

**Impact Forces at the Knee Joint –
A Comparative Study on Running Styles**

By

Constanza Sol, MBA

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**A Thesis Submitted to the Faculty of
the College of Education
in Partial Fulfillment of the Requirements for Degree of
Master of Science**

Florida Atlantic University

Boca Raton, Florida

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Don Torok, Department of Exercise Science and Wellness Education, and has been approved by the members of her supervisory committee. It was submitted to the faculty of the College of Education and was accepted in partial fulfillment of the requirements for the degree of Master of Science.

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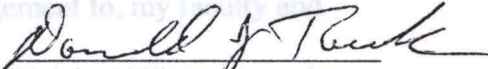
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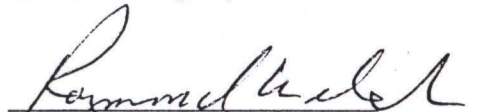
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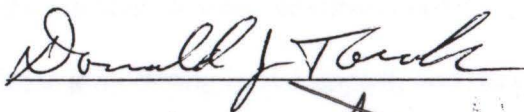
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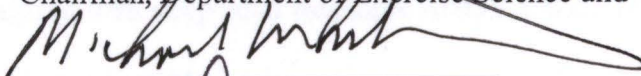
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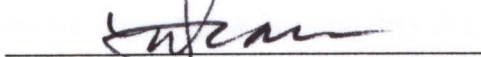

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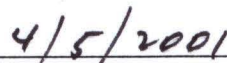


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ABSTRACT

Author:

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Title: The author wishes to acknowledge the Good Samaritan Medical Center Study

Orthopaedics Research Laboratory, Dr. Scott Banks and *especially* Kim Mitchell, for use of their facilities, all their time, cooperation, and input without which this study would not have been possible; Dr. Nicholas Romanov for providing his research and his time and effort in transforming runners; to the participants themselves for their effort and enthusiasm in completing the required sessions; to Dr. Kathy Campbell for getting the project started; to my advisory committee, Dr. Susan Graves, Dr. Scott Welsh; and last, but not least, a very special acknowledgement to, my faculty and thesis advisor, Dr. Don Torok, for his interminable patience in molding my words to actual literary expressions.

training consisted of drills that focused on landing on the midfoot as per the Pose Method of running. The kinematics variables quantified were stride rate, stride length, stance phase, and knee flexion angle at footstrike. The kinetics measured were maximum vertical ground reaction forces at the ground and at the knee joint during initial impact, and maximum loading rate. The data were analyzed with a repeated measures ANOVA with ($P < 0.05$). Significant decreases were found in stride rate, stance phase and in all kinetic variables. These preliminary results are encouraging because they demonstrate that changing the footstrike can result in a reduction in impact forces at the knee joint.

ABSTRACT

Author: Constanza Sol
Title: Impact Forces at the Knee Joint – A Comparative Study
of Running Styles
Institution: Florida Atlantic University
Thesis Advisor: Dr. Don Torok
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The focus of this study was to quantify changes in impact forces at the knee when changing footstrike. The subjects included 17 heelstrickers (trained=8, controls=9). The 12-week training consisted of drills that focused on landing on the midfoot as per the Pose Method of running. The kinematics variables quantified were stride rate, stride length, stance phase, and knee flexion angle at footstrike. The kinetics measured were maximum vertical ground reaction forces at the ground and at the knee joint during initial impact, and maximum loading rate. The data were analyzed with a repeated measures ANOVA with ($P<0.05$). Significant decreases was found in stride rate, stance phase and in all kinetic variables. These preliminary results are encouraging because they demonstrate that changing the footstrike can result in a reduction in impact forces at the knee joint.

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Running can be considered an uninterrupted series of small jumps from one foot

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estimated to be two to three times the body weight of the runner (2,13, 16,17,21,36).

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Applying this fact to a 150-pound runner, who has an average of 400 foot-strikes per foot

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2400 to 7200 tons of force (10). This is an astounding amount of stress to the lower

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The prevalence of injuries associated with the activity of running has compelled

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sport scientists to investigate the associated repeated impact stress to the body. In 1978,

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James, Bates, and Ostering studied 180 runners and identified 232 injuries associated

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The question remains why the knee is such a main point of convergence for

running related injuries. A study by Derrick, Hamill, and Caldwell (15) supplied some insight when they reported that, during the stance phase of jogging, energy is primarily dissipated at the knee joint, much like a shock absorber. LaFortune, Lake, and Hennig

Introduction

(22) also reported that the body relies on the knee joint as a principal mechanism to regulate the shockwave transmission as it travels from foot to head.

