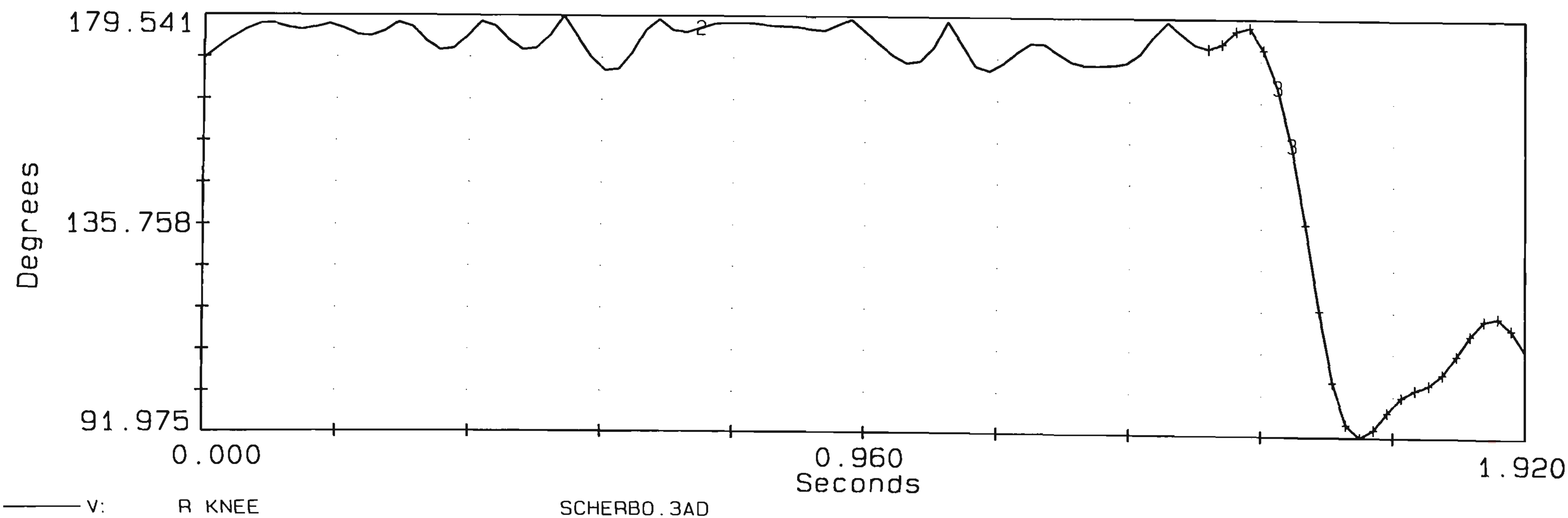
Parallel Bars Landing





Parallel Bars Landing





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