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KINETIC AND TEMPORAL CORRELATES TO SKILLFULNESS IN VERTICAL JUMPING

by

H. Scott Strohmeyer

A Dissertation submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

Greensboro
1995

Approved by

Dissertation Advisor

UMI Number: 9531855

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3/22/95

Date of Acceptance by Committee

3/21/95

Date of Final Oral Examination

STROHMEYER, H. SCOTT, Ph.D. Kinetic and Temporal Correlates to Skillfulness in Vertical Jumping. (1995) Directed by Dr. Kathleen Williams. 178pp.

Vertical ground reaction forces of countermovement jumps with armswing (CMWA) were examined to determine kinetic and temporal strategies related to skillfulness in vertical jumping. Effective integration of the system (EIS) was introduced to examine skillfulness separate from the influences of genetic talent or training. Vertical jump height was considered susceptible to both genetic talents and extensive training. Kinetic and temporal variables from force-time curves of 51 subjects were evaluated for their relationship to skillfulness using both EIS and vertical jump height. It was hypothesized that more of the variance in EIS could be explained by kinetic and temporal variables than by vertical jump height. A second purpose of this investigation was to examine the effects of standardizing force-time curves mathematically to produce a smooth rise to a single peak force. Smooth rises to peak force were attained by fitting a parabolic trajectory to the force record. It was hypothesized that EIS scores and vertical jump heights would improve as a result of the standardization process. Results of this investigation did not fully support the hypothesis that more variance in skillfulness could be explained when skillfulness was determined by EIS. Explained variance for vertical jump height from kinetic and temporal variables was stronger whether the data were examined in standardized or non-standardized forms. When individuals with highest EIS scores or vertical jump heights before standardization were examined (n=24), explained variance using vertical jump height did not occur. Analysis of individuals exhibiting poor performances (n=27) produced no prediction model for EIS. Standardization of force-time curves resulted in improved performance (i.e., hypothetical performance) for all individuals whose performances were standardized (n=43). The prediction model for skillfulness also increased significantly for EIS and vertical jump height following standardization. Prediction models suggested for EIS and vertical jump height, after standardization, used similar parameters for prediction of skillfulness. The results led to the conclusion that factors related to use of the stored elastic component in muscle are significant to skillfulness whether determined by EIS or vertical jump height.

ACKNOWLEDGMENTS

First and foremost, I wish to thank my wife Karen for the patience and fortitude to allow me to struggle through these last few years. Also to the rest of my families for the encouragement and the psychological support necessary to undertake all my many responsibilities. I would be remiss if I did not mention William, Robert, Ethan, Sarah, and Alyse. You're too young to remember this time in our lives, but you all were instrumental in reducing the stress levels of your father as he struggled to see this work to fruition.

In the last few years, It has been my honor to work with a multitude of people who have served to sharpen my thinking, refine my goals, and quite simply helped me to continue to progress as not only a professional, but also as an individual. My thanks to you all.

To Kate Barrett, Bob Muir, Sandy Powers, and Carole Zebas, thank you all for serving as committee members. All gave generously of their time and talents in an effort to make me a better profesional.

My development, however, is primarily the result of two very special individuals. My sincere appreciation goes out to:

Kathleen Williams - who was a strong shoulder to lean on. She offered support and guidance and allowed me to think beyond the bounds of my discipline. Thanks for the theory, and thanks for your encouragement.

Jackie Hudson - who allowed me to explore. I know of no other person with the confidence or the intellect who could have handled the wanderings of this student. Words can never express how this individual has guided my life as a biomechanist.

Finally, a special thank you to the folks at Central Missouri State University: Jim Conn, Ruth Ann Nyhus, Elois Pelton, Jim Pilkington, Bob Tompkins, and Ron Van Dam. Your counsel, pep talks, periodic prodding, and freely offered assistance and support were invaluable, and are the source of many great memories. Thank you all!!

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CHAPTER I

INTRODUCTION

Biomechanic technique is defined as the most efficient method of performing a skill regardless of any stylistic modifications, genetic abilities, and/or training practices of the performer. When determining biomechanic technique, close scrutiny to the physical laws of nature and the temporal coupling of segments must occur (Hochmuth, 1984). Examination of movement for technique parameters allows the researcher to determine the most effective method of executing a skill. Determination of appropriate technique consistently has relied on product measures. Product measures can reflect technique. However, product measures also can be the result of genetic predisposition for the skill or superior training techniques. For example, skill in vertical jumping is typically defined as the maximum height reached by the body's center of mass. In contrast, Hudson (1988) argued that jump height is a composite performance variable which is influenced by the talent and training of the individual performer. Success could be achieved as the result of 1) superior genetic talent (e.g., number of fast twitch muscle fibers), 2) extensive training (e.g., jump-specific weight training), and/or 3) good biomechanical technique (e.g., integrating the segments of the body most appropriately). Hudson stated using a product score such as jumping height is insensitive to differences in technique (Hudson, 1988; Hudson, Strohmeyer & Bird, 1991). She postulated process scores could more readily lead to biomechanic technique determinants by allowing the biomechanist to examine those performers "overachieving" expected standards.

Working from these assumptions about product and process scores, Hudson and colleagues investigated process variables related to vertical jumping. Hudson (1988) found when skillfulness was determined by the height jumped by the performer, process variables such as the use of stored elastic energy (SEE) were not highly correlated. However, when skillfulness was determined by performance differences between vertical jumps of different complexities, use of SEE was strongly related to performance as defined by effective integration. Effective Integration (EI), although related to product, is an index of skillful performance incorporating an intraindividual test to examine changes in performance with the inclusion of a greater number of body segments to the skill.

Hudson (1988) first examined effective integration in vertical jumping by determining the effect of the legs on vertical jumping performance. She called this index of skillfulness Effective Integration of the Legs (EIL). Effective Integration of the Arms (EIA) also has proven useful for determining those performers who use their arms effectively in the vertical jump (Hudson et al., 1991; Wilkerson & Hudson, 1987). In each of these investigations, variables related to timing and coordination were more highly correlated with effective integration (i.e., EIL or EIA) than with the typical product score of jump height (Hudson, 1986; Hudson, 1988). An intra-individually determined improvement measure such as effective integration controls for talent and long-term training. EI for the use of the arms or legs was developed to isolate biomechanical technique in those respective segments in vertical jumping.

These separate EI indices and their effectiveness for isolating segmental components of the jump can be questioned, since a "good" jump is the result of integration of segments of the whole body. If one changed the jump by executing a static squat vertical jump rather than the typical countermovement jump, are all changes in performance attributable to the dynamics of leg mechanics alone? Or, have other untested aspects of the skill also changed? In light of these concerns, a total body measure of EI was tested to examine total body changes in the vertical jump between the least complex form of vertical jump (e.g., static vertical jump without arms(SJ)) and the most complex form of laboratory vertical jump (i.e., countermovement jump with armswing (CMWA)). The EI index developed for this investigation was called Effective Integration of the System (EIS).

Purpose

The purpose of this investigation was to determine skillfulness in vertical jumping through use of a total body effective integration score. Specifically, the vertical ground reaction forces of two different standing vertical jumps were examined for use of kinetic and temporal strategies related to skillfulness in body projection. Previously, effective integration scores used for determination of skillfulness in vertical jumping were derived from kinematic data (Hudson, 1986; Hudson & Wilkerson, 1987; Hudson, 1988; Hudson et al., 1991). This investigation was the first attempt to examine kinetic variables as they related to skillfulness when determined by an EI score.

Effective integration of the system (EIS) was introduced to examine kinetic and temporal variables as they related to skillfulness. Effective integration is suggested as an alternative measure to vertical jump height, which has proven to be of little value in the search for technical parameters that define skillful vertical jumping (Dowling & Vamos, 1993; Jaric et al., 1989; Miller & East, 1976b; Oddsson, 1989). Dowling and Vamos (1993) and Oddsson (1989) speculated that if a large number of good jumpers (i.e., determined by jump height) were tested, a relationship would exist between movement characteristics and the objective of the skill (i.e., maximum jump height). Dowling and Vamos speculated if strong relationships did exist between kinetic and temporal variables, it should be possible to determine common characteristics of good performance that could be used to assess possible deficiencies in less talented performers. Dowling and Vamos used height of jump as a measure of skillfulness. Jump height, as discussed previously, is a measure that can be influenced by factors other than biomechanical technique. Would a stronger correlation between kinetic and temporal variables exist if skillfulness is redefined as an outcome variable that controls for the effects of genetic talents or training? Previous investigations using effective integration scores have indicated a stronger relationship does indeed exist between process variables and effective integration scores.

Unfortunately, determination of skillfulness using effective integration scores requires the use of data collection and analysis methods unavailable to most practitioners and many researchers. Practically, a less technologically demanding method to determine effective integration is needed. Because the jump and reach test is a common test for measuring vertical jump ability, an effective integration score might be developed using changes in jump height measures. If strong kinetic and temporal correlations exist, it should be possible to define an effective integration score as the difference in the product scores using jump height instead of maximal upward velocity of the performer. An intraindividual design still provides the method to factor out genetic talent and training effects to determine biomechanic technique.

Dowling and Vamos (1993) also speculated if strong relationships exist between kinetic and temporal variables, it should be possible to determine an optimal force-time curve. Payne, Slater, and Telford (1968) claimed the arm swing improved jump height and the addition of an armswing to the vertical jump caused a second peak in the force-time curve (see Figure 1). Data from other studies, however, show many individuals executing the vertical jump with armswing produce a single peak (Dowling & Vamos, 1993; Jaric et al., 1989; Oddsson, 1989). A significant relationship between the shape of the force-time curve and skillfulness, defined as a performance measure, has not been found for either double or single peaks. Single peak production found during pilot work and laboratory observations led to the hypothesis that single peaks in the force-time curve are more accurate indicators of a high level of skillfulness, when defined by a total body EI measure. Therefore, the final purpose of this investigation was to standardize the curves of the standing vertical jumps such that all force-time records exhibiting more than one peak were altered mathematically to exhibit only a single peak (see Figure 2). Kinetic and temporal relationships then were reevaluated using the standardized peaks.

Figure 1. CMWA showing double peaks and unsmooth rise to peak.

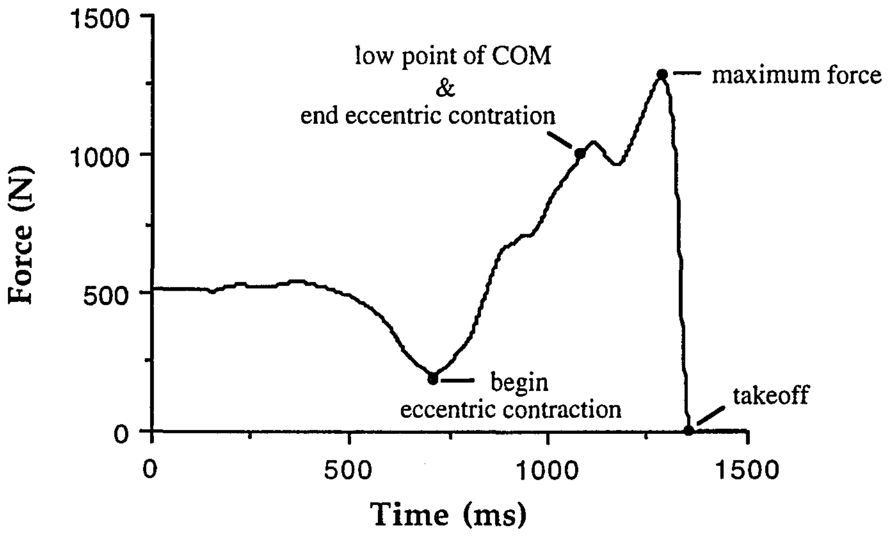
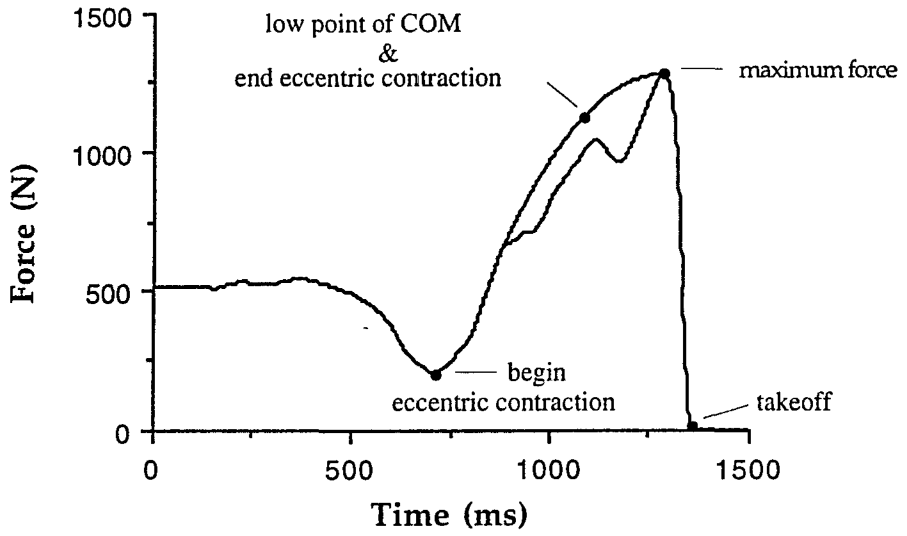


Figure 2. Standardized force-time curve using a parabolic trajectory.



Hypotheses.

The purposes of the current investigation with accompanying hypotheses were:

1. To use the vertical ground reaction force-time curve of the vertical jump to identify kinetic and temporal characteristics that are related to skillful performance as determined by Effective Integration of the System (EIS) using both the typical method of calculating effective integration and the method of calculating effective integration using jump heights.

   Hypotheses:

   a) More of the variance in EIS would be explained by kinetic and temporal variables than would be explained for jump height.

  - b) The relationship of kinetic and temporal variables to EIS calculated using jump heights will be strongly related to EIS using the standard calculation (i.e., calculated using maximum upward velocities of the body's center of mass).

2. To standardize the force-time curves of individuals exhibiting multiple peaks and examine the effect of standardization on EIS.

   Hypothesis

   - a) Standardizing to a single peak would increase the EIS scores of performers exhibiting multiple peaks.

Limitations

Limitations to the current investigation were:

1. Data were analyzed only through take-off. Landing was not considered in assessing skillfulness.
2. Standardization of the force-time curves was developed to examine changes in skillfulness only when multiple peaks or unsmooth rises to peak in the force-time curve were exhibited.

Summary

Biomechanic technique is the method of performance for any particular skill that should be strived for by all performers despite any stylistic changes, genetic constraints, and/or training processes that change the outcome of the skill. Examining movement for technique parameters allows the researcher to determine the most effective method of executing a skill for all individuals. However, determination of appropriate technique has consistently relied on product rather than process measures. If performers are evaluated solely on product, many individuals that make the most effective use of their abilities may be excluded from further technique investigations. Product scores should, therefore, be individually evaluated to avoid comparison with other performers that may be genetically predisposed to the task at hand or are training specifically for excellence in that task. To determine what process variables are most effective, the researcher must examine biomechanic technique to determine skillfulness using an intraindividual design.

The purpose of this investigation was to determine skillfulness through the use of a total body effective integration score. Specifically, a static jump (SJ) and a countermovement jump with armswing (CMWA) were used to determine Effective Integration of the System (EIS). EIS was used to determine how well the performer used the legs, arms and stored elastic energy to improve jump performance. Kinetic and temporal variables were examined for their relationship to EIS (calculated using maximum upward velocity of the body's center of mass and vertical jump height changes) and simple vertical jump height. It was hypothesized that more variance in skillfulness determined by EIS would be explained by kinetic and temporal factors than would be explained for skillfulness determined by simple vertical jump height achievement.

Subsequently, it was speculated that mathematical optimization by the researcher would immediately and positively affect the force-time curve and performance outcomes. The effect would be a change from exhibiting two peaks in the force-time curve to exhibiting a single peak. Force-time curves with multiple peaks or unsmooth rises to peak positive force were mathematically modified to standardize the shape and evaluated for the effect on EIS.

CHAPTER II

REVIEW OF LITERATURE

A purpose of this investigation was to examine the vertical ground reaction force of the standing vertical jump for kinetic and temporal strategies related to skillfulness in body projection. The concept of skillfulness was defined as an improvement in maximum upward velocity of the body's center of mass between the simple static vertical jump (SJ) and the more complex countermovement jump with armswing (CMWA). Both the SJ and the CMWA are jumps used in a laboratory situation, thus literature concerning sport-specific jumping was not the focus of the current review. This review is organized into four sections:

(1) defining effective integration of the system (EIS),
(2) use of stored elastic energy and EI,
(3) kinetic and temporal strategies in vertical jumping,
(4) optimizing the curve.

Defining Effective Integration of the System (EIS)

In an investigation of process variables related to vertical jumping, Hudson (1988) suggested the selection of the dependent variable is critical to the interpretation of results obtained pertaining to the use of stored elastic energy (SEE). Hudson found when skillfulness was determined by the height jumped by the performer, use of SEE was not highly correlated with skill (r = 0.685). However, when skillfulness was determined by intraindividual performance differences between two complexities of vertical jumps, use of SEE was strongly related to performance (r = 0.860). Hudson tested the improvement in performance between a static jump (SJ) and a counter-movement jump without armswing (CMNA). The index developed for the identification of skillfulness was called Effective Integration of the Legs (EIL). Effective integration is an indicator of how well the performer uses body segments to improve performance between simple and more complex movement variations of the same skill (Hudson, 1986; Hudson, 1988). Hudson argued that a composite performance variable such as jump height is influenced by the talent and training of the individual performer. However, an intra-individually determined improvement measure such as EIL controls for talent and long-term training. EIL was developed to isolate biomechanical technique in vertical jumping, giving the researcher a method for examining biomechanic technique.

To determine EIL, Hudson and Wilkerson (1987) tested each subject as she executed a simpler SJ and a more complex CMNA jump. EIL was determined as a percent increase in maximum upward velocity of the body's center of mass between the two jumps. By using an intra-individual design, talent and training could be controlled and change in performance could be explained by biomechanical technique (Hudson, 1988; Hudson et al., 1991).

EIL has proven useful for identifying subjects who use their legs effectively in vertical jumping. Hudson and Wilkerson (1987) classified jumping based on height scores and improvements using EIL. They found that only four of 10 "high" ability performers (based on height scores) were also skilled, based on EIL scores. Hudson's and Wilkerson's (1987) explanation of this follows:

> One possible explanation for this unexpected realignment of subjects could be that some individuals with lesser assets in talent and/or training had compensated by developing biomechanical technique and that some individuals with greater assets in talent and/or training did not need to develop biomechanical technique to be successful jumpers.
>
> Although the six members of the low ability group who were distinguished in EIL would be considered mediocre when evaluated using jumping height, their achievement exceeded expectation and, therefore, they could be considered biomechanical "overachievers". That is, they produced maximum output with minimum resources in talent and training. Because these biomechanical overachievers may have discovered technical secrets that are of value to others, it could be fruitful, as we search for the biomechanical determinants of successful performance, to explore strategies for the investigation of biomechanical overachievers. (p. 21)

Effective Integration of the Arms (EIA) has proven useful for identifying subjects who use their arms effectively in vertical jumping (Hudson et al., 1991; Wilkerson & Hudson, 1987). In each instance, variables related to timing and coordination were more highly correlated to effective integration scores (EI) than to the typical product score of jump height. Improvement scores for EIL and EIA ranged from 0 - 13% (Hudson, 1986) and 0 - 22% (Hudson et al., 1991), respectively.

To date, EI scores have been discussed separately as Effective Integration of the Legs (EIL) and Effective Integration of the Arms (EIA) (Hudson, 1986; Hudson et al., 1991). The use of these terms may not dutifully represent effective integration of just the legs or just the arms. That is, EIL scores may include other factors than how the legs are integrated into the jump. Incorporating the legs into the vertical jump using a countermovement also may alter the action of the trunk. Further changes such as adding the arms to the countermovement jump may alter the use of elastic energy in the legs as well as change the dynamics of trunk movement. In each case, the term EIL or EIA may not fully represent changes occurring in the movement pattern. This investigation focused on a total body representation of EI using change in upward velocity and jump heights between the SJ and the CMWA jump. Effective Integration of the System (EIS) represents changes that occur throughout the entire system.

Use of Stored Elastic Energy and EI

The use of efficiency ratios such as EI scores is not uncommon for the evaluation of vertical jumping. The determination of EI scores is calculated using the same principle behind calculating use of stored elastic energy (SEE). Both are based on performance differences between two levels of complexity of the same skill. SEE use is the more widely reported measure and, therefore, the research regarding SEE is more extensive. This section evaluates EI scores with respect to SEE performance measures and provides support for further examination of EI.

Evaluation of skills from an efficiency or effectiveness standpoint was suggested first by Dickinson (1929). An efficiency ratio greater than the concentric contractile mechanism of the muscle was attributed to stored mechanical energy. The contractile mechanism alone was found to account for about 25% of the efficiency ratio. Dickinson (1929) reported an efficiency ratio of approximately 25% for cycling. Since 25% of the efficiency in use of stored elastic energy can be attributed to concentric contraction of the muscle, a return in mechanical energy attributed to stored elastic energy as the result of the negative work phase in pedaling does not occur. Efficiency ratios of 45% for walking and 45% - 80% for running also have been determined (Cavagna, Saibene & Margaria, 1964; Cavagna & Kaneko, 1977). These percentages indicate walking and running are enhanced by use of elastic energy by 20 - 55 percent. Further, Asmussen and Bonde-Petersen calculated the efficiency of knee bends with a rebound and knee bends without a rebound and arrived at efficiency ratio ranges of 39% - 41% and 21% - 26% respectively. Knee bends without rebound have an efficiency ratio the same as the concentric contractile component executing positive work. Knee bends with rebound, however, incorporate the use of an elastic energy component. These data indicate certain movement behaviors seem to incorporate an elastic energy strategy.

Walking is more efficient than cycling, knee bends with rebound are more efficient than knee bends without rebound and running is more efficient than either walking or knee bends.

Stored elastic energy has been proposed as available for the enhancement of jump performance. Use of stored elastic energy is inferred from observation of the following phenomena: (1) when one performs two consecutive maximal-effort vertical jumps, the height achieved on the second jump is greater than the height achieved on the first (Cavagna & Kaneko, 1977); and (2) when comparing heights of vertical jumps performed with and without a countermovement, the countermovement jump results in greater height (Asmussen & Bonde-Petersen, 1974a, b). In each case, the increased height achieved by the body's center of mass in the countermovement jump is explained as a function of elastic energy stored in the muscles.

The ability to store elastic energy is a function of the extensibility and elasticity of the muscle being stretched. Activities that take advantage of SEE all incorporate an eccentric phase (a lengthening of the muscle under tension) into the movement. In theory, the musculotendinous unit, the series elastic component (SEC) and the cross-bridges within the muscle fiber sarcomere are the structures primarily responsible for the storage of elastic energy. To take advantage of the structural mechanisms in the muscle, time is a critical factor. Stored elastic energy is used if concentric contraction immediately follows a period of eccentric contraction (Asmussen &

Bonde-Petersen, 1974a; Cavagna, Dusman & Margaria, 1968). Time is a critical element in the use of stored elastic energy because the musculotendinous unit is typically represented as a spring with constant stiffness and damping parameters (Cavagna, 1970; Hill, 1950). If the time in transition from eccentric to concentric contraction is too long, then the characteristics of the 'spring' are modified. What occurs is a change in structural characteristics of the sarcomere via degradation of energy to heat or by changes in innervation which alter the stiffness of the muscle (Cavagna, 1970; Hill, 1961; van Ingen Schenau, 1984). Further, if the transition period between the eccentric and concentric phases is too long, the cross-bridges re-establish connections and elastic energy is lost.

Time is also a critical factor for explaining EI scores. Coordination sequences and temporal couplings are factors that relate significantly to skillfulness in vertical jumping. Temporally, the more closely each body segment used in vertical jumping reaches maximum angular velocity with respect to other body segments, the more skilled the individual performer. Large time differences (i.e., sequential coordination) in each segment's attaining maximum angular velocity lowers EI scores (Hudson, 1986; Hudson et al., 1991).

Magnitudes of joint angular displacements and velocities are related in that larger displacements are associated with lower final velocities. Slower angular velocities result in reduced average concentric force. The use of a countermovement enhances average force output (Bosco, Komi & Ito, 1981). Factors related to enhanced output are small joint angle displacements, high joint velocities just before reversal to extension, high force at the end of the eccentric phase, and short transition time between eccentric and concentric phases (Bosco et al., 1981; Bosco et al., 1982; Luhtanen & Komi, 1980). These factors correlate highly with improved jump height (Komi & Bosco, 1978). EI scores also indicate that quick transitions enhance skillfulness (Hudson, 1986; Hudson et al., 1991).

Based on a mass-spring model of muscle action, utilization of elastic energy is assumed whenever the efficiency of an action is greater than the 25% efficiency of the concentric contraction mechanism. Skillfulness determinations are based on the use of stored elastic energy. No significant correlations were found between use of stored elastic energy and jump height. Gains in peak upward velocity, however, were related to stored elastic energy use (Hudson & Owen, 1985; Hudson, 1986; Komi & Bosco, 1978). EI scores are derived as a function of gains in peak upward velocity of the body's center of mass (Hudson, 1986). EI is assumed to occur for any value attained greater than 0% improvement. However, "overachievers" have been identified as those with improvements of over 10% for EIL (Hudson, 1986) and 15% for EIA (Hudson et al., 1991). These determinations were arbitrary based upon the distribution of EI scores among the subjects. That is, the higher EI scores were grouped above 10% and 15% for EIL and EIA, respectively.

In the typical experimental protocol, the general trend in utilization of stored elastic energy is to show a significant increase in energy use in the countermovement jump over the static jump (Asmussen & Bonde-Petersen, 1974b; Bosco et al., 1983; Hudson & Owen, 1985; Hudson, 1986, 1988; Hudson & Wilkerson, 1987; Hudson et al., 1991; Komi & Bosco, 1978; Payne et al., 1968a; Wilkerson & Hudson, 1987). For EI scores, the intent is to show an increase in the gains of upward velocity (Hudson, 1986; Hudson et al., 1991). In either case, similarities in performance characteristics are examined to determine what factors affect stored elastic energy usage or how the legs or arms are effectively integrated into the skill to obtain superior performances.

With such apparent similarities between the process measures of stored elastic energy use and EI scores, why bother with developing EI scores? The importance placed on the role of SEE usage has been challenged (Bobbert et al., 1987; Bobbert & van Ingen Schenau, 1988; van Ingen Schenau, 1984; van Ingen Schenau, 1986). The argument against sole reliance on use of SEE focuses on mechanical changes that occur due to differences in task demands. The use of SEE is still considered to influence gains in upward velocity (Bobbert et al., 1986). Tight temporal couplings and attainment of maximum angular velocities of the segments also seem to play an extensive role in upward velocity gains (Bobbert et al., 1986; Hudson, 1986; Hudson et al., 1991). EI scores evaluate gains in upward velocities and have been related to angular velocity of segments and temporal couplings of various events involved in the task of vertical jumping. Therefore, using EI scores to evaluate skillfulness should prove to be a more comprehensive measure of the efficiency of the performance and the use of SEE.

