BIOMECHANICAL ANALYSIS OF THE CLASSICAL *GRAND PLIÉ* AND TWO STYLISTIC VARIATIONS

A DISSERTATION

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CHAPTER I

ORIENTATION TO THE STUDY

The *plié* or knee bend is the basis upon which all dance technique is built. It is one of the first motions learned by young dancers and is continually practiced throughout the entire career of the dancer. Dancers usually include *pliés* in "warm-up" activity and almost all movements begin and end with the *demi plié*, so called if the base of support is on two legs or a *fondu* if the support is on one leg.

The classical *grand plié*, hereafter referred to as the *grand plié*, or *Plié* I, can be described as a deep knee bend. The movement is used in virtually all forms of dance as part of the technical training of the dancer (Vaganova, 1969; Radcliff, 1948; Kersley, 1962). The purposes of the *plié* according to sources in classical ballet are (a) to stretch and strengthen the legs (Hammond, 1974; Van Praagh, 1948), (b) to stretch and strengthen the back (Lawson, 1973), (c) to increase outward rotation at the hip (Vaganova, 1969), and (d) to develop a sense of balance (Kersley, 1962). In the ballet, the *plié* is executed in one of five basic outwardly rotated positions of the legs with the spine held erect.

Modern dancers traditionally have stressed complete freedom and expression of the body, and particularly the torso, whether they are on a static or traveling base. In the modern dance, the *plié* is performed essentially in the same manner as in the ballet, but with the addition, at times, of torso movements. These torso movements consist of spinal flexion and extension in the sagittal plane, lateral flexion and extension in the frontal plane, and even circumduction. With or without torso movements, the *grand plié* is included in the training of the modern dancer for the purposes of (a) aligning and strengthening the back, thighs, and feet and (b) developing general mastery of control (Sherbon, 1975).

Sources are in agreement as to the proper performance of the *grand plié* in first position (Lawson, 1973; Hammond, 1974; Vaganova, 1969; Grant, 1967; Schurman & Clark, 1972; Stuart & Kirstein, 1972; Arnheim, 1975; Sherbon, 1975; Lockhart & Pease, 1977; Van Praagh, 1948; Radcliff, 1948; Kersley, 1962; Sparger, 1970; Featherstone, 1970), but there is no known research which provides evidence that the *plié*, when performed properly fulfills its presumed purposes; further, there is no scientifically based evidence of the results of improperly performed *pliés*. Since the *plié* action is accepted as the foundation for almost all motion in dance, it should be of great importance to performers and teachers to know more about the practice of the technique. The scope of this investigation was to determine the biomechanics of the *grand plié* action with particular emphasis upon the manner in which the performance of the *grand plié* is affected mechanically by the addition of torso movements.

Purpose of the Study

The purpose of the study was to describe the mechanics of the *grand plié* with the hope that the research (a) will add to the general body of knowledge concerning the scientific basis of dance technique, (b) will validate the purposes of the *grand plié* as currently practiced and as presented in existing literature, and (c) will provide a sound mechanical rationale for the use of torso flexion movements during performance of the *grand plié*.

Hypotheses

Central to the investigation were four hypotheses. It was expected that: (a) the moments of force at the hip, knee, and ankle joints during the performance of the *grand plié* would differ from those of the *grand plié* performed with spinal flexion in the sagittal plane and with lateral flexion in the frontal plane; (b) the sequence of the force moments at the hip, knee, and ankle joints during the performance of the *grand plié* would differ from that of the *grand plié* performed with torso movements; (c) the pattern for types of muscle contraction during the performance of the *grand plié*, determined by relating the moments of force at the joint to the angular displacement of the limb, would be the same for all three styles of *plié*, and (d) the path of the total body center of gravity during performance of the three styles of *plié* would be similar for all subjects.

Statement of the Problem

The investigation entailed conducting, through the use of cinematography, a biomechanical analysis of the motion of the legs during the performance of the classical *grand plié* and two stylistic variations. Subjects were selected from the Department of Dance at the Texas Woman's University, Denton, Texas, during the summer of 1977. Specific information sought included (a) the resultant moments of force at the hip, knee, and ankle joints,

(b) the sequence of dominant muscle group action, and (c) the pattern of types of muscle contraction during performance of the grand plié. The excursion of the total body center of gravity resulting from spinal flexion in the sagittal and frontal planes was also examined.

Definitions and/or Explanations of Terms

For the purpose of clarification, the following definitions and/or explanations of terms and symbols were established for use throughout the study:

Classical Grand Plié or Plié I: The grand plié is a deep knee bend. A sense of lift in the body is followed by simultaneous flexion of the hip, knee, and ankle joints. While maintaining outward rotation of the legs, in first position, the knee is aligned over the center of the foot. The spine is held erect, shoulders directly over the hips, with the abdominals activated to prevent forward pelvic tilt. When the ankles are completely dorsiflexed, the descent continues, causing the heels to come off the floor. On the rising phase, the heels return to the floor before the ankle, knee, and hip joints extend, returning the body to its original upright alignment (Lawson, 1973; Hammond, 1974; Vaganova, 1969; Grant, 1967; Schurman & Clark, 1972;

Stuart & Kirstein, 1972; Arnheim, 1975; Sherbon, 1975; Lockhart & Pease, 1977; Sparger, 1970; Featherstone, 1970).

First Position: First position of the legs is achieved by standing with feet together in a parallel position, shifting the weight onto the heels, and outwardly rotating both legs equally.

Plié II: Plié II is defined as a grand plié performed with torso flexion and extension in the sagittal plane. During the descending phase, the spine sequentially flexes beginning at the neck and continuing through the lumbosacral joint. On the rising phase, the spine sequentially extends beginning with the lumbosacral joint and continuing through the neck until upright alignment is reached.

Plié III: Plié III refers to a grand plié performed with lateral flexion and extension in the frontal plane. On the descent, the spine laterally flexes to the right side through the lumbosacral joint. At the deepest point of the plié, the spine passes through an upright extended position and flexes laterally to the left side. On the ascent, the spine extends laterally to return to the starting position.

Biomechanics: Biomechanics is defined as "the science that examines the internal and external forces acting on a human body and the effects produced by these forces" (Hay, 1973, p. 3).

Moment of Force (M_o): Moment of force refers to the "sum of all muscle forces times the sum of their resultant insertion distances from the joint center" (Plagenhoef, 1971, p. 37). It can be determined through direct calculation of the external and inertial forces acting on the body (Plagenhoef, 1971). Moment of force is synonymous with torque (Miller & Nelson, 1973).

Center of Gravity: The center of gravity is the "point through which a single upward vector passes that is equal to all downward forces applied to a body by the earth's gravity, putting the body in equilibrium" (Plagenhoef, 1971, p. 47).

Concentric Contraction: A concentric contraction refers to a muscle contraction which is characterized by tension development in the muscle sufficient to overcome resistance so that a muscle visibly shortens and a body part moves as a result (Rasch & Burke, 1974).

Eccentric Contraction: Eccentric contraction refers to a muscle contraction which occurs when a muscle is innervated but is overcome by resistance and is lengthened during the contraction (Rasch & Burke, 1974).

Skilled Dancers: Skilled dancers are defined as individuals who in the opinion of five dance professionals have mastered the *grand plié*.

Dance Professional: A dance professional is defined as an individual whose profession is that of teaching, performing, choreographing, or directing a company of dancers.

Cinematography: Cinematography refers to a method of data collection which involves the use of a motion picture camera to record the performance of a subject for subsequent kinetic analysis (Plagenhoef, 1971).

Kinetic Analysis: Kinetic analysis is defined as analysis which is devoted to a study of the forces that initiate, alter, and stop motion (Miller & Nelson, 1973).

Kinematic Analysis: A kinematic analysis ". . . concentrates upon the geometry of motion without regard to the forces producing it. Displacement, velocity and acceleration are included" (Miller & Nelson, 1973, p. 39).

Delimitations of the Study

Among the restrictions set by the investigator was the determination that the subjects for the study would be 12 dancers selected on the basis of the ratings of five judges. The subjects were enrolled in summer dance classes at the Texas Woman's University, Denton, Texas, 1977. Film data on 3 of the 12 dancers were selected on the basis of accuracy of performance of the grand plié as evaluated by five additional judges.

The filming took place in available light, supplemented by two portable high intensity lamps, in a gymnasium at the Texas Woman's University. Data were collected from the front by a Redlake Locam 16mm motion picture camera, from the side by an Actionmaster 200, and from overhead through the use of a Bell and Howell Model 70 DR, each set to record at 48 frames per second. A Kako 818 Microstrobe Transistorized Electronic Flash was fired once at the beginning and once at the end of each film trial. Preliminary to final analysis, the joint centers were hand digitized with a Graf/Pen while the film was being projected via a Lafayette Motion Analyzer onto a Graphic Tablet Film Analysis Frosted Plate.

Limitations of the Study

It was assumed by the investigator that the grand plié was accurately performed by the final three dancers and that the torso movements during the plié were performed by all three dancers in a similar manner.

Further, in interpreting the data, the force moments could not be considered absolute since the head and the hands were omitted. The program LAMB.FOR was originally written for two dimensional data. The present investigator merged front and side view data prior to using LAMB.FOR. Finally, since 60% of the overhead data were lost by the film processor, the analysis was conducted using front and side view data only.

CHAPTER II

SURVEY OF RELATED LITERATURE

A computer search of available data bases and a subsequent review of all known related research studies indicated that the study did not duplicate any previously completed investigation. Research in dance to date has been concerned primarily with questions involving the history of dance, movement education, various cultural phenomena, and the creative process (Research in Dance, 1968, 1973), with biomechanical research being relatively new to the dance field.

Available research studies on the mechanics of human motion in general carry various titles such as biomechanical, kinematic, kinetic, and cinematographic analyses. The kinematic and kinetic studies are specific to the parameters of displacement, velocity and acceleration, and joint-moments of force, respectively. The terms biomechanical and cinematographic are used more broadly and involve a variety of research parameters and instrumentation.

Several analyses of dance techniques have been done through the use of cinematography. Most describe what is apparent to the viewer by examining the film frame by frame, with one exception, a study by Ryman (1978) which describes the displacement, velocity, and acceleration of selected dance skills. Whereas much valuable information has been gained through these methods, a more complete interpretation of any movement depends on the calculations of joint-moments of force of the entire body in action (Plagenhoef, 1966).

These moments of force are the measures of torque at the joints (Miller & Nelson, 1973; Evans, 1971) and can be obtained by kinetic analysis, one of the areas of biomechanical research previously mentioned. Kinetic analysis consists of deriving equations of motion, based upon principles of engineering dynamics, for the particular problem under investigation (Dillman, 1971). If the kinematics (or the displacement, velocity, and acceleration, Miller & Nelson, 1973) are known, as well as specific body segment parameters, these equations can be solved for the resultant muscular force-moments which produced the movement of the segments (Dillman, 1971). Such information provides a better understanding of exactly what motion has occurred and how.

A thorough search of the literature revealed that there is no published research of any kind on the *grand plié*. Further, there are no published or unpublished studies to this date which determine the kinetics of any dance movement thereby providing a complete biomechanical analysis. The following review of literature therefore is confined to two unpublished studies on the *plié* and to those studies which deal with cinematographic analysis of other dance movement techniques.

The Plié

Beal, Moore, and Scearce (1976) through electromyography examined the muscle action potentials of the erector spinae and rectus abdominus muscles in six female dancers of three skill levels during performance of the *demi* and *grand plié* in first position. Their thesis was that skilled dancers would involve the rectus abdominus more than the erector spinae and that for less skilled dancers the opposite would hold true. Results of the study indicated that as skill level increases there is less activity in the erector spinae and therefore only the muscles necessary are utilized for the dance action. The decrease in activity in the erector spinae which accompanied an increase in activity in the rectus abdominus was attributed by the writers to reciprocal inhibition.

In 1975, Nichols completed a study the object of which was to objectify factors that influence the postural alignment of the dancer during performance of the plié. Specifically, Nichols' motivation was to determine (a) if morphology affects the efficiency of the plié, (b) if the dancer's amount of experience relates to verticality of alignment, (c) if use of the barre has any effect on spinal verticality during performance of the plié, and (d) if the alignment of the spine changes in relation to the vertical at different positions during execution of the plié.