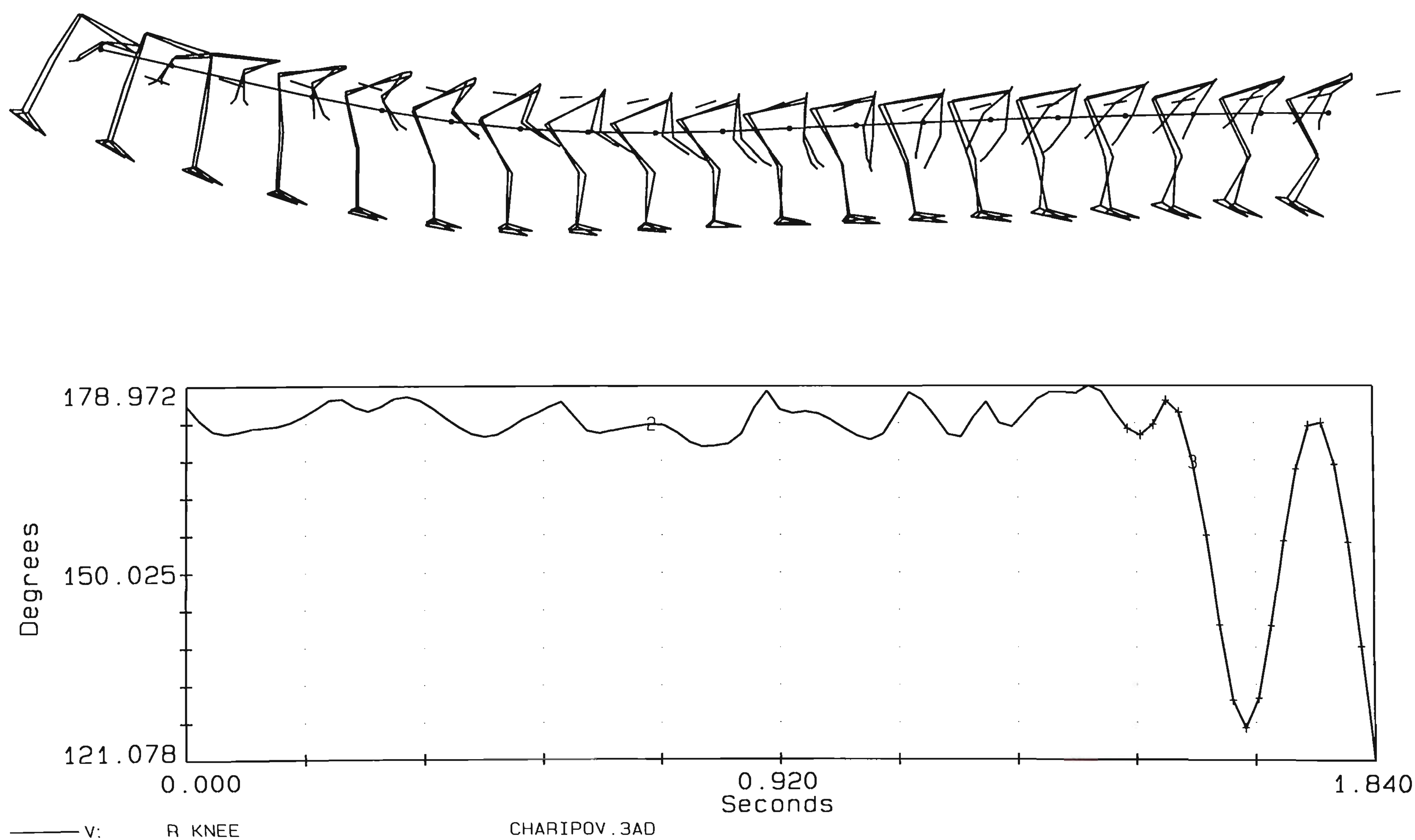
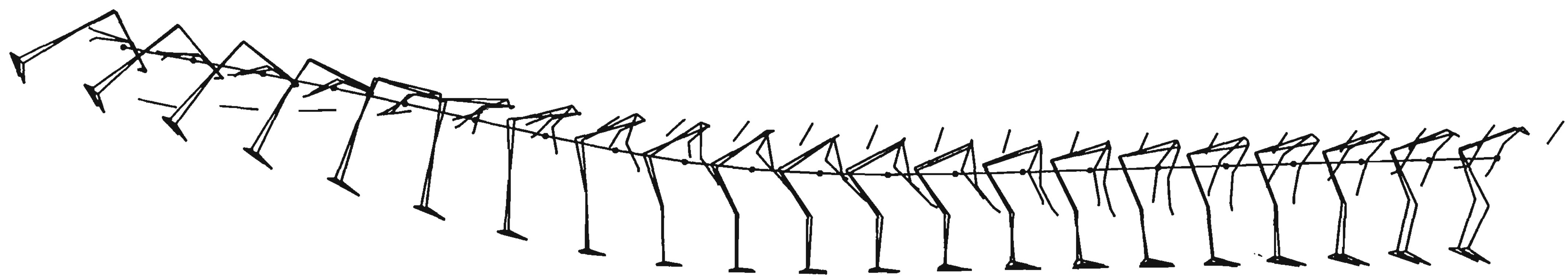
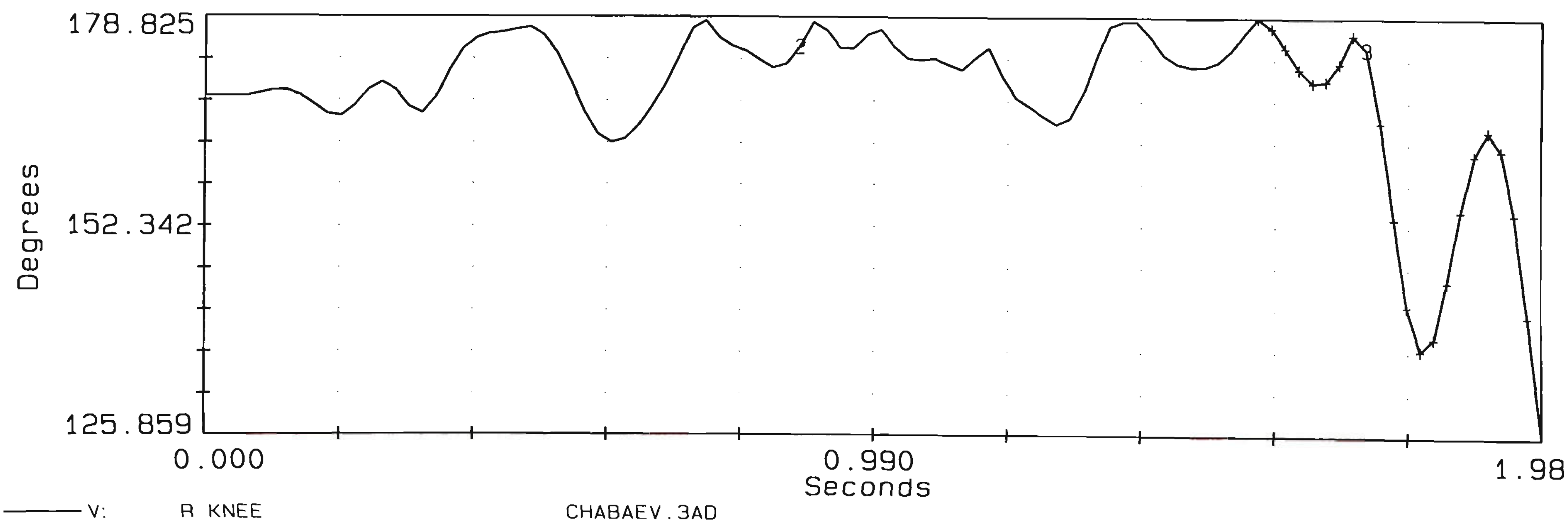
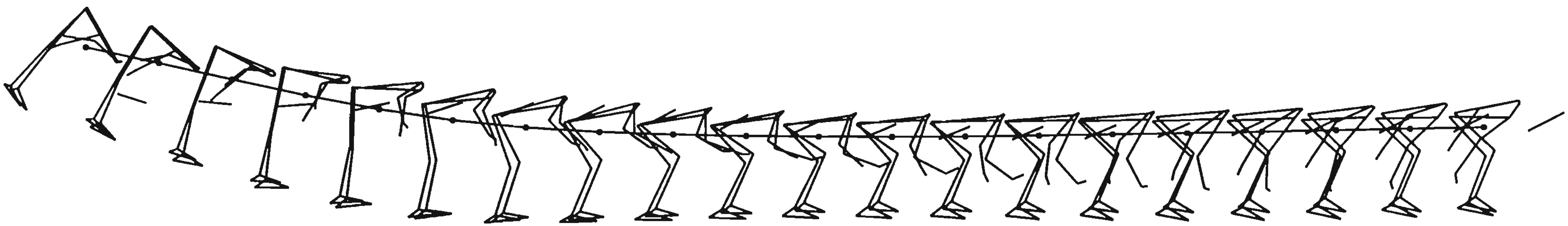