Running can be considered an uninterrupted series of small jumps from one foot to the other (16,34). During each foot strike the body is exposed to repeated impact forces

The biomechanics of running is composed of mechanical variables that include estimated to be two to three times the body weight of the runner (2,13, 16,17,21,36). foot strike position, stride length, stride rate, knee angle at foot strike, and maximal knee Applying this fact to a 150-pound runner, who has an average of 400 foot-strikes per foot flexion angle during support (38). Each of these variables has an impact on the forces per mile, during a one-mile run each foot would endure between 60 and 90 tons of force endured by the body during running. Any change in the application of these mechanical (14). Typical runners training from 40 to 80 miles per week could expect to expose their variables will result in a change in the ground reaction forces (GRF). This bodies to approximately 16,000 to 32,000 impacts per leg per week, equivalent to about interrelationship has been documented by studies such as Cavanagh and LaFortune's 2400 to 7200 tons of force (10). This is an astounding amount of stress to the lower study that identified the characteristic differences in center of pressure and as an over- extremities that increases the likelihood of injury.

The prevalence of injuries associated with the activity of running has compelled investigation that compared elite versus good distance runners (11); the Derrick, Hamill, sport scientists to investigate the associated repeated impact stress to the body. In 1978, and Caldwell (1997) research on the relationship between shock attenuation and stride James, Bates, and Osternig studied 180 runners and identified 232 injuries associated length (15), and the Nigg, Cole, and Brüggemann (1995) review of impact mechanics with the act of running. Of the 232 injuries identified, approximately 29% were during heel-to-toe running (31). The idea of the knee acting as a shock absorber is associated with knee pain. Closer analysis of these injuries indicated that the another important consideration in running biomechanics. The knee flexion angle at foot patellofemoral joint was found to be the most frequent site injured (18,21). Since 1978, a strike (KFA@FS) is believed to have significant influence on the body's capacity to large amount of research has been devoted to running shoe design and to training dissipate the impact loading and shock transmission occurring during running (22) techniques. Despite these efforts, the incidence of knee injuries in the running population

One aspect of running that has not been researched extensively is how the has remained unchanged at about 25% (4,26,37).

changing of one's running style affects the impact load the knee joint encounters. The present study examined how changing a runner's landing style from heel to midfoot

running related injuries. A study by Derrick, Hamill, and Caldwell (15) supplied some insight when they reported that, during the stance phase of jogging, energy is primarily dissipated at the knee joint, much like a shock absorber. LaFortune, Lake, and Hennig (22) also reported that the body relies on the knee joint as a principal mechanism to regulate the shockwave transmission as it travels from foot to head.

The biomechanics of running is composed of mechanical variables that include foot strike position, stride length, stride rate, knee angle at foot strike, and maximal knee flexion angle during support (38). Each of these variables has an impact on the forces endured by the body during running. Any change in the application of these mechanical variables will result in a change in the ground reaction forces (GRF). This interrelationship has been documented by studies such as Cavanagh and LaFortune's study that identified the characteristic differences in center of pressure and mean force-time curves for rearfoot and forefoot strikers (10); Cavanagh, Pollock, and Landa's investigation that compared elite versus good distance runners (11); the Derrick, Hamill, and Caldwell (1997) research on the relationship between shock attenuation and stride length (15); and the Nigg, Cole, and Brügemann (1995) review of impact mechanics during heel-to-toe running (31). The idea of the knee acting as a shock absorber is another important consideration in running biomechanics. The knee flexion angle at foot strike (KFA@FS) is believed to have significant influence on the body's capacity to dissipate the impact loading and shock transmission occurring during running (22).

One aspect of running that has not been researched extensively is how the changing of one's running style affects the impact load the knee joint encounters. The present study examined how changing a runner's landing style from heel to midfoot

striking (defined as landing on the ball of the foot) affected the impact forces on the knee joint. The investigators used a 12-session training process to change the participants' running styles using the "Pose Method of Running" developed by Nicholas Romanov

Literature Review

(34). The Pose Method technique taught heel strikers of any level to learn to emulate

The study proposed to change running styles by altering the main kinematic variables that comprise running biomechanics, and as a result, decrease the initial impact forces at the knee joint. The literature review that follows examines the impact of stride, a higher stride rate, and increased knee flexion angle during the support phase of different running styles, their associated kinematic and kinetic influence, and the the running gait cycle. The desired goal was to change the biomechanics, and in doing so, associated changes proposed in the study.

decrease the impact of vertical forces at the knee joint by enhancing the knee joint's role as a shock absorber through an increased knee flexion angle.