Nichols identified the upper, lower, and torso portions of the spine. The relationship of each portion of the spine was used as the measure of verticality and the relative length of the spinal segments yielded a ratio which was considered a valid measure of morphology. On the basis of this ratio and their previous dance training, 28 subjects were categorized as High Ratio Inexperienced (long waisted), Middle Ratio Inexperienced, Middle Ratio Experienced, and Low Ratio Inexperienced (short waisted). The inexperienced subjects were randomly selected from students at Briarcliff College and the experienced subjects were advanced level volunteer dancers from the Juilliard School. Sixteen millimeter film data were collected, analyzed, and treated statistically by a 4x2x5 factorial arrangement with repeated measures on the last two factors. Variables studied were spinal ratio, experience, no experience, *barre*, no *barre*, and the five positions during execution of the skill. Results of the study were (a) the spinal ratio had no effect on deviation from the vertical, (b) verticality was not a factor related to experience in dance, (c) the effect of experience was evident in the between trial consistency of movement in the total spine, (d) the effectiveness of the *barre* differed with the relative length of the upper spine, and (e) lack of flexibility of the body limited development of consistency of movement.

Cinematographic Analysis of Dance Technique

Several investigators have employed high speed motion photography to study various dance techniques. Ryman's (1978) study was the only study available which included kinematic data on dance movement. The investigation applied anatomical, kinesiological, and biomechanical information to six *grand allegro* jumps: (a) *pas de chat* *jeté*, (b) *grand jeté en avant*, (c) *temps levé en avant en arabesque*, (d) *grand ballonné en avant*, (e) *grand jeté dessus en tournant*, and (f) *grand fouetté sauté*. Of particular interest to the investigator were alignment, depth of crouch, accompanying arm and leg gestures, height of jump, breadth of jump, illusion of suspension, timing, and turning during jumps.

Three filmed trials were taken by means of a Locam 16 millimeter camera at 100, 200, and 300 frames per second, respectively. The six jump sequence was performed by a professional dancer associated with the National Ballet of Canada. The subject was dressed in a white leotard, pink tights, and point shoes with red circular markers on her shoulder, elbow, wrist, hip, knee, and ankle joints. Data were extracted from the film by utilizing a Vanguard Motion Analyzer. The total body center of gravity, displacement, velocity, and acceleration were obtained through the use of a WATFIV computer program designed for the study. Methodology included defining the jump; scientifically describing the movement sequence from the preparatory phase through the landing; describing the nature, range, and sequence of joint action for each phase; presenting quantitative results using tracings, tables, and graphs; and verbally describing the qualitative results of the frame by frame observation.

Ryman's findings indicate that the depth of the preparatory plié is not the sole influencing factor on the height of the jump as most technical manuals imply. In general, the vertical level of the head remained the same for several frames while the limbs continued to adjust, thereby creating the illusion of suspension. During turning jumps, Ryman confirmed that contrary to the belief that the turn happens at the height of the jump, 90 degrees of rotation occur before flight and 90 degrees during flight. Finally, during the turning jumps, the foot was found to be "sickled" or supinated during takeoff. The twisting action of the foot, undetectable to the eye, directs the rotational force necessary to achieve a turn in the air.

Mangelsdorf, in 1976, through cinematographic analysis, compared the Swedish fall, the front slide fall, and the forward straight fall. The study involved examination of (a) body alignment from head to ankle during the falls, (b) the angle of the body at impact, (c) the placement of the hands on the floor, and (d) the action of the arms before and after contact with the ground. Subjects for the study included one faculty member and three members of the dance touring group of the Texas Woman's University Dance Department. Film data were collected by means of two 16 millimeter Bell and Howell movie cameras, set at 64 frames per second, with 25mm lenses and placed at right angles to each other. Selected anatomical reference points were marked in white on black leotards and tights worn by the subjects. Each dancer performed three trials of each of the three falls in a randomly selected order. The frontal and sagittal views, with an electric clock included for time reference, were filmed simultaneously. The standing heights of the dancers were used as the known measure.

After the best front and lateral view of each dancer were selected, the Recordak MPE-1 Film Reader was used to analyze the front view for data pertaining to the angle of the arms at impact and the placement of the hands on the ground. A Vanguard Motion Analyzer was used for the remainder of the data. Every 10th frame was examined, the information was computed by an IBM 320/50 computer, and the results were converted into point and line drawings and graphs. Mangelsdorf's findings are summarized as follows: (a) The initial body positions varied with subjects but the final body positions were similar for all. (b) The hands were placed on the floor similarly by all four subjects. (c) Larger angles of the trunk of the body at impact of the Swedish fall facilitated greater hyperextension of the hip of the elevated leg. (d) Larger angles of the trunk of the body at impact during the front sliding fall facilitated placement of the diaphragm on the floor for a smooth forward slide. (e) Flexion of the elbows after contact with the ground was similar in the Swedish fall and the straight forward fall. The front slide fall included the same action as the Swedish fall and the straight forward fall until the forward thrust of the body occurred.

The grand jeté was analyzed cinematographically by Gaffney (1976) to determine selected movement patterns for one skilled subject. The investigator examined the depth of the plié before takeoff, depth of plié during landing, height of the leap, movement of the arms, length of time in the air, length of time consumed for the execution of the entire leap, amount of outward rotation of the legs, angle of the torso throughout the leap, and movement of the shoulders.

The subject was a professional dancer who resided in the Dallas-Fort Worth area of Texas. Film data were collected during the summer of 1976 by a Locam movie camera set at 80 frames per second and a 16 millimeter Bell and Howell movie camera set at 60 frames per second. Selected anatomical reference points were marked in white against the subject's black leotard and tights. The dancer was filmed three times from the frontal and sagittal views concurrently and three times from the sagittal and overhead views concurrently. A Minolta Electroflash-3 was used to synchronize the cameras and a meter stick was included for the known measure. The Vanguard Film Analyzer was employed to make tracings of the entire body from eight selected frames from all three performances of the sagittal and frontal views. The findings of the study were that all three of the subject's performances of the grand jeté were similar and that, generally, she performed the grand jeté as described by the literature. Observations which deviated from the literature were (a) Whereas the opening of the arms to the side is considered good form, a backward arm action appears to supplement a forward reaction. (b) Whereas the arms are supposed to be held en attitude throughout the leap, it may not be possible to achieve the pose as quickly as stated in the literature. (c) Whereas no movement is supposed to occur in the spine and shoulders, slight movement may occur as a result of arm action. (d) Whereas the leading leg should be thrown to an angle of 90 degrees as the supporting foot pushes off the floor, the leading leg of the subject of this study did not reach the 90 degree angle. No determination was made as to whether this fact affected the actual height of the leap.

In 1976, Plastino examined the mechanical properties found in five selected ballet techniques. Using nine male dancers of varying degrees of technical proficiency, she recorded the performance of the port de corps derrière, the grand battement with hip up, the grand battement with hip down, the grand jeté en avant and elevé in passé, balanced on the left leg.

The subjects, clad in bikini swimsuits, were measured anthropometrically and prominent bony landmarks were then marked. A variable speed battery operated Beaulieu 400 82m camera was used to record the front, side, and overhead views of the body simultaneously in a laboratory equipped with six mirrors strategically arranged. An operating speed of 32 frames per second was used to film all skills except the *grand jeté* for which a faster speed of 72 frames per second was used. A chronometer was included in the field of view for exact timing of the frames and a six foot stick, marked in six inch increments, was included as the known measure. A computer program which produced stick figures was modified to read the data from the triaxial cinematography. From comparisons of the stick figures, the film, the raw data, and the calculated body angles, Plastino's primary findings were (a) that subjects performed the *port de corps derrière* at different speeds and executed the maximum bend in slightly different parts of the spine and (b) that within the group of professional dancers, the younger the dancer the higher the performance level and the greater the flexibility. Her overall conclusions were that (a) the final line of the *port de corps derrière* results from continuous flexion at the shoulder after the spine is hyperextended fully, (b) it is impossible for the human body to remain balanced on one leg, half-toe, for any great length of time, and (c) there is a constant shift of center of gravity during performance of the *port de corps derrière* so that balance can be maintained.

The purpose of Buckman's (1974) study was to examine the technique of the performance of the *tour jeté*. Specifically, she investigated (a) the depth of the *plié* before takeoff, (b) body angle during takeoff, (c) relation between thrusted leg and supporting leg in *grand battement*, (d) the point when rotation began, (e) height of the jump, (f) relationship of legs upon completion of rotation, (g) angle of torso upon completion of rotation, (h) relation between legs in arabesque position, (i) depth of *plié* during landing, and (j) distance covered between takeoff and landing.

Subjects used were nine female dancers, three representing each of skilled, semiskilled, and non-skilled levels. Selected anatomical reference points were marked and each semiskilled and non-skilled dancer was filmed three times and each skilled dancer was filmed four times performing the *tour jeté*.

Film data were collected from the lateral view with a Bell and Howell HR 70 movie camera with a 10 millimeter lens and set at an operating speed of 60 frames per second. An electric clock to record time and a yardstick to provide a known measure were included in the film. A Recordak Film Reader was used to make tracings of the seven main phases of the tour jeté as performed by each dancer, then a composite tracing was made to represent each phase for each skill group.

Findings of the study were that (a) in contrast with the other two groups, the skilled subjects demonstrated the proper characteristic elements defined for the tour jeté and (b) rotation was initiated before actual flight began instead of at the top of the leap. Finally, in order to have prevented horizontal travel, the body should have been inclined backward.

Beck (1973) analyzed the kinesiological mechanics of the foot as it was involved in the vertical jump. She also attempted to determine the relationship of length of toes to the elevation obtained from the vertical jump.

Three high, three average, and three low scoring female performers of the vertical jump were selected from 60 semiskilled dancers from the Texas Woman's University during the spring of 1973. A Locam motion picture camera set at 170 frames per second was used to collect film data. A Lange skinfold caliper was used to measure toe length after the investigator had established reliability for the instrumentation. Five anatomical reference points on and around the feet were selected and marked. Each subject was filmed from the frontal and sagittal views and a yardstick was included in the film as a known measure. A Recordak MPE-1 Film Reader was employed to make tracings of every fourth frame of the initial upward movement until the toes lost contact with the floor. Similarities and differences were determined through analysis of the data and a Pearson Product Moment Correlation was calculated between toe length and the obtained elevation in the performance of the vertical jump. Beck concluded from her findings that the second toe is the most important toe in the final stages of performance of the jump. Performers who used their feet progressively through the toes were able to perform a jump which was successful as measured by its height. No significant correlation was found between the length of any toe and the elevation obtained in the jump.

The purpose of Macduff's (1972) study was to determine if performing to music would alter the mechanics of the *grand jeté*. Specifically, she examined performance of the *grand jeté* under conditions of no sound at all, sound of a metronome, and sound of music composed especially for the movement and underlined with the metronome. The biomechanical factors isolated for study included (a) the vertical displacement, (b) horizontal displacement and stride length, (c) time duration, and (d) angles between the legs at critical points during the leap. Twelve experienced dancers who were members of the Pennsylvania State University Dance Club were filmed performing the *grand jeté* under all three conditions. The study was replicated one week later.

Film data were collected through use of a Locam 16 millimeter camera set at 100 frames per second while the sound data were recorded on a Crown four track stereo tape recorder. A special timing device was used to record the beat of the metronome on the film. Subjects were marked at 15 selected reference points. For the two best trials per dancer a Vanguard Motion Analyzer was utilized to obtain the x and y coordinates from every fourth frame of the stepping phase and every second frame of the leap. A correlated t-test was used to determine whether there were practice effects from the first week to the second week. A noncorrelated t-test was used to compare the effects of order of presentation of the accompaniment conditions. A chi square analysis was used to compare the accuracy of the subjects' timing when accompanied by music or the beat of a metronome. Analysis of variance was done to determine the effects of the three experimental conditions on the biomechanical variables. The investigator found that (a) it made no difference in the performance of the <u>grand jeté</u> which form of accompaniment was introduced first to the subject, (b) the dancers did not differ in their execution of the <u>grand jeté</u> from the first to the second week, (c) there was no meaningful difference in the biomechanics of the <u>grand jeté</u> when accompanied by music or a rhythmic beat, and (d) highly significant differences were shown in the ability to follow the beat when the movement had metronome accompaniment as compared with a musical accompaniment. Subjects were consistently early when accompanied by a rhythmic beat and consistently late when accompanied by music.