Kinetic and Temporal Strategies in Vertical Jumping

To date, EI scores have been computed to examine movement using kinematic data (Hudson, 1986, 1988; Hudson & Wilkerson, 1987; Hudson et al., 1991). Kinematic studies lead to visual cues which direct intervention practices of teachers and coaches. While this is the ultimate goal for determining skillful performance, kinetic evaluation of movement may offer a means to more fully understand that movement. Force-time curve evaluation also can provide kinetic and temporal information that can be used to objectively evaluate and modify various types of athletic movements (Hochmuth, 1984).

How does the sport scientist identify the parameters of an individual's performance that are appropriate for individual success or the intervention method that will best improve performance? With deficiencies in talent and training, why do some individuals achieve superior performance levels? Could it be these individuals have technical proficiencies that all performers could benefit from understanding and applying? These questions have not been examined. However, the preceding questions are only slight modifications of the following excerpts taken from Dowling and Vamos (1993):

1) How does the sport scientist identify the aspect in which a particular individual is deficient or the modality that will best improve the performance?
2) Apart from the rather obvious differences in strength and stature, why does one athlete jump higher than another? (p. 95)

The answer to these questions may come from the shape of what Hochmuth (1984) calls biomechanical characteristic curves. Hochmuth asserts that a close relationship exists between sports technique and the data contained in the structure of movement represented by the characteristic curves used in biomechanics. That is, characteristic curves (i.e., acceleration, force-time, power, etc.) contain information that can be used objectively to select optimum curves to represent skillful performance in various types of athletic movements. Hochmuth also suggested the force-time curve be the first characteristic curve examined to identify kinetic and temporal factors related to optimum technique in a sport skill.

Few investigations examined the force-time curve to identify characteristics of skilled performance with respect to the questions of how and why some performers consistently jump higher than others (Dowling & Vamos, 1993; Miller, 1976; Miller & East, 1976; Oddsson, 1989). What have these initial investigations shown the sport scientist about the usefulness of the force-time curve for evaluating skillfulness?

In a qualitative investigation of the force-time curves of four individuals, Miller and East (1976) found their subjects each produced curves that indicated very little intra-subject variability.

The best performer, based upon time in air, produced a force-time pattern with two peaks of equal magnitude. However, among all trials collected, patterns containing single peaks and triple peaks also were observed. The authors did not draw any conclusions about what constituted a most appropriate force-time curve of skilled vertical jumping.

The first comprehensive study of the relationship of the force-time curve of kinetic and temporal measures to skillfulness (as defined by height of jump) was conducted by Oddsson (1989). Oddsson speculated if certain characteristics of the force-time curve could predict jumping height (skillfulness) and be influenced by specific training methods, then it should be possible to test athletes for each characteristic and optimize training practices for each individual performer.

Oddsson (1989) examined 106 subjects (73 males and 33 females) executing three types of vertical jumps on a force platform: 1) a maximal countermovement jump without armswing (CMNA), 2) a maximal countermovement jump with armswing (CMWA), and 3) repeated bounce jumps without armswing (BJ) (These are not discussed further here). Oddsson found the force-time curves displayed by individuals in the investigation were characterized by either one or two peaks during the propulsive phase of the task. The investigator indicated the majority of subjects, including the best jumpers, exhibited two peaks in the force-time curve. Statistical analysis indicated two variables were significantly related to jump height. These were: 1) the magnitude of the second peak force; and 2) the slope of the curve from the time of the second peak force to the time of takeoff were significantly related to jump height. Using multiple regression to determine the contribution of these factors to the prediction of jump height, Oddsson found the magnitude of the second peak force for the CMWA jump was the best overall predictor of skill ($r = .66$, $p < 0.01$). Overall, the variables selected by Oddsson accounted for approximately 73% of the variance in vertical jumping.

Caution should be exercised when interpreting Oddsson's (1989) data. First, force values were not normalized to body weight. Dowling and Vamos (1993) found a significant positive relationship existed between body weight and jump height. Although not reported, if this same relationship existed for Oddsson's data, the relationship of force to jump height was overestimated. Second, as discussed previously, jump height is a composite variable that can reflect properties of inherent talents, training, and technique. Oddsson found the magnitude of the force generated by the individual was significant to the prediction of jump height. This magnitude could be greater if the subject is fairly heavy (talent), has a predominance of fast twitch muscle fiber (talent), or trains the muscles used in the vertical jump through rigorous weight training. Variation in technique also could account for high magnitudes of force.

Dowling and Vamos (1993), also attempted to identify the kinetic and temporal correlates to skillfulness in vertical jumping. Their purpose was to use the vertical force-time curve of the vertical jump to identify kinetic and temporal characteristics related to performance (jump height). Also, they hoped that a characteristic kinetic pattern could be determined that would prove useful for the evaluation of the jump.

Ninety-seven subjects (46 male and 51 female) of various skill levels executed CMWA vertical jumps. They found seven variables significantly related ($p>.01$) [sic] to vertical jump height. They were:

1) Maximum force ($r=0.519$)
2) Duration from maximum force to takeoff ($r=-0.274$)
3) Maximum negative power ($r=-0.298$)
4) Maximum positive power ($r=0.928$)
5) Duration from maximum positive power to takeoff ($r=-0.406$)
6) Ratio of negative impulse to positive impulse ($r=-0.514$)
7) Maximum negative velocity ($r=-0.295$)

The investigators intended to examine the force-time curve for correlates to skillfulness in vertical jumping. However, nine of 19 variables chosen for investigation are not obtained directly from the force-time curve. For power to be calculated, the mass of the individual performer is removed from the force data to yield acceleration. The acceleration data must be integrated twice to obtain displacement data. Then, the displacement data are multiplied by the original force data and divided by the collection rate. These data, if graphed, do not resemble the force-time curve. If the intent is to offer a tool that is useful for the teacher/coach, the addition of derived variables seems to cloud the conceptual simplicity that made the question appealing to explore in the first place.

Dowling and Vamos (1993) noted other problems with their analysis. When the raw data were analyzed graphically, there were examples of individual performances that did not support the statistical findings. For example, statistical analysis indicated a positive correlation between maximum force and jump height. That is, the more force an individual could generate, the higher the jump would be. It was found, in qualitative analysis, that there were examples of very poor performances in which the performer exhibited high maximum forces. The authors concluded the inter-individual variability in vertical jump performances could not be explained by many temporal and kinetic variables.

Standardizing the Curve

Optimization of performance has been examined primarily through computer simulation (Levine, Zajac, Belzer & Zomlefer, 1983; Pandy, 1990; Pandy, Zajac, Sim & Levine, 1990; Pandy & Zajac, 1991; Zajac & Winters 1990). These investigations control muscle and lever properties a priori to determine the optimum coordinative patterns for executing various vertical jumps. The general finding of these simulations is that too little is currently known about the multiple constraints on the human body. Computer generated optimizations of movement are physically impossible to execute (Pandy & Zajac, 1991; Zajac & Winters, 1990). The inferences made in computer optimization investigations are made with no deference to actual performance profiles. Given the current knowledge of the human system and physical laws, the computer models generated are strictly optimized patterns. No work has been done to examine optimization of performance variables by manipulating actual performance profiles of individual performers to examine hypothetical effects on skilled performance.

If more variance in vertical jump performance can be explained using EIS than using jump height, it should be possible to identify an optimum curve. In other words, a force-time curve representative of skillful technique can be determined. Determination of an optimum curve will allow performers to be tested and evaluated for technique parameters of movement that should change to attain optimal performance for that individual. Another purpose of the current investigation is to mathematically standardize the force-time curve to explore the effect on the pattern exhibited by individual performers.

A question frequently asked is, What are the qualities that distinguish skilled from unskilled performers? The use of EI scores provides insight into the coordinative constraints of the task. That is, the pattern of movement a skilled jumper uses is more thoroughly examined. Typically, the temporal coupling of segmental movements are determined and evaluated for their effectiveness in skillful execution of the movement. Deviations from what could be considered skillful also should manifest themselves in the kinetic record of individual performers. Often, the research question is whether or not there is an optimal sequence and/or timing of segmental behaviors to achieve the goal. The clearest means of answering the question is through the design of a standardization algorithm. To date, the simulation-optimization models for jumping are restricted to a limited number of segments (Duck, 1985; Komor, Morawski & Pruski, 1981; Pandy et al., 1990; Pandy & Zajac, 1991; Zajac, Wicke & Levine, 1984) and/or are predominantly muscle models (Bobbert et al., 1986; Bobbert & van Ingen Schenau, 1988; Hudson, 1986; Pandy et al., 1990; Pandy & Zajac, 1991; Zajac et al., 1984; Zajac & Winters, 1990). For the purposes of this investigation, the more informative work was that which focused on the behavioral evidence for optimum patterns of sequence and timing.

Hudson (1986) and Bobbert and van Ingen Schenau (1988) investigated the coordination of segments in vertical jumping. Hudson explored the sequencing and timing of segmental behaviors to examine achievement of maximum angular velocities. Using a countermovement jump, Hudson evaluated the degree of simultaneity in initiation of extension of the trunk, thigh, and shank, as well as the temporal spacing between maximum segmental velocities. Hudson suggested sequence variations were not significantly detrimental to performance. The more critical factor appeared to be tight temporal coupling in the initiation of extension with delays less than 25 ms separating adjacent segments. Bobbert and van Ingen Schenau (1988) found segmental extension delays approaching 70 ms. Maximal joint extension angular velocities, in both investigations, were achieved nearly simultaneously. Jensen and Phillips (1991) altered the constraints on vertical jumping by requiring increasing horizontal displacement. They found tight temporal couplings in attaining maximal angular velocities remained consistent across jumping conditions.

Kinematic characteristics of propulsion in vertical jumping remain constant for skilled jumpers. These consistencies in movement also related significantly to EI scores (Hudson, 1986, 1988; Hudson & Wilkerson, 1987; Wilkerson & Hudson, 1987). From the investigations of optimum patterns of kinematic parameters, is it possible to determine an optimum pattern for kinetic parameters?

Payne et al. (1968) examined the kinetic patterns of the SJ, CMNA, and the CMWA jumps produced by a single skilled subject. They concluded the addition of arms to the vertical jump adds an extra (second) peak to the force-time curve. No investigator systematically examined that second peak. Observations were made in two studies with regard to number of peaks (Dowling & Vamos, 1993; Shetty & Etnyre, 1989). Shetty and Etnyre (1989) found the armswing did improve vertical jump, and primarily found the force-time curve possesses only one peak. Dowling and Vamos (1993) indicated that 54 of 97 subjects produced force-time curves with a single peak. In pilot work for the current investigation, higher EIS scores were associated with smoother rises to a single maximum peak in the force-time record.

The anecdotal information from two studies (Dowling & Vamos, 1993; Shetty & Etnyre, 1989) and pilot work led to speculation that a single peak in the force-time profile of vertical jumping may be an optimum pattern for skilled performance when EIS is used as the performance measure. Certain assumptions were made to explore these changes. First, intervention would immediately change the technique exhibited by the performer. Second, the subjects in the current study executed vertical jumps maximally. Therefore, when alterations are made in the force-time profile, the subject's maximum force would not change. Finally, a technique-oriented intervention would change coordination patterns such that the force-time profile for an individual would have a smooth rise to peak. That is, if the segments of the body are used optimally, the result of effective integration (proper technique) would produce a force-time curve with a smooth rise to maximum force. If smoothness matters, further investigations could be conducted to find out what visual variables relate to multiple vs. single peaks.

Summary

EIS is determined as a difference in product measures between two varying complexities of vertical jump. Those individuals exhibiting the greatest improvements show the most advanced technique. It is also an index of how well an individual incorporates the use of a greater number of segments into the task. First developed for use with kinematic investigations, EIS has been chosen to explain variables related to the kinetic and temporal strategies in vertical jumping. Although a relatively new method for determining skillfulness, evaluation of jumping effectiveness using variations of the same skill has occurred since the late 1920s. EI scores have been found to relate significantly to the use of SEE (Hudson, 1986; Hudson et al., 1991). Use of stored elastic energy investigations evaluate effectiveness gains by comparing gains in kinetic energy between SJs and CMNAs. However, gains in product scores cannot be explained strictly as gains in elastic energy. Therefore, EIS was developed to incorporate all changes in performance. That is, high scores on EIS are considered indicators of effective use of the arms, legs, trunk, countermovement, and elastic energy.

Differences exist, however, in the kinetic and temporal parameters that are significantly related to skilled vertical jumping. Investigations examining kinetic profiles in vertical jumping typically evaluated skillfulness using vertical jump height. Although the initial purpose of these investigations was to find correlates to vertical jump height using the kinetic profile, the strongest relationships were found using variables derived (mathematically) from the original kinetic data. These investigators found that inconsistencies in the profiles of their subjects led to disappointing results when trying to determine the most appropriate force-time curve to evaluate skillfulness. It was speculated in the current investigation that vertical jump height scores are influenced by factors that are not related to technique (i.e., talent and training) and therefore should not be used to determine skillfulness.

Finally, optimization of skill has been conducted using mathematical modeling. Studies conducted to date have simply used an idealized model that does not incorporate individual differences of performers into calculations of the "most skilled performance". As a result, many of the movement parameters suggested by these models are physically impossible to execute. This investigation used existing human data and, based upon laboratory observations, mathematically imposed an hypothesized single peak to the performance. Analysis evaluated increases in process characteristics of vertical jumping.

CHAPTER III

METHODS AND PROCEDURES

The standing vertical jump was performed under two conditions to answer the research questions: 1) what are the kinetic and temporal correlates to skillfulness (EIS) in vertical jumping, and 2) will standardizing the force-time curve enhance skillfulness (EIS). Subjects executed a countermovement jump with armswing (CMWA) and a static jump without arms (SJ). Force-time data were collected using a force platform and a purpose-made electrogoniometer. The following information describes the methods and procedures used in data acquisition, reduction, and analysis.

Subjects

Vertical ground reaction forces during the jumps were collected for 53 subjects. All subjects (aged 9-46 years) had 2-10 years experience in jumping intensive sports (e.g., volleyball, basketball, etc.). Subject health was obtained through self report before the testing session. All subjects were in good health with no recent history of ankle, leg, knee, thigh, hip, back, or shoulder injury. Effective Integration of the System (EIS) is intra-individually calculated. Therefore, homogeneity (i.e., all elite subjects or all novice subjects) of the sample population was not considered important to the investigation. Due to collection error, data for 51 subjects were used in subsequent analyses.

Instrumentation

Force-time data were acquired using a Kistler Force Platform (type 9281B) interfaced with a Kistler 9861A electronic unit that scaled the data and stored it in a Macintosh II computer. Crouch depth for the Static Jumps was controlled by a purpose-made electrogoniometer interfaced with an IBM DACA A/D board connected to an American XT 286 computer.

Force Platform.

Vertical ground reaction forces were collected using a Kistler Force Platform (type 9281B) mounted into the floor of the Biomechanics Laboratory at the University of North Carolina at Greensboro. The force platform was a rigid aluminum plate, 400 x 600 mm. Measurements of force depend on the linear response to compression of four piezoelectric transducers placed at each corner of the platform. Although the force platform is capable of recording forces in vertical, antero-posterior, and medio-lateral directions, only vertical forces were used in this investigation. The analog force signal was sampled at1000 samples per second using the Kistler 9861A electronic unit. Kistler 9861A also scaled the data into known units and stored the data in a Macintosh II computer.

Before each trial, the force platform was reset to zero. Resetting the force platform to zero for each trial allowed the scaling procedure of the Kistler 9861A to adjust for any vibrations that affected the force platform as a result of placement.

Electrogoniometer.

Knee joint angles were recorded for the purpose of maintaining similar movement patterns of the legs between the CMWA and the SJ jumps. A purpose-made electrogoniometer (elgon) was used to measure knee joint angle. The elgon used for this investigation was made of a simple linear taper, 3/4 turn, 10 ohm potentiometer. The potentiometer was attached to two plastic angle arms that were approximately 20.5 cm in length. The angle arms were affixed to the left leg of the subject such that the arms of the elgon ran parallel to the long axis of the femur and the tibia. The axis of rotation of the elgon closely approximated the axis of rotation of the knee joint. The potentiometer was attached to a power/output cable approximately three meters in length.

The potentiometer was powered by an external five volt power source. Based on the position of the angle arms, the potentiometer supplied analog output encompassing a range of zero to five volts to an IBM DACA A/D board. The A/D board converted the analog signal to a digital signal and sent the digital signal to an American (IBM clone) 286 XT computer. The digital signal was scaled using a BASIC program entitled ELGON.BAS (see Appendix B). ELGON.BAS displayed the current and minimum knee angle on a video monitor. The minimum value was recorded for future use with SJ jumps.

Data Acquisition

Subjects performed multiple repetitions of maximal vertical jumps under the CMWA and SJ conditions. The CMWA trials were executed first as it was necessary for the knee angles in the crouch position of SJ trials to closely approximate the knee angles for CMWA trials.

Task.

To determine effective integration scores for vertical jumping, it was necessary for the subjects to execute three trials each of the two types of jump. The first was a CMWA jump. The CMWA began with the performer standing erect on the force platform and arms at the side. The command "go" was used to indicate the beginning of the trial. The performer then executed a maximal vertical jump using arms and a countermovement to assist in attaining maximal velocity of the center of mass of the body. Each subject was encouraged to maintain symmetry in arm action.

The second type of jump was a static jump (SJ). The SJ is executed from a crouch position with hands placed on the hips. The subject maintained a stationary crouch position for 4 seconds before the "go" command was given. A time delay in the crouch allowed for the depletion of any stored elastic energy left in the muscles as a result of stretch (Wilson, Elliott & Wood, 1991). After the signal to begin was given, the performer jumped maximally. Trials were repeated if an unloading phase occurred before pushing out of the crouch position. Subjects were expected to push directly out of the crouch position to avoid benefit to the jump of additional stretching of the muscles.

Testing Protocol.

Subjects participating in this investigation were tested in the Biomechanics Laboratory at the University of North Carolina at Greensboro. After being informed of testing procedures and the Human Subjects Consent Form (Appendix A), the subjects were given an opportunity to ask questions concerning any of the procedures. The Human Subjects Consent Form then was signed before testing proceeded. Participants were provided a copy of the consent form for their records.

A subject-regulated warm-up, with respect to time and intensity, was recommended before data collection. When the performer was ready, the elgon was affixed to the left leg and additional practice as needed was encouraged.

Subjects performed three maximal CMWA jumps recorded by the force platform. The subject stepped onto the force platform and stood erect with hands to the side. When ready, the investigator gave the command to "go". From the instant the "go" command was given, subjects had two seconds to jump from the force platform. Pilot study had shown that two seconds was ample time to execute the propulsive phase of the jump. It was important that maximum vertical jumps were obtained. Therefore, subjects were asked if each jump was a maximum attempt. If the subject felt maximum effort was not exhibited, that trial was discarded and repeated. Collection continued until three maximum CMWA jumps were recorded. After each CMWA, trial minimum knee angle was recorded. The minimum knee angles for these three jumps were averaged to find a mean minimum angle for use in determining crouch depth when performing SJs.

Before collection of each SJ trial, the subject was required to crouch and hold that crouch for 4 seconds. The depth of the crouch was determined by having the subject crouch until the minimum knee angle was the same as the average minimum knee angle found for the CMWA jumps. After 4 seconds holding the crouch position, subjects were directed to "go". Collection of SJ data continued until three trials were recorded.

SJs are not a natural variation of jumps used in sport. Pilot work suggested there were difficulties in getting subjects to perform this type of jump without additional unloading. As a result, SJs were required to pass three validity tests before being retained for subsequent analysis. As with CMWAs, subjects were asked if their effort was maximal. Additionally, the performers' hands must have remained on the hips throughout the entire jump. Finally, after each jump, force-time records were examined to determine if there was additional unloading before the execution of the propulsion phase of the jump. If any of the three criteria (i.e., subject feedback, hands on hips, further unloading) were not met for a particular trial, that trial was discarded and repeated.

Treatment of Raw Data

Ground reaction force data then were transported to StatView SE+ Graphics, a statistical software program for the Macintosh. The data were placed into a 1 x 2000 vertical ground reaction force ASCII code matrix. EI scores were generated from the propulsive phase of the jump.

Examination of pilot data of vertical forces revealed that non-random high frequency noise was present. A Fourier (spectral) analysis was conducted to determine what frequency patterns were present in the data. Kistler (1990) reports that the 9281b type force platform possesses a natural resonance of approximately 700-750 Hz. For a Fourier analysis to be effective, Derenzo (1985) recommended that data be sampled at twice the frequency of the expected noise. A random selection of 10 trials of SJ and CMWA jumps was evaluated for natural resonance content. Spectral analysis of these trials was conducted using Mathematica v2.1 (1992). Fourier analysis revealed that some human content was present at 22 Hz. It was determined that smoothing would occur at a frequency of 25 Hz.

The vertical force data were smoothed using a quintic spline routine developed by Woltring (1986). This program was run in mode 4 with the degrees of freedom set at approximately 95% of the number of data points. Information contained below a frequency of 25 Hz was not altered or removed from the data array when the data were smoothed using mode 4. A 1% change in residuals served as a tolerance limit for judging the appropriateness of the smoothing routine.

Biomechanical Variables

All the biomechanical variables analyzed were obtained from the smoothed vertical ground reaction force data. Each kinetic variable was related to the kinetic characteristics of the center of mass (COM) of the subject (see Figure 3). The following kinetic variables were used:

1. Minimum force (Fmin)-The minimum force applied to the force platform during the unloading phase of the countermovement.
2. Maximum force (Fmax)-The maximum force applied to the force platform.
3. Maximum positive slope of force (y)- The maximum positive slope of the force curve between the times of minimum force and maximum force applications.
4. Average slope from minimum force to maximum force ($\bar{y}$)- The average slope of the force curve from the instant of minimum force to the instant of maximum force application.
5. Force at the low point of the Center of mass ($\downarrow F$)-The force applied to the force platform when the body's center of mass has reached its lowest point in the countermovement.
6. Shape factor of the major positive impulse phase (Λ)-The shape factor is a ratio of the area of the positive impulse

to the area of a rectangle bounded by Fmax vertically and the duration of the time interval for the positive impulse.

7. Ratio of negative impulse to positive impulse (R)- Ratio of the area for the negative (unloading) impulse to the area for the positive (loading) impulse.

The temporal data represented durations of time before take-off for the vertical jump (see Figure 3). The following temporal variables were used:

1. Time for the major negative impulse phase (t1)-Duration of the major negative impulse phase was calculated as the time between when the force applied to the force platform becomes less than body weight to when the force applied to the force platform returns to body weight.
2. Time from the low point of the COM to maximum force (t2)- The time from the low point of the body's center of mass to the application of maximum force was calculated as the time between when the force applied to force platform at COM reversal until maximum force application to the force platform was exhibited. Com reversal was determined from velocity calculations.
3. Time for the positive impulse (t3)-Calculated as the duration of the positive impulse.

4. Time from Fmax to takeoff (t4)-Time calculated from the instant of maximum force application to takeoff from the force platform.
5. Time of eccentric contraction (t5)-Time calculated from minimum force application on the force platform to the lowest point of the body's center of mass.

The kinetic and temporal variables were correlated with EIS and vertical jump height. The dependent variables were calculated as follows:

1. Effective integration of the system (EIS)-EIS is the ratio of the difference between maximum vertical velocity of the body's center of mass in the CMWA and SJ to the maximum vertical velocity of the body's center of mass in the SJ multiplied by 100 (((VMAX CMWA - VMAX SJ)/VMAX SJ) * 100). To calculate EIS, the SJ trial that exhibited the greatest force application was used. Vertical velocity is calculated using the following equations:

$F=ma$	Newton's second law
$F/m=a$	Dividing by mass
$F/m=dv/dt$	Acceleration as the derivative of velocity
$F/m \ dt=dv$	Multiplying by dt
$\int_{t=0}^{t} F/m \ dt=\int_{v=0}^{v} dv$	Integration
$(F/m)t=v$	Final equation for vertical velocity at time t

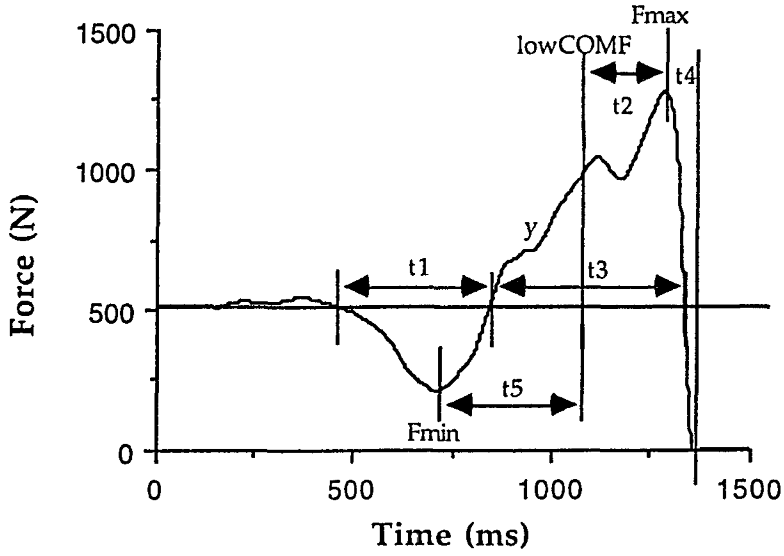
Where F = force (N), m = mass (kg), a = acceleration of the body's center of mass (m/s^2), v = velocity (m/s), t = time (s).

2. Height of jump (HT) - The height of the jump will be calculated using the following formula :

   $ht = v^2/2g$

   Where ht = calculated height of the jump (m), v = takeoff velocity and g = acceleration due to gravity (9.81 m/s^2) (Dowling and Vamos, 1993).

Figure 3. Biomechanical variables.



All variables were obtained through files created by SSJUMP1.FORTRAN (See Appendix C). SSJUMP1.FORTRAN created files using the smoothed force data. <FILENAME>F contained data consisting of the raw force data and the smoothed force data. <FILENAME>A contained the acceleration, velocity, and displacement data for each trial. <FILENAME>R was developed for smoothing analysis to examine the residuals created by the smoothing function.

Secondary Treatment of Data

An hypothesis of this investigation was that skillful jumpers would exhibit force curves with single peaks. In a pilot investigation, approximately three subjects in every ten exhibited vertical jumps with a single peak. To simulate a technique change in vertical jumping, the data were "standardized" by converting all original force curves with multiple peaks to single peak force curves. CricketGraphwas used to produce standardized force-time curves. The positive impulse phase of the force curve was examined for the occurrence of multiple peaks (Payne, 1968b).

Standardizing the Curve.

Standardization of the force curve occurred if there were two or more distinct peaks or if the positive slope of the force curve deviated by more than 5% before approaching a single peak. To "standardize" the force curve, one-half of a parabola was used. The parabola took the form of: $f(x) = a(x - h)^2 + k$ (Larson & Hostetler, 1985), where the axis for the parabola was the vertical line x = time, h = time of maximum force application, the vertex lies at the point (h,k), k = magnitude of maximum force application, and $a < 0$. This formula created a smooth trajectory for the force curve. The beginning point for the parabola was that point on the force curve that caused the slope of the curve to change by more than 5%. The parabola ended at Fmax.