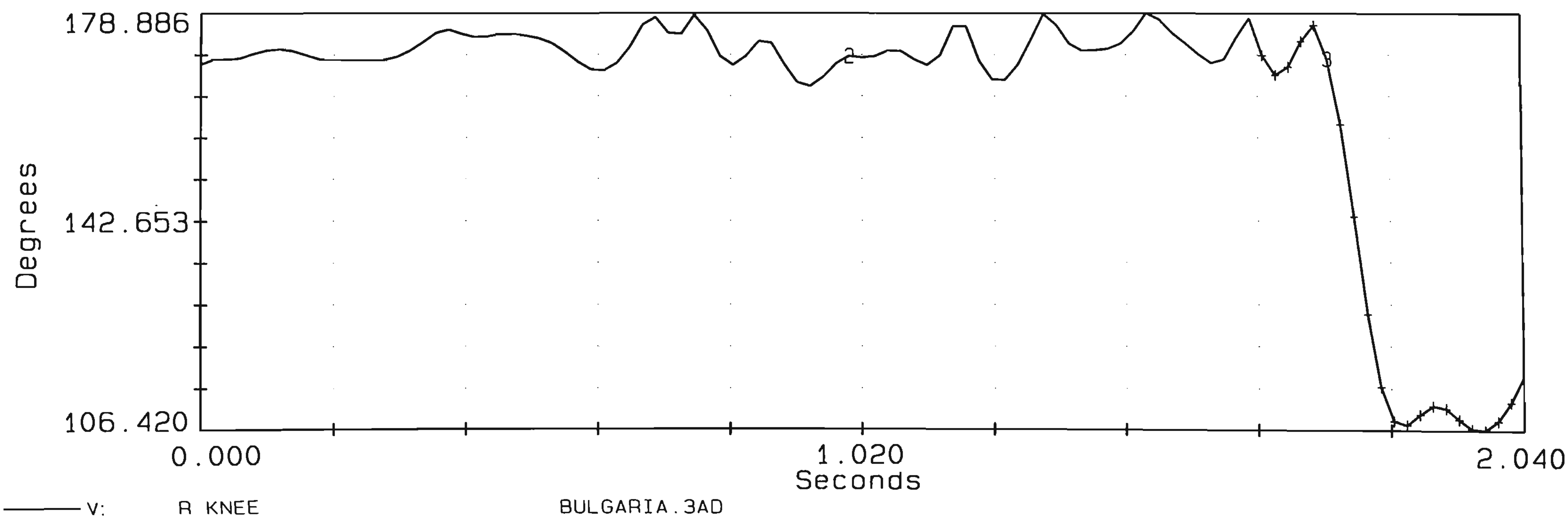
Parallel Bars Landing



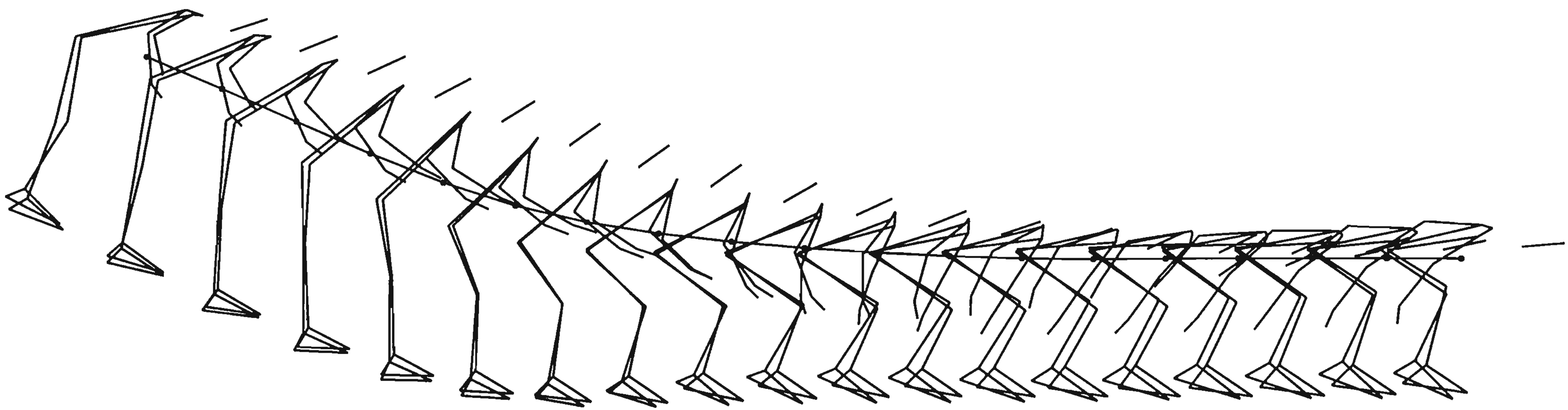


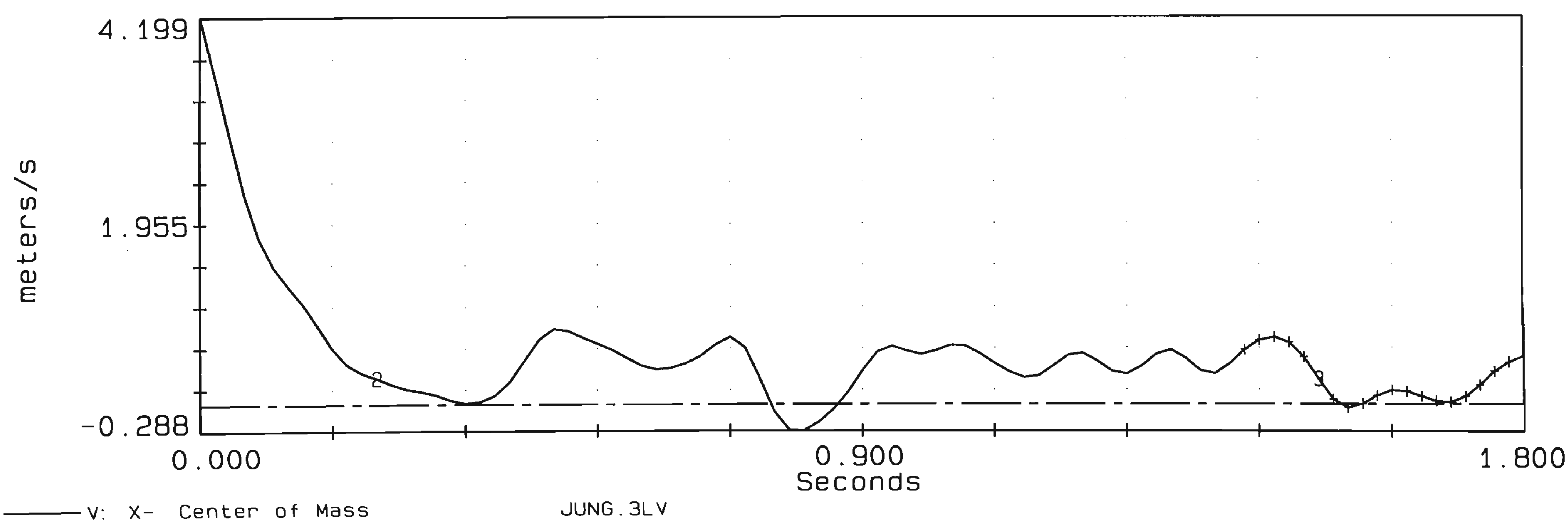