McMillan's (1972) investigation was concerned with the cinematographic analysis of characteristic likenesses and differences among three skill levels in performance of the <u>pirouette en dehors</u>. The analysis focused on the preparation, the turning, and the concluding phases of the technique. Subjects were nine individuals, three in each skill level, residing in the Dallas-Fort Worth, Texas metropolitan area during 1970-71. The nine subjects were chosen on the basis of eight criteria for good form in the *pirouette en dehors* from fourth position. Film data were collected with a 16 millimeter Bell and Howell motion picture camera set at 64 frames per second. Selected anatomical reference points were marked against white leotards and tights worn by the subjects. Each subject was filmed from the frontal and sagittal views against a black background while performing three single *pirouettes*. An electric clock was included in the film to provide a timing device and a yardstick provided a known measure. The best frontal and sagittal view of each dancer was selected and tracings were made on the Dagmar Super Microfilm Reader. Findings with respect to similarities and differences were presented in relation to the three phases.

In the preparatory phase all three groups were similar with the highly skilled subjects employing larger movements and less total time than subjects in other skill levels. During the turning phase, there were notable differences in position of arms, placement of right feet, spotting, and period of acceleration during the turn among skill levels. At the conclusion of the *pirouette* it was found that members of the skilled group, when compared to other subjects, extended their right legs more posteriorly from the *passé* position, maintained their arms in second position, and terminated the *pirouette* with their weight over their left legs. All subjects showed movement in the horizontal plane of the supporting leg.

CHAPTER III

PROCEDURES IN THE DEVELOPMENT OF THE STUDY

The purpose of the investigation was to examine through the use of cinematographic and kinetic analysis selected biomechanical aspects of the *grand plié*. Twelve subjects were selected from 25 volunteer dance majors at the Texas Woman's University. They were auditioned by a panel of judges during the summer of 1977. Chapter III provides a detailed description of the procedures followed during the development of the project. The information is presented under the headings of (a) preliminary procedures, (b) procedures in the selection of subjects, (c) procedures in the collection of data, (d) procedures in analyzing the film data, and (e) procedures in preparing the final written report.

Preliminary Procedures

Prior to initiating the study, several preliminary procedures were followed. Since human subjects were involved, permission was obtained from the Texas Woman's

University Human Subjects Review Committee. All available documentary and human sources of information pertaining to the *grand plié* and to cinematographic analysis of dance technique were surveyed, studied, and assimilated. An extensive review of related literature revealed that the study did not duplicate any existing research. Further, it was learned that there was no published or unpublished research in dance which dealt with the kinetics of motion and that there were only two studies which deal with the *plié*. They were both unpublished.

A tentative outline of the study was developed and presented to the dissertation committee. Revisions of the outline were made in accordance with the recommendations of the committee members and a prospectus of the approved study was filed in the office of the Provost of the Graduate School.

Procedures in the Selection of Subjects

Permission was obtained from the Dean of the College of Health, Physical Education, and Recreation, Texas Woman's University, to announce in dance classes that volunteer subjects for the study would be auditioned on June 24, 1977. A form for rating the accuracy of performance of the grand plié was developed and subsequently revised in accordance with the suggestions made by members of the dissertation committee. Five dance professionals from the Denton, Dallas, Fort Worth area were contacted and asked to serve as judges for the study. A meeting was held to orient the judges to the study and to the rating form. Their resumés appear in the Appendix.

Each volunteer dancer performed the classical grand plié twice in first position for the panel of judges. The performance took place with the subject's body at a right angle to a mirror so that the judges had a clear view of the motion in the frontal and sagittal planes. On the basis of the mean rating of the five judges, the 12 subjects who were rated as having performed most accurately were selected for filming. A significant coefficient of .893, $p < .01$ (Seigel, 1956, pp. 229-239; Downie & Heath, 1974, pp. 232, 322), was obtained with Kendall's test for concordance among judges. This indicated that the judges were in agreement in their ratings. Each of the 12 subjects chosen agreed to participate in the study and signed a consent form permitting the investigator to use the film data for educational purposes.

Procedures in the Collection of Data

Preparation of Subjects

Two practice sessions were held to instruct the 12 dancers in the correct performance of the two stylistic variations of the *grand plié*. The first variation, *Plié* II, involved performing the *grand plié* with torso flexion in the sagittal plane. The second variation, *Plié* III, involved performing the *grand plié* with lateral torso flexion in the frontal plane. It was assumed that skilled dancers who perform *Plié* I correctly could also perform *Plié* II and *Plié* III accurately.

Personal data including height, weight, age, and number of years of experience were collected from each dancer. Subjects were instructed to wear a two piece swim suit and a scarf to hold the hair close to the head. Joint centers on the Caucasion subjects were marked with a black felt marker and on the Negroid subject with white self adhesive circles. The joint centers were marked as follows: (a) at the back, right side, and front of the neck at the level of the seventh cervical vertebra (Hinson, 1977), (b) at the top and front of the shoulder at the glenohumeral joint (Plagenhoef, 1971), (c) in the crease of the elbow between the medial and lateral heads of the epicondyles of the humerus (Plagenhoef, 1971), (d) on the wrist at the palmaris longus (Hinson, 1977), (e) at the side of the hip approximately three centimeters above the bony prominence of the greater trochanter and at the front of the hip in the skin fold (Plagenhoef, 1971), (f) at both sides of the knee at the center of the flat portion of the condyles of the femur and in front of the knee immediately under the patella (Plagenhoef, 1971), and (g) at the ankle on the lateral and medial malleoli (Hinson, 1977). At the waist the subjects wore white belting fastened with velcro and with bands two centimeters square marked with a black pen. After the dancers were scheduled for filming, each randomly drew an order for the performance of the three pliés. Finally, an orientation to the filming procedure was given.

Preparation of the Laboratory

A gymnasium on the Texas Woman's University campus was chosen as the site for data collection because a catwalk was available which permitted filming from the overhead view. Three cameras were arranged at 90 degrees to each other and to the dancer from the front, side, and overhead views. Each camera was loaded, positioned, leveled, and focused. The leg positions of the tripods were marked on the floor with tape. Measurements were taken from camera to object and from lens to floor. A square meter was measured off on the floor with white tape with a mark in the center of the square to delineate the position of the dancer's feet. Light from the windows was blocked out to provide a contrasting dark background, and two high intensity lamps were positioned to provide adequate illumination on the subject. A metal stand with white tape covering the distal end was used for a zero reference point in space. The stand was located to the right and behind the dancer placing the subject in the first quadrant. A metronome used to control tempo was set at 120 beats per minute. It was determined that an electronic flash would be fired twice during each filmed trial to synchronize the three cameras. Other necessary equipment included power cords, a meter stick, a plumb bob, and a light meter. A complete description of the instrumentation used to collect data may be found in Table 1.

Students who were enrolled during the summer of 1977 in PHED 5643, Measures of Human Movement: Photogrammetry,

Table 1

Description of Instruments Used for Data Collection

16mm Camera	Lens	Operating speed	Shutter speed	Distance in meters from camera to object	Distance in centimeters from lens to ground
Model 70-HR Bell & Howell	25mm	48 fps	432	7.53	104
Model 51 Redlake Locam	10x12a Angenieux-Zoom (22, focal distance 5m)	48 fps	144	7.32	95.5
Actionmaster 200	6x12.5a Angenieux-Zoom (15, focal distance 5.8m)	48 fps	144	5.46	96.5
Model 70-DR Bell & Howell	25mm	48 fps	96	*	773

*Camera to object distance ranged from 1.57 to 1.75m depending upon height of dancer.

volunteered to serve as members of the film crew for the study. The crew members were oriented to the study and to the instrumentation to be used in it. Each crew member assisted in the set up of the laboratory and in operating the instruments during the data collection process.

Collection of the Data

Immediately prior to data collection, the procedures were simulated with all dancers and crew members present. Necessary adjustments were made before the actual filming took place.

On the day of the filming, in order to provide a known measure, film data were taken of a plumb bob suspended in the field of view from a dancer's hand and of a meter stick held overhead, at waist level, and resting on the floor. Data from the frontal view for subject number one were recorded at 48 frames per second (fps) on a Model 70-HR Bell and Howell 16 millimeter motion picture camera. The remaining 11 subjects were filmed from the front at 48 fps by a Model 51 Redlake Locam. Data from the sagittal view were collected by an Actionmaster 200 set at an operating speed of 48 fps, and the overhead data were obtained through the use of a

Model 70-DR Bell and Howell mounted on a catwalk above the filming area (see Table 1). The film used in the study was Kodak TRI-X Reversal Film 7278.

The two high intensity lamps provided illumination sufficient to record with an f-stop of 1.9 on the Bell and Howell cameras and 2.2 on the Locam and the Actionmaster. A Kako 818 Microstrobe Transistorized Electronic Flash was fired once at the beginning and once at the end of each filmed trial in order to synchronize frames from the three different camera views.

Additionally, as a means of documenting the research process, black and white photographs and color slides were taken. The film data were submitted to PSI Film Laboratories, Dallas, Texas, for processing.

Procedures in Analyzing the Film Data

An initial viewing of the film revealed that approximately 60% of the overhead data were lost at the film laboratory during processing. It was determined, however, that an analysis could be conducted using the front and side view data even though the third dimension could not be verified from overhead.

Selection of Final Three Subjects

A second group of five dance professionals chosen from the Phoenix metropolitan area agreed to rate the filmed version of Plié I as performed by the original 12 subjects. The judges, using a rating form identical to the one used previously, evaluated each subject's performance while the film was being projected at 24 frames per second, causing the plié action to be exactly twice as slow as real time.

Based upon the judges' ratings, the dancers were ranked and the top three performers were selected. The calculation of a coefficient of concordance confirmed that the judges' ratings were in close agreement, $W=.606$, $p<.01$ (Siegel, 1956; Downie & Heath, 1974). On closer examination of the film, it was learned that data were missing from the side view of Plié III for the dancer who was ranked third among the top three. It was decided that the footage of the dancer ranked fourth would be used instead.

Synchronizing the Front and Side View Data

A transistorized strobe was fired twice, once at the beginning and once at the end of each filmed trial. In viewing the film, the flash was not visible except occasionally. It was assumed by the investigator that the lack of continuity in the appearance of the flash could be attributed to the fact that a shutter speed of 144 was obtained. The shutter, in all probability, was closed in the instances where the strobe did not appear. Consequently, another method of synchronizing the film was devised.

The Locam, used for front view data, was equipped with a built-in strobe which flashes at the rate of 100 times per second. It was possible to verify that the Locam was operating at 48 frames per second by counting the number of frames within 100 strobe marks on the film. The Actionmaster 200 had no built-in timing device, hence, it was necessary to study the film frame by frame to locate visual clues in order to match the two sets of data. There were three points clearly evident on each filmed trial: (a) when the heels left the floor, (b) at the depth of the plié where the motion changed directions, and (c) when the heels returned to the floor. With the use of an F&B CECO/SOS Magnasync Moviola 16mm table viewer, the frames between these points in time were manually counted. By matching these three reference points, it was possible to verify that the Actionmaster was also operating at approximately 48 fps. Every third frame, from a point in time just prior to knee flexion, through the descending and rising phases, until the knees returned to an extended position, yielded between 80 and 88 frames per dancer per plié for study.

Analyzing the Data

Preliminary to analyzing the film data, attention was given to the percentage of error inherent in the digitizing process. The accuracy of the Graf/Pen used to obtain the data points is listed as .1% of full scale. The resolution is .01 inch or .1mm, and the repeatability is ± one count. The error of the investigator over 15 trials was found to be .659% and because the motion was stationary, the error due to parallax was not a consideration.