Design and Analysis

Statistics were computed using SAS (see Appendix D) on an IBM/VM mainframe computer. Correlational analysis was used for smoothed and "standardized" data sets to determine if relationships existed between kinetic and temporal variables and skillfulness. Also, stepwise multiple linear regression was performed to compare the relationship of the kinetic and temporal variables to skillfulness and jump height. Stepwise procedures were used because variables are rigidly constrained to significant contribution after multicollinearity was tested. Variables are entered or removed at each step of the prediction model based upon unique contribution to the prediction of the dependent variable. Repeated measures ANOVA was used to examine whether or not differences occurred between groups when the force curves were "standardized". Tests for significance were performed at the 0.05 level.

Analyses also were conducted using split groups based on the concept of "overachieving". Those subjects with EIS scores above 20% (n = 24) were analyzed separately from the subjects with EIS scores less than 20% (n = 27) to explore differences in process parameters. For purposes of examining similar parameters for jump height, the highest 24 jumps also were examined.

Power analyses were conducted to test the probability that the statistical tests of the null hypotheses would lead to the rejection of the null hypothesis. Power analysis, therefore, is a measure reflecting the probability that an effect will indeed be found. The method used for all power calculations was proposed by Cohen (1977). The following equation was used:

$$f^2 = R^2/(1-R^2)$$

Where R^2 = the proportion of the dependent variable variance accounted for by entry into the model. Partial correlations were used to calculate f^2 to avoid exaggerated power values. A value (L) incorporating effect size and sample size to determine power then was calculated using $L = f^2 v$, where v = error. Power values were then obtained using the tables provided by Cohen (1977). Tests of significance were performed for α = the probability of making a type I error = .05. The power for each statistic reported in the results was greater than .55. Ranges for power were .56 to .995.

CHAPTER IV

RESULTS

The purpose of this investigation was to examine kinetic and temporal relationships to skillfulness in vertical jumping. Two research questions were posed: 1) What was the relationship of kinetic and temporal measures to EIS scores and vertical jump height for 'actual' vertical jump data; and 2) What were the relationships of kinetic and temporal measures to EIS scores and vertical jump height when a standardizing procedure changed the kinetic profile of the individual's vertical jump with armswing. Results of analyses performed to answer these questions are reported in this chapter.

First, descriptive data for the variables are reported. Pearson Product Correlations are provided to examine relationships to skillfulness. Prediction models for the smoothed force-time curves also are provided. Then, the same analyses for vertical jump height measures of skillfulness are presented. Within each of these sections, the data were examined: 1) for all subjects (n = 51); 2) separately for best performances (n = 24); and 3) separately for poorest performances (n = 27). All subsequent analyses used this grouping scheme for consistency of interpretation. Finally, the data were standardized and the results of repeated measures analysis of variance are presented. Analyses were repeated using the same procedure described previously for the nonstandardized data.

Descriptive Data

Data were collected for fifty-three subjects. A heterogeneous sample (i.e., various ages and experience levels) was tested for this investigation. Data for two subjects, however, were unusable and were eliminated from further analyses. Performance means and standard deviations for fifty-one subjects are reported in Table 1. Skillfulness, as determined by EIS, ranged from -12.59% to 52.86% for EIS_{vmax}, and -26.19% to 169.28% for EIS_{vj}. Vertical jump height scores for CMWA jumps ranged from 17.95cm to 59.24cm.

Table 1. Means and Standard deviations for all variables. (n=51)

Variable	Mean (SD)
Fmin	0.45 BW (0.22)
Fmax	2.59 BW (0.45)
y	16.86BW/s (10.96)
$\bar{y}$	5.35BW/s (2.59)
$\downarrow F$	2.15 BW (0.47)
Λ	0.38 (0.07)
R	-0.27 (0.07)
t1	0.40s (0.16)
t2	0.14s (0.09)
t3	0.42s (0.08)
t4	0.17s (0.09)
t5	0.30s (0.10)
EIS_{vmax}	18.96% (11.26)
EIS_{vj}	54.81% (35.26)
Jump Height	33.66cm (10.41)

BW = body weight
s = seconds.
BW/s = body weight per second

The original data were divided into groups of best performances and poorest performances. Examination of best and poorest groups was conducted to determine if differences existed in the relationships between kinetic and temporal variables when best performance was the objective. The groups were initially divided by EIS performance. Of the 51 subjects, 24 had performances that were better than SJ performances by 20%. A top one-half and bottom one-half grouping was not conducted, as there was no clear delineation of skillfulness as measured by EIS among the next two or three highest EIS performances. That is, the next three best performances varied in level of skillfulness by little more than one-thousandth of a percentage point. Additional analyses in the current investigation continued to use a 24 best and 27 worst grouping for consistency in examining skillfulness and vertical jump data. For those analyses, group membership varied based upon the measure used to determine skillfulness. That is, the best 24 EIS subjects may not have been the best 24 vertical jump height subjects.

Performance means and standard deviations for 24 subjects with the best EIS scores and best vertical jump height scores are reported in Table 2. The ranges for skillfulness using EIS were 20.47% to 52.86% for EIS_{vmax}, 57.36% to 169.28% for EIS_{vj}. Vertical jump height scores for subjects with the best EIS scores ranged from 18.28cm to 59.24cm. The range for the best vertical jump height scores (n=24) was 34.05cm to 59.24cm. EIS scores for subjects with the best vertical jump height scores were 9.22% to 52.86% for

EIS_{vmax}, and 22.24% to 169.28% for EIS_{vj}. Fourteen subjects were considered skilled as determined by either EIS or vertical jump height. Ten subjects in the EIS group were not considered skilled if vertical jump height was the sole criterion for skillfulness.

Table 2. Means and standard deviations for subjects with the best EIS (EIS > 20% (n=24)) and vertical jump height scores (vertical jump height > 34 cm (n=24)).

Variable	EIS Mean (SD)	Vertical Jump Height Mean (SD)
Fmin	0.42BW (0.27)	0.45BW (0.22)
Fmax	2.69BW (0.56)	2.84BW (0.46)
$\underline{y}$	21.57BW/s (14.07)	19.93BW/s (11.14)
$\bar{y}$	5.65BW/s (3.23)	5.92BW/s (2.37)
↓F	2.30BW (0.61)	2.33BW (0.58)
Λ	0.38 (0.08)	0.39 (0.07)
R	-0.27 (0.08)	-0.27 (0.07)
t1	0.43s (0.18)	0.42s (0.16)
t2	0.14s (0.10)	0.13s (0.08)
t3	0.43s (0.08)	0.41s (0.06)
t4	0.18s (0.09)	0.18s (0.09)
t5	0.31s (0.11)	0.29s (0.08)
EIS_{vmax}	28.13% (7.94)	22.69% (11.13)
EIS_{vj}	83.46% (27.55)	64.81% (37.45)
Jump Height	37.23cm (10.66)	42.72cm (6.80)

BW = body weight
BW/s = body weight per second
s = seconds.

Performance means and standard deviations for 27 subjects with EIS_{vmax} scores less than 20.00% are reported in Table 3. Ranges for skillfulness as determined by EIS were -12.59% to 18.56% for EIS_{vmax}, and -26.19% to 55.07% for EIS_{vj}. Vertical jump height scores for subjects with the poorest EIS scores ranged from 17.95cm to 47.32cm. Performance means and standard deviations of 27 subjects with jump height scores less than 34.50cm also are reported in Table 3. Ranges for jump height were 17.95cm to 34.04cm. The range for EIS scores for subjects with the poorest vertical jump height scores was -12.59% to 34.55% for EIS_{vmax} and -26.19% to 99.90% for EIS_{vj}.

Table 3. Means and standard deviations for subjects with the lowest EIS (EIS < 20% (n=27)) and vertical jump height scores (vertical jump height < 34cm (n=27)).

Variable	EIS Mean (SD)	Vertical Jump Height Mean (SD)
Fmin	0.48BW (0.16)	0.46BW (0.23)
Fmax	2.49BW (0.31)	2.36BW (0.30)
y	12.67BW/s (4.15)	14.12BW/s (10.24)
$\bar{y}$	5.08BW/s (1.86)	4.84BW/s (2.70)
↓F	2.03BW (0.25)	1.99BW (0.28)
Λ	0.38 (0.05)	0.36 (0.06)
R	-0.26 (0.07)	-0.26 (0.08)
t1	0.38s (0.13)	0.38s (0.15)
t2	0.15s (0.08)	0.16s (0.09)
t3	0.42s (0.07)	0.44s (0.09)
t4	0.16s (0.09)	0.16s (0.09)
t5	0.29s (0.08)	0.31s (0.11)
EIS_{vmax}	10.81% (6.45)	15.64% (10.49)
EIS_{vj}	29.34% (16.97)	45.92% (31.23)
Jump Height	30.49cm (9.25)	25.61cm (4.93)

BW = body weight
BW/s = body weight per second
s = seconds.

Kinetic and Temporal Correlates to Skillfulness (EIS)

One independent variable related significantly to skillfulness as determined by either EIS score. This variable was maximum positive slope of the force (y) (Table 4). Across the entire subject pool, skillfulness and vertical jump heights also were significantly related. Maximum positive slope, although significantly related to skillfulness, did not exhibit a clearly definable linear relationship to skillfulness and could account for an R^2 of only 0.26. To better predict skillfulness, multiple linear regression was performed on all twelve independent variables. Regression equations for the best prediction model resulting in an $R^2 = 0.44$ and 0.45 for EIS_{vmax} and EIS_{vj}, respectively, are given by:

$$EIS_{vmax} = -5.13 + 0.83(y) + 61.56(R) + 62.19(t3)$$

$$EIS_{vj} = -27.13 + 2.61(y) + 198.81(R) + 174.81(t3)$$

Where y = maximum positive slope, R = ratio of the negative impulse to the positive impulse, and t3 = time of positive impulse. These three variables increased R^2 over use of a single predictor, but the model still accounted for less than half of the variability in EIS_{vmax} and EIS_{vj}. The models suggested, however, were significant at $p<0.01$ ($F_{3,47}=12.18$ and $F_{3,47}=12.62$ for EIS_{vmax} and EIS_{vj} respectively). RMS errors of 8.71% and 27.06%, respectively for EIS_{vmax} and EIS_{vj}, also were calculated.

Table 4. Correlation Coefficients (r) of the 12 independent variables with EIS. (n=51)

Variable	EIS$_{vmax}$ r	EIS$_{vj}$ r
Fmin	-0.22	-0.27
Fmax	0.27	0.25
y	0.51**	0.53**
$\bar{y}$	0.13	0.13
↓F	0.26	0.25
Λ	-0.08	-0.10
R	-0.06	-0.10
t1	-0.04	-0.06
t2	-0.05	-0.05
t3	0.11	0.13
t4	0.21	0.21
t5	-0.02	-0.04
EIS$_{vmax}$	1.00	0.99**
EIS$_{vj}$	0.99**	1.00
Jump Height	0.42**	0.37**

* $p<.05$
**$p<.01$

When the best 24 EIS performances were analyzed, maximum positive slope again was the only independent variable related significantly to skillfulness (see Table 5). However, the significant relationship that existed between skillfulness and vertical jump height no longer existed when only the best performances were analyzed. Maximum positive slope accounted for 17% of the total variance when only the best performances were analyzed. Multiple linear regression was performed on all twelve independent variables to find the best prediction model for determining EIS. Regression equations for the best prediction model resulting in an $R^2 = 0.45$ and 0.48 for EIS_{vmax} and EIS_{vj}, respectively, are given by:

$$EIS_{vmax} = 11.21 + 0.45(y) + 50.98(t3) - 1.19(\bar{y}) -25.59(t5)$$

$$EIS_{vj} = 23.38 + 1.62(y) + 183.81(t3) - 4.27(\bar{y}) -94.36(t5)$$

Where y = maximum positive slope, t3 = time of positive impulse, $\bar{y}$ = average slope from Fmin to Fmax, and t5 = time of eccentric contraction. The model still accounted for less than half of the variability in EIS_{vmax} and EIS_{vj}. The models suggested were significant at $p<0.05$ ($F_{4,19}=3.92$ and $F_{4,19}=4.43$ for EIS_{vmax} and EIS_{vj} respectively). RMS errors of 6.46% and 21.80%, respectively for EIS_{vmax} and EIS_{vj}, also were calculated.

When least skillful performances as determined by EIS were analyzed, no independent variable related significantly to skillfulness (Table 5). Additionally, jump height was not related to skillfulness when poorest performances were analyzed. No regression equation predicted the poor EIS scores.

Table 5. Correlation Coefficients (r) of the 12 independent variables with skillfulness when the best performances (n=24) and the poorest performances (n=27) were analyzed.

Variable	EIS_{vmax} r best scores	EIS_{vj} r best scores	EIS_{vmax} r poorest scores	EIS_{vj} r poorest scores
Fmin	-0.26	-0.32	-0.07	-0.12
Fmax	0.26	0.21	-0.04	-0.08
y	0.41*	0.42*	0.20	0.16
$\bar{y}$	0.05	0.05	0.11	0.12
↓F	0.13	0.09	-0.11	-0.14
Λ	-0.25	-0.25	0.08	0.02
R	-0.18	-0.20	0.18	0.11
t1	-0.29	-0.33	-0.24	-0.26
t2	-0.02	-0.02	-0.02	-0.04
t3	0.19	0.19	0.09	0.14
t4	0.15	0.14	0.19	0.22
t5	-0.13	-0.14	-0.15	-0.12
EIS_{vmax}	1.00	0.99**	1.00	0.99**
EIS_{vj}	0.99**	1.00	0.99**	1.00
Jump Height	0.30	0.22	0.27	0.17

* $p<.05$
**$p<.01$

Kinetic and Temporal Correlates to Jump Height

Three independent variables related to vertical jump height. These variables were maximum force (Fmax), maximum positive slope of force (y), and force at the low point of the center of mass (↓F) (Table 6). These three variables accounted for 31%, 10%, and 11% of the total variance, respectively, when considered separately. The regression equation that best predicted skillful performance when determined by vertical jump height ($R^2 = 0.78$ and an RMS error of 5.20) was given by:

$$\text{Jump Height} = -146.068 + 31.356(\text{Fmax}) + 183.018(\Lambda) + 125.379(t3) + 49.127(R) - 6.947(\downarrow F) + 16.087(t5)$$

Where Fmax = maximum force applied to the force platform, Λ = shape factor of the force time curve, R = ratio of the negative impulse to the positive impulse, $\downarrow F$ = force at the low point of the body's center of mass, and t5 = time of eccentric contraction. The model was significant at $p<0.01$ ($F_{5,45}=57.816$).

Table 6. Correlation Coefficients (r) of the 12 independent variables with jump height for all subjects. (n=51)

Variable	r
Fmin	-0.01
Fmax	0.56**
y	0.31*
$\bar{\bar{y}}$	0.22
$\downarrow F$	0.34*
Λ	0.27
R	0.11
t1	0.19
t2	-0.10
t3	-0.23
t4	-0.04
t5	-0.04
EIS_{vmax}	0.42**
EIS_{vj}	0.37**

* $p<.05$ **$p<.01$

Best jump height performances were analyzed for their relationship to the independent variables. No significant relationships occurred (Table 7). The model suggested through stepwise regression was not significant ($F_{4,22}=0.13$, $p>0.05$).

For the poorest jump height performances, maximum force (Fmax), maximum positive slope(y), shape factor (Λ) and force at the low point of the center of mass ($\downarrow F$) related significantly to jump height (Table 7). Jump height was not related to skillfulness. The regression equation for the best prediction model ($R^2 = 0.32$ and an RMS error of 4.03cm) was given by:

$$\text{Jump Height} = 0.322 + 9.425(\text{Fmax}) + 7.946(\text{t1})$$

Where Fmax = maximum force applied to the force platform and t1 = time of the major negative impulse. Although not a strong predictor of the variability in vertical jumping, the model suggested was significant at $p<0.01$ ($F_{2,24}=7.452$).

Table 7. Correlation Coefficients (r) of the 12 independent variables with the best (n=24) and the poorest (n=27) jump height performances

Variable	r best scores	r poorest scores
Fmin	0.15	0.04
Fmax	0.08	0.65**
$\underline{y}$	0.04	0.40*
$\bar{y}$	-0.06	0.29
↓F	-0.07	0.60**
Λ	0.07	0.63**
R	0.3	0.09
t1	0.10	0.27
t2	0.11	-0.07
t3	-0.04	-0.32
t4	-0.12	-0.11
t5	0.33	-0.04
EIS_{vmax}	0.31	0.27
EIS_{vj}	0.28	0.17

* $p<.05$
**$p<.01$

Standardization

Statistical evidence provided minimal support that any force-time curve could serve as a pattern of skillful jumping whether using EIS or vertical jump height as determinants. However, such a heterogeneous group of performers was tested that very few subjects exhibited smooth rises to peak. Therefore, information was not present in the original data to support conclusions that smooth force-time curves or unsmooth force-time curves are more indicative of more skillful performance. Previous work in vertical jumping research and statements made by other researchers (Dowling & Vamos, 1993; Shetty & Etnyre, 1989), led to the hypothesis that smooth force-time curves may, in fact, lead to more skillful performance. Thus, another purpose of the current investigation was to manipulate existing force-time data by fitting a parabolic trajectory to determine kinetic and temporal relationships to single peak, smooth curve performances. Maximum force and time of jump execution was not affected through curve fitting or "standardization".

Data were standardized to obtain a smooth rise to a single peak in the force-time curve. Of the 51 trials that were analyzed originally, all but eight trials were standardized. To accomplish this alteration in the original data, a parabolic trajectory was fit to the line of the positive impulse when the slope of a line connecting the data deviated by more than five percent either before or after maximum force attainment. Trials not fit with a parabolic curve exhibited a force-time curve that was smooth. The remainder of the analysis examined the changes in the relationships of kinetic and temporal characteristics that occurred as a result of the standardization procedure. All standardized and the unaltered trials were analyzed (n=51).

Performance measures for all individuals whose original data were standardized increased significantly. Group non-standardized and standardized means and standard deviations for the dependent measures are reported in Table 8. Significant performance differences ($p<0.01$) were found between the non-standardized and standardized means ($F_{1,50}$=23.47 for EIS_{vmax}, $F_{1,50}$=13.48 for EIS_{vj}, $F_{1,50}$=14.05 for vertical jump height) for the variables indicated in Table 8.

Although performance measures for all individuals whose original data were standardized increased significantly, only four independent variables changed significantly. These variables were: 1) $\downarrow F$; 2) Λ; 3) R; and 4) t2. Non-standardized and standardized means and standard deviations for the independent measures influenced by standardization also are reported in Table 8. A significant difference ($p<0.01$) was found between the non-standardized and standardized means ($F_{1,50}$=29.23 for $\downarrow F$, $F_{1,50}$=48.30 for Λ, $F_{1,50}$=26.39 for R, and $F_{1,50}$=8.72 for t2).

Values for $\downarrow F$, Λ, and t2 all increased in magnitude. The ratio of the negative and positive impulse decreased in size as expected. This change resulted from increases in the shape factor (Λ), an indicator of the size of the positive impulse.

Standardized Descriptive Data

Performance means and standard deviations for the standardized data for all subjects are reported in Table 8. The ranges for skillfulness were 1.68% to 181.27% as measured by EIS_{vmax}, 4.44% to 910.77% as measured by EIS_{vj}, and 19.70cm to 194.97cm as measured by jump height.

Table 8. Means and Standard deviations of nonstandardized and standardized data for all subjects. (n=51)

Variable	Nonstandardized Mean (SD)	Standardized Mean (SD)
Fmin	0.45 BW (0.22)	0.45BW (0.22)
Fmax	2.59BW (0.45)	2.59BW (0.45)
y	16.86BW/s (10.96)	16.52BW/s (11.01)
$\bar{y}$	5.35BW/s (2.59)	5.35BW/s (2.59)
↓F	2.15BW (0.47)	2.22BW** (0.44)
Λ	0.38 (0.07)	0.42** (0.04)
R	-0.27 (0.07)	-0.24** (0.06)
t1	0.40s (0.16)	0.40s (0.16)
t2	0.14s (0.09)	0.15s** (0.09)
t3	0.42s (0.08)	0.42s (0.08)
t4	0.17s (0.09)	0.17s (0.09)
t5	0.30s (0.10)	0.29s (0.09)
EIS_{vmax}	18.96% (11.26)	40.43%** (36.54)
EIS_{vj}	54.81% (35.26)	141.89%** (184.93)
Jump Height	33.66cm (10.41)	50.08cm** (33.81)

**p<.01

To maintain consistency with the previous non-standardized analyses, standardized data also were divided into groups of the best performances and poorest performances. As in the earlier analyses, groups were divided by the 24 best and the 27 worst scores. Again, group membership varies based upon the measure used to determine skillfulness. That is, the best 24 EIS subjects may not have been the best 24 vertical jump height subjects. Changes also occurred in the subjects chosen as the best or poorest performers. Of the 24 best performers, as measured by EIS, in the non-standardized data, one-third (8) of the subjects were reclassified, due to greater changes for other performers, into the poor performance group. Only one-sixth (4) of the performers were reclassified into the poor performance group when vertical jump height was used to determine skill.

Performance means and standard deviations for 24 subjects with the best EIS scores and the best vertical jump height scores are reported in Table 9. The ranges for skillfulness using EIS were 31.18% to 181.27% for EIS_{vmax} and 94.24% to 910.77% for EIS_{vj}. Vertical jump height scores for the subjects with the best EIS scores ranged from 25.64cm to 194.97cm. Performance means and standard deviations for 24 subjects with the greatest jump height scores also are reported in Table 11. The range for the best vertical jump height scores was 41.27cm to 194.97cm for jump height. EIS scores for the subjects with the best vertical jump height scores were 10.63% to 181.27% for EIS_{vmax}, and 26.26% to 910.77% for EIS_{vj}. Nine subjects in the "best" EIS group were not considered skilled when vertical jump height was the criterion for skillfulness after standardization.

Table 9. Means and standard deviations for subjects with best EIS (EIS > 31% (n=24)) and vertical jump height scores (vertical jump height > 41 cm (n=24)).

Variable	EIS Mean (SD)	Vertical Jump Height Mean (SD)
Fmin	0.45BW (0.21)	0.44BW (0.22)
Fmax	2.61BW (0.56)	2.75BW (0.48)
y	17.52BW/s (11.99)	18.22BW/s (10.67)
$\bar{y}$	4.91BW/s (2.40)	5.61BW/s (2.12)
↓F	2.25BW (0.59)	3.32BW (0.53)
Λ	0.41 (0.04)	0.43 (0.04)
R	-0.23 (0.05)	-0.23 (0.05)
t1	0.40s (0.16)	0.42s (0.16)
t2	0.16s (0.10)	0.15s (0.10)
t3	0.46s (0.08)	0.44s (0.07)
t4	0.18s (0.11)	0.18s (0.10)
t5	0.28s (0.07)	0.30s (0.08)
EIS_{vmax}	63.12% (42.66)	55.33% (47.34)
EIS_{vj}	238.37% (235.36)	208.13% (250.68)
Jump Height	64.55cm (44.10)	70.40cm (40.54)

BW = body weight
BW/s = body weight per second
s = seconds

Performance means and standard deviations for 27 subjects with EIS scores less than 31% are reported in Table 10. The ranges for skillfulness as determined by EIS were 1.68% to 30.81% for EIS_{vmax}, and 4.44% to 93.55% for EIS_{vj}. Vertical jump height scores for the subjects with the poorest EIS scores ranged from 19.70cm to 64.60cm. Performance means and standard deviations for 27 subjects with jump height scores less than 40.5cm also are reported in Table 10. The range for jump height was 19.70cm to 40.40cm. The range for EIS scores for subjects with the poorest vertical jump height scores was 1.68% to 61.14% for EIS_{vmax} and 4.44% to 224.29% for EIS_{vj}.

Table 10. Means and standard deviations for subjects with the lowest EIS (EIS < 31% (n=27)) and vertical jump height scores (vertical jump height < 41cm (n=27)).

Variable	EIS Mean (SD)	Vertical Jump Height Mean (SD)
Fmin	0.46BW (0.23)	0.46BW (0.23)
Fmax	2.57BW (0.34)	2.44BW (0.38)
y	15.63BW/s (10.20)	14.99BW/s (11.28)
$\bar{y}$	5.74BW/s (2.72)	5.12BW/s (2.96)
↓F	2.20BW (0.25)	2.14BW (0.33)
Λ	0.42 (0.05)	0.41 (0.04)
R	-0.25 (0.07)	-0.24 (0.08)
t1	0.40s (0.16)	0.38s (0.15)
t2	0.13s (0.08)	0.14s (0.09)
t3	0.40s (0.06)	0.41s (0.08)
t4	0.16s (0.07)	0.16s (0.08)
t5	0.30s (0.11)	0.29s (0.10)
EIS_{vmax}	20.27% (7.78)	27.19% (14.06)
EIS_{vj}	56.13% (23.14)	83.01% (50.26)
Jump Height	37.23cm (10.62)	32.02cm (4.96)

BW = body weight
BW/s = body weight per second
s = seconds

Kinetic and Temporal Correlates to Skillfulness for Standardized Data

Five independent variables related significantly to skillfulness as measured by EIS following standardization. These variables were

Fmax, y, ↓F, t3, and t4 (Table 11). When the entire subject pool was evaluated, skillfulness and vertical jump heights were significantly related ($r=0.91$ for EIS_{vmax} and $r=0.91$ for EIS_{vj}). The best single predictor of skillfulness was t3 ($r=0.534$ for EIS_{vmax} and $r=0.501$ for EIS_{vj}) accounting for an R^2 of 0.29. Multiple linear regression was performed on all twelve independent variables to find the best prediction model for determining skillfulness. The regression equations for the best prediction model resulting in an $R^2 = 0.88$ and 0.85, respectively, for EIS_{vmax} and EIS_{vj} are given by:

$$EIS_{vmax} = -5.13 + 0.83(y) + 61.56(R) + 62.19(t3)$$

$$EIS_{vj} = -27.13 + 2.61(y) + 198.81(R) + 174.81(t3)$$

Where y = maximum positive slope of the curve, R = negative/positive impulse ratio, and t3 = duration of the positive impulse. RMS errors of 14.14% and 78.03%, respectively for EIS_{vmax} and EIS_{vj}, also were calculated. The amount of variance accounted for in predicting skillfulness was significantly better than the amount of variance accounted for using the non-standardized data. The models suggested were significant at $p<0.01$ ($F_{5,45}=57.816$ for EIS_{vmax}, $F_{5,45}=47.16$ for EIS_{vj}).