Parallel Bars Landing



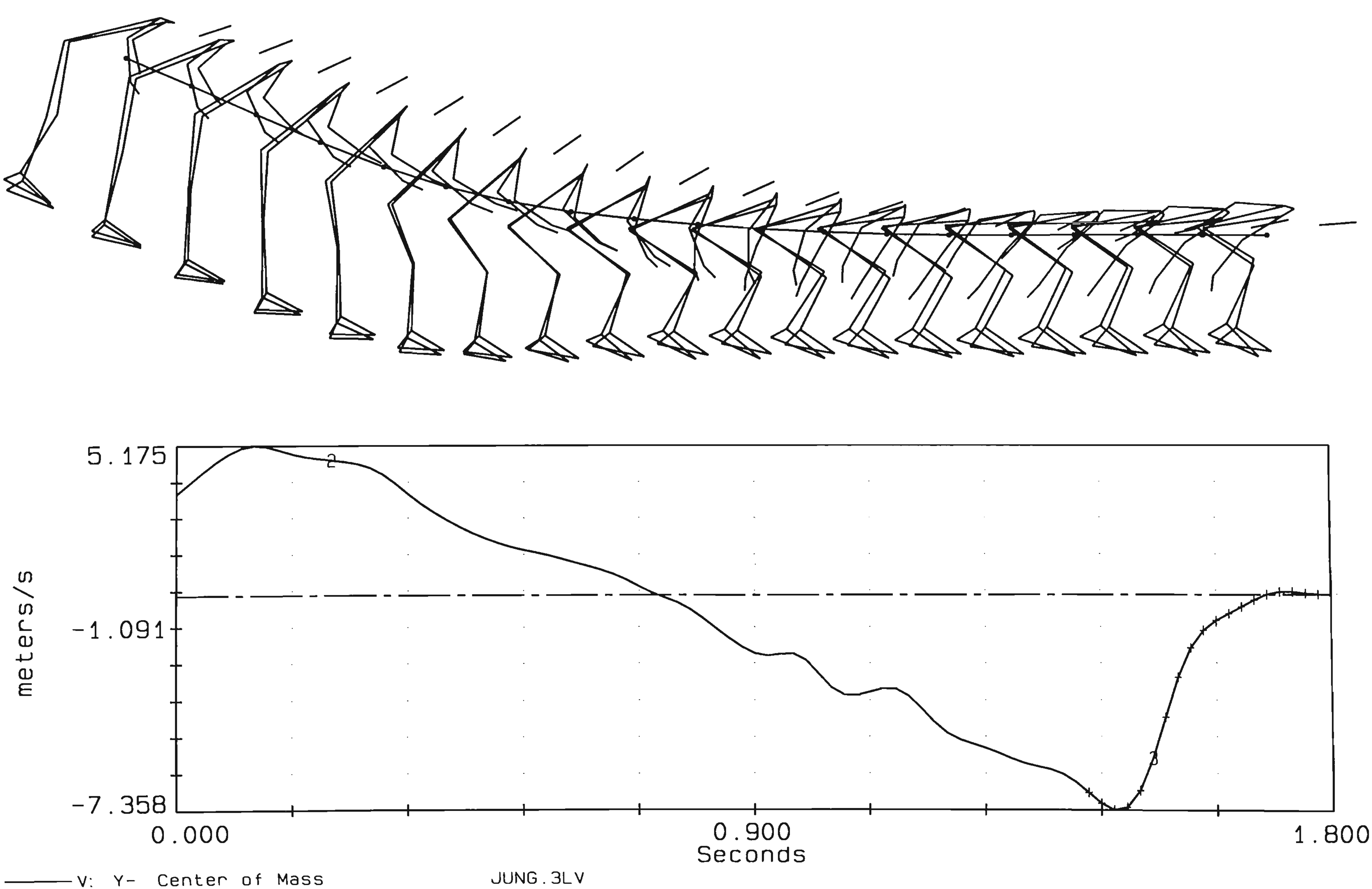


Horizontal Bar Landing

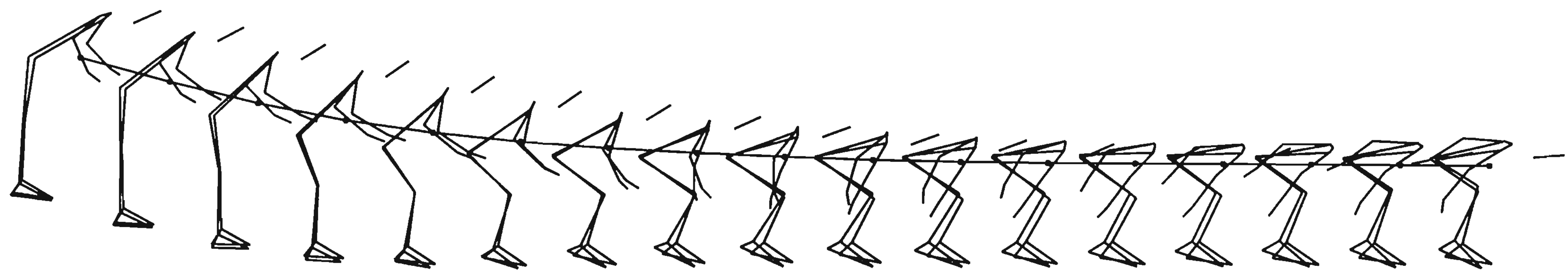