The film data were projected by means of a Model #00300 Lafayette Motion Analyzer directly onto a Graphic Tablet Film Analysis frosted plate. The GP-3 Graf/Pen was linked to a Infoton Vistar/GTx terminal with access to the Univac 1110/42 Digital Computer at Arizona State University. Touching the joint centers with the pen produced the x,y coordinates on the terminal scope and subsequently stored them on disc, to be punched onto cards later. Data for every third frame from the front view were recorded in the following order: Card I (a) zero, zero reference point, (b) top of the head, (c) seventh cervical vertebra, (d) right hand, at the third metacarpophalangeal joint, (e) right wrist, (f) right elbow, (g) right shoulder; Card II (h) lumbosacral joint or waist, (i) right hip, (j) right knee, (k) right ankle, (l) right foot at the head of the first metatarsal, (m) left hand at the third metacarpophalangeal joint, (n) left wrist; Card III (o) left elbow, (p) left shoulder, (q) left hip, (r) left knee, (s) left ankle, (t) left foot at the head of the first metatarsal, and (u) frame number. Data from the side view were recorded for points a through l above plus the frame number. The data cards were read and stored on disc in file at the Texas Woman's University.

Since the left side of the body was not visible from the side view, symmetry was assumed for the arms and legs on *Plié* I and *Plié* II. Symmetry was assumed for *Plié* III with the data for the left arm being the inverse of the data for the right arm. The missing data points were supplied by a computer program entitled REFORM.DAT written by Deborah Odoms of the Texas Woman's University Computer

Center. An additional program was written by Paul Long, a student at North Texas State University, to merge the x,y coordinates of the front view with the y,z coordinates of the side view. The program entitled MERGE.FOR zeroed the reference point in space for the side view to coincide with the reference point in space for the front view. Additionally, the program converted the known measure into a multiplier and applied the factor to the data. The output was segment lengths in centimeters to two decimal places and absolute and relative angular displacement for each position.

A study of the lengths of each segment recorded from approximately 80 positions indicated varying amounts of deviation among observations. A program MEANS.CTL was devised by Odoms to access an SPSS program to determine the mean, the standard deviation, the standard error of the mean, the variance, the maximum and minimum observations, and the range for the segment lengths (see Tables 2, 3, and 4).

CHANGE.FOR and CHANG2.FOR were devised to reformat the data for the final program LAMB.FOR, a version of the program found in Plagenhoef's Patterns of Human Motion: A Cinematographic Analysis (1971), revised by Luke Kelly,

Table 2

Descriptive Statistics for Segment Lengths in Centimeters as Calculated from Digitized Data for Dancer A

Segment	Mean	SD	SEm	Min	Range	Max
Left Foot	13.98	.542	.061	12.17	3.72	15.89
Right Foot	14.33	.532	.060	12.70	3.36	16.06
Left Shank	35.05	1.600	.180	31.42	7.10	38.52
Right Shank	35.75	.839	.094	33.88	4.00	37.88
Left Thigh	40.13	1.356	.153	37.34	6.79	44.13
Right Thigh	39.34	.96	.109	37.03	4.74	41.77
Head	24.23	.773	.087	22.43	4.70	27.13
Torso	40.81	.578	.065	38.46	4.50	42.96
Pelvis	13.80	.869	.098	11.47	4.57	16.04
Left Hand	9.46	.811	.091	7.39	4.12	11.51
Right Hand	10.11	.441	.087	7.04	5.89	12.93
L. Forearm	24.68	1.090	.124	20.53	7.52	28.05
R. Forearm	25.84	.591	.066	24.06	3.28	27.34
L. Upperarm	26.66	.937	.106	24.17	6.13	30.30
R. Upperarm	26.95	.961	.110	25.11	7.67	32.78

N=237

Table 3

Descriptive Statistics for Segment Lengths in Centimeters as Calculated from Digitized Data for Dancer B

Segment	Mean	SD	SEm	Min	Range	Max
Left Foot	14.02	.461	.052	12.62	3.20	15.82
Right Foot	14.92	.474	.053	13.49	3.11	16.60
Left Shank	33.71	1.758	.197	30.07	7.67	37.74
Right Shank	33.87	1.030	.115	30.44	6.22	36.66
Left Thigh	38.67	.828	.093	35.43	6.30	41.73
Right Thigh	39.47	.811	.091	36.94	6.15	43.09
Head	24.04	.972	.109	19.96	7.31	27.27
Torso	42.05	.717	.081	40.18	4.99	45.17
Pelvis	15.38	1.022	.115	11.95	7.06	19.01
Left Hand	9.08	.634	.071	6.73	4.28	11.01
Right Hand	10.40	.691	.077	7.84	4.84	12.68
L. Forearm	23.80	.689	.078	21.96	4.83	26.79
R. Forearm	23.91	.692	.078	21.25	4.70	25.95
L. Upperarm	26.19	.634	.071	23.47	4.57	28.04
R. Upperarm	27.42	.777	.087	24.95	5.88	30.83

N=240

Table 4

Descriptive Statistics for Segment Lengths in Centimeters as Calculated from Digitized Data for Dancer C

Segment	Mean	SD	SEm	Min	Range	Max
Left Foot	14.27	.539	.058	12.30	3.85	16.15
Right Foot	14.56	.510	.056	12.87	3.17	16.04
Left Shank	36.95	1.318	.144	33.58	5.67	39.25
Right Shank	36.93	1.155	.126	32.24	6.75	38.99
Left Thigh	41.18	.998	.109	38.20	5.32	43.55
Right Thigh	41.89	1.362	.149	38.10	6.25	44.35
Head	23.70	1.142	.124	19.63	2.15	26.07
Torso	39.77	.465	.051	38.32	3.19	41.51
Pelvis	15.17	.963	.103	8.32	8.71	17.08
Left Hand	11.97	.544	.060	10.08	3.39	13.47
Right Hand	11.47	.431	.047	10.29	1.99	12.28
L. Forearm	24.58	.537	.058	22.70	2.68	25.38
R. Forearm	24.34	.573	.063	22.67	6.50	28.82
L. Upperarm	27.07	.755	.083	25.18	4.04	29.22
R. Upperarm	29.75	.065	.071	27.32	4.51	31.83

N=251

a research associate at the Texas Woman's University, and Odoms, for use at the Texas Woman's University. This final program was utilized to obtain velocities, accelerations, vertical and horizontal forces, moments of force, and total body center of gravity.

Procedures in the Preparation of the Final Written Report

The final written report was prepared by developing chapters in accordance with the tentative outline. The document was submitted to members of the dissertation committee for suggestions and corrections and was revised accordingly. A summary of the research was prepared; the final findings were interpreted, discussed, and presented; recommendations for further studies were suggested; and the appendices and references were developed.

CHAPTER IV

PRESENTATION OF THE RESULTS OF THE STUDY

The dearth of research in dance leaves many unanswered questions about dance technique. Practices which have evolved through intuition or through trial and error need to be studied for actual validation. At this time, however, few dancers possess the research skills and tools to engage in biomechanical analysis of movement. In addition, researchers who have access to highly sophisticated technology and methodology and who have the interest and experience in the dance to adequately interpret the findings of such studies are few in number.

The present study was an attempt to determine the kinetics of the <u>grand plié</u> with and without torso movements through the use of an available validated computer program. Since the computer program was designed to yield forces based upon two dimensional input, the data from front and side views of this study were merged to obtain a theoretical third view, which in actuality was two dimensional in output. For this reason and since the program had been validated on a motion which maintained only one foot on the ground, the resultant force data must be viewed not as absolute in value, but in a relative sense.

Because of the length of the computer program and the massive volume of raw data resulting from the study, neither is reproduced in this document. Both the program LAMB.FOR and the raw data for the study are on file at the Computer Center of the Texas Woman's University.

In Chapter IV a description of the subjects used in the study and the results of the investigation are presented. The results are discussed under the headings: (a) patterns of force moments, (b) sequence of dominant muscle groups, (c) patterns of types of muscle contraction, (d) excursion of total body center of gravity, and (e) purposes of the *grand plié*.

Description of the Subjects

Three subjects were selected for the study on the basis of the ratings of a panel of judges. They were mature dancers enrolled in a summer dance workshop at the Texas Woman's University. The dancers had an average of

16 years of formal training in modern dance and 12 years of training in ballet. The subjects ranged in age from 24 to 34 years and were of varying body types. The heights ranged from 52 to 65.5 inches and body weights were from 100 to 118.5 pounds. Subject A had received specific training in both stylistic variations of the *plié* in previous professional study. Subjects B and C learned the two variations during the practice sessions (Table 5).

Patterns of Force Moments

The patterns of force moments recorded for the hip, knee, and ankle joints were remarkably similar within *plié* for each dancer. The graphs for each joint are almost identical (Figures 1, 2, and 3). The patterns, therefore, will be presented by style of *plié* for each dancer with particular mention of variance where there is noticeable occurrence.

For Dancer A the moments decreased slightly on the descending phase of all three *pliés*, with the lowest figure recorded at the depth of the *plié*, at the point where the motion changed direction. On the ascending phase, the moments rose sharply reaching a maximum peak when the heels returned to the floor. The moments then dropped

Table 5

Descriptive Data on Subjects

Subject	Age in years	Height in inches	Weight in pounds	Years of dance training	
				Modern	Ballet
A	34.5	63.5	100	14	4
B	29.25	52.0	118.5	4	25
C	24.0	65.5	115.5	9	7