Table 11. Correlation Coefficients (r) of the 12 independent variables with skillfulness. (n=51)

Variable	EIS_{vmax} r	EIS_{vj} r
Fmin	-0.19	-0.17
Fmax	0.42**	0.47**
y	0.32*	0.32*
$\bar{y}$	0.12	0.15
↓F	0.39**	0.42**
Λ	-0.14	-0.18
R	-0.18	-0.18
t1	-0.07	-0.04
t2	0.05	0.03
t3	0.53**	0.50**
t4	0.31*	0.31*
t5	0.16	0.18
EIS_{vmax}	1.00	0.99**
EIS_{vj}	0.99**	1.00
Jump Height	0.91**	0.91**

* $p<.05$
**$p<.01$

When the best 24 EIS performances were analyzed, Fmax, y, $\bar{y}$, ↓F, t3, t4, and t5 were significantly related to skillfulness when determined by EIS (Table 12). The relationship between EIS and vertical jump height also was significant (r=0.941 for EIS_{vmax} and r=0.927 for EIS_{vj}). The best single predictor of skillfulness was Fmax. Fmax alone accounted for an $R^2 = 0.41$ for EIS_{vmax} and $R^2 = 0.40$ for EIS_{vj} when only best performances were included in the analysis. Multiple linear regression was performed on all twelve independent variables to find the best prediction model for determining EIS. Regression equations for the best prediction model resulting in an $R^2 = 0.95$ and 0.82 for EIS_{vmax} and EIS_{vj}, respectively, are given by:

$$EIS_{vmax} = -319.22 + 67.21(Fmax) - 175.77(t3) + 824.65(t4) + 857.89(t2)$$

$$EIS_{vj} = -1516.07 + 337.92(Fmax) + 1914.82(t3)$$

Where Fmax = maximum force applied to the force platform, t3 = duration of the positive impulse, t4 = time from Fmax to take-off, and t2 = time from the low point of the center of mass to Fmax. The models were significant at $p<0.01$ ($F_{4,19}=94.39$ and $F_{2,21}=46.86$ for EIS_{vmax} and EIS_{vj} respectively). RMS errors of 10.27% and 21.80% for EIS_{vmax} and EIS_{vj}, respectively, also were calculated.

When the least skillful performances as determined by EIS were analyzed, Fmax and t2 were related significantly to skillfulness (Table 12). Additionally, jump height was not related to skillfulness when poor EIS performances were analyzed. The best single predictors of EIS were t2 for EIS_{vmax} and Fmax for EIS_{vj}. T2 alone accounted for an $R^2 = 0.16$ for EIS_{vmax} while Fmax accounted for an $R^2 = 0.15$ for EIS_{vj}. Multiple linear regression was performed to find the best prediction model for determining skillfulness. The regression equations of the best prediction model resulting in an $R^2 = 0.60$ and 0.58, respectively, for EIS_{vmax} and EIS_{vj} are given by:

$$EIS_{vmax} = -16.36 + 150.51(t2) + 102.82(t4) + 0.37(y) - 13.18(t1)$$

$$EIS_{vj} = -54.91 + 440.45(t2) + 303.68(t4) + 1.20(y) - 34.74(t1)$$

Where t2 = time from the low point of the center of mass to Fmax, t4 = time from Fmax to take-off, y = average positive slope from Fmin to Fmax, and t1 = time for the major negative impulse. These models were significant at $p<0.01$ ($F_{4,22}=8.19$ and $F_{4,22}=7.60$ for EIS_{vmax} and EIS_{vj}, respectively). RMS errors of 5.36% and 16.30%, respectively for EIS_{vmax} and EIS_{vj} also were calculated.

Table 12. Correlation Coefficients (r) of the 12 independent variables with skillfulness when the best 24 performances (n=24) and the poorest performances (n=27) were analyzed.

Variable	EIS_{vmax} r best scores	EIS_{vj} r best scores	EIS_{vmax} r poorest scores	EIS_{vj} r poorest scores
Fmin	-0.30	-0.25	-0.25	-0.32
Fmax	0.64**	0.63**	-0.39*	-0.39*
y	0.44*	0.42*	0.12	0.17
$\bar{y}$	0.49*	0.44*	-0.22	-0.18
↓F	0.52*	0.51*	-0.32	-0.29
Λ	-0.23	-0.26	0.16	0.14
R	-0.17	-0.20	0.15	0.09
t1	-0.10	-0.07	-0.24	-0.22
t2	-0.15	-0.13	0.40*	0.37
t3	0.47*	0.46*	0.36	0.35
t4	0.41*	0.39	-0.13	-0.10
t5	0.46*	0.47*	0.13	0.14
EIS_{vmax}	1.00	0.99**	1.00	0.99**
EIS_{vj}	0.99**	1.00	0.99**	1.00
Jump Height	0.94**	0.93**	0.32	0.23

* p<.05
**p<.01

Kinetic and Temporal Correlates to Jump Height for Standardized Data

Four independent variables related significantly to vertical jump height. These variables were Fmax, y, ↓F, and t3 (Table 13). Jump height also was related to EIS (r=0.911 for EIS_{vmax} and r=0.915 for EIS_{vj}, $p < 0.01$). The best single predictor of jump height was Fmax, accounting for approximately 42% of the variance in vertical jump height. Multiple regression analysis detected that other variables could significantly add to the prediction of jump height. The regression equation of the best prediction model resulting in an $R^2 = 0.95$ and an RMS error of 8.34 cm was given by:

$$\text{Jump Height} = -313.970 + 50.611(\text{Fmax}) + 200.285(\Lambda) + 352.728(t3) + 179.508(R) + 16.759(\downarrow F) + 0.330(y)$$

Where Fmax = maximum force applied to the force platform, Λ = the shape factor of the positive impulse, t3 = time of positive impulse, R = ratio of the negative impulse to the positive impulse, $\downarrow F$ = force at the low point of the body's center of mass, and y = average positive slope from Fmin to Fmax. The model was significant at $p<0.01$ ($F_{6,44}=129.57$).

Table 13. Correlation Coefficients (r) of the 12 independent variables with jump height. (n=51)

Variable	r
Fmin	-0.12
Fmax	0.65**
y	0.36*
$\bar{y}$	0.21
$\downarrow$F	0.55**
Λ	-0.05
R	0.20
t1	0.06
t2	-0.00
t3	0.37**
t4	0.24
t5	0.17
EIS_{vmax}	0.91**
EIS_{vj}	0.92**

* $p<.05$
**$p<.01$

When the best standardized jump height performances were analyzed, five independent variables related significantly to vertical jump height. These variables were Fmax, y, $\bar{y}$, $\downarrow$F, and t3 (Table 14). The regression equation for the best prediction model resulting in an $R^2 = 0.99$ and an RMS error of 4.78cm was given by:

$$\text{Jump Height} = -415.203 + 70.565(\text{Fmax}) + 192.941(\Lambda) + 559.878(t2) + 463.292(t4) + 13.759(\downarrow F) + 39.282(t5)$$

Where Fmax = maximum force applied to the force platform, Λ = the shape factor of the positive impulse, t2 = time from the low point of the body's center of mass to Fmax, t4 = time from Fmax to take-off, ↓F = force at the low point of the body's center of mass, and t5 = time of eccentric contraction. The model was significant at $p<0.01$ ($F_{6,17}=273.25$).

When the poorest standardized jump height performances were analyzed, no independent variables related significantly to vertical jump height.

Table 14. Correlation Coefficients (r) of the 12 independent variables with the best (n=24) and poorest (n=27) jump height performances.

Variable	r best scores	r poorest scores
Fmin	-0.17	0.04
Fmax	0.77**	0.07
y	0.51*	-0.01
$\bar{y}$	0.41*	-0.31
↓F	0.65**	-0.03
Λ	-0.35	0.02
R	0.28	0.18
t1	-0.05	0.05
t2	-0.07	0.27
t3	0.45	0.12
t4	0.32	-0.23
t5	0.28	-0.01
EIS_{vmax}	0.95**	0.38*
EIS_{vj}	0.95**	0.33

* $p<.05$
**$p<.01$

Summary

The purpose of the current investigation was to determine kinetic and temporal correlates to skillfulness using the force-time curve. Variables related to skillfulness, determined by EIS, explained approximately 50% of the variance in performance for all subjects together, and for the highest skilled subjects. No significant relationships occurred when the lowest skilled subjects were analyzed separately. Analysis of relationships to the more traditional product variable of jump height indicated that approximately 78% of the variance could be explained. Surprisingly, when analysis was conducted on the high skilled jump height group, no variables were found to relate significantly to performance. The low performance jump height group produced relationships similar to the entire group.

A second purpose of this investigation was to examine changes in performance as a result of manipulating the force-time curves, such that all trials exhibiting two peaks, or an unsmooth rise to peak, were standardized. Analysis of variance indicated that all performance measures, whether determined by EIS or vertical jump height, increased significantly following standardization. Four independent variables were affected by standardizing the force-time curves. They were:

1) the force at the low point of the body's center of mass ($\downarrow$F);
2) the shape factor of the positive impulse (Λ);

3) the ratio of the negative to the positive impulse (R); and
4) the time from the low point of the body's center of mass to the maximum application of force on the platform (t2).

All changes were significant at $p < 0.01$. $^{\downarrow}F$, Λ, and t2 increased in magnitude after standardization. R became smaller after standardization.

Kinetic and temporal correlates to skillfulness using the force-time curve also were examined using the standardized data. Variables related to skillfulness, determined by EIS, then accounted for approximately 88% of the variance in performance for all subjects together, and 95% of the variance for the highest skilled subjects. Relationships found for lowest skilled subjects, as determined by EIS, accounted for 60% of the variance. Analysis of relationships to the more traditional product variable of jump height indicated that approximately 95% of the variance could be explained. When analysis was conducted on the high skilled jump height group, regression analysis explained almost 99% of the variance. This is a significant difference in the amount of variance explained in the high performance group before standardizing the curves. There were no significant relationships found between kinetic and temporal variables and jump height for the low skilled group.

CHAPTER V

DISCUSSION

In this investigation, biomechanical force-time curves were examined with the intent that more useful evaluative information could be obtained about vertical jump performance when skillfulness was redefined using an EI score. The formulation of the specific research questions was based on the fundamental assumption that product measures of movement (i.e., vertical jump height) are influenced by factors, such as genetic talent and training, that influence performance but may not be accurate indicators of biomechanical technique. The choice of EIS scores as dependent measures, then, was based on the need to highlight properties of the vertical jump force-time record that typify skillful (technically sound) performance. Following the method proposed by Hudson (1986), EIS was determined for each individual. Then, analysis proceeded using the method proposed by Dowling and Vamos (1993) to identify specific variables related to skillfulness, using EIS and vertical jump heights to determine skill. Research questions were posed to investigate (1) the relationships of selected variables to EIS and vertical jump height, (2) the relationships between determining EIS using maximum upward velocity and determining EIS using vertical jump height, and (3) the effect of standardizing the force-time record on determining the relationships of the variables to EIS. Ultimately, if the characteristics of skillful performance are determined, it should be possible to use these measures to assess possible deficiencies in less talented performances (Dowling & Vamos, 1993).

Kinetic and Temporal Correlates to Skillfulness

It was hypothesized that more of the variance in skillfulness could be explained by kinetic and temporal correlates when EIS was used as the determinant of skillfulness rather than vertical jump height. The results of the current investigation indicate that approximately 45% of the variability in skillfulness as determined by EIS could be explained by the chosen kinetic or temporal variables. Conversely, when skill was examined using vertical jump height, the explained variance of 78% was similar to previous investigations of this type (Dowling & Vamos, 1993; Oddsson, 1989). Standardization of the force-time curves increased the predictability of regression analysis to 88% and 95% for EIS and vertical jump height, respectively. Given these results, the current investigation did not support the hypothesis.

It was hoped that when groups were split into best and poorest performances, more of the variance in skillfulness could be explained by kinetic and temporal correlates when EIS was used as the determinant of skillfulness rather than vertical jump height. Analysis of the best non-standardized trials revealed that approximately 45% of the variance in skillfulness could be explained. When skill was examined using vertical jump height, explained variance was low and not significant. Standardization of the best jumps resulted in almost 90% of the variability in EIS being explained by kinetic or temporal variables. Explained variance was 99% for vertical jump height.

Analysis of the poorest non-standardized trials revealed that none of the variance in skillfulness could be explained by the available variables. However, unlike best performances, when poorly skilled vertical jump heights were examined, explained variance was approximately 32%. Standardization resulted in 60% of the variability in EIS being explained by kinetic or temporal variables. No variance was explained for vertical jump height. Splitting the data into best and poorest performances supported the hypothesis that more EIS could be predicted by kinetic and temporal variables for non-standardized data than could be explained for a product measure such as vertical jump height. The results of the current investigation did not support the hypothesis, that more variance in EIS would be explained, when the data were standardized. Although discouraging, the inability of regression analysis to increase the predictability of kinetic and temporal correlates to skillfulness using EIS over skillfulness using jump height may not be as important to this investigation as once hoped. Dowling and Vamos (1993) stated that even if all variables suggested through regression explained 100% of the variance, the interactions of these variables could greatly confuse any interpretation of what exactly was important to vertical jumping. It would, therefore, be more beneficial to examine the variables suggested by regression to determine commonalities in interpreting a variable's importance to skillfulness, whether determined by EIS or vertical jump height.

Effects of Standardization.

Standardization of the force-time curve was conducted to produce a single peak in the curve. To examine the effect of a single peak, the original (i.e., non-standardized) data were standardized by fitting a parabolic curve to those force curves that exhibited an unsmooth rise to peak force, or double peaks. It was hypothesized that a single peak would enhance skillfulness. A single peak in the force-time curve did enhance performance in the current investigation. In movement terms, this result would mean that subjects exhibiting a single peak may be integrating the system into the movement most effectively. A significant main effect on skillfulness was found as a result of standardization of the force-time curve. A possible explanation for these findings is that the smooth rise to peak force maintains positive acceleration in the system and allows the velocity of the system to maintain a consistent rise to peak. Not only does velocity increase more consistently, but it is also likely that velocity also is accelerating more rapidly resulting in a faster velocity for the entire system.

Four independent variables were affected by standardization. They were: 1) force applied to the force platform at the low point of the body's center of mass; 2) shape factor; 3) negative/positive impulse ratio; and 4) time from the low point of the center of mass to maximum force application. Maximum force was not altered for any subject. The assumption guiding standardization of the force-time curve was that all individuals were executing the skill maximally and, therefore, could not apply more force to the platform.

Standardization increased the force applied to the force platform at the low point of the body's center of mass. This finding would suggest that unsmooth rises to peak force or double peaks dissipate the force of the system during the eccentric phase. The human musculoskeletal system can handle greater forces during eccentric contraction than during concentric contraction (Kreighbaum & Barthels, 1992). Thus, it is possible that subjects whose initial performances were altered were not getting the full benefit of the eccentric load imposed by countermovement. Smooth rises to peak force may allow performers to load the muscle more effectively prior to concentric impetus.

Shape factor of the positive impulse also increased significantly as a result of standardization. The shape factor is a ratio between the area of the force-time curve and the area of a rectangle bounded by the duration of the positive impulse and maximum force application to the force platform. Fitting a parabolic curve to smooth out the rise to peak force increases the area under the force-time curve. Results of this manipulation indicated the ratio increased when a smooth rise to peak occurred. The perfect impulse would be rectangular or a 1:1 ratio between the force-time curve and the rectangle bounded by the duration of the positive impulse and the maximum force (Adamson & Whitney, 1971; Dowling, 1982). A 1:1

ratio is physically impossible as all muscle contractions need time to develop force. However, a smooth rise to peak force more closely approximates the rectangular ideal by providing greater area under the force-time curve than unsmooth or dual peaked curves (see Figure 2).

The negative/positive impulse ratio decreased as a result of the positive impulse becoming larger. The negative/positive impulse ratio changed from 0.265 to 0.235. It appears that although a certain amount of negative impulse is necessary, larger amounts of negative impulse are not necessary for increased skillfulness whether it is determined by EIS or vertical jump height.

The time between the low point of the body's center of mass and the maximum application of force also increased significantly as the result of standardization. This result would indicate that performers who can produce a smooth rise to peak force will be able to concentrically contract the muscle over a longer period of time before the force-velocity trade-off rendering further contraction ineffective. Again, a square impulse bounded by the duration of the positive impulse and maximum force would be the optimum pattern of force application for the force-time curve (Adamson & Whitney, 1971; Dowling, 1982). A longer time interval from the low point of the body's center of mass to maximum would "square-off" the force-time curve such that it more closely resembles the rectangular shape suggested by Adamson and Whitney (1971) and Dowling (1982).

Kinetic and Temporal Correlates to EIS.

The variables selected for prediction of skillfulness using EIS were identical across subjects, whether the data were standardized or not. These variables were: 1) maximum positive slope of the curve; 2) ratio of the negative to positive impulse; and 3) duration of the positive impulse. Ratio for the negative to positive impulse decreased as the result of standardization. Values for maximum positive slope of the curve and duration of the positive impulse were not affected by standardization.

Maximum positive slope of the force-time curve was significantly related to EIS (r=0.511) but explained less than 30% of the variance in EIS. The variance explained by maximum positive slope was similar to the variance Fmax explained for vertical jump height for Dowling and Vamos (1993). Maximum positive slope, in all observations, occurred between the beginning of eccentric contraction and the body's COM reaching its lowest position. In other words, the maximum positive slope occurred during the eccentric braking phase of the countermovement. Maximum positive slope is the rate change of force per unit of time. If the rate of change is rapid, the amount of eccentric loading on the muscle will not necessarily end up being greater, but loading will occur very quickly. Quick eccentric loading of the muscles has been found to be a significant factor in the use of stored elastic energy (Assmussen & Bonde-Petersen, 1974a; Cavagna, Dusman & Margaria, 1968).

Also of importance to the prediction of skillfulness using EIS was the magnitude of the negative/positive impulse ratio. Consistent with the findings of Dowling and Vamos (1993), the jumps analyzed had low negative/positive impulse ratios around 0.265. Low ratios are due to larger positive impulses with respect to the negative (unweighting) phase of the jump. Van Ingen Schenau (1984) suggested the purpose of the negative work phase was to take up the "slack" present in the muscle and was not necessarily used to store elastic energy. A certain amount of negative impulse is necessary, but has not been associated with high jumps, as determined by vertical jump height (Asmussen & Bonde-Petersen, 1974; Bosco, Tihanyi, Komi, Fekete, & Apor, 1982; Dowling & Vamos, 1993; Komi & Bosco, 1978; Oddsson, 1989). The data for this investigation indicated that there indeed was a need to execute a countermovement (i.e., negative impulse) for success in vertical jumping. That is, a countermovement enhanced skillfulness regardless of the performance measure. It was speculated that there may exist some negative/positive impulse ratio that would lead to the most efficient use of the stored elastic component of the muscles involved in jumping. Values below some critical value of the negative/positive ratio would decrease jump height through inefficient eccentric loading of the powerful muscles involved in vertical jumping. Higher negative/positive ratios may be indicative of poorly integrating the segments of the system and would also serve to diminish jump height. Too great a load on the jumping muscles would also serve to diminish the effects of the stored elastic component developed through the incorporation of a quick countermovement. The ideal ratio may be somewhere around .23, which is less than suggested by Dowling and Vamos (1993).

The duration of the positive impulse also significantly added to the prediction of EIS. Impulse is the product of the applied force and the time of force application (Impulse = Ft). This relationship ultimately affects the velocity of the system (Ft = mv; where m = mass of the system). EIS typically is determined by the maximum velocity of the system. Therefore, longer time of force application led to higher velocities, resulting in higher EIS scores.

When the best EIS performances were analyzed, maximum positive slope of the curve was the only variable related to skillfulness. However, the variables selected, through regresion, for the best performances using EIS were: 1) maximum positive slope of the curve; 2) duration of the positive impulse; 3) average positive slope of the curve; and 4) duration of eccentric contraction.

For the best EIS jumps, it also was important to exhibit high average slopes. Although related to maximum slope of the force-time curve, average slope can be influenced by the shape of the curve before reaching maximum force application. Average slope will be less if the curve does not rise smoothly to peak force. Higher average slope to peak force or smoother applications of force indicated that performances with a single peak exhibited better EIS scores. Higher average slope provided further evidence that the eccentric load applied to the muscle should be executed quickly to take advantage of the stored elastic component (Assmussen & Bonde-Petersen, 1974a; Cavagna, Dusman & Margaria, 1968). Time of eccentric contraction also was considered to be a useful predictor of skillfulness for better jumpers. The shorter the time interval of eccentric contraction, the better the jump with respect to EIS. Shorter time of eccentric contraction also leads to high average and maximum positive slope. This finding supports the argument that quicker eccentric contractions enhance a performer's ability to use the stored elastic component of the muscle.

Standardization of the force-time curve dramatically altered the prediction equation suggested for best performances. Significant variables were: 1) maximum force application on the force platform; 2) duration of the positive impulse; 3) duration from maximum force application to take-off; and 4) duration from the low point of the center of mass to maximum force application. Duration from the low point of the center of mass to maximum force application increased as a result of standardization.

Longer duration of positive impulse and shorter durations of time from low center of mass to maximum force and from maximum force to take-off lead to a more "rectangular-like" force-time curve. The optimal pattern of force application was hypothesized to be rectangular in shape (Adamson & Whitney, 1971; Dowling, 1982). Although a rectangular shape to the curve is physically impossible due to tension development constraints of muscle, the findings of this investigation would support the speculation that a rectangular shape is best. However, shape factor (i.e., a variable specifically chosen to measure rectangularity) was not significantly related to the best EIS jumps. Failure to find significance here also could be indicative of the tension development constraints in the muscle system. That is, the inability of muscles to produce instantaneous tension may have led to shape factor values that were too small to influence the prediction of skillfulness.

Surprisingly, maximum force application was significant to prediction of best performances following standardization. A premise of the current investigation was that maximum force was influenced by genetic talents and training practices of the individual performer. However, standardized performances using EIS may indicate that maximum force application is indeed important to skillful performance. There may be some relative minimum force application that an individual must produce to attain some degree of skillfulness. This finding is surprising in another way as well. Maximum force was not affected by standardization, yet the trials chosen as the best performances after standardization were characterized by lower maximum forces than the trials chosen as best performances prior to standardization. Although high maximum force was important to skillfulness, it also was quite possible that higher maximum forces could be the result of too great a crouch in the countermovement. Too deep of a crouch could possibly exceed the effective concentric force contribution possible in the musculature or exceed the limits of the muscle for the storage of elastic energy. Intersegmental contributions to the skill should be examined in future investigations to determine if maximum force beyond some maximum percentage of body weight is detrimental to performance.

Using the measures investigated, prediction of poorer EIS performances was not possible before standardization. After standardization, however, the variables significantly contributing to the prediction of poor performances were: 1) duration from low point of the center of mass to maximum force; 2) duration from maximum force application to take-off; 3) maximum positive slope of the curve; and 4) duration of the negative impulse. Poorest EIS performances were characterized by longer durations from low point of center of mass to maximum force application and time from maximum force application to take-off. Greater values of these two variables would serve to round off the "rectangular-like" optimum shape of the force-time curve (Adamson & Whitney, 1971; Dowling, 1982). Likewise, the rounding nature of the increases in these two time intervals also would lead to lower maximum positive slopes of the curve. This created a slower transition from eccentric to concentric contraction and thus depleted the contribution of elastic recoil to skillfulness. Further, poor EIS performances also had a longer negative impulse phase. These subjects crouched to a greater extent than did better EIS performers. Deeper crouches lead to greater concentric contribution over a longer period of time, but this is not conducive to skillfulness using EIS or the effective use of stored elastic energy (Hudson, 1986; Hudson, Strohmeyer, & Bird, 1991).

Individuals who minimized durations related to use of stored elastic energy and produced a more "rectangular-like" shape of the force-time curve were more skillful jumpers. Quickness in vertical jumping was therefore important to success when determined by EIS. However, explained variance for EIS was not greater than the variance explained for vertical jump height. Before speculating about why this may have occurred, a discussion of the variables related to vertical jump height is warranted.

Kinetic and Temporal Correlates to Vertical Jump Height.

The variables suggested for prediction of skillfulness using vertical jump height were similar for the entire group, whether the data were standardized or not. For the non-standardized data, they were: 1) maximum force application; 2) shape factor; 3) time of positive impulse; 4) ratio of the negative and positive impulses; 5) force applied at the low point of the body's center of mass; and 6) time of eccentric contraction. Prediction of standardized vertical jump height was identical except that time of eccentric contraction was replaced by maximum average slope of the curve. Three variables, force applied at the low point of the body's center of mass, shape factor and the ratio for the negative to positive impulse changed as the result of standardization. The other values were not affected by standardization.

Maximum force was significantly related to vertical jump height (R= 0.559) and explained approximately 31% of jump height variance. These values are consistent with those reported by Dowling & Vamos (1993). Better jumps (i.e., those above 35 cm) produced maximum forces in excess of 2.5 times performers' body weight. High peak forces were necessary for superior jump height attainment. As with Dowling and Vamos (1993) and Oddsson (1989), however, high peak forces did not ensure high jumps. Some subjects in this investigation produced maximum forces in excess of 2.5 times body weight and attained vertical jump heights less than 30 cm in height. These results were not surprising since researchers have found that ankle plantar flexors alone are capable of producing ground reaction forces greater than twice body weight (Levine, Zajac, Belzer, & Zomlefer, 1983; Zajac, Wicke, & Levine, 1984). When jumping occurs using strictly plantar flexors of the ankle, vertical jump height is usually less than 10 cm. Following standardization, maximum force also was significantly related to jump height (R= 0.647) and explained approximately 42% of jump height variance. Jump height values are greater than those reported by Dowling & Vamos (1993), but their data were not standardized. High peak forces were necessary for superior jump height attainment when analyzing standardized and non-standardized trials.

Positive impulse duration also was selected as a predictor of skillfulness as determined by jump height. Higher vertical jumps had longer positive impulse times. This skillfulness parameter was consistent regardless of the skillfulness measure incorporated into the analysis. As previously suggested, the more "rectangular-like" the shape of the positive impulse, the better the physics of the impulse. For vertical jump height, shape factor was a good predictor of skillfulness. Larger values of the positive impulse shape factor meant the individual would jump higher. Although this was not an indicator of skillfulness using EIS, this finding was important because it was the first time the area under the force-time curve found to be related to performance.

Dowling and Vamos (1993) found that a relationship existed between vertical jump height and duration between Fmax and takeoff. This investigation supported their conclusions with respect to non-standardized data. Maximum velocity of the performer's center of mass is reached approximately 30ms prior to lifting off the ground. If the time from Fmax to takeoff is too long, the slope of the curve will be lower. A lower slope increases the time that maximum upward velocity precedes takeoff, decreasing maximum upward velocity. As a result, takeoff velocity also will be slower, thus decreasing vertical jump height and EIS.

As with EIS, the magnitude of the negative/positive impulse also was important to skillfulness using vertical jump height. Again, it is generally accepted that some form of a countermovement is necessary for skilled vertical jumping (Asmussen & Bonde-Petersen, 1974; Bosco, Tihanyi, Komi, Fekete, & Apor, 1982; Dowling & Vamos, 1993; Komi & Bosco, 1978; Oddsson, 1989). How much countermovement is necessary is still open to debate. Evidence reported here would indicate that there is some critical point at which a countermovement becomes too large (or conversely, too small). Therefore, van Ingen Schenau's (1984) argument that the countermovement simply "takes up the slack" in the muscle was unsubstantiated in this investigation. Further work examining this ratio with respect to elastic energy computations is necessary.