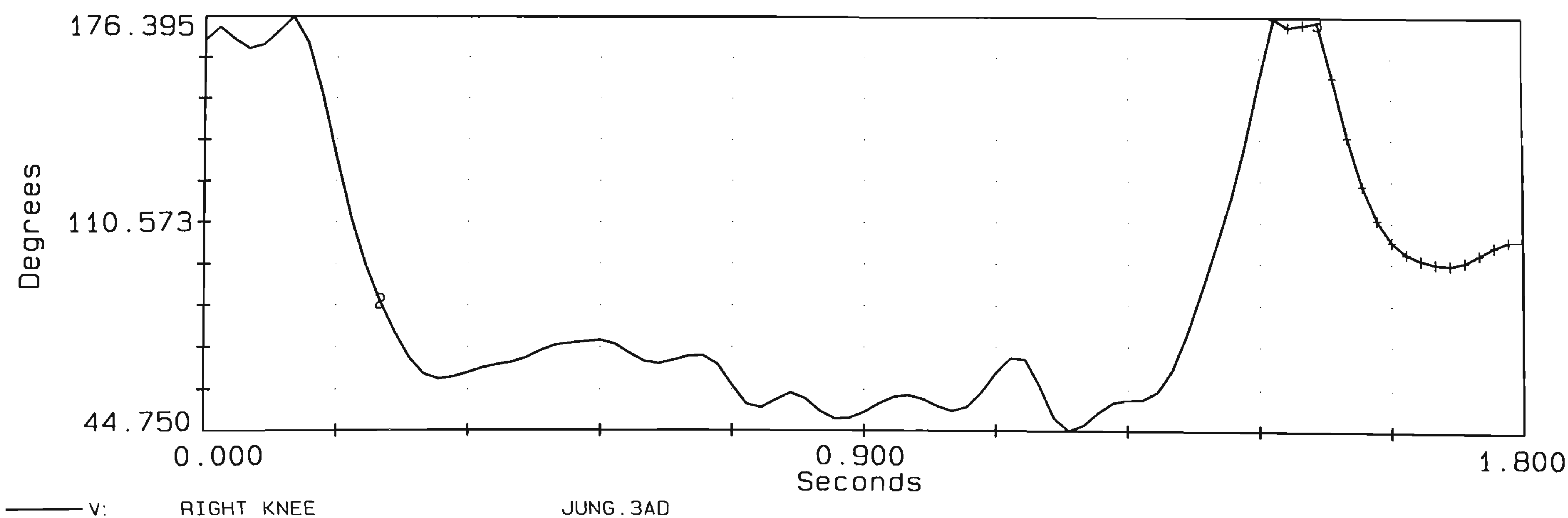


Horizontal Bar Landing

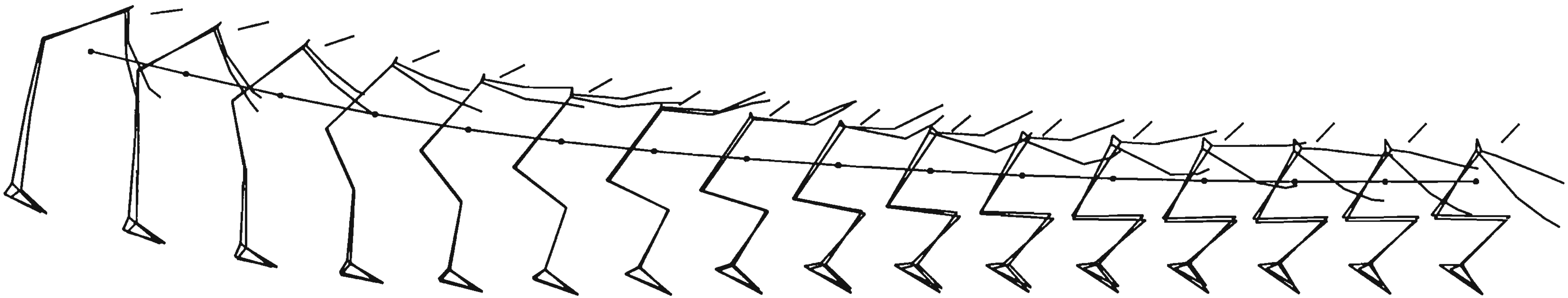