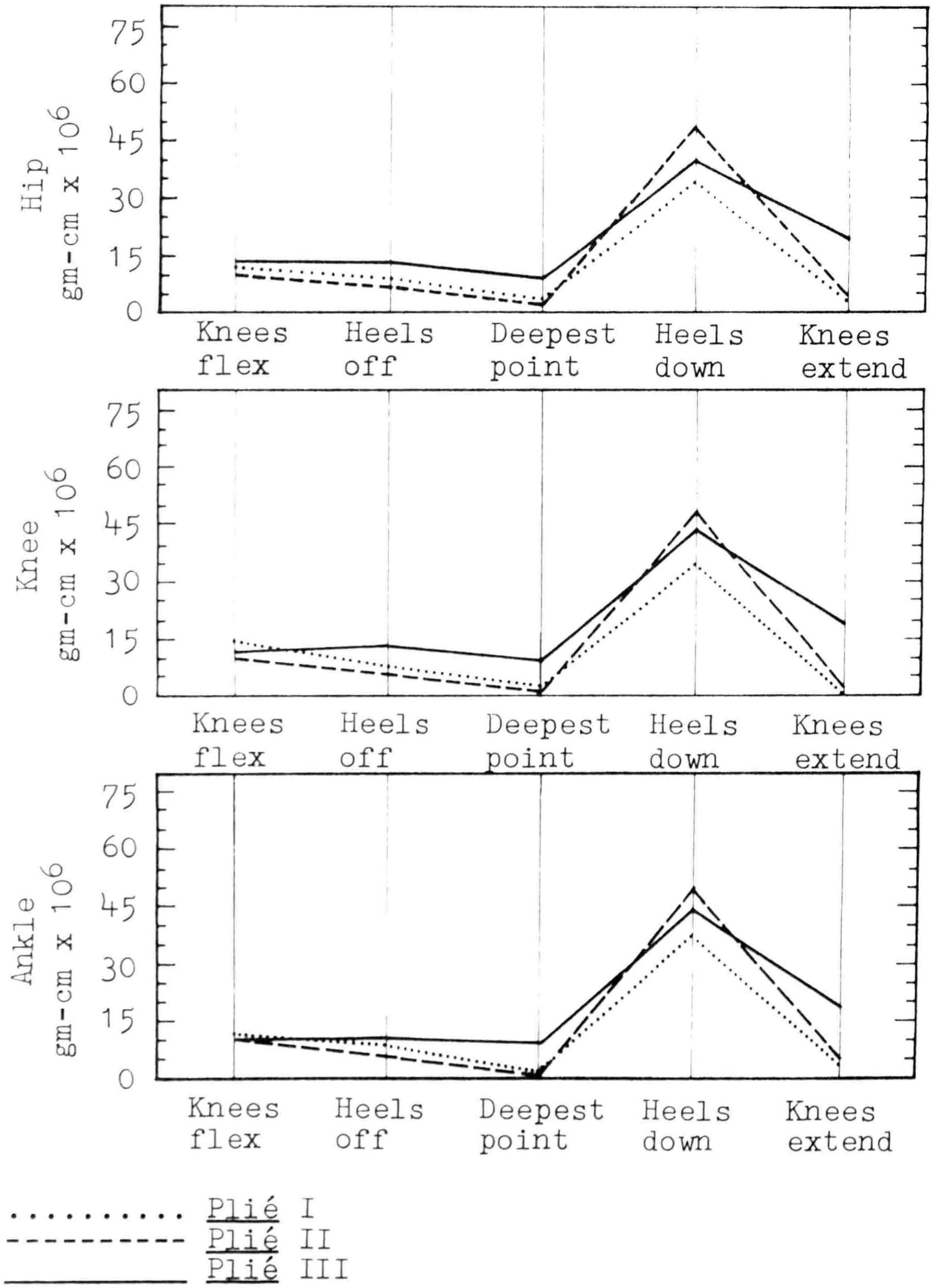
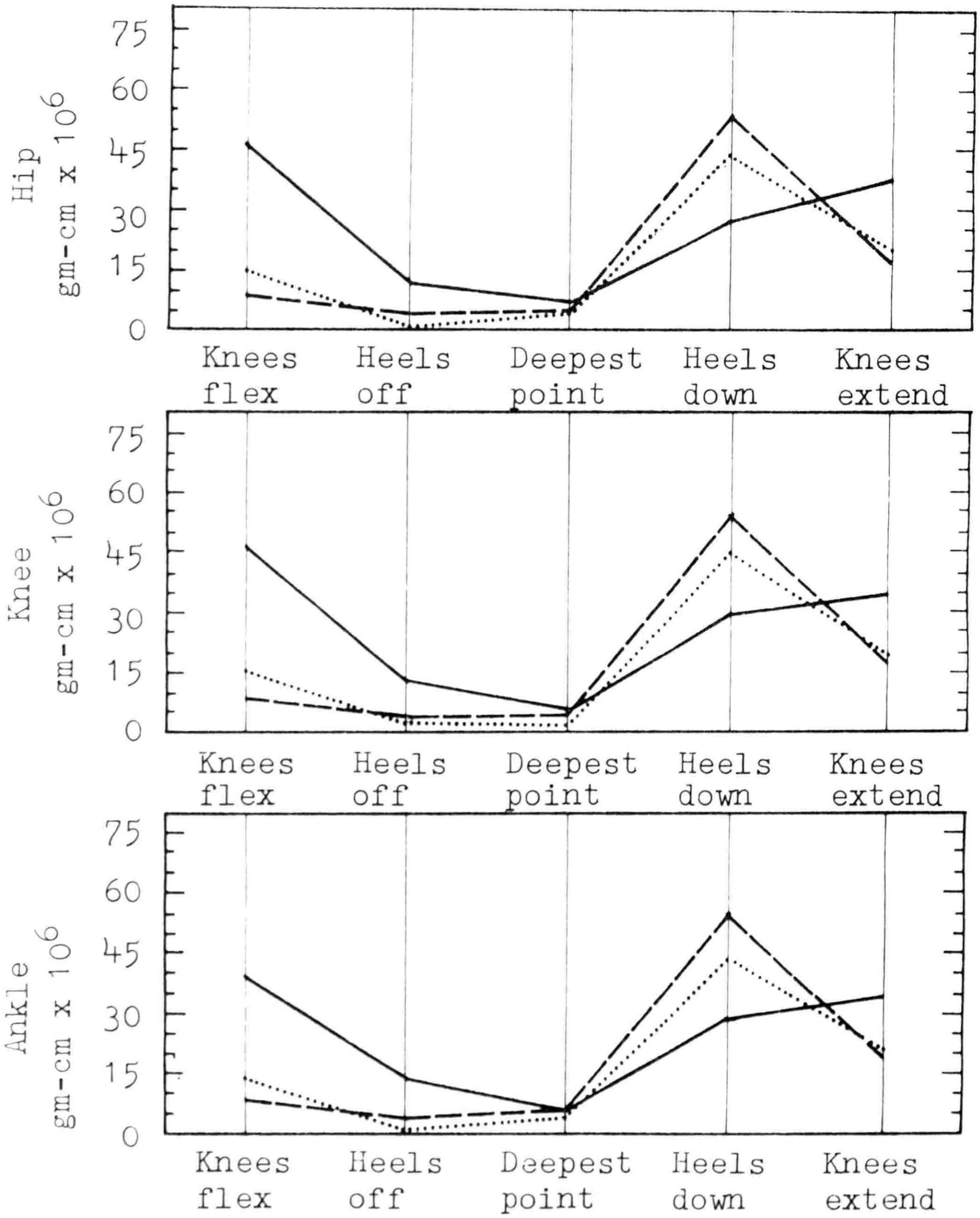


Figure 1. Moments of Force for Ankle, Knee, and Hip Joints During Performance of Three Styles of *Plié* by Dancer A



.... *Plié* I
---------- *Plié* II
―――――― *Plié* III

Figure 2. Moments of Force for Ankle, Knee, and Hip Joints During Performance of Three Styles of *Plié* by Dancer B

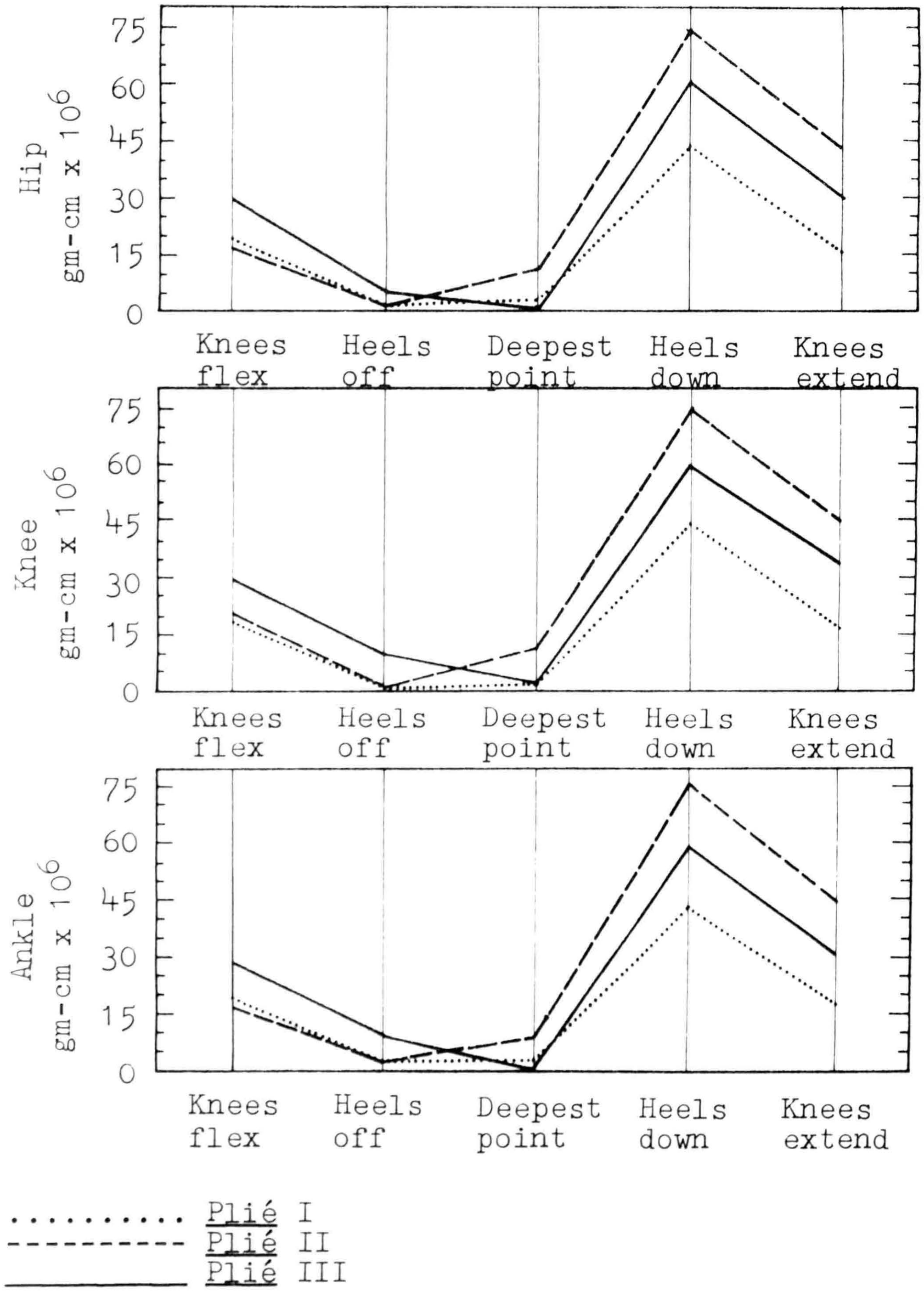


Figure 3. Moments of Force for Ankle, Knee, and Hip Joints During Performance of Three Styles of *Plié* by Dancer C

sharply to return to a level approximating that at the beginning of knee flexion. When Dancer A's heels returned to the floor, the moment recorded for Plié I was the lowest of the three pliés. That of Plié III was approximately 11% greater than that of Plié I. Plié II showed force moments 25% greater than for Plié I and 15% greater than for Plié III (Figure 1).

The overall pattern for Dancer C was very similar to that of Dancer A. The same decrease appeared on the descent with the lowest moment recorded at the depth of the plié. The same sharp rise occurred with the maximum moments at the point where the heels returned to the floor. The moments then fell to approach the original levels at knee flexion. For Dancer C, Plié I yielded the lowest overall peak moment during performance. As in the case of Dancer A, Dancer C's Plié III showed a 25% increase over Plié I; Plié II showed a 38% increase over Plié I and a 25% gain on Plié III. For both dancers, Plié II seemed to cause the greatest amount of torque at the hip, knee, and ankle joints and Plié I the least, with Plié III falling in between (Figure 3).

The pattern for Dancer B was almost identical to that of Dancers A and C with respect to performance of Pliés I and II. A variation occurred, however, in the overall pattern of _Plié_ III and also in the relationship of the moments of _Pliés_ II and III to those of _Plié_ I. The results for Dancer B showed that at the point of heel contact on the ascending phase, _Plié_ III generated a lesser amount of torque than did _Pliés_ I and II. In fact, the data showed that at the point where one might expect the greatest amount of torque the numbers were lower than at the point of initial knee flexion and final knee extension. The force for _Plié_ III appears to be 31% lower than for _Plié_ I as opposed to the pattern of the other two dancers, whose _Pliés_ III showed a considerably higher indication of torque than for _Plié_ I (Figure 2).

Sequence of Dominant Muscle Groups

The sequence of dominant muscle group action for each dancer was the same for the hip, knee, and ankle joints. There was variation, however, among styles of _plié_ for each subject. There were approximately 80 positions analyzed for each dancer with the descending and rising phases occupying about 40 positions each. Four patterns were apparent immediately but on closer examination it was determined that the pattern for all three _pliés_ for all dancers was essentially the same with the exception of *Plié* III for Dancer C (Tables 6, 7, and 8).

For eight of the nine sets of data the extensor groups were dominant during the major portion of the descending and rising phases. It appears that in some cases the flexors simply initiated the movement at the point of knee flexion and that the flexors came into play at the end of the rising phase to terminate the motion. In other cases the flexors seemed to dominate until the heels left the floor. In those cases where a few frames were analyzed before knee flexion and after knee extension, the extensors were dominant in the postural or anti-gravity role.