Time of eccentric contraction also was an indicator of skillfulness when performance was determined by vertical jump height. The results here indicate that shorter duration between the onset of eccentric contraction and the onset of concentric contraction was conducive to the execution of higher vertical jumps. For the prediction of skillfulness, time of eccentric contraction seems important to the vertical jump regardless of the method used for determining skillfulness.

When skillfulness was determined by vertical jump height, the force at the low point of the center of mass was an important predictor of skill. Larger forces were generally needed for better performance. Larger forces at lowest point of the center of mass, however, were not necessarily indicative of high EIS performances. Force at the low point of the center of mass could be the result of larger masses moving in a downward direction or stronger muscles capable of producing greater forces acting to slow the descent of the center of mass at a rapid pace. Larger mass was controlled for by examining this variable with respect to body weight. Eccentric capabilities of the muscle, however, could not be controlled. Regardless, the magnitude of this variable is implicitly related to the genetic abilities or the training of the individual performer.

Further analysis of the highest and lowest vertical jump height performances changed the prediction of skillfulness considerably. When regression analysis was executed on the best non-standardized vertical jump height performances, no equation was suggested. That is, none of the variables chosen for analysis could explain why the good jumps were better than the entire group or the poor performers. Prediction of poorest jump height performances was significant for the non-standardized data, but produced only two variables to help explain variance. One of these variables was Fmax. Fmax scores explained more variance in poor vertical jumps than was explained when the group was examined in its entirety. Similar to Dowling and Vamos' (1993) subjects, the individuals in this investigation also could produce inferior jumps with high maximum force application to the force platform.

General Discussion

The quandary of this investigation is that the independent variables selected do not fully support use of either EIS or vertical jump height for determining skillfulness. Some variables used to predict skill using EIS also were considered predictors of vertical jump height. An argument could be made that variables chosen to predict EIS are influenced by genetic talent and/or prior training. For example, maximum and average positive slopes were indicators of skillfulness using EIS. It was hypothesized that these values indicate the speed with which muscles are loaded during eccentric and concentric contractions. Faster time duration in the eccentric phase or the positive impulse phase would lead to steeper slopes. It then could be argued that those performers with a predominance of fast twitch muscle fiber would be more skilled because they are capable of producing muscle tension at a faster rate, thus using their genetic ability to produce better performances.

Extending this argument, it would seem that the variables selected for analysis in the current investigation were not appropriate for determining skillfulness using EIS or vertical jump height. The argument could be made for all the independent variables presented that some genetic influence could affect the magnitude of the variable. That is, fast twitch muscle would predispose any performer to executing the vertical jump with some degree of success regardless of the method used to calculate skillfulness. On the other hand, it would be expected that the prediction of skillfulness using vertical jump height would increase if only the best jumpers were analyzed. Are there variables that were not examined that could lead to greater insights?

EIS is a measure of improvement in an individual's performance of two complexities of vertical jumping. The intent of its use is to factor out genetic talents and training by comparing anindividual with her/himself. It would seem then, that any variables selected should be examined relative to individual performances. The variables in this investigation were magnitude scores and were taken directly from the force-time record of the jump. Magnitudes were not normalized with respect to the individual performance. Would ratio scores be more indicative of skilled performance and at the same time control for genetic and training factors? For example, if it took one performer approximately 0.18s to execute the eccentric portion of the vertical jump and another individual took .21s to execute the eccentric load, the individual with the fastest load time would be more skilled according to the prediction equations determined in the current analysis. If the individual who executed the faster eccentric load took 0.72s and the "slower" individual took 0.95s to execute the entire jump, would the results remain the same if talent and training were factored out of the independent variable? Although the "fast" eccentric load performer would be considered more skilled, if the variable is analyzed with respect to the total performance, this individual spent approximately 25% of the duration of the entire skill execution in eccentric contraction. The "slow" individual only spent 22% of the time for skill execution in eccentric contraction. With respect to the individual performance, the "slow" performer actually spent less time executing the eccentric contraction. The "fast" performer may have produced faster times simply by having more fast twitch muscle fiber or by training the muscle to be more explosive. Using ratio scores would allow the researcher to evaluate technique parameters of skillful jumping.

Ability to predict skillfulness increased significantly after standardization. For every example of standardization of the force-time data performance increased whether skillfulness was determined using EIS or vertical jump height. For the current investigation, this would indicate that smooth rises to peak force are more indicative of skillfulness than non-smooth rises. Generalizations of these findings would be purely conjecture since other alterations of the force-time profile were not examined as to their influence on skillfulness. However, it is believed that the smoother the rise to a single peak exhibited by any performer, the more technically sound their execution of the vertical jump.

EISvmax vs EISvj.

Historically, EIS has been calculated using the maximum velocity of the body's center of mass. While this measure is easily obtained by the researcher, most practitioners do not have equipment available to determine maximum velocity. Practitioners do, however, have the ability to measure vertical jump height and often do measure jump height as an integral part of fitness testing. As a result, there was a need to determine an EIS equivalent using jump height so practitioners may eventually apply these methods in the classroom. It was hypothesized that EIS calculated using vertical jump height would be strongly related to EIS calculated using maximum velocity of the body's center of mass.

In all instances, EIS calculated using vertical jump heights exhibited a correlation coefficient of approximately 0.99 when compared to EIS calculated in the traditional manner. This relationship remained just as strong after standardization. Both methods of determining EIS are the result of comparing product scores of two complexities of the vertical jump. Individual values may vary simply because of magnitude differences in the variables used for calculation. Most importantly, however, these findings indicate that determining EIS can be accomplished using any product score comparison between different complexities of vertical jump performance.

For the purposes of the current investigation, EIS using maximum upward velocity of the body center of mass was a more accurate measure of product. Altering the force data by removing the mass of the individual yields acceleration data. Integrating once results in the velocity of the center of mass. To obtain vertical jump height in this investigation, another integration needed to occur which introduced more error to the calculation. However, if jump height were measured directly, it would be less prone to error than velocity for determining EIS.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The purpose of this investigation was to examine kinetic and temporal relationships to skillfulness in vertical jumping. Specifically, this study took the form of investigating the determination of skillfulness using EIS. Vertical jump height skill also was examined for comparative purposes. The choice of the dependent EIS measure was based on the previous research finding that EI scores were better indicators of skillfulness than vertical jump height. EI scores were hypothesized to factor out the influences of genetic talents and/or training. Investigation of EI using kinetic data had not been attempted. Thus, an implicit purpose of the current investigation was to determine if the underlying principles of EI examination of vertical jumping held for kinetic analyses.

The relationship between EIS calculated using the maximum velocity of the body's center of mass and EIS calculated using vertical jump height was extremely strong. In all cases, this relationship was above 0.90. The purpose here was to show that a strong relationship did indeed exist. The reasoning behind this modification in EIS calculation method was to provide practitioners a way to incorporate EIS into the assessment of skillfulness in vertical jumping.

Finally, standardization was used to examine the effects of a smooth rise to a single peak. Specifically, this study took the form of mathematically manipulating the original data such that all the original peaks with unsmooth rises to peak or two peaks were altered. The choice of dependent measures was maintained for the standardized analyses as were the independent variables.

Hypotheses were made based upon pilot investigation and the findings of previous investigators. It was hypothesized that:

1) More of the variance in EIS would be explained by kinetic and temporal variables than would be explained for vertical jump height,
2) The relationship of kinetic and temporal variables to EIS calculated using jump heights would be strongly related to EIS using the standard calculation (i.e., calculated using maximum upward velocities of the body's center of mass),
3) Standardizing to a single peak would increase the EIS scores of performers exhibiting multiple peaks or an unsmooth rise to a single peak.

The first task was to find relationships to EIS and vertical jump height using kinetic and temporal data obtained from nonstandardized and standardized force-time profiles of individual performers. It was hypothesized that more of the variance in EIS would be explained by kinetic and temporal variables than would be explained for vertical jump height.

Conclusions based on this hypothesis were:

1) Determination of skillfulness using EIS did not explain the variance in performance more than was the case for vertical jump height. However, the variables selected for the prediction of EIS would be considered indicative of better use of the stored elastic component. Following standardization, the differences in stored elastic energy use between vertical jump height and EIS were less apparent.
2) Before standardization, prediction of EIS improved when the best EIS performances were analyzed. When the best vertical jump height performances were analyzed, no prediction equation was suggested for determining factors involved in obtaining superior jump heights. Lack of support for vertical jump height as a measure of skillfulness indicates that the variables chosen for analysis were either inappropriate to explain variance, or their relationship to jump height was not linear.
3) Following standardization, prediction of best performances was strong for both methods of determining skillfulness.
4) These findings support Dowling and Vamos' (1993) work, to the extent that approximately the same amount of variance in vertical jump height could be explained.

5) After standardization, EIS and jump height were both useful for identifying skillfulness and many of the variables used to identify superior performance for each were similar.

Second, the method of determining EIS is the result of comparing product scores between two complexities of vertical jumps. Thus, it was hypothesized that the results of EIS examination would be the same regardless of the method of EIS determination. The results of this investigation led to the conclusion that EIS calculated using vertical jump height is just as good an indicator of EIS as EIS calculated using maximum velocity of the body's center of mass.

Finally, it was hypothesized that standardizing the force-time curve to a single peak would increase the EIS scores of performers exhibiting multiple peaks or unsmooth rises to a single peak. It was found that standardization of the force-time curves resulted in increased performance whether the indicator of skillfulness was EIS or vertical jump height. Fundamental to this portion of the investigation was the assumption that technically skilled performers would exhibit smooth rises to a single peak force.

These results demonstrate that the uniqueness of EIS to determining biomechanic technique in vertical jumping is not clear. Standardization of the data, also did not offer a clear picture of the parameters explaining skillfulness. Dowling and Vamos (1993) stated that even if 100% of the variance could be explained by several variables, the interactions of the variables would continue to interfere with the determination of causal relationships. The results of this investigation supported their concerns. Further, the variables related to time could be influenced by genetics and/or training. Future investigations should address these concerns.

Recommendations

Recommendations for future studies are:

1) The independent variables should also be intraindividually controlled. For example, absolute time measures do not control the effects of talent or training. Normalizing time with respect to the individual performance (i.e., take time events as a ratio of the total time for the performance), would control for excesses or deficiencies in talent and/or training
2) The small amount of variance in EIS explained by the variables examined suggested they could be influenced by talent or training. Methods of more clearly eliminating the factors of talent and training should be examined.
3) Results of the current investigation show that most of the variables related to skillfulness also were related to use of stored elastic energy. What are the intersegmental dynamics that lead to the most efficient use of the stored elastic component?

4) The kinetic and kinematic records must be examined concurrently if the information is to be applicable to a performer. Analysis using both kinetics and kinematics will allow for greater understanding of the coordinative needs for projection tasks.

5) For the purpose of application, EIS also should be examined kinematically. Often, the teacher or coach has no other resource from which to draw information about the performance than through visual cues. Visual cues should assist the practitioner in determining effective intervention cues.

6) Smooth rise to a single peak was investigated for skillfulness based upon observation of skilled performers using EIS to indicate skill. Many performers exhibit performances with two equal peaks in the force-time curve. Others have a smaller final peak. Still others exhibit a larger final peak. The question to be answered is what are the effects on skillfulness if the data are mathematically manipulated to exhibit any of these other force-time patterns?

7) The results of the current investigation indicate that most of the variables related to skillfulness are also related to the use of stored elastic energy. What are the effects of other standardization models on the use of stored elastic energy?

8) The force-time record is such that the intersegmental dynamics of the system can not be fully appreciated without the visual influence produced through kinematic analysis. If there are kinematic examples of other performance models, further analysis should involve determining events in the skill that lead to other force-time records.

9) Could kinematic data be found that are also accompanied by smooth rises to a single peak? If so, what are the intersegmental dynamics needed to produce this type of force-time record?

10) EIS calculated using vertical jump height also should be considered as a dependent variable. Continuing to examine both methods of EIS calculation will provide additional evidence of their relationship, or it will magnify inconsistencies between them.

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APPENDIX A

CONSENT FORM

THE UNIVERSITY OF NORTH CAROLINA AT GREENSBORO
Consent to Act as a Human Subject
(Short Form)

Subject's Name____
Date of Consent____

I hereby consent to participate in the research project entitled "Kinetic And Temporal Correlates to Skillfulness In Vertical Jumping". An explanation of the procedures and/or investigations to be followed and their purpose, including any experimental procedures, was provided to me by H. Scott Strohmeyer. I was also informed about any benefits, risks, or discomforts that I might expect. I was given the opportunity to ask questions regarding the research and was assured that I am free to withdraw my consent to participate in the project at any time without penalty or prejudice. I understand that I will not be identified by name as a participant in this project.

I have been assured that the explanation I have received regarding this project and this consent form have been approved by the University Institutional Review Board which ensures that research projects involving human subjects follow federal regulations. If I have any questions about this, I have been told to call the Office of Research Services at (919)334-5878.

I understand that any new information that develops during the project will be provided to me if that information might affect my willingness to continue participation in the project. In addition, I have been informed of the compensation/treatment or the absence of compensation/treatment should I be injured in this project.

______________________	______________________________
Subjects Signature	Witness to Oral Presentation and Signature of Subject

If subject is a minor or for some other reason unable to sign, complete the following: Subject is_____years old or unable to sign because____

____
Parent(s)/Guardian Signature

ORAL PRESENTATION

The Exercise and Sports Sciences Department at the University of North Carolina at Greensboro supports the practice of protection for human subjects participating in research. The following information is provided for you to decide whether you wish to participate in the present study. You should be aware that even if you agree to participate, you are free to withdraw at any time without affecting opportunities for participation in other projects offered by this department.

The purpose of the current investigation will be the determine kinetic and temporal factors related to skillfulness in vertical jumping. Skillfulness is not determined by how high you jump, but is a measure of improvement between two similar vertical jumping tasks.

Measures of knee joint range of movement will be obtained through the use of an electrogoniometer. An electrogoniometer will be affixed to your left knee. It does not limit range of movement or hinder performance in any way, but allows the investigator to control the range of movement you will use in static jump condition. You will then be requested to execute two types of vertical jumps from a force platform as per investigator instuctions. The entire procedure should take approximately 1/2 hour of your time.

This investigation is being conducted by an experienced and trained professor in sport biomechanics from Central Missouri State University. All procedures have been approved by liaison in the ESS Department at UNCG. We do solicit your participation but it is strictly voluntary. Do not hesitate to ask any questions about the study either before participating or during the time that you are participating. We would be happy to share our findings with you after the research is complete. Be assured that your name will not be associated with the research findings in any way. Names will be deleted from all research data before use.

The expected benefits associated with your participation include information concerning your present level of skill in vertical jumping.

The discomforts and/or risks are minimal and include the possibility of experiencing slight soreness and/or stiffness that frequently accompanies exercise. There is little chance of injury other than accidental incidents that accompany any vertical jumping activity.

Please sign your consent with full knowledge of the nature and purpose of the procedures, the benefits you may expect, and the discomforts and/or risks which may be encountered. We appreciate your assisstance.

____
Signature of Person Obtaining Consent

____
Signature of Auditor/Witness
on Behalf of UNCG

APPENDIX B

ELGON.BAS

```
5     REM  PROGRAM ELGON.BAS
10    REM  PROGRAM MANY A/D
20    REM  LABORATORY AUTOMATION USING THE IBM PC
30    REM  PROGRAM TO CONTINUALLY COLLECT ANGLE DATA AND
           RECORD MINIMUM ANGLE OF THE KNEE
40    REM  ************************************************************
50    DIM  RESULT%(1000)
60    REM  DEFINE ALL REGISTERS USING THEIR PORT ADDRESSES
70    BASEADD% = &H2E2      'BASE ADDRESS--CHANGE IF NOT ADAPTER 0
80    SELECT% = BASEADD%  'DEVICE SELECT IS REGISTER C(HEX)
90    CONTROL% = BASEADD%        'A/D CONTROL IS REGISTER 0 (WRITE)
100   STATUS% = BASEADD%         'A/D STATUS IS REGISTER 0 (READ)
110   DATUM% = &H2000 + BASEADD%   'A/D DATUM IS REGISTER 2
(READ)
120   REM*************************************************************
130   REM                      MAIN PROGRAM
135        LVALUE% = 50
140        GOSUB  230                    'GET USER INPUT
150        GOSUB  300                    'SET UP BOARD
160        WHILE Y$<>"Q" AND Y$<>"q"
162   REM                      COLLECT ONE DATUM
164        OUT CONTROL%, 1
166        OUT CONTROL%+1, CHAN%
168        WAIT STATUS%, &H1, &H1
170        OUT CONTROL%, 0
172        OUT CONTROL%+1, CHAN%
174        LOW% = INP(DATUM%)
176        HIGH% = INP(DATUM%+1)
178        RESULT%(I%) = LOW% + (256 * (HIGH% - 8))
180        LOCATE 10,40:  PRINT RESULT%(I%) * (260/2047) + 60'MIN
ANGLE
182        VALUE% = RESULT%(I%)
184        IF VALUE% <= LVALUE% THEN 190
186        LVALUE% = VALUE%
188        LOCATE 5,40:  PRINT "MAX VALUE"; LVALUE% * (260/2047) +
                60'MIN  ANGLE
190   WEND
200   END
210   REM  ************************************************************
220        REM   GET PARAMETERS FROM USER
```

```
230          CLS: INPUT "WHAT IS THE CHANNEL NUMBER?",CHAN%
265          CLS
270          RETURN
280   REM    ***********************************************************
290   REM    SET UP BOARD FOR CORRECT OPERATION
300          OUT SELECT%,9     'SET DEVICE REGISTER FOR ANALOG I/O
310          OUT CONTROL%,0          'SET UP CORRECT CHANNEL, START BIT =
320          OUT CONTROL%+1,CHAN%
330   REM    MUST WAIT AT LEAST 20 MICROSECONDS FOR A/D TO BE READY
335   RETURN
```