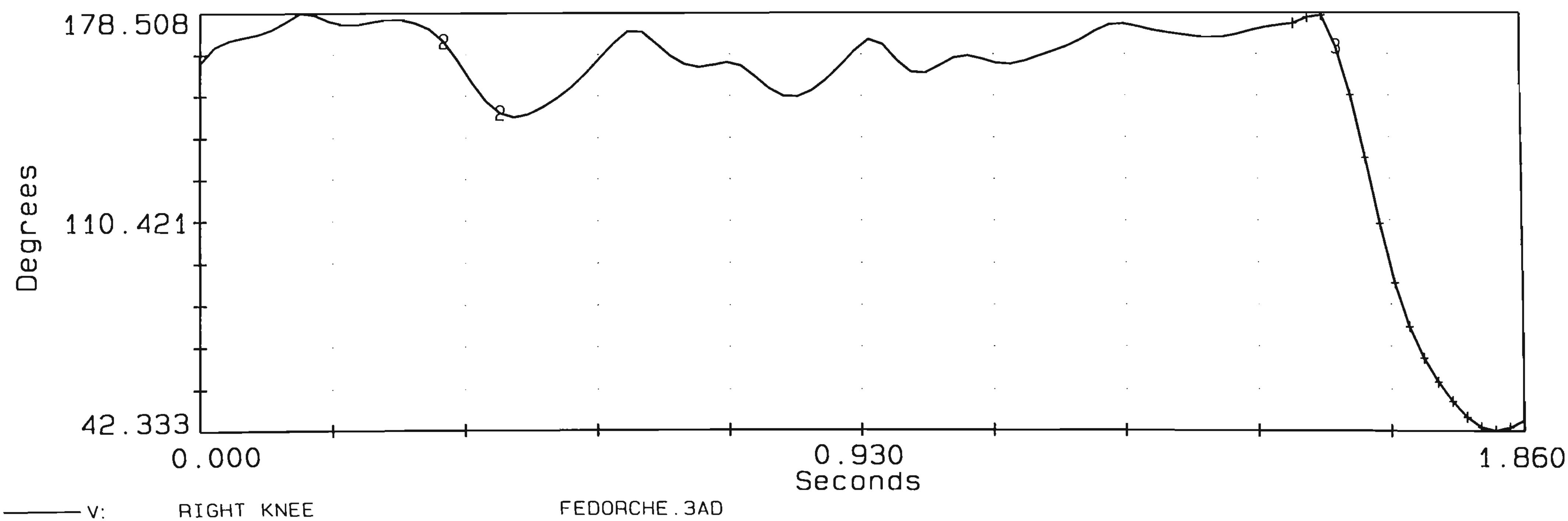
Horizontal Bar Landing



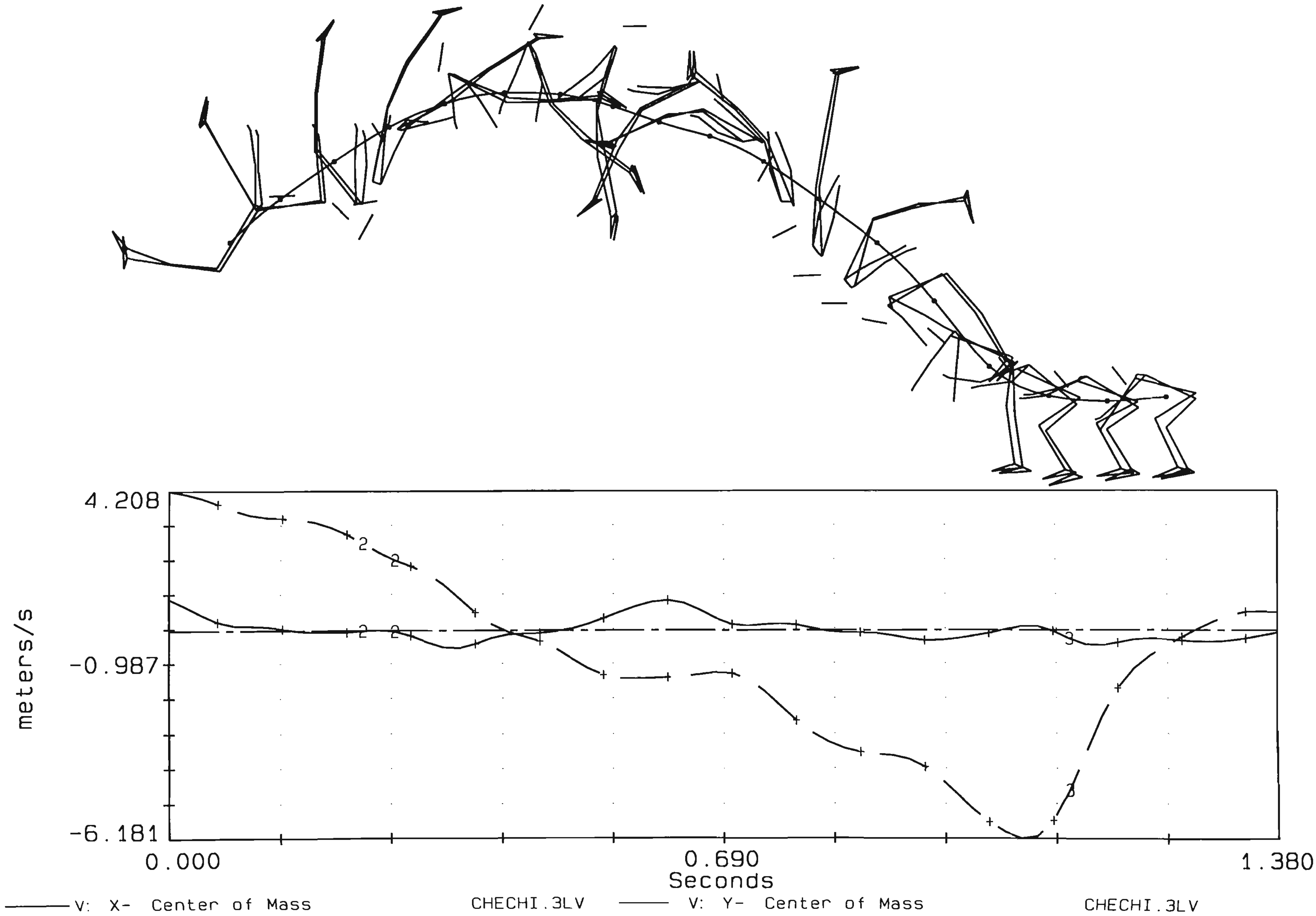


Horizontal Bar Landing