The number of frames for analysis and the varying starting and stopping points were dictated by the quality and availability of the film data. The front view data were complete; however, some of the side view data were missing. By starting the analysis at the moment of knee flexion and continuing through knee extension a thorough study was possible. In some cases a few extra frames at the beginning and ending of the motion were included because they were available. If a consistent number of frames had been accessible for study, all patterns might

Table 6

Dominant Muscle Groups and Types of Muscle Contraction During Performance of Three *Pliés* by Dancer A

Positions	Ankle, knee, and hip action	Dominant muscle group	Type of muscle contraction
		Plié I	
1-42*	Flexion	Extensors	Eccentric
43-50	Extension	Extensors	Concentric
51-73	Extension	Flexors	Eccentric
73-81	Extension	Extensors	Concentric
		Plié II	
1-5	Flexion	Extensors	Eccentric
6-8	Flexion	Flexors	Concentric
9-41*	Flexion	Extensors	Eccentric
42-50	Extension	Extensors	Concentric
51-70	Extension	Flexors	Eccentric
71-80	Extension	Extensors	Concentric
		Plié III	
1-12	Flexion	Flexors	Concentric
13-37*	Flexion	Extensors	Eccentric
38-50	Extension	Extensors	Concentric
51-75	Extension	Flexors	Eccentric

*Depth of *plié*

Table 7

Dominant Muscle Groups and Types of Muscle Contraction During Performance of Three *Pliés* by Dancer B

Positions	Ankle, knee, and hip action	Dominant muscle group	Type of muscle contraction
		Plié I	
1-17	Flexion	Flexors	Concentric
18-40*	Flexion	Extensors	Eccentric
41-51	Extension	Extensors	Concentric
52-82	Extension	Flexors	Eccentric
		Plié II	
1-13	Flexion	Flexors	Concentric
14-39*	Flexion	Extensors	Eccentric
40-50	Extension	Extensors	Concentric
51-80	Extension	Flexors	Eccentric
		Plié III	
1-24	Flexion	Flexors	Concentric
25-40*	Flexion	Extensors	Eccentric
41-50	Extension	Extensors	Concentric
51-78	Extension	Flexors	Eccentric

*Depth of *plié*

Table 8

Dominant Muscle Groups and Types of Muscle Contraction During Performance of Three *Pliés* by Dancer C

Positions	Ankle, knee, and hip action	Dominant muscle group	Type of muscle contraction
		Plié I	
1-40*	Flexion	Extensors	Eccentric
41-50	Extension	Extensors	Concentric
50-78	Extension	Flexors	Eccentric
79-82	Extension	Extensors	Concentric
		Plié II	
1-20	Flexion	Flexors	Concentric
21-43*	Flexion	Extensors	Eccentric
44-50	Extension	Extensors	Concentric
51-88	Extension	Flexors	Eccentric
		Plié III	
1-24	Flexion	Flexors	Concentric
25-31	Flexion	Extensors	Eccentric
32-39*	Flexion	Flexors	Concentric
40-81	Extension	Flexors	Eccentric

*Depth of *plié*

have followed that for Dancer A, Plié II, with the obvious exception of Dancer C's Plié III.

As indicated in Table 6, all three plié patterns for Dancer A were similar except that the flexors initiated the movement on Pliés II and III, and on Plié I, the extensors were dominant during the entire descent. The two more complex styles may have caused the dancer, through tension or anticipation, to consciously work the flexors, whereas the standard plié seems to have been accomplished by simply resisting gravitational pull.

Dancer B was consistent in that the flexors were dominant until the heels were listed, and the extensors accomplished the remaining descent and the ascent to a point where the heels touched again. The flexors apparently were activated to finish or stop the motion (Table 7).

The pattern for Dancer C's Plié I was almost identical to Dancer A's and her pattern for Plié II was quite similar to that of Dancer B. Plié III, however, was completely different from any of the other pliés. Results indicated that during Plié III for Dancer C the flexors initiated the motion and the extensors were activated for a few positions toward the end of the descent. For several positions at the depth of the *plié* and on the rise, the flexors appeared to be the prime movers (Table 8).

Patterns of Types of Muscle Contraction

The data resulting from the study revealed that all three subjects were alike with respect to the types of muscle contraction involved with the performance of the *plié* except for Dancer C's performance of *Plié* III. Eight trials by three dancers utilized eccentric contractions on the descent and concentric contractions on the ascent. As indicated by Tables 6, 7, and 8, employment of the flexors during joint flexion resulted in muscular contraction that was concentric. When the dancer employed the extensors, a lengthening or eccentric contraction was obtained. On the ascent a concentric contraction resulted if the extensors were employed during extension; if the flexors were activated, an eccentric contraction was present. In the case of *Plié* III by Dancer C which did not conform to the expected sequence of dominant muscle group action, the pattern of muscular contraction was exactly opposite to the other eight cases.

Excursion of the Total Body Center of Gravity

Graphs of the excursion of the total body center of gravity may be found in Figure 4. The data for center of gravity are graphically represented from a 45 degree angle between the sagittal and frontal views. Displacement upward, downward, forward, backward, and sideward are reflected.

One would expect the center of gravity path during Plié I to be essentially vertical in direction. For Plié II, the primary direction should be vertical with the addition of forward and backward movement to accommodate torso flexion in the sagittal plane. For Plié III, one would expect to find vertical displacement with lateral compensation for the torso movements in the frontal plane.

The vertical displacement of the center of gravity for Dancer A was similar in depth for Pliés I and II but the path was slightly longer for Plié III. The overall range of displacement in the frontal and sagittal planes was nominal indicating that the torso movements necessitated only slight shifting or realigning during the performance of Pliés II and III. For Plié I the path upward was consistent with the excursion downward. For

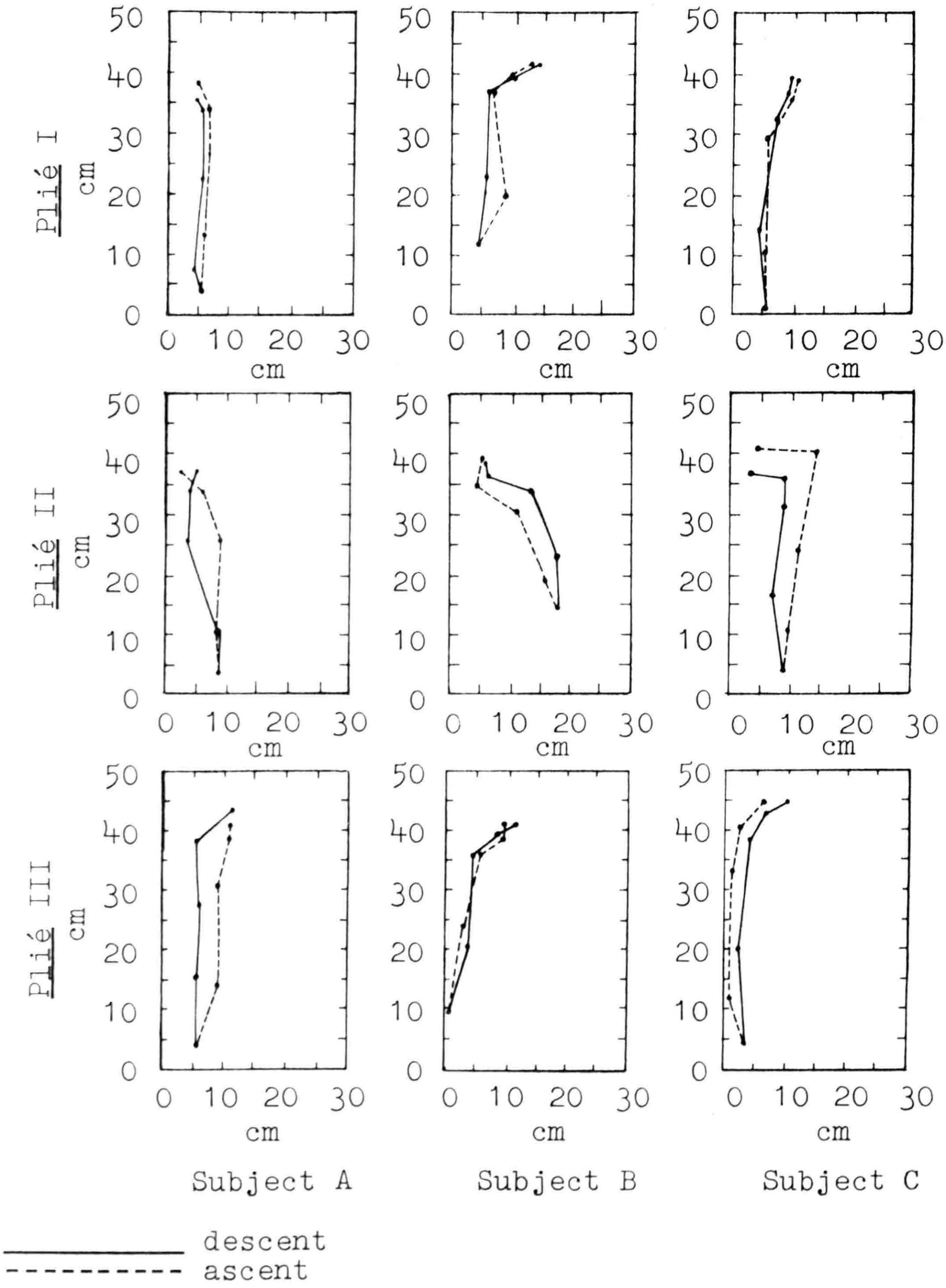


Figure 4. Excursion of Total Body Center of Gravity During Performance of Three Pliés by Three Subjects

Pliés II and III, the path upward approximated a mirror image of the downward excursion.

Dancer B's performance reflected varying amounts of vertical excursion with Pliés I and III noticeably deeper than the path of Plié II. The range of deviation in the frontal and sagittal planes was similar in all three pliés and was more than twice as great, relatively speaking, than that of Dancer A. The excursion path of Plié III was almost identical on the descending and rising phases and that for Pliés I and II, respectively, suggested mirror images.

For Dancer C, the range of the vertical aspect of excursion was similar for all three performances. The graph of the descent of Plié I is almost identical to that of the ascending phase. During Plié II there appeared to be an abrupt shift of weight at the beginning and at the conclusion of the performance. Plié III seemed to have a path similar to that of Plié I. Overall, indications were that the vertical path of the center of gravity showed more depth on Plié III for all dancers than on the other two styles. Likewise, the path for Plié II was consistently the most shallow.

Purposes of the Grand Plié

Judging empirically from study of the filmed data, the investigator found that the *grand plié* has the potential for fulfilling its presumed purposes of stretching and strengthening the legs, increasing outward rotation at the hips, improving balance, and stretching and strengthening the back. The results of the study, as presented under the section entitled "Patterns of Types of Muscle Contraction" (see page 62), further substantiate the claim that stretching and strengthening of the leg can occur. This purpose of the *plié* and the remaining three which were judged solely by observation will be discussed in Chapter V.

CHAPTER V

SUMMARY, CONCLUSION, DISCUSSION, AND RECOMMENDATIONS FOR FURTHER STUDIES

In this chapter a summary of the investigation is given. A conclusion is presented and the findings of the study are discussed in relation to the hypotheses and the purpose of the investigation. Finally, recommendations for further research are proffered.

Summary of the Investigation

The *grand plié* is used in virtually all forms of dance as the basis of the technical training of the dancer. Sources are in agreement as to the proper performance of the *grand plié* but there is no known research which provides evidence that the *plié*, when properly performed, fulfills its presumed purposes. Further, there is no scientifically based evidence of the results of improperly performed *pliés*. Since the *plié* is accepted to be the foundation for almost all dance motion, it should be of great interest to teachers and performers to know more about the practice of the technique.

The scope of the present investigation was to determine through the use of cinematography the biomechanics of the *grand plié* with particular emphasis upon the manner in which the performance is affected mechanically by the addition of torso movements. The investigator's intent was to validate the purposes of the *grand plié* as presented in existing literature and to provide a sound mechanical rationale for the use of torso flexion movements during the performance of the *grand plié*. A search of the literature revealed that there is no published research of any kind on the *grand plié* and no studies which deal with the kinetics of dance motion.

In the present study, film data were collected on the 12 most highly skilled subjects as determined by a panel of five judges on the basis of accuracy of performance of the *grand plié*. The final three subjects were those selected as the best of the 12 on the basis of their filmed performance of the *grand plié* by five additional judges. Front and side view film data were synchronized, digitized, and merged for subsequent computer analysis.