APPENDIX C

SSJUMP1.FORTRAN

```
c     PROGRAM SSJUMP1
C
c
c        initializes and dimensions variables and files
c
c
      IMPLICIT REAL*8 (A-H,O-Z), LOGICAL (L)
       PARAMETER ( K=1, NN=2060, MM=10, MM2=MM*2,
       NWK=NN+6*(NN*MM+1))
        parameter ( iz = 0 )
      DIMENSION WX(NN), WY(NN), C(NN), WK(NWK), V(MM2)
c
        dimension x(NN), yf(NN), yacc(NN), iyf(NN), resid(NN)
     DIMENSION YSMF(NN), YVEL(NN), YPOS(NN), AJERK(NN)
C
        DATA zero/0.00/
        SCALE = 125D-3 / DATAN(1D0) !1/(2*PI)
c
c
        open(5, file='/9731 DATA A')
        open(11, file='/A9731 DATA A')
        open(8, file='/K9731 DATA A')
        open(10, file='/F9731 DATA A')
        open(9, file='/J9731 DATA A')
C
c
C*****************************************************
c
c       statements 1 - 100 input data & construct time array
c
c******************************************************
c
c
c        reads subject/trial info
c          id4 contains type of jump
c            1 = cmja
c            3 = sj
c
      READ(5,5) ID1, ID2, ID3, ID4
 5     FORMAT(4I1)
```

```
c
c        reads raw data
c            nf = number of frames (data points)
c            iyf = integer value of vertical force
c            yf = decimal value of vertical force
c
      nf = 0
      do 10 nct = 1,NN
      nf =  nf + 1
 10      read(5,*,end=20)   iyf(nct)
c
c
 20      nf=nf-1
c
      do 30 i = 1,nf
 30      yf(i) = float(iyf(i))
c
c        x = time array
c        at = sampling interval
c
      AT =  0.001
      DO 40 J=1,NN
      RJ = J
40     X(J) = RJ*AT
c
c
c*****************************************************************
c
c          statements 101 - 200 prepare for smoothing
c           m = 3 is for quintic spline
c            mode = 4 is for degrees of freedom criterion
C          VAL = 1900IS FOR INITIAL DF (DATA PTS * 0.95)
c
C*****************************************************************
C

 101     m = 3
      mode = 4
      VAL = 1900.0
```

```
c
c        zero out or set arrays for smoothing
c
       do 110 j = 1,nn
 110     c(j) = zero
c
       do 120 j = 1,nwk
 120     wk(j) = zero
c
       do 130 j = 1,nn
       wx(j) = 1.0
 130     wy(j) = 1.0
c
c
c*******************************************************
c
c        statements 201 - 300
c          call spline program
c           write diagnostic information
c           fine-tune 'val' for spline of best fit
c
c*******************************************************
c
c
 201    iflag = 0
      DFRE = 25.5
      VCONST =  5.0

       WRITE(11,205) ID1, ID2, ID3, ID4
 205     format( ' subject ',4i1)

 210    iflag = iflag + 1

         call gcvspl(x,yf,NN,wx,wy,m,nf,K,mode,val,c,nf,wk,ier)
      IF (IER.NE.0) THEN
         WRITE(11,215) IER
        GO TO 999
      ELSE
        VAR = WK(6)
        IF (WK(4).EQ.0D0) THEN
```

```
            FRE = 5D-1 / AT
         ELSE
            FRE = SCALE * (WK(4)*AT)**(-0.5/M)
         ENDIF
          WRITE(11,220) VAR, (WK(IK), IK=1,4), FRE
      ENDIF
  215     format( '  error ',i3)
  220     format( ' var =',1PD15.6,', GCV =',D15.6,',  msr =',D15.6/
     1     ' df =',0PF8.3,',          p =',1PD15.6,
     2     ', fre =',1PD15.6)
c
c         tests for desired frequency (dfre)
c           if current fre is too low, val is reduced
c           if current fre is too high, val is increased
c            this procedure stops after 10 iterations
c
C       IF((ABS(FRE - DFRE)).LE.2.5) GO TO 301
C       IF(FRE.LT.DFRE) VAL = VAL - VCONST
C       IF(FRE.GT.DFRE) VAL = VAL + VCONST
C       IF(IFLAG.LE.10) GO TO 210
c
c
c*****************************************************
c
c        statements 301 - 400
c            construct ysmf = smoothed vertical forces
c            compute apparent zero (when in air)
c            normalize ysmf wrt apparent zero
c            compute apparent weight
c           write diagnostic info
c
c*****************************************************
c
c
 301      continue
c
c        calls splder to obtain ysmf
c
        do 310 i = 1,nf
       jx = i
```

```
        q = splder(iz, m, nf, x(i), x, c, jx, v)
        ysmf(i) = q
C
C
       AJERK(I) = SPLDER(1, M, NF, X(I), X, C, JX, V)
        WRITE(9,931) AJERK(I)
 931    FORMAT ( F20.5)
 310    CONTINUE
c         adjusts for apparent zero
c             determines when subject is in air
c              averages apparent zero for 100 points
c             subtracts azero from ysmf
c              also computes azero from raw data (razero)
c
        do 320 i = 1,nf
       ic = i
       IF (YSMF(I) .GT. 20.0) GO TO 320
       IF (YSMF(I+1) .GT. 20.0) GO TO 320
       IF (YSMF(I+2) .GT. 20.0) GO TO 320
       IF (YSMF(I+3) .GT. 20.0) GO TO 320
       IF (YSMF(I+4) .GT. 20.0) GO TO 320
        go to 330
 320      continue

 330     ic = ic + 10
        azero = 0.0
        razero = 0.0
        do 340 i = ic,ic+99
         razero = razero + yf(i)
 340       azero = azero + ysmf(i)
         azero = azero / 100.0
         razero = razero / 100.0

        do 350 i = 1,nf
 350      ysmf(i) = ysmf(i) - azero

c
c          determine apparent wt while standing at rest
c              also compute apparent wt from raw data (rwt)
c
```

```
      awt = 0.0
      rwt = 0.0
       do 360 i = 21,120
       rwt = rwt + yf(i)
 360     awt = awt + ysmf(i)
        awt = awt / 100.0
        rwt = rwt / 100.0
c
c         system weight = apparent weight
c        total mass = syswt / g (in Greensboro)
c
       syswt = awt
        tmass = syswt / 9.7976
c
c        assesses fluctuations in force
c          during air time
c               rdzero = raw mean deviation around razero
c               sdzero = smoothed mean deviation around azero
c          during stance
c               rdst = raw mean deviation around rwt
c               sdst = smoothed mean deviation around awt
c
      rdzero = 0.0
      sdzero = 0.0
      do 370 i = ic,ic+99
        rdzero = rdzero + abs(yf(i) - razero)
 370     sdzero = sdzero + abs(ysmf(i))
        rdzero = rdzero / 100.0
        sdzero = sdzero / 100.0

      rdst = 0.0
      sdst = 0.0
       do 380 i = 21,120
        rdst = rdst + abs(yf(i) - rwt)
 380     sdst = sdst + abs(ysmf(i) - awt)
        rdst = rdst / 100.0
        sdst = sdst / 100.0
c
c         compute mean absolute residual (aresid) w/o landing
c
```

```
      aresid = 0.0
      fr = ic + 99
      do 390 i = 1,ic+99
 390    aresid = aresid + abs(yf(i) - ysmf(i))
      aresid = aresid / fr
c
c      write diagnostic info
c
      WRITE(11,391) IC, AZERO
 391    format( ' air time begins by',i5,' apparent zero is',f6.3)
      WRITE(11,392) SDZERO
 392    format( ' smoothed mean deviation from zero =',f6.3)
      WRITE(11,393) RDZERO
 393    format( ' raw mean deviation from zero =',f6.3)
      WRITE(11,394) SDST
 394    format( ' smoothed mean deviation from stance =',f6.3)
      WRITE(11,395) RDST
 395    format( ' raw mean deviation from stance =',f6.3)
      WRITE(11,396) ARESID
 396    format( ' mean absolute residual w/o landing =',f6.3)
      WRITE(11,397) TMASS
 397    format( ' tmass =',f8.3)

c
c
c*******************************************************
c
c      statements 401 - 500
c          convert vertical force to vertical acceleration
c          integrate for vertical velocity, position
c         write output files
c
c*******************************************************
C
c
      DO 410 I = 1,NF
 410  YACC(I) = ((YSMF(I) - SYSWT) / TMASS) * 100.0
c
c      find frame number (nppfor) & magnitude (ppfor) of
c        peak propulsive force
```

```
c
        ppfor = ysmf(1)
       nppfor = 1
       do 420 i = 2,ic
         if(ysmf(i).gt.ppfor) go to 415
        ppfor = ysmf(i)
       nppfor = i
 415     continue
 420     continue

173      nct1 = iz
        nct2 = iz

        do 255 i = 1,nf
       RESID(I) = YSMF(I) - YF(I)
        WRITE (10,241) X(I), YF(I), YSMF(I), RESID(I)
  241  FORMAT ( F6.3, F10.3, F10.3, F10.3)

  255     continue
  257    it = nct1 + nct2
        if (it .gt. 30) go to 899
        if(id4 .eq. 3) then
         nst = 1
        i = 1
  630       if ((yacc(i) .lt. zero).and.(yacc(i+1) .ge. zero)) then
           nst = i
            go to 680
         else
          i = i + 1
           go to 630
         endif

       else
        i = 1

  710      kt = 0
         nst = i
  720      if (yacc(i+1) .lt. zero) then
          i = i + 1
```

```
         kt = kt + 1
          if (kt .ge. 50) go to 680
         go to 720
        else
         i = i + 1
          go to 710
        endif
       endif

  680     nst = nst + 1
 799     continue
       nst = 1
c
c   integrate
c
       do 690 j = nst,nf
          if(j .eq. nst) yvel(j) = AT * yacc(j)
        if(j .ne. nst) yvel(j) = (AT * yacc(j)) + yvel(j-1)
  690   continue

       do 700 j = nst,nf
          if(j .eq. nst) ypos(j) = AT * yvel(j)
           if(j .ne. nst) ypos(j) = (AT * yvel(j)) + ypos(j-1)
  700   continue

  899   continue

        do 300 jk = nst,nf-3
           write(8,115) x(jk), yacc(jk), yvel(jk), ypos(jk)
  300   continue

  115    format( f7.4, f13.5, f14.6, f15.8)

c
C
 999    stop

      END
```

```
C GCVSPL.FOR, 1986-02-19
C
C Author: H.J. Woltring
C
C Organizations: University of Nijmegen, and
C                Philips Medical Systems, Eindhoven
C               (The Netherlands)
C
C**********************************************************************
*
C
C SUBROUTINE GCVSPL (REAL*8)
C
C Purpose:
C*******
C
C        Natural B-spline data smoothing subroutine, using the Generali-
C        zed Cross-Validation and Mean-Squared Prediction Error
Criteria
C        of Craven & Wahba (1979). Alternatively, the amount of
smoothing
C        can be given explicitly, or it can be based on the effective
C        number of degrees of freedom in the smoothing process as
defined
C        by Wahba (1980). The model assumes uncorrelated, additive
noise
C        and essentially smooth, underlying functions. The noise may be
C        non-stationary, and the independent co-ordinates may be
spaced
C        non-equidistantly. Multiple datasets, with common
independent
C        variables and weight factors are accommodated.
C
C
C Calling convention:
C*****************
C
C    CALL GCVSPL ( X, Y, NY, WX, WY, M, NF, K, MD, VAL, C, NC, WK,
IER )
C
```

```
C Meaning of parameters:
C ********************
C
C       X(N)     ( I )  Independent variables: strictly increasing knot
C                        sequence, with X(I-1).lt.X(I), I=2,...,N.
C       YF(NY,K) ( I )  Input data to be smoothed (or interpolated).
C      NY       ( I )  First dimension of array YF(NY,K), with NY.ge.N.
C       WX(N)    ( I )  Weight factor array; WX(I) corresponds with
C                        the relative inverse variance of point YF(I,*).
C                        If no relative weighting information is
C                        available, the WX(I) should be set to ONE.
C                       All WX(I).gt.ZERO, I=1,...,N.
C       WY(K)    ( I )  Weight factor array; WY(J) corresponds with
C                        the relative inverse variance of point YF(*,J).
C                        If no relative weighting information is
C                        available, the WY(J) should be set to ONE.
C                       All WY(J).gt.ZERO, J=1,...,K.
C                        NB: The effective weight for point YF(I,J) is
C                       equal to WX(I)*WY(J).
C       M        ( I )  Half order of the required B-splines (spline
C                        degree 2*M-1), with M.gt.0. The values M =
C                        1,2,3,4 correspond to linear, cubic, quintic,
C                        and heptic splines, respectively.
C       N        ( I )  Number of observations per dataset, with N.ge.2*M.
C      K        ( I )  Number of datasets, with K.ge.1.
C      MD       ( I )  Optimization mode switch:
C                       |MD| = 1: Prior given value for p in VAL
C                                 (VAL.ge.ZERO). This is the fastest
C                               use of GCVSPL, since no iteration
C                                 is performed in p.
C                       |MD| = 2: Generalized cross validation.
C                         |MD| = 3: True predicted mean-squared error,
C                                 with prior given variance in VAL.
C                        |MD| = 4: Prior given number of degrees of
C                                freedom in VAL (ZERO.le.VAL.le.N-M).
C                         MD  < 0: It is assumed that the contents of
C                                X, W, M, N, and WK have not been
C                                  modified since the previous invoca-
C                               tion of GCVSPL. If MD < -1, WK(4)
C                                  is used as an initial estimate for
```

```
C                          the smoothing parameter p.
C                      Other values for |MD|, and inappropriate values
C                      for VAL will result in an error condition, or
C                      cause a default value for VAL to be selected.
C                      After return from MD.ne.1, the same number of
C                      degrees of freedom can be obtained, for identical
C                      weight factors and knot positions, by selecting
C                      |MD|=1, and by copying the value of p from WK(4)
C                      into VAL. In this way, no iterative optimization
C                      is required when processing other data in Y.
C       VAL      ( I )  Mode value, as described above under MD.
C       C(NC,K) ( O )  Spline coefficients, to be used in conjunction
C                      with function SPLDER. NB: the dimensions of C
C                      in GCVSPL and in SPLDER are different! In SPLDER,
C                      only a single column of C(N,K) is needed, and the
C                      proper column C(1,J), with J=1...K should be used
C                      when calling SPLDER.
C       NC       ( I )  First dimension of array C(NC,K), NC.ge.N.
C       WK(IWK) (I/W/O) Work vector, with length
IWK.ge.6*(N*M+1)+N.
C                      On normal exit, the first 6 values of WK are
C                      assigned as follows:
C
C                      WK(1) = Generalized Cross Validation value
C                      WK(2) = Mean Squared Residual.
C                      WK(3) = Estimate of the number of degrees of
C                              freedom of the residual sum of squares
C                              per dataset, with 0.lt.WK(3).lt.N-M.
C                      WK(4) = Smoothing parameter p, multiplicative
C                              with the splines' derivative constraint.
C                      WK(5) = Estimate of the true mean squared error
C                              (different formula for |MD| = 3).
C                      WK(6) = Gauss-Markov error variance.
C
C                      If WK(4) -->  0 , WK(3) -->  0 , and an inter-
C                      polating spline is fitted to the data (p --> 0).
C                      A very small value > 0 is used for p, in order
C                      to avoid division by zero in the GCV function.
C
C                      If WK(4) --> inf, WK(3) --> N-M, and a least-
```

```
C                      squares polynomial of order M (degree M-1) is
C                      fitted to the data (p --> inf). For numerical
C                      reasons, a very high value is used for p.
C
C                      Upon return, the contents of WK can be used for

C                      covariance propagation in terms of the matrices
C                      B and WE: see the source listings. The variance
C                      estimate for dataset J follows as WK(6)/WY(J).
C
C     IER      ( O )   Error parameter:
C
C                   IER = 0:       Normal exit
C                   IER = 1:       M.le.0 .or. N.lt.2*M
C                   IER = 2:       Knot sequence is not strictly
C                                  increasing, or some weight
C                                  factor is not positive.
C                   IER = 3:       Wrong mode  parameter or value.
C
C Remarks:
C *******
C
C     (1) GCVSPL calculates a natural spline of order 2*M (degree
C     2*M-1) which smoothes or interpolates a given set of data
C     points, using statistical considerations to determine the
C     amount of smoothing required (Craven & Wahba, 1979). If the
C     error variance is a priori known, it should be supplied to
C     the routine in VAL, for |MD|=3. The degree of smoothing is
C     then determined to minimize an unbiased estimate of the true
C     mean squared error. On the other hand, if the error variance
C     is not known, one may select |MD|=2. The routine then deter-
C     mines the degree of smoothing to minimize the generalized
C     cross validation function. This is asymptotically the same
C     as minimizing the true predicted mean squared error (Craven &
C     Wahba, 1979). If the estimates from |MD|=2 or 3 do not appear
C     suitable to the user (as apparent from the smoothness of the
C     M-th derivative or from the effective number of degrees of
C     freedom returned in WK(3) ), the user may select another
C     value for the noise variance if |MD|=3, or a reasonably large
C     number of degrees of freedom if |MD|=4. If |MD|=1, the proce-
```

```
C         dure is non-iterative, and returns a spline for the given
C         value of the smoothing parameter p as entered in VAL.
C
C         (2) The number of arithmetic operations and the amount of
C         storage required are both proportional to N, so very large
C         datasets may be accommodated. The data points do not have
C         to be equidistant in the independent variable X or uniformly
C         weighted in the dependent variable Y. However, the data
C         points in X must be strictly increasing. Multiple dataset
C         processing (K.gt.1) is numerically more efficient dan
C         separate processing of the individual datasets (K.eq.1).
C
C        (3) If |MD|=3 (a priori known noise variance), any value of
C        N.ge.2*M is acceptable. However, it is advisable for N-2*M
C        to be rather large (at least 20) if |MD|=2 (GCV).
C
C        (4) For |MD| > 1, GCVSPL tries to iteratively minimize the
C         selected criterion function. This minimum is unique for |MD|
C        = 4, but not necessarily for |MD| = 2 or 3. Consequently,
C         local optima rather that the global optimum might be found,
C         and some actual findings suggest that local optima might
C         yield more meaningful results than the global optimum if N
C         is small. Therefore, the user has some control over the
C         search procedure. If MD > 1, the iterative search starts
C         from a value which yields a number of degrees of freedom
C         which is approximately equal to N/2, until the first (local)
C         minimum is found via a golden section search procedure
C        (Utreras, 1980). If MD < -1, the value for p contained in
C        WK(4) is used instead. Thus, if MD = 2 or 3 yield too noisy
C         an estimate, the user might try |MD| = 1 or 4, for suitably
C         selected values for p or for the number of degrees of
C        freedom, and then run GCVSPL with MD = -2 or -3. The con-
C        tents of N, M, K, X, WX, WY, and WK are assumed unchanged
C     if MD < 0.
C
C        (5) GCVSPL calculates the spline coefficient array C(N,K);
C         this array can be used to calculate the spline function
C         value and any of its derivatives up to the degree 2*M-1
C         at any argument T within the knot range, using subrou-
C        tines SPLDER and SEARCH, and the knot array X(N). Since
```

```
C        the splines are constrained at their Mth derivative, only
C        the lower spline derivatives will tend to be reliable
C        estimates of the underlying, true signal derivatives.
C
C       (6) GCVSPL combines elements of subroutine CRVO5 by Utre-
C       ras (1980), subroutine SMOOTH by Lyche et al. (1983), and
C       subroutine CUBGCV by Hutchinson (1985). The trace of the
C        influence matrix is assessed in a similar way as described
C       by Hutchinson & de Hoog (1985). The major difference is
C         that the present approach utilizes non-symmetrical B-spline
C        design matrices as described by Lyche et al. (1983); there-
C        fore, the original algorithm by Erisman & Tinney (1975) has
C         been used, rather than the symmetrical version adopted by
C      Hutchinson & de Hoog.
C
C References:
C **********
C
C       P. Craven & G. Wahba (1979), Smoothing noisy data with
C        spline functions. Numerische Mathematik 31, 377-403.
C
C       A.M. Erisman & W.F. Tinney (1975), On computing certain
C        elements of the inverse of a sparse matrix. Communications
C      of the ACM 18(3), 177-179.
C
C      M.F. Hutchinson & F.R. de Hoog (1985), Smoothing noisy data
C        with spline functions. Numerische Mathematik 47(1), 99-106.
C
C      M.F. Hutchinson (1985), Subroutine CUBGCV. CSIRO Division of
C       Mathematics and Statistics, P.O. Box 1965, Canberra, ACT 2601,
C      Australia.
C
C       T. Lyche, L.L. Schumaker, & K. Sepehrnoori (1983), Fortran
C         subroutines for computing smoothing and interpolating natural
C       splines. Advances in Engineering Software 5(1), 2-5.
C
C        F. Utreras (1980), Un paquete de programas para ajustar curvas
C        mediante funciones spline. Informe Tecnico MA-80-B-209,
Depar-
```

```
C       tamento de Matematicas, Faculdad de Ciencias Fisicas y
Matema-
C       ticas, Universidad de Chile, Santiago.
C
C        Wahba, G. (1980). Numerical and statistical methods for mildly,
C         moderately and severely ill-posed problems with noisy data.
C         Technical report nr. 595 (February 1980). Department of Statis-
C       tics, University of Madison (WI), U.S.A.
C
C  Subprograms required:
C *******************
C
C    BASIS, PREP, SPLC, BANDET, BANSOL, TRINV
C
C***********************************************************************
*
C
     SUBROUTINE GCVSPL ( X, Y, NY, WX, WY, M, N, K, MD, VAL, C, NC,

    1              WK, IER )
C
       IMPLICIT REAL*8 (A-H,O-Z)
        PARAMETER ( RATIO=2D0, TAU=1.618033983D0, IBWE=7,
    1         ZERO=0D0, HALF=5D-1 , ONE=1D0, TOL=1D-6,
    2          EPS=1D-15, EPSINV=ONE/EPS )
     DIMENSION X(N), Y(NY,K), WX(N), WY(K), C(NC,K),
WK(N+6*(N*M+1))
      SAVE M2, NM1, EL
       DATA M2, NM1, EL / 2*0, 0D0 /
C
C***      Parameter check and work array initialization
C
      IER = 0
C***     Check on mode  parameter
      IF ((IABS(MD).GT.4) .OR.( MD.EQ. 0 ) .OR.
    1  ((IABS(MD).EQ.1).AND.( VAL.LT.ZERO)).OR.
    2  ((IABS(MD).EQ.3).AND.( VAL.LT.ZERO)).OR.
    3  ((IABS(MD).EQ.4).AND.((VAL.LT.ZERO) .OR.(VAL.GT.N-M))))
THEN
         IER = 3      !Wrong mode value
```

```
        RETURN
      ENDIF
C***    Check on M and N
      IF (MD.GT.0) THEN
        M2  = 2 * M
        NM1 = N - 1
      ELSE
        IF ((M2.NE.2*M).OR.(NM1.NE.N-1)) THEN
           IER = 3   !M or N modified since previous call
         RETURN
        ENDIF
      ENDIF
      IF ((M.LE.0).OR.(N.LT.M2)) THEN
        IER = 1       !M or N invalid
        RETURN
      ENDIF
C***     Check on knot sequence and weights

      IF (WX(1).LE.ZERO) IER = 2
      DO 10 i=2,N
        IF ((WX(i).LE.ZERO).OR.(X(i-1).GE.X(i))) IER = 2
        IF (IER.NE.0) RETURN
   10 CONTINUE
      DO 15 J=1,K
        IF (WY(J).LE.ZERO) IER = 2
        IF (IER.NE.0) RETURN
   15 CONTINUE
C
C***      Work array parameters (address information for covariance
C***     propagation by means of the matrices STAT, B, and WE). NB:
C***     BWE cannot be used since it is modified by function TRINV.
C
       NM2P1 = N*(M2+1)
       NM2M1 = N*(M2-1)
C      ISTAT = 1                !Statistics array STAT(6)
C      IBWE  = ISTAT + 6        !Smoothing matrix BWE( -M:M  ,N)
       IB    = IBWE  + NM2P1    !Design matrix    B  (1-M:M-1,N)
       IWE   = IB    + NM2M1    !Design matrix    WE ( -M:M  ,N)
C      IWK   = IWE   + NM2P1    !Total work array length N +
6*(N*M+1)
```

```
C
C***    Compute the design matrices B and WE, the ratio
C***    of their L1-norms, and check for iterative mode.
C

      IF (MD.GT.0) THEN
        CALL BASIS ( M, N, X, WK(IB), R1, WK(IBWE) )
        CALL PREP  ( M, N, X, WX, WK(IWE), EL )
          EL = EL / R1 !L1-norms ratio (SAVEd upon RETURN)
      ENDIF
      IF (IABS(MD).NE.1) GO TO 20
C***        Prior given value for p
        R1 = VAL
        GO TO 100
C
C***    Iterate to minimize the GCV function (|MD|=2),
C***    the MSE function (|MD|=3), or to obtain the prior
C***    given number of degrees of freedom (|MD|=4).
C
   20 IF (MD.LT.-1) THEN
           R1 = WK(4)    !User-determined starting value
      ELSE
        R1 = ONE / EL        !Default (DOF ~ 0.5)
      ENDIF
      R2 = R1 * RATIO
     GF2 = SPLC(M,N,K,Y,NY,WX,WY,MD,VAL,R2,EPS,C,NC,
    1        WK,WK(IB),WK(IWE),EL,WK(IBWE))
   40 GF1 = SPLC(M,N,K,Y,NY,WX,WY,MD,VAL,R1,EPS,C,NC,
    1        WK,WK(IB),WK(IWE),EL,WK(IBWE))
      IF (GF1.GT.GF2) GO TO 50
         IF (WK(4).LE.ZERO) GO TO 100  !Interpolation
        R2  = R1
        GF2 = GF1
         R1  = R1 / RATIO
        GO TO 40
   50 R3 = R2 * RATIO
   60 GF3 = SPLC(M,N,K,Y,NY,WX,WY,MD,VAL,R3,EPS,C,NC,
    1        WK,WK(IB),WK(IWE),EL,WK(IBWE))
      IF (GF3.GT.GF2) GO TO 70
          IF (WK(4).GE.EPSINV) GO TO 100 !Least-squares polynomial
```

```
         R2  = R3
         GF2 = GF3
         R3  = R3 * RATIO
         GO TO 60
   70  R2  = R3
       GF2 = GF3
        ALPHA = (R2-R1) / TAU
       R4 = R1 + ALPHA
       R3 = R2 - ALPHA
      GF3 = SPLC(M,N,K,Y,NY,WX,WY,MD,VAL,R3,EPS,C,NC,
     1        WK,WK(IB),WK(IWE),EL,WK(IBWE))
      GF4 = SPLC(M,N,K,Y,NY,WX,WY,MD,VAL,R4,EPS,C,NC,
     1        WK,WK(IB),WK(IWE),EL,WK(IBWE))
   80  IF (GF3.LE.GF4) THEN
         R2  = R4
         GF2 = GF4
          ERR = (R2-R1) / (R1+R2)
        IF ((ERR*ERR+ONE.EQ.ONE).OR.(ERR.LE.TOL)) GO TO 90
         R4  = R3
         GF4 = GF3
          ALPHA = ALPHA / TAU
          R3  = R2 - ALPHA
        GF3 = SPLC(M,N,K,Y,NY,WX,WY,MD,VAL,R3,EPS,C,NC,
     1          WK,WK(IB),WK(IWE),EL,WK(IBWE))
       ELSE
         R1  = R3
         GF1 = GF3
          ERR = (R2-R1) / (R1+R2)
        IF ((ERR*ERR+ONE.EQ.ONE).OR.(ERR.LE.TOL)) GO TO 90
         R3  = R4
         GF3 = GF4
          ALPHA = ALPHA / TAU
         R4 = R1 + ALPHA
        GF4 = SPLC(M,N,K,Y,NY,WX,WY,MD,VAL,R4,EPS,C,NC,
     1          WK,WK(IB),WK(IWE),EL,WK(IBWE))
       ENDIF
       GO TO 80
   90  R1 = HALF * (R1+R2)
C
C***     Calculate final spline coefficients
```

```
C
 100  GF1 = SPLC(M,N,K,Y,NY,WX,WY,MD,VAL,R1,EPS,C,NC,
    1         WK,WK(IB),WK(IWE),EL,WK(IBWE))
C
C***    Ready
C
      RETURN
      END

C  BASIS.FOR,  1985-06-03
C
C*********************************************************************
*
C
C SUBROUTINE BASIS (REAL*8)
C
C  Purpose:
C *******
C
C         Subroutine to assess a B-spline tableau, stored in vectorized
C      form.
C
C  Calling  convention:
C ******************
C
C     CALL BASIS ( M, N, X, B, BL, Q )
C
C  Meaning  of  parameters:
C ********************
C
C       M                ( I )   Half order of the spline (degree 2*M-1),
C                         M > 0.
C      N              ( I )   Number of knots, N >= 2*M.
C      X(N)            ( I )   Knot sequence, X(I-1) < X(I), I=2,N.
C       B(1-M:M-1,N)    ( O )    Output tableau. Element B(J,I) of array
C                              B corresponds with element b(i,i+j) of
C                             the tableau matrix B.
C      BL             ( O )  L1-norm of B.
C       Q(1-M:M)        ( W )    Internal work array.
C
```

```
C Remark:
C ******
C
C        This subroutine is an adaptation of subroutine BASIS from the
C        paper by Lyche et al. (1983). No checking is performed on the
C        validity of M and N. If the knot sequence is not strictly in-
C        creasing, division by zero may occur.
C
C Reference:
C *********
C
C        T. Lyche, L.L. Schumaker, & K. Sepehrnoori, Fortran subroutines
C         for computing smoothing and interpolating natural splines.
C        Advances in Engineering Software 5(1983)1, pp. 2-5.
C
C***********************************************************************
*
C
      SUBROUTINE BASIS ( M, N, X, B, BL, Q )
C
       IMPLICIT REAL*8 (A-H,O-Z)
      PARAMETER ( ZERO=0D0, ONE=1D0 )
       DIMENSION X(N), B(1-M:M-1,N), Q(1-M:M)
C
      IF (M.EQ.1) THEN
C***        Linear spline
        DO 3 I=1,N
          B(0,I) = ONE
   3    CONTINUE
        BL = ONE
        RETURN
      ENDIF
C
C***    General splines
C
       MM1 = M - 1
      MP1 = M + 1
      M2  = 2 * M
      DO 15 L=1,N
**      1st row
```

```
      DO 5 J=-MM1,M
        Q(J) = ZERO
  5   CONTINUE
      Q(MM1) = ONE
      IF ((L.NE.1).AND.(L.NE.N))
   1    Q(MM1) = ONE / ( X(L+1) - X(L-1) )
C***       Successive rows
      ARG = X(L)
       DO 13 I=3,M2
          IR = MP1 - I
         V  = Q(IR)
         IF (L.LT.I) THEN
C***              Left-hand B-splines
           DO 6 J=L+1,I
             U     = V
             V     = Q(IR+1)
             Q(IR) = U + (X(J)-ARG)*V
             IR    = IR + 1
  6        CONTINUE
        ENDIF
          J1 = MAX0(L-I+1,1)
          J2 = MIN0(L-1,N-I)
         IF (J1.LE.J2) THEN
C***             Ordinary B-splines
           IF (I.LT.M2) THEN
             DO 8 J=J1,J2
               Y     = X(I+J)
               U     = V
               V     = Q(IR+1)
                Q(IR) = U + (V-U)*(Y-ARG)/(Y-X(J))
               IR = IR + 1
  8          CONTINUE
           ELSE
             DO 10 J=J1,J2
               U     = V
               V     = Q(IR+1)
               Q(IR) = (ARG-X(J))*U + (X(I+J)-ARG)*V
               IR    = IR + 1
 10           CONTINUE
           ENDIF
```

```
            ENDIF
             NMIP1 = N - I + 1
             IF (NMIP1.LT.L) THEN
C***                Right-hand B-splines
               DO 12 J=NMIP1,L-1
                 U     = V
                 V     = Q(IR+1)
                 Q(IR) = (ARG-X(J))*U + V
                 IR    = IR + 1
   12          CONTINUE
            ENDIF
   13     CONTINUE
          DO 14 J=-MM1,MM1
            B(J,L) = Q(J)
   14     CONTINUE
   15   CONTINUE
C
C***      Zero unused parts of B
C
        DO 17 I=1,MM1
          DO 16 K=I,MM1
            B(-K,    I) = ZERO
            B( K,N+1-I) = ZERO
   16     CONTINUE
   17   CONTINUE
C
C***      Assess L1-norm of B
C
        BL = 0D0
        DO 19 I=1,N
          DO 18 K=-MM1,MM1
            BL = BL + ABS(B(K,I))
   18     CONTINUE
   19   CONTINUE
        BL = BL / N
C
C***     Ready
C
        RETURN
        END
```

```
C PREP.FOR, 1985-07-04
C
C*********************************************************************
*
C
C SUBROUTINE PREP (REAL*8)
C
C Purpose:
C *******
C
C        To compute the matrix WE of weighted divided difference
coeffi-
C        cients needed to set up a linear system of equations for sol-
C        ving B-spline smoothing problems, and its L1-norm EL. The
matrix
C       WE is stored in vectorized form.
C
C Calling convention:
C *****************
C
C     CALL PREP ( M, N, X, W, WE, EL )
C
C Meaning of parameters:
C ********************
C
C       M                ( I )   Half order of the B-spline (degree
C                          2*M-1), with M > 0.
C      N              ( I )   Number of knots, with N >= 2*M.
C       X(N)             ( I )   Strictly increasing knot array, with
C                          X(I-1) < X(I), I=2,N.
C       W(N)             ( I )   Weight matrix (diagonal), with
C                          W(I).gt.0.0, I=1,N.
C        WE(-M:M,N)        ( O )   Array containing the weighted divided
C                              difference terms in vectorized format.
C                        W**-1 * E.
C
C Remark:
C

C ******
```

```
C
C       This subroutine is an adaptation of subroutine PREP from the
paper
C       by Lyche et al. (1983). No checking is performed on the validity
C       of M and N. Division by zero may occur if the knot sequence is
C       not strictly increasing.
C
C Reference:
C *********
C
C       T. Lyche, L.L. Schumaker, & K. Sepehrnoori, Fortran subroutines
C        for computing smoothing and interpolating natural splines.
C       Advances in Engineering Software 5(1983)1, pp. 2-5.
C
C***********************************************************************
*
C
      SUBROUTINE PREP ( M, N, X, W, WE, EL )
C
       IMPLICIT REAL*8 (A-H,O-Z)
      PARAMETER ( ZERO=0D0, ONE=1D0 )
       DIMENSION X(N), W(N), WE((2*M+1)*N) !WE(-M:M,N)
C
C***    Calculate the factor F1
C

       M2   = 2 * M
       MP1  = M + 1
        M2M1 = M2 - 1
        M2P1 = M2 + 1
       NM   = N - M
       F1   = -ONE
       IF (M.NE.1) THEN
         DO 5 I=2,M
           F1 = -F1 * I
  5      CONTINUE
          DO 6 I=MP1,M2M1
           F1 = F1 * I
  6      CONTINUE
       END IF
```

```
C
C***       Columnwise evaluation of the unweighted design matrix E
C
       I1 = 1
       I2 = M
       JM = MP1
      DO 17 J=1,N
         INC = M2P1
        IF (J.GT.NM) THEN
           F1 = -F1
           F  =  F1
        ELSE
           IF (J.LT.MP1) THEN
              INC = 1
              F   = F1
          ELSE
              F   = F1 * (X(J+M)-X(J-M))
          END IF
        END IF
         IF ( J.GT.MP1) I1 = I1 + 1
         IF (I2.LT.  N) I2 = I2 + 1
        JJ = JM
C***         Loop for divided difference coefficients
        FF = F
        Y = X(I1)
         I1P1 = I1 + 1
          DO 11 I=I1P1,I2
           FF = FF / (Y-X(I))
  11     CONTINUE
        WE(JJ) = FF
        JJ = JJ + M2
          I2M1 = I2 - 1
         IF (I1P1.LE.I2M1) THEN
            DO 14 L=I1P1,I2M1
             FF = F
             Y  = X(L)
              DO 12 I=I1,L-1
                FF = FF / (Y-X(I))
  12         CONTINUE
             DO 13 I=L+1,I2
```

```
              FF = FF / (Y-X(I))
 13           CONTINUE
             WE(JJ) = FF
             JJ = JJ + M2
 14        CONTINUE
        END IF
        FF = F
         Y = X(I2)
          DO 16 I=I1,I2M1
            FF = FF / (Y-X(I))
 16       CONTINUE
        WE(JJ) = FF
        JJ = JJ + M2
        JM = JM + INC
 17   CONTINUE
C
C***     Zero the upper left and lower right corners of E
C
      KL = 1
      N2M = M2P1*N + 1
      DO 19 I=1,M
        KU = KL + M - I
       DO 18 K=KL,KU
          WE(   K) = ZERO
          WE(N2M-K) = ZERO
 18       CONTINUE
        KL = KL + M2P1
 19   CONTINUE
C
C***     Weighted matrix WE = W**-1 * E and its L1-norm
C
 20   JJ = 0
      EL = 0D0
      DO 22 I=1,N
         WI = W(I)
         DO 21 J=1,M2P1
           JJ     = JJ + 1
            WE(JJ) = WE(JJ) / WI
           EL     = EL + ABS(WE(JJ))
 21      CONTINUE
```

```
  22  CONTINUE
      EL = EL / N
C
C***    Ready
C
     RETURN
     END

C SPLC.FOR, 1985-12-12
C
C Author: H.J. Woltring
C
C Organizations: University of Nijmegen, and
C                  Philips Medical Systems, Eindhoven
C                 (The Netherlands)
C
C*********************************************************************
*
C
C FUNCTION SPLC (REAL*8)
C
C Purpose:
C *******
C
C        To assess the coefficients of a B-spline and various statistical
C         parameters, for a given value of the regularization parameter p.
C
C Calling convention:
C *****************
C
C     FV = SPLC ( M, N, K, Y, NY, WX, WY, MODE, VAL, P, EPS, C, NC,
C    1         STAT, B, WE, EL, BWE)
C
C Meaning of parameters:
C ********************
C
C      SPLC            ( O )  GCV function value if |MODE|.eq.2,
C                           MSE value if |MODE|.eq.3, and absolute
C                              difference with the prior given number of
C                           degrees of freedom if |MODE|.eq.4.
```

```
C     M              ( I )  Half order of the B-spline (degree 2*M-1),
C                      with M > 0.
C     N              ( I )  Number of observations, with N >= 2*M.
C     K              ( I )  Number of datasets, with K >= 1.
C     Y(NY,K)        ( I )  Observed measurements.
C     NY             ( I )  First dimension of Y(NY,K), with NY.ge.N.
C     WX(N)          ( I )  Weight factors, corresponding to the
C                             relative inverse variance of each measure-
C                      ment, with WX(I) > 0.0.
C     WY(K)          ( I )  Weight factors, corresponding to the
C                             relative inverse variance of each dataset,
C                      with WY(J) > 0.0.
C     MODE           ( I )  Mode switch, as described in GCVSPL.
C     VAL            ( I )  Prior variance if |MODE|.eq.3, and
C                             prior number of degrees of freedom if
C                      |MODE|.eq.4. For other values of MODE,
C                      VAL is not used.
C     P              ( I )  Smoothing parameter, with P >= 0.0. If
C                             P.eq.0.0, an interpolating spline is
C                      calculated.
C     EPS            ( I )  Relative rounding tolerance*10.0. EPS is
C                             the smallest positive number such that
C                      EPS/10.0 + 1.0 .ne. 1.0.
C     C(NC,K)        ( O )  Calculated spline coefficient arrays. NB:
C                      the dimensions of in GCVSPL and in SPLDER
C                       are different! In SPLDER, only a single
C                        column of C(N,K) is needed, and the proper
C                       column C(1,J), with J=1...K, should be used
C                      when calling SPLDER.
C     NC             ( I )  First dimension of C(NC,K), with NC.ge.N.
C     STAT(6)        ( O )  Statistics array. See the description in
C                      subroutine GCVSPL.
C     B (1-M:M-1,N)  ( I )  B-spline tableau as evaluated by
subroutine
C                      BASIS.
C     WE( -M:M  ,N)  ( I )  Weighted B-spline tableau (W**-1 * E) as
C                        evaluated by subroutine PREP.
C     EL             ( I )  L1-norm of the matrix WE as evaluated by
C                      subroutine PREP.
C     BWE(-M:M,N)    ( O )  Central 2*M+1 bands of the inverted
```

```
C                         matrix ( B  +  p * W**-1 * E )**-1
C
C Remarks:
C *******
C
C        This subroutine combines elements of subroutine SPLC0 from
the
C        paper by Lyche et al. (1983), and of subroutine SPFIT1 by
C        Hutchinson (1985).
C
C References:
C **********
C
C        M.F. Hutchinson (1985), Subroutine CUBGCV. CSIRO division of
C         Mathematics and Statistics, P.O. Box 1965, Canberra, ACT 2601,
C        Australia.
C
C        T. Lyche, L.L. Schumaker, & K. Sepehrnoori, Fortran subroutines
C         for computing smoothing and interpolating natural splines.
C         Advances in Engineering Software 5(1983)1, pp. 2-5.
C
C***********************************************************************
*
C
      FUNCTION SPLC( M, N, K, Y, NY, WX, WY, MODE, VAL, P, EPS,
     1         C, NC, STAT, B, WE, EL, BWE)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      PARAMETER ( ZERO=0D0, ONE=1D0, TWO=2D0 )
      DIMENSION Y(NY,K), WX(N), WY(K), C(NC,K), STAT(6),
     1        B(1-M:M-1,N), WE(-M:M,N), BWE(-M:M,N)
C
C***    Check on p-value
C
      DP = P
      STAT(4) = P
      PEL = P * EL
C***    Pseudo-interpolation if p is too small
      IF (PEL.LT.EPS) THEN
        DP = EPS / EL
```

```
      STAT(4) = ZERO
     ENDIF
C***      Pseudo least-squares polynomial if p is too large
     IF (PEL*EPS.GT.ONE) THEN
       DP = ONE / (EL*EPS)
        STAT(4) = DP
     ENDIF
C
C***    Calculate BWE = B + p * W**-1 * E
C
      DO 40 I=1,N
         KM = -MIN0(M,I-1)
         KP =  MIN0(M,N-I)
        DO 30 L=KM,KP
          IF (IABS(L).EQ.M) THEN
            BWE(L,I) =          DP * WE(L,I)
          ELSE
            BWE(L,I) = B(L,I) + DP * WE(L,I)
          ENDIF
  30      CONTINUE
  40    CONTINUE
C
C***    Solve BWE * C = Y, and assess TRACE [ B * BWE**-1 ]
C
     CALL BANDET ( BWE, M, N )
     CALL BANSOL ( BWE, Y, NY, C, NC, M, N, K )
      STAT(3) = TRINV ( WE, BWE, M, N ) * DP !trace * p = res. d.o.f.
      TRN = STAT(3) / N
C
C***      Compute mean-squared weighted residual
C
     ESN = ZERO
      DO 70 J=1,K
         DO 60 I=1,N
           DT = -Y(I,J)
             KM = -MIN0(M-1,I-1)
            KP =  MIN0(M-1,N-I)
          DO 50 L=KM,KP
            DT = DT + B(L,I)*C(I+L,J)
  50        CONTINUE
```

```
          ESN = ESN + DT*DT*WX(I)*WY(J)
   60     CONTINUE
   70   CONTINUE
        ESN = ESN / (N*K)
C
C***      Calculate statistics and function value
C
         STAT(6) = ESN / TRN              !Estimated variance
         STAT(1) = STAT(6) / TRN           !GCV function value
         STAT(2) = ESN                   !Mean Squared Residual
C          STAT(3) = trace [p*B * BWE**-1] !Estimated residuals' d.o.f.
C         STAT(4) = P                    !Normalized smoothing factor
        IF (IABS(MODE).NE.3) THEN
C***        Unknown variance: GCV
           STAT(5) = STAT(6) - ESN
         IF (IABS(MODE).EQ.1) SPLC = ZERO
          IF (IABS(MODE).EQ.2) SPLC = STAT(1)
           IF (IABS(MODE).EQ.4) SPLC = sqrt(( STAT(3) - VAL )**2)
        ELSE
C***          Known variance: estimated mean squared error
          STAT(5) = ESN - VAL*(TWO*TRN - ONE)
          SPLC = STAT(5)
        ENDIF
C
        RETURN
        END

C BANDET.FOR, 1985-06-03
C
C*****************************************************************
*
C
C SUBROUTINE BANDET (REAL*8)
C
C  Purpose:
C *******
C
C        This subroutine computes the LU decomposition of an N*N
matrix
```

```
C        E. It is assumed that E has M bands above and M bands below
the
C        diagonal. The decomposition is returned in E. It is assumed that
C        E can be decomposed without pivoting. The matrix E is stored in
C        vectorized form in the array E(-M:M,N), where element E(J,I) of
C        the array E corresponds with element e(i,i+j) of the matrix E.
C
C Calling convention:
C *****************
C
C     CALL BANDET ( E, M, N )
C
C Meaning of parameters:
C ********************
C
C       E(-M:M,N)       (I/O)   Matrix to be decomposed.
C       M, N            ( I )   Matrix dimensioning parameters,
C                       M >= 0, N >= 2*M.
C
C Remark:
C ******
C
C        No checking on the validity of the input data is performed.
C       If (M.le.0), no action is taken.
C
C**********************************************************************
*
C
      SUBROUTINE BANDET ( E, M, N )
C
       IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION E(-M:M,N)
C
      IF (M.LE.0) RETURN
      DO 40 I=1,N
        DI = E(0,I)
         MI = MIN0(M,I-1)
        IF (MI.GE.1) THEN
          DO 10 K=1,MI
            DI = DI - E(-K,I)*E(K,I-K)
```

```
  10       CONTINUE
           E(0,I) = DI
        ENDIF
         LM = MIN0(M,N-I)
        IF (LM.GE.1) THEN
          DO 30 L=1,LM
            DL = E(-L,I+L)
              KM = MIN0(M-L,I-1)
            IF (KM.GE.1) THEN
              DU = E(L,I)
              DO 20 K=1,KM
                DU = DU - E( -K,  I)*E(L+K,I-K)
                DL = DL - E(-L-K,L+I)*E( K,I-K)
  20            CONTINUE
              E(L,I) = DU
            ENDIF
             E(-L,I+L) = DL / DI
  30       CONTINUE
        ENDIF
  40   CONTINUE
C
C***    Ready
C
      RETURN
      END

C BANSOL.FOR, 1985-12-12
C
C*******************************************************************
*
C
C SUBROUTINE BANSOL (REAL*8)
C
C  Purpose:
C *******
C
C         This subroutine solves systems of linear equations given an LU
C         decomposition of the design matrix. Such a decomposition is
pro-
C         vided by subroutine BANDET, in vectorized form. It is assumed
```

```
C       that the design matrix is not singular.
C
C Calling convention:
C ******************
C
C     CALL BANSOL ( E, Y, NY, C, NC, M, N, K )
C
C Meaning of parameters:
C *********************
C
C       E(-M:M,N)         ( I )   Input design matrix, in LU-decomposed,
C                                 vectorized form. Element E(J,I) of the
C                                 array E corresponds with element
C                                 e(i,i+j) of the N*N design matrix E.
C       Y(NY,K)           ( I )   Right hand side vectors.
C       C(NC,K)           ( O )   Solution vectors.
C       NY, NC, M, N, K   ( I )   Dimensioning parameters, with M >= 0,
C                                 N > 2*M, and K >= 1.
C
C Remark:
C ******
C
C       This subroutine is an adaptation of subroutine BANSOL from
the
C       paper by Lyche et al. (1983). No checking is performed on the
C       validity of the input parameters and data. Division by zero may
C       occur if the system is singular.
C
C Reference:
C *********
C
C       T. Lyche, L.L. Schumaker, & K. Sepehrnoori, Fortran subroutines
C       for computing smoothing and interpolating natural splines.
C       Advances in Engineering Software 5(1983)1, pp. 2-5.
C
C***********************************************************************
*
C
      SUBROUTINE BANSOL ( E, Y, NY, C, NC, M, N, K )
C
```

```
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION E(-M:M,N), Y(NY,K), C(NC,K)
C
C***    Check on special cases: M=0, M=1, M>1
C
      NM1 = N - 1
      IF (M-1) 10,40,80
C
C***    M = 0: Diagonal system
C
   10 DO 30 I=1,N
        DO 20 J=1,K
          C(I,J) = Y(I,J) / E(0,I)
   20   CONTINUE
   30 CONTINUE
      RETURN
C
C***    M = 1: Tridiagonal system
C
   40 DO 70 J=1,K
        C(1,J) = Y(1,J)
        DO 50 I=2,N            !Forward sweep
          C(I,J) =  Y(I,J) - E(-1,I)*C(I-1,J)
   50   CONTINUE
        C(N,J) = C(N,J) / E(0,N)
        DO 60 I=NM1,1,-1       !Backward sweep
          C(I,J) = (C(I,J) - E( 1,I)*C(I+1,J)) / E(0,I)
   60   CONTINUE
   70 CONTINUE
      RETURN
C
C***    M > 1: General system
C
   80 DO 130 J=1,K
        C(1,J) = Y(1,J)
        DO 100 I=2,N           !Forward sweep
          MI = MIN0(M,I-1)
          D  = Y(I,J)
          DO 90 L=1,MI
            D = D - E(-L,I)*C(I-L,J)
```

```
 90        CONTINUE
          C(I,J) = D
100      CONTINUE
        C(N,J) = C(N,J) / E(0,N)
          DO 120 I=NM1,1,-1     !Backward sweep
            MI = MIN0(M,N-I)
          D  = C(I,J)
           DO 110 L=1,MI
             D = D - E( L,I)*C(I+L,J)
110        CONTINUE
           C(I,J) = D / E(0,I)
120      CONTINUE
130   CONTINUE
      RETURN
C
      END

C  TRINV.FOR,  1985-06-03
C
C  Author:  H.J.  Woltring
C
C  Organizations:  University  of  Nijmegen,  and
C                 Philips  Medical  Systems,  Eindhoven
C                (The  Netherlands)
C
C**********************************************************************
*
C
C FUNCTION TRINV (REAL*8)
C
C  Purpose:
C *******
C
C      To calculate TRACE [ B * E**-1 ], where B and E are N * N
C        matrices  with  bandwidth  2*M+1,  and  where  E  is  a  regular
matrix
C        in  LU-decomposed  form.  B  and  E  are  stored  in  vectorized  form,
C       compatible  with  subroutines  BANDET  and  BANSOL.
C
C  Calling  convention:
```

```
C ******************
C
C     TRACE = TRINV ( B, E, M, N )
C
C Meaning of parameters:
C ********************
C
C       B(-M:M,N)       ( I ) Input array for matrix B. Element B(J,I)
C                         corresponds with element b(i,i+j) of the
C                       matrix B.
C       E(-M:M,N)       (I/O) Input array for matrix E. Element E(J,I)
C                         corresponds with element e(i,i+j) of the
C                        matrix E. This matrix is stored in LU-
C                         decomposed form, with L unit lower tri-
C                         angular, and U upper triangular. The unit
C                        diagonal of L is not stored. Upon return,
C                         the array E holds the central 2*M+1 bands
C                        of the inverse E**-1, in similar ordering.
C       M, N            ( I ) Array and matrix dimensioning parameters
C                       (M.gt.0, N.ge.2*M+1).
C      TRINV            ( O ) Output function value TRACE [ B * E**-1 ]
C
C Reference:
C *********
C
C       A.M. Erisman & W.F. Tinney, On computing certain elements of
the
C       inverse of a sparse matrix. Communications of the ACM
18(1975),
C       nr. 3, pp. 177-179.
C
C**********************************************************************
*
C
      FUNCTION TRINV ( B, E, M, N)
C
       IMPLICIT REAL*8 (A-H,O-Z)
      PARAMETER ( ZERO=0D0, ONE=1D0 )
       DIMENSION B(-M:M,N), E(-M:M,N)
C
```

```
C***     Assess central 2*M+1 bands of E**-1 and store in array E
C
      E(0,N) = ONE / E(0,N)    !Nth pivot
      DO 40 I=N-1,1,-1
        MI = MIN0(M,N-I)
        DD  = ONE / E(0,I)   !Ith pivot
C***        Save Ith column of L and Ith row of U, and normalize U row
        DO 10 K=1,MI
          E( K,N) = E( K,  I) * DD  !Ith row of U (normalized)
          E(-K,1) = E(-K,K+I)       !Ith column of L
  10    CONTINUE
      DD = DD + DD
C***        Invert around Ith pivot
        DO 30 J=MI,1,-1
        DU = ZERO
        DL = ZERO
          DO 20 K=1,MI
            DU = DU - E( K,N)*E(J-K,I+K)
            DL = DL - E(-K,1)*E(K-J,I+J)
  20      CONTINUE
         E( J,  I) = DU
         E(-J,J+I) = DL
        DD = DD - (E(J,N)*DL + E(-J,1)*DU)
  30    CONTINUE
       E(0,I) = 5D-1 * DD
  40  CONTINUE
C
C***     Assess TRACE [ B * E**-1 ] and clear working storage
C
     DD = ZERO
      DO 60 I=1,N
        MN = -MIN0(M,I-1)
        MP =  MIN0(M,N-I)
       DO 50 K=MN,MP
        DD = DD + B(K,I)*E(-K,K+I)
  50    CONTINUE
  60  CONTINUE
     TRINV = DD
     DO 70 K=1,M
      E( K,N) = ZERO
```

```
      E(-K,1) = ZERO
  70  CONTINUE
C
C***   Ready
C
      RETURN
      END

C SPLDER.FOR, 1985-06-11
C
C***********************************************************************
*
C
C FUNCTION SPLDER (REAL*8)
C
C Purpose:
C *******
C
C        To produce the value of the function (IDER.eq.0) or of the
C        IDERth derivative (IDER.gt.0) of a 2M-th order B-spline at
C        the point T. The spline is described in terms of the half
C        order M, the knot sequence X(N), N.ge.2*M, and the spline
C       coefficients C(N).
C
C Calling convention:
C ******************
C
C     SVIDER = SPLDER ( IDER, M, N, T, X, C, L, Q )
C
C Meaning of parameters:
C *********************
C
C       SPLDER  ( O )  Function or derivative value.
C       IDER    ( I )  Derivative order required, with 0.le.IDER
C                      and IDER.le.2*M. If IDER.eq.0, the function
C                        value is returned; otherwise, the IDER-th
C                        derivative of the spline is returned.
C       M       ( I )  Half order of the spline, with M.gt.0.
C       N       ( I )  Number of knots and spline coefficients,
C                    with N.ge.2*M.
```

```
C       T       ( I )   Argument at which the spline or its deri-
C                         vative is to be evaluated, with X(1).le.T
C                       and T.le.X(N).
C       X(N)    ( I )   Strictly increasing knot sequence array,
C                       X(I-1).lt.X(I), I=2,...,N.
C       C(N)    ( I )   Spline coefficients, as evaluated by
C                       subroutine GCVSPL.
C       L       (I/O)   L contains an integer such that:
C                       X(L).le.T and T.lt.X(L+1) if T is within
C                       the range X(1).le.T and T.lt.X(N). If
C                       T.lt.X(1), L is set to 0, and if T.ge.X(N),
C                       L is set to N. The search for L is facili-
C                         tated if L has approximately the right
C                       value on entry.
C       Q(2*M)  ( W )   Internal work array.
C
C Remark:
C ******
C
C       This subroutine is an adaptation of subroutine SPLDER of
C       the paper by Lyche et al. (1983). No checking is performed
C       on the validity of the input parameters.
C
C Reference:
C *********
C
C       T. Lyche, L.L. Schumaker, & K. Sepehrnoori, Fortran subroutines
C        for computing smoothing and interpolating natural splines.
C        Advances in Engineering Software 5(1983)1, pp. 2-5.
C
C***********************************************************************
*
C
      FUNCTION SPLDER ( IDER, M, N, T, X, C, L, Q )
C
      IMPLICIT REAL*8 (A-H,O-Z)
      PARAMETER ( ZERO=0D0, ONE=1D0 )
      DIMENSION X(N), C(N), Q(2*M)
C
C***    Derivatives of IDER.ge.2*M are alway zero
```

```
C
       M2 =  2 * M
       K  = M2 - IDER
       IF (K.LT.1) THEN
        SPLDER = ZERO
         RETURN
       ENDIF
C
C***     Search for the interval value L
C
      CALL SEARCH ( N, X, T, L )
C
C***      Initialize parameters and the 1st row of the B-spline
C***     coefficients tableau
C
       TT   = T
       MP1  =  M + 1
       NPM  =  N + M
        M2M1 = M2 - 1
       K1   =  K - 1
       NK   =  N - K
       LK   =  L - K
       LK1  = LK + 1
       LM   =  L - M
       JL   =  L + 1
       JU   =  L + M2
        II  =  N - M2
       ML   = -L
      DO 2 J=JL,JU
         IF ((J.GE.MP1).AND.(J.LE.NPM)) THEN
            Q(J+ML) = C(J-M)
         ELSE
          Q(J+ML) = ZERO
         ENDIF
   2  CONTINUE
C
C***     The following loop computes differences of the B-spline
C***     coefficients. If the value of the spline is required,
C***     differencing is not necessary.
C
```

```
      IF (IDER.GT.0) THEN
        JL = JL - M2
        ML = ML + M2
        DO 6 I=1,IDER
          JL = JL + 1
           II = II + 1
          J1 = MAX0(1,JL)
           J2 = MIN0(L,II)
           MI = M2 - I
          J  = J2 + 1
          IF (J1.LE.J2) THEN
            DO 3 JIN=J1,J2
              J  =  J - 1
              JM = ML + J
               Q(JM) = (Q(JM) - Q(JM-1)) / (X(J+MI) - X(J))
  3         CONTINUE
          ENDIF
          IF (JL.GE.1) GO TO 6
            I1 =  I + 1
            J  = ML + 1
            IF (I1.LE.ML) THEN
              DO 5 JIN=I1,ML
                J    =  J - 1
                Q(J) = -Q(J-1)
  5           CONTINUE
            ENDIF
  6     CONTINUE
        DO 7 J=1,K
          Q(J) = Q(J+IDER)
  7     CONTINUE
      ENDIF
C
C***    Compute lower half of the evaluation tableau
C
      IF (K1.GE.1) THEN          !Tableau ready if IDER.eq.2*M-1
        DO 14 I=1,K1
          NKI  =  NK + I
          IR   =   K
          JJ   =   L
          KI   =   K - I
```

```
          NKI1 = NKI + 1
C***          Right-hand B-splines
          IF (L.GE.NKI1) THEN
            DO 9 J=NKI1,L
              Q(IR) = Q(IR-1) + (TT-X(JJ))*Q(IR)
              JJ    = JJ - 1
              IR    = IR - 1
  9         CONTINUE
          ENDIF
C***          Middle B-splines
          LK1I = LK1 + I
           J1 = MAX0(1,LK1I)
           J2 = MIN0(L, NKI)
          IF (J1.LE.J2) THEN
            DO 11 J=J1,J2
             XJKI  = X(JJ+KI)
             Z     = Q(IR)
              Q(IR) = Z + (XJKI-TT)*(Q(IR-1)-Z)/(XJKI-X(JJ))
              IR    = IR - 1
              JJ    = JJ - 1
 11         CONTINUE
          ENDIF
C***          Left-hand B-splines
          IF (LK1I.LE.0) THEN
            JJ    = KI
             LK1I1 =  1 - LK1I
            DO 13 J=1,LK1I1
              Q(IR) = Q(IR) + (X(JJ)-TT)*Q(IR-1)
              JJ    = JJ - 1
              IR    = IR - 1
 13         CONTINUE
          ENDIF
 14     CONTINUE
      ENDIF
C
C***    Compute the return value
C
      Z = Q(K)
C***    Multiply with factorial if IDER.gt.0
      IF (IDER.GT.0) THEN
```

```
        DO 16 J=K,M2M1
          Z = Z * J
  16    CONTINUE
      ENDIF
      SPLDER = Z
C
C***    Ready
C
      RETURN
      END

C SEARCH.FOR, 1985-06-03
C
C**********************************************************************
*
C
C SUBROUTINE SEARCH (REAL*8)
C
C  Purpose:
C *******
C
C        Given a strictly increasing knot sequence X(1) < ... < X(N),
C         where N >= 1, and a real number T, this subroutine finds the
C       value L such that X(L) <= T < X(L+1).  If T < X(1), L = 0;
C      if X(N) <= T, L = N.
C
C  Calling  convention:
C *****************
C
C      CALL SEARCH ( N, X, T, L )
C
C  Meaning  of  parameters:
C ********************
C
C        N        ( I )   Knot array dimensioning parameter.
C        X(N)     ( I )   Stricly increasing knot array.
C        T        ( I )   Input argument whose knot interval is to
C                        be found.
C         L        (I/O)   Knot interval parameter. The search procedure
C                             is facilitated if L has approximately the
```

```
C                   right value on entry.
C
C Remark:
C ******
C
C       This subroutine is an adaptation of subroutine SEARCH from
C       the paper by Lyche et al. (1983). No checking is performed
C       on the input parameters and data; the algorithm may fail if
C       the input sequence is not strictly increasing.
C
C Reference:
C *********
C
C       T. Lyche, L.L. Schumaker, & K. Sepehrnoori, Fortran subroutines
C        for computing smoothing and interpolating natural splines.
C       Advances in Engineering Software 5(1983)1, pp. 2-5.
C
C*********************************************************************
*
C
      SUBROUTINE SEARCH ( N, X, T, L )
C
       IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X(N)
C
      IF (T.LT.X(1)) THEN
C***       Out of range to the left
        L = 0
        RETURN
      ENDIF
      IF (T.GE.X(N)) THEN
C***       Out of range to the right
        L = N
        RETURN
      ENDIF
C***    Validate input value of L
      L = MAX0(L,1)
      IF (L.GE.N) L = N-1
C
C***    Often L will be in an interval adjoining the interval found
```

```
C***     in a previous call to search
C
      IF (T.GE.X(L)) GO TO 5
       L = L - 1
      IF (T.GE.X(L)) RETURN
C
C***     Perform bisection
C
       IL = 1
    3   IU = L
    4   L = (IL+IU) / 2
       IF (IU-IL.LE.1) RETURN
      IF (T.LT.X(L)) GO TO 3
       IL = L
      GO TO 4
    5  IF (T.LT.X(L+1)) RETURN
      L = L + 1
      IF (T.LT.X(L+1)) RETURN
       IL = L + 1
       IU = N
      GO TO 4
C
      END
```