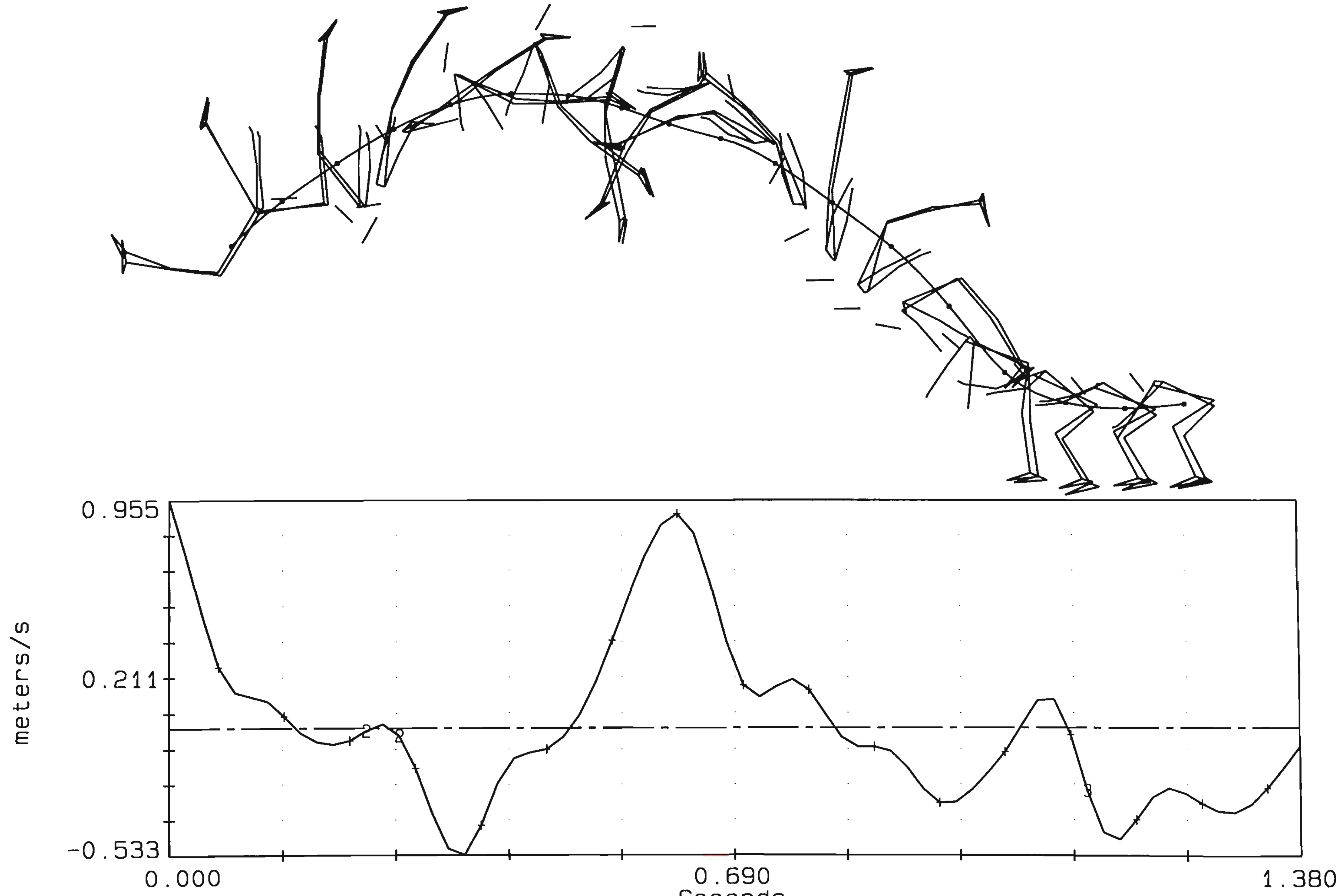




RINGS LANDING

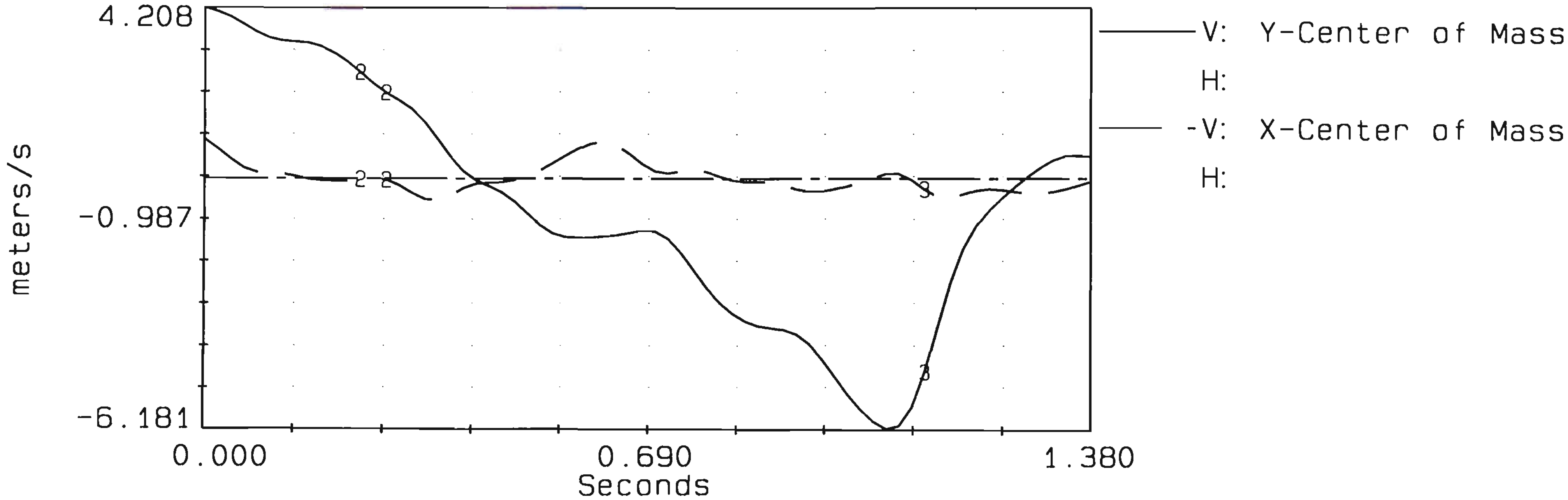


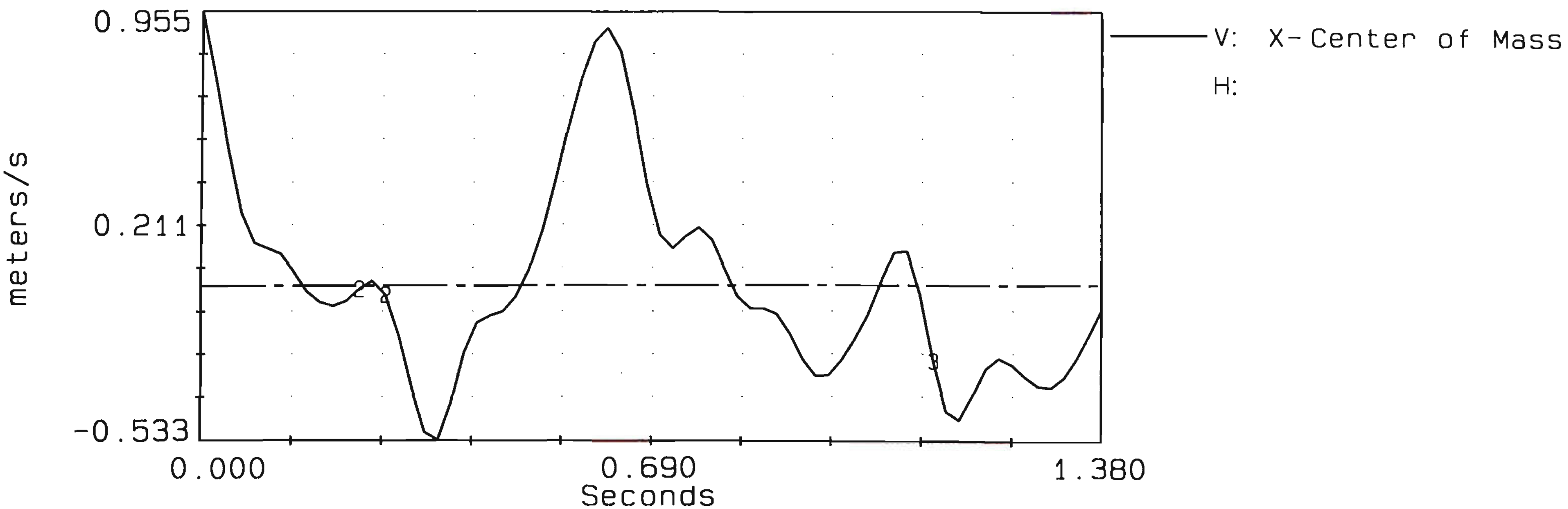
RINGS LANDING



V: X- Center of Mass CHECHI.3LV — V: X- Center of Mass CHECHI.3LV

RINGS LANDING





RINGS LANDING