A computer program entitled LAMB.FOR was utilized to obtain moments of force for the ankle, knee, and hip joints and excursion of total body center of gravity. The findings of the study are summarized as follows:

1. Force moments for ankle, knee, and hip joints were almost identical within *plié* for each dancer.

2. The greatest amount of torque occurred at the point where the heels returned to the floor during the ascending phase for eight of the nine performances.

3. The least amount of torque was generated on the descent at the point where the heels lifted and at the depth of the *plié*.

4. *Plié* II generated a greater amount of force on heel contact than *Plié* I and *Plié* III for all three subjects.

5. The lowest peak force moment was recorded for *Plié* I in eight of the nine performances.

6. The sequence of dominant muscle group action was the same for the ankle, knee, and hip joints within *plié* for all dancers.

7. The sequence of dominant muscle group action was the same in eight of the nine performances.

8. The extensor group was dominant during the descending and ascending phases in eight of the nine performances.

9. The pattern of types of muscle contraction was identical for the ankle, knee, and hip joints within *plié* for each dancer.

10. The pattern of eccentric contraction on the descent and concentric contraction on the rise prevailed in eight of the nine performances.

11. The total body center of gravity excursion for *Plié* I was essentially vertical for all three subjects.

12. The path of the total body center of gravity for *Pliés* II and III was vertical with noticeable displacement in the sagittal and frontal planes.

13. The depth of excursion of the center of gravity for *Plié* III was greater than that for *Plié* I and *Plié* II for all dancers.

14. The depth of excursion of the center of gravity for *Plié* II was less than that for *Plié* I and *Plié* III for all dancers.

15. Frontal and sagittal deviations of the center of gravity were twice as great for Dancers B and C than for Dancer A.

Conclusion

The performance of the *grand plié* is accurately described by the literature and the potential exists to fulfill its purposes. The rationale for adding torso movements to the performance of the *grand plié* appears to be mechanically sound; but the addition of torso movements increases the level of difficulty of the *plié*.

Discussion

The following discussion will center about three areas. First, points of interest with respect to the findings of the study are presented. A discussion of the claims for the plié made in the literature are examined, and finally, attention is given to the advisability of adding torso movements to the performance of the grand plié.

Discussion of Findings of the Study

The moments of force at the hip, knee, and ankle joints during performance of the plié were different from those of the plié when performed with torso movements. Overall, the force moments were similar except at the point of heel contact. At that instant, the least amount of force was recorded for Plié I and in two out of three cases the greatest amount was recorded for Plié II. The exception was Dancer B's performance of Plié III. The force moments were completely out of sequence with the other performances. In viewing the film the only noticeable difference in Dancer B's performance was that the subject appeared to shift the rib cage sideward, instead of sequentially flexing in a lateral direction from the head through the lumbosacral joint as the other dancers did. At this time the investigator is unable to offer any further explanation.

The sequence of force moments, as reflected in the sequence of dominant muscle group action, during the performance of the plié was the same as for the plié performed with torso movements. The sequence was consistent for eight of the nine performances. In the case of Dancer C's performance of Plié III the sequence was exactly opposite to the established pattern. In viewing the film, nothing was observed to explain this phenomenon.

The pattern for types of muscle contraction during the performance of the plié was the same for all three styles of plié. The basic pattern of eccentric contraction on the descent and concentric contraction on the rise prevailed in eight of the nine performances. Plié III as performed by Dancer C, again, was the exception. The pattern obtained was exactly opposite to that of the other eight cases since the pattern of force moments, as mentioned above, was also opposite. It is possible that Dancer C employed the flexors on the descent to counterbalance the weight of the torso during lateral flexion of ✓ the spine in an effort to maintain a stable pelvis. The same action would be necessary on the rise. This could account for the unusual pattern.

The path of the total body center of gravity during the performance of the respective styles of plié was similar for all dancers. The path for Plié I for each of the three subjects was the most comparable. The paths for Plié II showed the most disparity with Dancer C's being least similar. In studying the film data, it was learned that Dancer C flexed the cervical spine at the beginning of the motion and held the torso relatively stationary during the descent and the rise. At knee extension the cervical spine extended. This action probably accounted for the abrupt change of the path at the start and finish of the performance. The greatest amount of deviation in the sagittal plane occurred during Dancer B's performance of Plié II. It was apparent from the film that the subject possessed unusual flexibility in the lumbar spine. The greater range of flexion caused a broader range of deviation in the sagittal plane.

Plié III for all three subjects produced the deepest excursion of the center of gravity. Examination of the film data revealed that the dancers tended to "sit" slightly deeper into Plié III while moving the torso from the laterally flexed position through extension to the laterally flexed position on the other side. It is accepted that "sitting" into the grand plié places undue stress on the ligamentous structure of the knee joint (Rasch & Burke, 1974). By complicating the plié with lateral torso flexion movements, the dancers tended to allow this unwanted action to occur.

It would be conjecture at this point to suggest that authentication of the purposes of the plié could be obtained by examining the results of this investigation. An attempt has been made, however, to answer certain questions about the grand plié by employing the results of the study and through careful perusal of the film.

Of particular interest to the investigator were the following: (a) how accurately the plié is described in the literature, (b) whether the plié fulfills its supposed purposes, and (c) whether torso movements should be added to the performance of the plié as part of the studio training of the dancer.

Some sources describe the grand plié more thoroughly than others. All agree that one aspect of proper performance is control of forward pelvic tilt. Study of the slow motion film data revealed that there was some pelvic tilt exhibited by every subject. If the slight tilt is present in all dancers, perhaps teachers should ensure that students adjust the upper torso slightly forward to prevent shortening or hyperextension of the lumbar portion of the spine.

The literature also recommends that the knee should be aligned over the center of the foot, emphasizing the importance of outward rotation only at the hip joint. This caution stems from the fact that once the knee is flexed there is a tendency among dancers to attempt to increase the illusion of rotation by pressing the heels forward and consequently rotating the tibia. Tibial rotation causes the knee to fall inside the medial border of the foot, a position which is stressful to the knee and foot. The investigator found that after flexion began one subject could increase outward rotation at the hip to the point where the knee was beyond the outer border of the foot. The question remains as to whether the dancer should withhold rotation or promenade the balls of the feet to maintain knee over foot alignment.

The literature suggests that the purposes of the *plié* include stretching and strengthening the legs, increasing turnout, improving balance, and stretching and strengthening the back. In the opinion of the writer, the *plié*, to some extent, can accomplish these purposes. Since gravity is a flexor, the *plié* action could stretch and strengthen the legs. The descending phase is accomplished by an eccentric contraction and the rise involves a concentric contraction, both of which enhance strength. By definition, the *plié* is performed in an outwardly rotated position. By repetitious practice the musculature surrounding the hip joint could be strengthened and thereby encouraged to hold the turnout at the maximum range allowed by the skeletal and ligamentous structure. Balance could be improved by virtue of the fact that the dancer is working on a very small base of support, but it would appear that minimal strengthening and stretching of the back muscles would take place. Though none of these purposes was specifically validated by the present study, there were no contradictions.

Rationale for Adding Torso Movements to the Plié

The literature as well as teachers of the dance agree that *pliés* should be done carefully and slowly. The *demi plié* seems to be a good place to work toward corrections on alignment. Kersley (1962) referred to the fact that some teachers complicate *pliés* with elaborate *port de bras* (arm movements). Kersley believes that arm movements should be minimal since *pliés* are preparatory and closing movements and that the student runs the risk of forming habits which may result in a clumsy opening or a blurred finish. The investigator's primary concern was not one of the aesthetics of clean stops and starts, but of safety and efficiency. It appeared that when the torso was displaced, a shift in the center of gravity was accompanied by realignment in the remainder of the body, particularly in the base of support, in order to maintain balance. If the alignment of the hips, knees, and ankles must change to accommodate the displacement of the torso, the investigator believes that it would be unwise to include torso movements with the *plié* as part of the fundamental training of the beginning dancer.

Recommendations for Further Studies

The following are recommendations for further research studies:

1. Replicate the study using dancers who are professionally trained in the two stylistic variations of the *grand plié*.

2. Replicate the study collecting in addition electromyographic data on the subjects.

3. Conduct a complete biomechanical analysis of other dance movements such as *battements*, jumps, leaps, falls, and turns.