APPENDIX D

STROHMEY.SAS

```
DATA one;
  INFILE 'STROHMEY DATA A';
   INPUT SUBJECT FMIN FMAX MSLOPE AVslope lowcomf lamda ratio
         T1 - T5 EISvmax eisvj jump subject2 fmin2 fmax2 mslope2
          avslope2 lowcomf2 lamda2 ratio2 t6 - t10 eisvmax2 eisvj2
      jump2;
PROC GLM;
   MODEL EISvmax eisvmax2=/nouni;
  REPEATED time 2;
PROC GLM;
   MODEL EISvj eisvj2=/nouni;
  REPEATED vjt 2;
PROC GLM;
   MODEL JUMP jump2=/nouni;
  REPEATED jumpt 2;
proc glm;
    model fmin fmin2=/nouni;
    repeated fmint 2;
proc glm;
    model fmax fmax2=/nouni;
    repeated fmaxt 2;
proc glm;
    model mslope mslope2=/nouni;
    repeated mst 2;
proc glm;
    model avslope avslope2=/nouni;
    repeated avst 2;
proc glm;
    model lowcomf lowcomf2=/nouni;
    repeated lowt 2;
proc glm;
    model lamda lamda2=/nouni;
    repeated lamt 2;
proc glm;
    model ratio ratio2=/nouni;
    repeated ratt 2;
proc glm;
    model t1 t6=/nouni;
    repeated t1t 2;
proc glm;
```

```
    model t2 t7=/nouni;
    repeated t2t 2;
proc glm;
    model t3 t8=/nouni;
    repeated t3t 2;
proc glm;
    model t4 t9=/nouni;
    repeated t4t 2;
proc glm;
    model t5 t10=/nouni;
    repeated t5t 2;
proc means;
```