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APPENDIX A

ILLUSTRATIONS

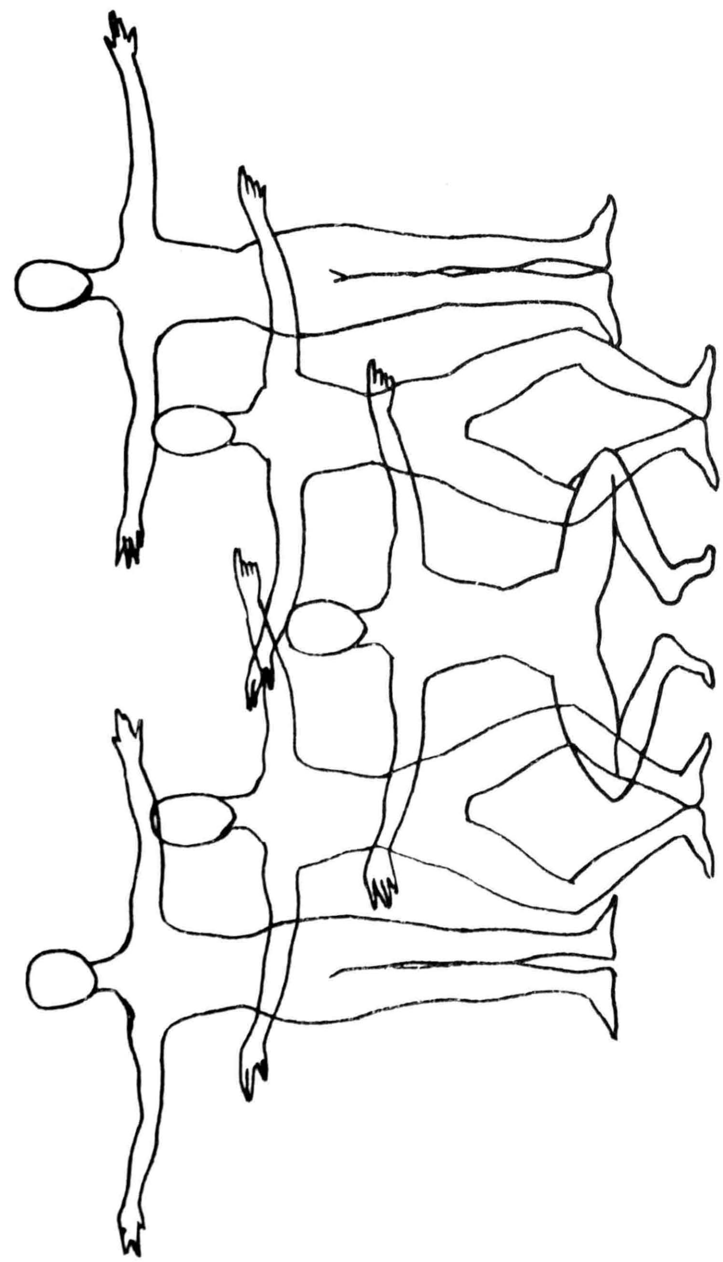

Illustration 1. Plié I

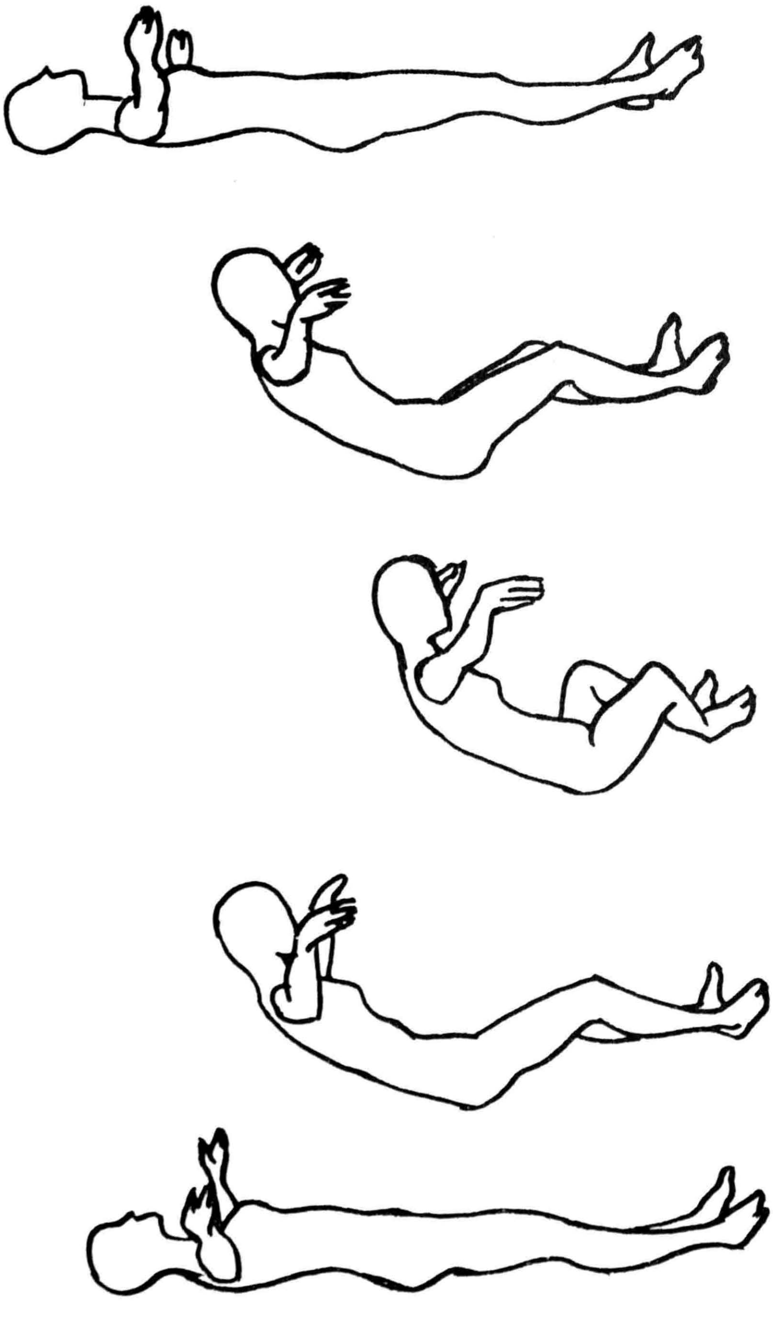

Illustration 2. *Plié* II

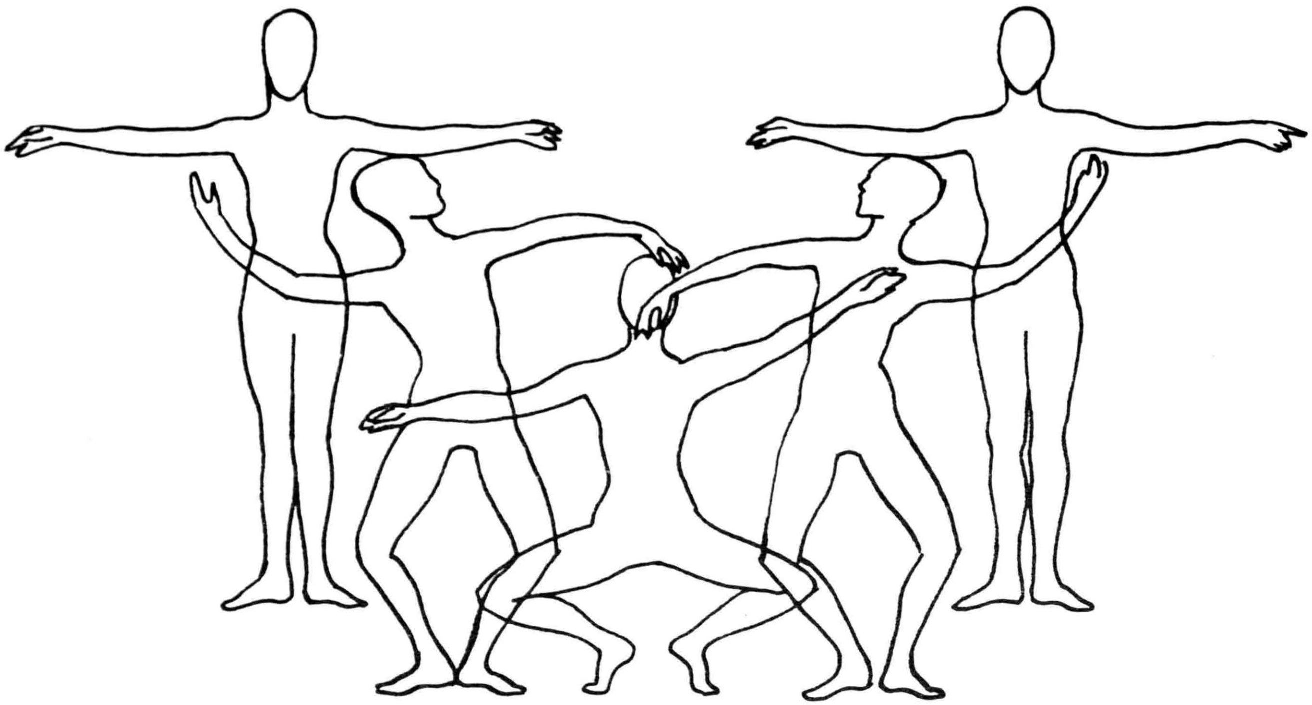

Illustration 3. <u>Plié</u> III

APPENDIX B

RESUMÉS OF JUDGES

RESUMÉ

Mary Moe Adams

Mary Adams, born and educated in Malaysia, entered the Royal Academy of Dancing, London, England where she received certificates from the Royal Academy and from the Academy's Teacher Training College, graduating with High Honors. She taught in Malaysia, London, and Phoenix before forming her own academy in Tempe, Arizona. Mrs. Adams taught part time as a faculty associate at Arizona State University for four years while continuing to operate her private school.

RESUMÉ

Mary Jane Bird

Mary Jane Bird received her early training in ballet from Nina Coppola and Rozella Kinslow in Albuquerque, New Mexico. She performed with the Oklahoma Civic Ballet Company before moving to Arizona. After completing the Bachelor's Degree in Dance at Arizona State University, she taught for three years at Trevor Browne High School in Phoenix. She returned to Arizona State University as a graduate teaching assistant while working toward the Master of Arts Degree. Mrs. Bird, an authority on Native American Indian dance, has lectured and performed throughout the Southwest under the name Blue Horizon Bird. She currently teaches dance at Park City High School in Park City, Utah.

RESUMÉ

Donald Bradburn

Don Bradburn received dance training from the American School of Dance, the San Francisco Ballet, and the University of California at Los Angeles. His performing credits include the San Francisco Ballet, the Australian Ballet, the Los Angeles Dance Theater, and over 40 musicals. He has directed and choreographed stage reviews, night club acts, and cabaret shows for such well known entertainers as Glen Campbell, Bobby Gentry, Carol Lawrence, Tina Louise, Barbara Eden, and Frank Sinatra. Bradburn co-founded and directed his own company and, in addition to his other dance activities, is a professional photographer and writer who serves as the West Coast Representative for _Dance Magazine_.

RESUMÉ

Marilyn Jo Brightman

Marilyn Brightman operated two private studios in Lansing, Michigan for four years before teaching dance at Jefferson High School in Monroe, Illinois. She earned the Bachelor of Arts degree at Eastern Michigan University and the Master of Arts degree from the University of Michigan. Marilyn was an instructor of dance at Fort Hays State University in Kansas for five years. While in Kansas, she served as Dance Chair of the Kansas Association for Health, Physical Education, and Recreation and Chair of the Hays Arts Council. She resigned from Hays State to pursue doctoral work at the Texas Woman's University.

RESUMÉ

Rosann McLaughlin Cox

Rosann Cox received a Bachelor of Arts degree from Sam Houston College, Huntsville, Texas. She continued her training at the University of Wisconsin, Madison, before attending the University of Houston where she received the Master of Education degree. After professional study at the Connecticut College Summer School of Dance, she returned to Houston where she taught on the dance faculty of the University of Houston for several years. For seven years of her tenure at Houston, she performed professionally in musicals for the Theater Incorporated of Houston. She completed the Doctor of Philosophy degree at the Texas Woman's University while teaching part time at that institution. Dr. Cox has been listed in <u>Who's Who in American Education</u> and was program director for the 1978 National Dance Association Conference. She is currently the Dance Coordinator for the Dallas Independent School District Arts Magnate High School.

RESUMÉ

Lisa Ann Fusillo

Lisa Fusillo received her early training in ballet from the Washington School of Ballet and the Barbara Sheppard Academy of Dancing. She majored in dance at Butler University and continued her training at the Royal Academy of Dance in London, England. She holds the Bachelor of Science degree from George Washington University and a Master of Arts degree from the Texas Woman's University. She is certified to teach the ballet technique of Leonide Massine and is a member of the Royal Academy of Dancing and the Imperial Society of Teachers of Dancing. Ms. Fusillo is presently on the dance faculty at Skidmore College.

RESUMÉ

Margaret Gisolo

Margaret Gisolo received the Bachelor of Science degree from Indiana State College and the Master of Arts degree from New York University. Her professional study was with Doris Humphrey, Charles Weidman, Mary Wigman, and Hanya Holm. A leader in the field of dance in the Southwest, she developed and chaired the dance program at Arizona State University from 1956 through 1977. Among numerous honors she was listed in Who's Who of American Women and received the Arizona State University Distinguished Teacher Award for 1979. Ms. Gisolo retired in 1980 as Professor Emeritus of Dance.

RESUMÉ

John Hofsas

John Hofsas began his theatrical training as an actor and director at Knox College where he received a Bachelor of Arts degree in theater. After becoming interested in dance, he studied with Beverly Blossom, Chester Wolensky, Rudy Perez, Shirley Ririe, Peggy Hackney, and others. He completed a Master of Arts degree in theater from the University of Illinois and a Master of Fine Arts degree in dance from Southern Methodist University. He was founder and artistic director of the Contemporary Dance Theater of Dallas and taught for the Dallas Independent School District Arts Magnate High School. Mr. Hofsas is currently in New York studying and performing.

RESUMÉ

Gary Naylor

Gary Naylor received his early training in Phoenix, Arizona with Mary Girard Tierney. He studied with the Royal Ballet in England, the American School of Dance in Los Angeles, the San Francisco Ballet, and in New York City before completing the Bachelor of Fine Arts degree in musical theater at the United States International University in San Diego. Mr. Naylor has extensive performing and choreographic experience with musicals, night clubs, and cabarets. He danced professionally in Las Vegas, toured the world with Disney on Parade, and performed and choreographed for the Phoenix Metropolitan Dance Theater. He is a member of Actors Equity Association, has been a professional costume designer for Las Vegas shows, and has taught jazz part time at Arizona State University. He is the founder and director of the Gary Naylor Dance Company and the Phoenix Dance Center both in Phoenix, Arizona.

RESUMÉ

Jack Slater

Jack Slater began performing professionally immediately after high school with the Dorothy Hild Dancers. Trained at the Camryn-Stone Studios in Chicago, he continued his career, becoming a member of Equity Actors Association, and performing in the Chicago and Milwaukee areas with the Melody Top Theater chain. He moved to Peoria, Illinois where he founded and directed the Peoria Civic Ballet Company and directed the dance activities at Illinois Central College for 10 years. He has choreographed 41 musicals for summer and winter stock in university theaters. Since moving to Arizona, he founded and directed the Scottsdale Civic Dance Theater for one year and taught part time at Arizona State University. He currently teaches privately.

APPENDIX C

RATING FORM

RATING FORM

DANCER______________________________

Check the box which most accurately describes performance of the Grand Plié

	Never	Sometimes	Most of the time	Always
1. Shoulders were over hips				
2. Head was aligned properly				
3. Pelvic alignment was correct				
4. Knees were over arches				

	No	Yes
1. Heels were lifted after demi plié was completed		
2. Heels were returned to the floor as early as possible		

	Poor	Fair	Good	Excellent
1. The dancer's overall alignment was				
2. Overall performance was				