APPENDIX E

RAW DATA

	subject	Fmin	Fmax	y	average y	LowCOMF
▶ Type:	Integer	Real	Real	Real	Real	Real
▶ Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
▶ Class:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
▶ Format:	•	Free Form...	Free Form...	Free Form...	Free Form...	Free Form...
▶ Dec. Places:	•	7	7	5	7	7
Mean:	2684.333	.4542711	2.5862041	16.85725	5.3489486	2.1525251
Std. Deviation:	1529.777	.2198526	.4512725	10.96364	2.5850304	.4736036
Std. Error:	214.212	.0307855	.0631908	1.53522	.3619767	.0663178
Variance:	2340218....	.0483351	.2036469	120.20141	6.6823822	.2243003
Coeff. of Variation:	.570	.4839677	.1744922	.65038	.4832782	.2200223
Minimum:	121	.0312643	1.9655564	6.32184	1.2597745	1.6409889
Maximum:	5311	.8399124	4.1167615	59.99834	14.1692870	4.0805488
Range:	5190.000	.8086481	2.1512051	53.67650	12.9095125	2.4395599
Count:	51	51	51	51	51	51
Missing Cells:	0	0	0	0	0	0
Sum:	136901.000	23.1678259	131.8964...	859.71955	272.7963...	109.7787...
Sum of Squares:	484498851	12.9412310	351.2933...	20502.57...	1.793292...	247.5165...

	shape factor	-/+ ratio	t1	t2	t3	t4
▶ Type:	Real	Real	Real	Real	Real	Real
▶ Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
▶ Class:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
▶ Format:	Free Form...	Free Form...	Free Form...	Free Format...	Free Format...	Free Format...
▶ Dec. Places:	5	5	3	3	3	3
Mean:	.37520	-.26480	.400	.142	.424	.169
Std. Deviation:	.06463	.07413	.156	.089	.077	.090
Std. Error:	.00905	.01038	.022	.012	.011	.013
Variance:	.00418	.00549	.024	.008	.006	.008
Coeff. of Variation:	.17226	-.27993	.390	.626	.182	.535
Minimum:	.17140	-.48670	.130	-.047	.269	.093
Maximum:	.51300	-.07550	.949	.346	.655	.454
Range:	.34160	.41120	.819	.393	.386	.361
Count:	51	51	51	51	51	51
Missing Cells:	0	0	0	0	0	0
Sum:	19.13499	-13.50470	20.385	7.218	21.608	8.630
Sum of Squares:	7.38822	3.85075	9.361	1.414	9.454	1.870

	t5	eisvmax	eisvj	jump height	subject1	Fmin1
▶ Type:	Real	Real	Real	Real	Integer	Real
▶ Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
▶ Class:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
▶ Format:	Free Format...	Free Format...	Free Format...	Free Format...	•	Free Format...
▶ Dec. Places:	3	5	5	6	•	7
Mean:	.299	18.95802	54.80802	33.662098	2684.333	.4542711
Std. Deviation:	.096	11.26095	35.25659	10.405264	1529.777	.2198526
Std. Error:	.013	1.57685	4.93691	1.457028	214.212	.0307855
Variance:	.009	126.80902	1243.02733	108.269525	2340218.667	.0483351
Coeff. of Variation:	.320	.59399	.64327	.309109	.570	.4839677
Minimum:	.165	-12.59383	-26.19209	17.951153	121	.0312643
Maximum:	.648	52.85617	169.28130	59.243511	5311	.8399124
Range:	.483	65.45000	195.47339	41.292358	5190.000	.8086481
Count:	51	51	51	51	51	51
Missing Cells:	0	0	0	0	0	0
Sum:	15.249	966.85907	2795.20909	1716.767009	136901.000	23.1678259
Sum of Squares:	5.018	24670.18547	215351.24...	63203.455...	484498851	12.9412310

	Fmax1	y1	average y1	LowCOMF1	shape factor1	-/+ ratio1
▶ Type:	Real	Real	Real	Real	Real	Real
▶ Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
▶ Class:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
▶ Format:	Free Format...	Free Format...	Free Format...	Free Format...	Free Format...	Free Format...
▶ Dec. Places:	7	5	7	7	5	5
Mean:	2.5862041	16.51549	5.3489486	2.2240036	.41570	-.23547
Std. Deviation:	.4512725	11.01074	2.5850304	.4421238	.04298	.06234
Std. Error:	.0631908	1.54181	.3619767	.0619097	.00602	.00873
Variance:	.2036469	121.23639	6.6823822	.1954735	.00185	.00389
Coeff. of Variation:	.1744922	.66669	.4832782	.1987964	.10340	-.26476
Minimum:	1.9655564	6.32184	1.2597745	1.6409889	.32370	-.40100
Maximum:	4.1167615	59.99834	14.1692870	4.0805488	.51720	-.06770
Range:	2.1512051	53.67650	12.9095125	2.4395599	.19350	.33330
Count:	51	51	51	51	51	51
Missing Cells:	0	0	0	0	0	0
Sum:	131.8964105	842.29013	272.7963804	113.4241825	21.20090	-12.00880
Sum of Squares:	351.2933855	19972.65607	1793.2929...	262.0294624	8.90568	3.02200

	t1s	t2s	t3s	t4s	t5s	eisvmaxs
▶ Type:	Real	Real	Real	Real	Real	Real
▶ Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
▶ Class:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
▶ Format:	Free Format...	Free Format...	Free Format...	Free Format...	Free Format...	Free Format...
▶ Dec. Places:	3	3	3	3	3	5
Mean:	.400	.145	.424	.169	.291	40.42844
Std. Deviation:	.156	.091	.077	.090	.094	36.53777
Std. Error:	.022	.013	.011	.013	.013	5.11631
Variance:	.024	.008	.006	.008	.009	1335.00865
Coeff. of Variation:	.390	.623	.182	.535	.321	.90376
Minimum:	.130	-.045	.269	.093	.161	1.67627
Maximum:	.949	.346	.655	.454	.649	181.26746
Range:	.819	.391	.386	.361	.488	179.59119
Count:	51	51	51	51	51	51
Missing Cells:	0	0	0	0	0	0
Sum:	20.385	7.408	21.608	8.630	14.852	2061.85034
Sum of Squares:	9.361	1.486	9.454	1.870	4.763	150107.82...

	eisvjs	jump height s	Input Column
▶ Type:	Real	Real	Real
▶ Source:	User Entered	User Entered	User Entered
▶ Class:	Continuous	Continuous	Continuous
▶ Format:	Free Format...	Free Format...	Free Format Fixed
▶ Dec. Places:	5	6	3
Mean:	141.88826	50.084266	•
Std. Deviation:	184.92787	33.807556	•
Std. Error:	25.89508	4.734005	•
Variance:	34198.31590	1142.950868	•
Coeff. of Variation:	1.30333	.675014	•
Minimum:	4.44387	19.698033	•
Maximum:	910.77173	194.968840	•
Range:	906.32786	175.270807	•
Count:	51	51	•
Missing Cells:	0	0	•
Sum:	7236.30124	2554.297588	•
Sum of Squares:	2.73666E6	1.850777E5	•

	subject	Fmin	Fmax	y	average y	LowCOMF
1	121	.3034589	3.9729495	34.13289	9.4089592	3.7055810
2	221	.7710672	3.3324154	12.69363	6.3243153	2.1594214
3	321	.8399124	1.9753083	9.90009	2.0494540	1.8928298
4	431	.6580123	2.6415578	10.44056	3.0375926	2.1417171
5	521	.5658391	2.0872453	9.80937	3.2301540	1.7005798
6	621	.5983701	2.9476711	14.82283	5.4762217	2.1018213
7	711	.4026208	2.4974458	8.85426	3.6622758	1.9234480
8	831	.2030711	2.7257184	29.28156	5.7479636	1.8679383
9	911	.6447285	2.5371991	10.02814	3.9181609	1.8639639
10	1021	.6428987	2.4127937	12.29487	4.3379847	2.0209325
11	1131	.4075352	2.7818065	22.69120	3.2972680	1.6409889
12	1231	.4084665	4.1167615	44.80615	10.1043390	4.0805488
13	1331	.6600409	3.2258331	14.89056	7.0103617	2.6458825
14	1431	.5600541	2.6160205	14.87202	3.8865087	1.7967068
15	1531	.6932149	1.9667315	8.66458	1.8703824	1.9552747
16	1611	.6892386	2.8317797	12.37215	5.5650428	2.4107645
17	1731	.0415090	2.8186906	59.99834	14.1692870	2.8024008
18	1831	.4700761	2.1086981	9.00800	3.1694822	1.8965150
19	1911	.5203745	2.7169351	22.52166	6.8642459	2.3353039
20	2031	.1952789	2.8438367	24.25342	9.9569839	2.8387046
21	2221	.8040421	1.9655564	9.47116	1.2597745	1.9615281
22	2311	.5402988	3.0773232	13.42476	7.0072249	2.1779080
23	2421	.3604358	2.3903596	8.49744	3.6840675	1.8889861
24	2521	.0312643	2.7742923	44.64350	7.4336740	2.0833711
25	2631	.7167069	2.4914854	16.32196	5.1742774	2.0730042
26	2731	.3335224	2.4162292	8.17102	4.0917667	1.7998728
27	2831	.8171576	2.8046253	13.01321	2.9976893	2.0400915
28	2911	.7187376	2.3864703	7.82354	3.2700638	1.6757406
29	3031	.1975135	3.2901243	40.60310	1.6775455	3.1332078
30	3121	.6936789	2.4523128	10.85001	4.7275086	1.8420366
31	3231	.0752299	2.1797853	6.32184	2.3750488	1.7048037
32	3311	.3398142	2.5255364	13.12660	4.4789353	2.2799084
33	3421	.1574614	2.0162881	12.20969	6.5222043	1.9762492
34	3511	.2640303	2.3007371	13.90760	4.2431428	2.0963508
35	3631	.1642697	2.5370490	23.94899	6.3443333	2.1242121
36	3711	.3460985	2.2277335	13.67468	9.9432953	2.1806640
37	3811	.4850161	2.3422902	14.47330	5.6111062	2.2765728
38	3921	.2828919	2.6161856	19.17906	7.1354548	2.3426974
39	4011	.3355283	3.0671009	12.48687	8.0244367	2.3077289
40	4121	.4975517	2.1397219	10.89844	2.8860750	1.6969479
41	4221	.2119377	2.5466358	24.20244	9.4522164	2.5392790
42	4331	.6711061	2.6204796	10.04243	6.2280330	1.8797375
43	4421	.5615380	2.7679206	8.57350	4.1708576	1.7339078
44	4521	.1853173	2.5891248	21.80333	5.9248829	2.3025065
45	4611	.6993461	2.3801833	12.05550	4.7887066	1.8653339
46	4731	.2072298	1.9943186	12.04739	5.2254105	1.9940378
47	4831	.2779706	2.2817638	21.48675	8.2460653	2.1668579
48	4911	.4025646	2.4609223	11.38330	4.6887398	1.9607609
49	5011	.3969748	2.1550487	11.50524	2.4972615	1.8003308
50	5111	.5264568	2.4519881	8.98786	4.7426795	1.8744197
51	5311	.5903664	2.4894204	18.24876	4.8569192	2.2184028

	shape factor	-/+ ratio	t1	t2	t3	t4
1	.17140	-.48670	.451	.018	.474	.330
2	.36230	-.19200	.521	.125	.349	.116
3	.33760	-.17050	.435	.268	.495	.132
4	.40260	-.23860	.510	.123	.420	.162
5	.33699	-.21230	.249	.220	.444	.136
6	.38340	-.22990	.441	.171	.396	.116
7	.31910	-.30960	.393	.205	.487	.093
8	.38390	-.26780	.244	.186	.442	.144
9	.38150	-.22650	.638	.195	.447	.136
10	.38840	-.22170	.486	.163	.382	.134
11	.20770	-.25610	.322	.346	.655	.132
12	.25290	-.33090	.490	.006	.469	.356
13	.40940	-.26770	.611	.082	.310	.135
14	.33240	-.27880	.418	.261	.483	.095
15	.35340	-.24570	.487	.224	.441	.125
16	.44500	-.20910	.585	.098	.344	.158
17	.51300	-.40430	.253	.011	.287	.215
18	.37010	-.30990	.329	.206	.453	.129
19	.45680	-.20740	.281	.128	.335	.143
20	.46800	-.29990	.386	-.005	.396	.310
21	.38100	-.23390	.822	.275	.521	.128
22	.39810	-.24690	.405	.142	.347	.102
23	.32340	-.38250	.373	.180	.474	.096
24	.38250	-.29270	.208	.131	.410	.149
25	.41660	-.23210	.949	.153	.398	.151
26	.36820	-.23220	.243	.180	.459	.143
27	.37780	-.13010	.538	.198	.414	.110
28	.31860	-.24490	.558	.137	.420	.147
29	.48400	-.29500	.255	.052	.269	.168
30	.36080	-.09360	.147	.188	.354	.111
31	.31680	-.19890	.415	.191	.517	.166
32	.42010	-.28690	.443	.213	.452	.112
33	.35170	-.37510	.307	-.024	.532	.421
34	.41950	-.30970	.362	.203	.461	.129
35	.43020	-.29850	.291	.157	.381	.131
36	.39840	-.31340	.320	-.025	.436	.347
37	.40140	-.27880	.617	.050	.374	.218
38	.43590	-.27160	.234	.125	.330	.126
39	.38710	-.25050	.251	.113	.344	.129
40	.32830	-.30530	.339	.234	.509	.120
41	.45150	-.38130	.361	-.008	.403	.309
42	.37290	-.20320	.534	.138	.340	.117
43	.31450	-.23450	.344	.202	.478	.109
44	.43060	-.25260	.340	.141	.353	.128
45	.36640	-.07550	.130	.186	.350	.112
46	.31340	-.38710	.324	-.002	.604	.454
47	.46470	-.33540	.355	-.047	.450	.388
48	.38270	-.26790	.308	.150	.405	.138
49	.27670	-.23680	.325	.246	.546	.109
50	.37040	-.25210	.332	.140	.388	.141
51	.41490	-.24030	.425	.168	.380	.124

	t5	eisvmax	eisvj	jump height	subject1	Fmin1
1	.372	31.18525	93.34914	39.363820	121	.3034589
2	.280	23.09300	62.67238	46.759259	221	.7710672
3	.286	34.55609	99.89702	26.836095	321	.8399124
4	.530	14.48795	36.74939	46.050425	431	.6580123
5	.251	18.56256	55.06816	18.420368	521	.5658391
6	.258	24.68227	67.88304	47.104194	621	.5983701
7	.367	11.67533	31.74431	28.555913	711	.4026208
8	.252	52.85617	169.28130	55.026441	831	.2030711
9	.288	26.71439	76.56367	43.192421	911	.6447285
10	.245	30.04026	92.69003	28.814476	1021	.6428987
11	.374	30.41951	92.51840	30.066888	1131	.4075352
12	.361	38.00392	113.22303	41.128819	1231	.4084665
13	.284	1.67627	4.63873	34.039417	1331	.6600409
14	.268	12.88903	32.83008	37.253927	1431	.5600541
15	.457	20.47060	63.86413	18.275775	1531	.6932149
16	.287	10.70217	26.45050	47.318348	1611	.6892386
17	.185	22.17040	68.62332	28.317858	1731	.0415090
18	.311	10.06456	28.42881	21.866171	1831	.4700761
19	.193	16.45792	41.80125	42.210995	1911	.5203745
20	.271	22.09672	57.35714	55.163684	2031	.1952789
21	.648	25.33960	71.35376	32.091378	2221	.8040421
22	.220	16.06804	42.99323	40.394406	2311	.5402988
23	.371	-12.59383	-26.19209	17.951153	2421	.3604358
24	.239	44.02095	144.25735	46.788395	2521	.0312643
25	.190	22.99847	68.09706	38.950221	2631	.7167069
26	.330	22.00220	63.61726	36.275755	2731	.3335224
27	.465	23.67848	63.03886	59.243511	2831	.8171576
28	.373	5.05808	13.25534	20.364106	2911	.7187376
29	.195	33.64823	100.73519	38.952051	3031	.1975135
30	.184	8.46329	19.82916	25.046841	3121	.6936789
31	.444	23.75540	73.60232	30.071070	3231	.0752299
32	.275	9.22344	22.24095	46.351531	3311	.3398142
33	.309	29.18168	93.27710	20.741590	3421	.1574614
34	.277	10.02038	25.52589	36.804000	3511	.2640303
35	.217	15.02067	38.90965	32.924346	3631	.1642697
36	.296	10.71100	32.49193	26.819247	3711	.3460985
37	.281	1.42296	3.63608	23.347023	3811	.4850161
38	.203	21.02708	61.67321	27.097856	3921	.2828919
39	.227	12.15690	37.45092	35.033240	4011	.3355283
40	.335	9.92667	27.49168	19.698033	4121	.4975517
41	.255	28.21040	77.60965	35.799156	4221	.2119377
42	.175	17.32867	48.96129	26.578182	4331	.6711061
43	.327	14.13959	34.80462	39.662191	4421	.5615380
44	.256	22.94854	65.79101	33.465424	4521	.1853173
45	.165	6.92041	16.19242	23.177118	4611	.6993461
46	.344	18.28572	52.62316	19.986228	4731	.2072298
47	.291	13.29858	34.80618	36.394843	4831	.2779706
48	.289	10.58752	26.60102	29.263928	4911	.4025646
49	.459	13.90384	40.94314	22.395934	5011	.3969748
50	.266	15.38418	41.98347	25.283776	5111	.5264568
51	.223	21.91756	61.97445	34.049182	5311	.5903664

	Fmax1	y1	average y1	LowCOMF1	shape factor1	-/+ ratio1
1	3.9729495	34.13289	9.4089592	3.7055810	.32370	-.25780
2	3.3324154	12.69363	6.3243153	2.1594214	.36230	-.19200
3	1.9753083	9.90009	2.0494540	1.8562769	.37170	-.15490
4	2.6415578	10.44056	3.0375926	2.1417171	.40260	-.23860
5	2.0872453	9.80937	3.2301540	1.8600944	.39880	-.17940
6	2.9476711	10.79205	5.4762217	2.1704535	.43160	-.20420
7	2.4974458	8.85426	3.6622758	2.0360188	.40960	-.24120
8	2.7257184	29.28156	5.7479636	2.1422249	.44150	-.23280
9	2.5371991	10.02814	3.9181609	2.1032215	.42350	-.20400
10	2.4127937	12.29487	4.3379847	2.0731393	.41580	-.20710
11	2.7818065	8.84696	3.2972680	1.6409889	.37730	-.14100
12	4.1167615	44.80615	10.1043390	4.0805488	.42960	-.19480
13	3.2258331	14.89056	7.0103617	2.6458825	.40940	-.26770
14	2.6160205	14.87202	3.8865087	2.1015546	.44410	-.20860
15	1.9667315	8.66458	1.8703824	1.9239739	.39450	-.22010
16	2.8317797	12.37215	5.5650428	2.4218698	.44640	-.20850
17	2.8186906	59.99834	14.1692870	2.8051160	.51720	-.40100
18	2.1086981	9.00800	3.1694822	1.9840790	.40800	-.28120
19	2.7169351	22.52166	6.8642459	2.4107521	.47460	-.19960
20	2.8438367	24.25342	9.9569839	2.8435802	.50720	-.27670
21	1.9655564	9.47116	1.2597745	1.9152697	.38970	-.22870
22	3.0773232	13.42476	7.0072249	2.1779080	.39810	-.24690
23	2.3903596	8.49744	3.6840675	2.0893028	.39470	-.31350
24	2.7742923	44.64350	7.4336740	2.2118640	.44940	-.24910
25	2.4914854	16.32196	5.1742774	2.2030767	.43880	-.22030
26	2.4162292	8.17102	4.0917667	2.0090949	.39750	-.21510
27	2.8046253	13.01321	2.9976893	2.0400915	.37780	-.13010
28	2.3864703	7.68051	3.2700638	1.9660371	.36190	-.21560
29	3.2901243	40.60310	1.6775455	3.0938528	.48060	-.29710
30	2.4523128	10.85001	4.7275086	1.8938771	.40290	-.08380
31	2.1797853	6.32184	2.3750488	1.7048037	.32900	-.19150
32	2.5255364	13.12660	4.4789353	2.3420998	.46880	-.25710
33	2.0162881	12.20969	6.5222043	2.0151926	.40840	-.32300
34	2.3007371	13.90760	4.2431428	2.1594748	.44540	-.29170
35	2.5370490	23.94899	6.3443333	2.2718803	.46930	-.27360
36	2.2277335	13.67468	9.9432953	2.2171181	.41020	-.30440
37	2.3422902	14.47330	5.6111062	2.2765728	.40240	-.27820
38	2.6161856	19.17906	7.1354548	2.3623269	.44800	-.26420
39	3.0671009	12.48687	8.0244367	2.3077289	.38710	-.25050
40	2.1397219	10.89844	2.8860750	1.8195938	.39290	-.25520
41	2.5466358	24.20244	9.4522164	2.5392790	.45150	-.38130
42	2.6204796	10.63106	6.2280330	2.0609798	.41200	-.18400
43	2.7679206	8.57350	4.1708576	2.0227335	.38160	-.19350
44	2.5891248	21.80333	5.9248829	2.3585010	.45240	-.24040
45	2.3801833	12.05550	4.7887066	1.8962976	.40860	-.06770
46	1.9943186	12.04739	5.2254105	1.9943119	.40160	-.30210
47	2.2817638	21.48675	8.2460653	2.2786170	.50140	-.31080
48	2.4609223	11.38330	4.6887398	2.1288810	.41230	-.24860
49	2.1550487	11.50524	2.4972615	1.8239110	.32370	-.20240
50	2.4519881	8.98786	4.7426795	1.8744197	.37040	-.25210
51	2.4894204	18.24876	4.8569192	2.2625901	.44310	-.22510

	t1s	t2s	t3s	t4s	t5s	eisvmaxs
1	.451	.018	.474	.330	.372	146.99361
2	.521	.125	.349	.116	.280	23.09300
3	.435	.268	.495	.132	.286	50.90863
4	.510	.123	.420	.162	.530	14.48795
5	.249	.222	.444	.136	.249	46.93138
6	.441	.171	.396	.116	.258	45.10790
7	.393	.247	.487	.093	.325	56.21946
8	.244	.201	.442	.144	.237	81.41107
9	.638	.201	.447	.136	.282	44.48627
10	.486	.163	.382	.134	.245	41.83275
11	.322	.346	.655	.132	.374	172.34551
12	.490	.006	.469	.356	.361	181.26746
13	.611	.082	.310	.135	.284	1.67627
14	.418	.271	.483	.095	.258	64.33786
15	.487	.223	.441	.125	.458	39.03414
16	.585	.097	.344	.158	.288	10.62566
17	.253	.012	.287	.215	.184	23.21728
18	.329	.207	.453	.129	.310	26.00852
19	.281	.128	.335	.143	.193	22.18612
20	.386	-.006	.396	.310	.272	49.82207
21	.822	.274	.521	.128	.649	29.04161
22	.405	.142	.347	.102	.220	16.06804
23	.373	.196	.474	.096	.355	18.64129
24	.208	.174	.410	.149	.196	74.72499
25	.949	.154	.398	.151	.189	31.17615
26	.243	.186	.459	.143	.324	34.87115
27	.538	.198	.414	.110	.465	23.67848
28	.558	.146	.420	.147	.364	23.59624
29	.255	.050	.269	.168	.197	31.91356
30	.147	.187	.354	.111	.186	23.10572
31	.415	.191	.517	.166	.444	29.74713
32	.443	.214	.452	.112	.274	26.99923
33	.307	-.023	.532	.421	.308	61.13516
34	.362	.204	.461	.129	.276	19.78760
35	.291	.160	.381	.131	.214	29.75787
36	.320	-.024	.436	.347	.295	14.59146
37	.617	.050	.374	.218	.281	1.76068
38	.234	.125	.330	.126	.203	25.63205
39	.251	.113	.344	.129	.227	9.92667
40	.339	.243	.509	.120	.326	40.27335
41	.361	-.008	.403	.309	.255	17.32867
42	.534	.152	.340	.117	.161	32.56843
43	.344	.212	.478	.109	.317	45.38538
44	.340	.140	.353	.128	.257	30.81435
45	.130	.186	.350	.112	.165	21.68956
46	.324	-.002	.604	.454	.344	70.14255
47	.355	-.045	.450	.388	.289	26.11658
48	.308	.153	.405	.138	.286	22.21255
49	.325	.247	.546	.109	.250	39.00959
50	.332	.140	.388	.141	.266	15.38418
51	.425	.168	.380	.124	.223	32.77716

	eisvjs	jump height s	Input Column
1	684.93931	159.805260	
2	62.67238	46.759259	
3	160.82382	35.015493	
4	36.74939	46.050425	
5	158.10827	30.660385	
6	134.43391	65.776868	
7	179.12528	60.501110	
8	292.29821	80.164401	
9	137.86423	58.188255	
10	134.96577	35.136304	
11	872.00824	151.805040	
12	910.77173	194.968840	
13	4.63873	34.039417	
14	203.70233	85.177279	
15	129.87802	25.638307	
16	26.25708	47.245970	
17	71.96594	28.879204	
18	76.21299	30.001861	
19	57.83283	46.983229	
20	100.48282	70.282331	
21	83.40441	34.348242	
22	42.99323	40.394406	
23	49.16451	36.278966	
24	274.26516	71.691869	
25	94.24036	45.007956	
26	105.16775	45.487958	
27	63.03886	59.243511	
28	65.48897	29.756081	
29	94.89911	37.819578	
30	60.49218	33.546277	
31	93.55000	33.526369	
32	70.35992	64.597361	
33	224.28601	34.800850	
34	52.00900	44.568808	
35	82.31018	43.211136	
36	39.15571	28.168140	
37	4.44387	23.529000	
38	76.30922	29.550981	
39	27.49168	19.698033	
40	125.33457	34.815196	
41	48.96129	26.578182	
42	96.84700	35.122114	
43	131.35458	68.069102	
44	90.63130	38.479513	
45	56.80435	31.278055	
46	255.29936	46.526977	
47	71.53252	46.310186	
48	59.06270	36.767472	
49	123.37282	35.494051	
50	41.98347	25.283776	
51	96.31587	41.268204	