Running styles. Running is composed of two phases, the swing phase, when the leg is in the air, and the stance, or support phase, when the leg is on the ground. The running could be made and how these changes might contributed to the stress at the knee joint. Specific study objectives included: 1) the measurement of the kinematic variables, contact of the foot with the ground. The stance phase is further divided into the initial stance phase (SP), stride rate (SR), stride length (SL), and knee flexion angle at foot impact phase, when the foot initializes contact with the ground and the propulsive phase, strike (KFA@FAS); 2) the measurement of the maximal vertical ground reaction forces or toe off, when the foot terminates contact with the ground. at the ground (MVGRF) and at the knee joint (MVF@K); and 3) how the changes in

In studies of joggers, runners, and sprinters, three foot strike styles have been identified. Style identification is determined by what part of the foot strikes the ground first: the heel, the midfoot, or the forefoot. The most predominant style is heel or heel striking, with approximately 80% of the running population landing with their heels as they strike (13). Midfoot striking, the second most predominant style, consists of landing on the ball of the foot, while forefoot striking, the least common, consists of landing toward the toes.

How a runner first contacts the ground is very different when it comes to impact

biomechanics. The landing strategy adopted by a runner affects stress the body

experiences. Impact force is related to the foot strike, the shock wave sent by the

Literature Review

knee joint during impact that is related with an increase in stride length. This impact dynamic

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Impact Biomechanics

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beginning of the stance phase and the end of the swing phase are characterized by the

loads impacting on the bones and joint of the knee.

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Ground reaction forces. Heel and midfoot strikers, because of the way their feet

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first: the heel, the midfoot, or the forefoot. The most predominant style is that of heel

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Impact biomechanics address the force or shock to the system during foot strike

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during initiation of the impact shock wave (wave of acceleration and deceleration) that

toward the toes.

disseminates through the body (36). A force equal in magnitude and opposite in direction

How a runner first contacts the ground is very significant when it comes to impact biomechanics. The landing sets the stage for the level of impact stress the body is to sustain. Derrick et al. (15) observed that during heel striking, the shock sustained by the knee joint during impact increased with an increase in stride length. This impact dynamic influenced the amount of stress delivered at the knee joint. Cavanagh and LaFortune (10) observed that elite runners, as a group, took shorter strides. They exhibited the tendency to maintain the knee joint in flexion throughout the entire running cycle, setting the stage to land on the midfoot rather than the heel. Knee flexion throughout the run gait cycle allows the support leg to land on the ball of the foot (midfoot), under the body, as opposed to heel striking which requires the knee joint to extend at landing past the vertical line that extends from the hip (11). It seemed reasonable to assume from these studies that shorter stride lengths accompanying midfoot striking lead to smaller stress loads impacting on the bones and joint of the knee.

Ground reaction forces. Heel and midfoot strikers, because of the way their feet contact the ground, have very distinct ground reaction force (GRF) curves (Figures 1, 2). These curves represent the vertical ground reaction forces elicited from initial impact to toe off. The GRF curves revealed that the main difference between heel and midfoot striking was the absence (or only a trace present) of an initial vertical impact peak (F_{z1}) in midfoot landing (5,40).

Impact biomechanics address the force or shock to the system during foot strike with the ground (impact force), during lower limb deceleration (impact shock), and during initiation of the impact shock wave (wave of acceleration and deceleration) that disseminates through the body (36). A force equal in magnitude and opposite in direction

meet the force exerted during the landing phase by the push of the foot as it strikes the ground. The latter is the ground reaction force, which is comprised of three force components, vertical, anterior-posterior and medial-lateral. These three forces run in directions that are at right angles of each other, in a three dimensional manner. The vertical runs in the z-axis, the anterior posterior along the x-axis and the medial-lateral runs in the direction of the y-axis (Figure 3) (27, 32).

With respect to the foot strike, the vertical component or F_z is the measurement of the force (loading response of the body mass) directed back to the source of loading. All three components are measured by a force plate, and are subject to change with the vertical acceleration of the body's center of mass. In the absence of any acceleration, F_z is equal to the subject's body weight (BW). If the acceleration increases, such as when the runner's foot approaches the ground, the vertical force is greater than the subject's BW. Conversely, if the acceleration is less than zero, as it would be after impact, the vertical force is below BW. The collision of the foot with the ground (F_z) is the component of ground reaction that can reach two to three times the BW at impact (32).

The anterior-posterior force (F_x), the second component, also known as the fore and aft force. The anterior-posterior component is smaller than the vertical, at less than 25% of BW, and exhibits large variability from trial to trial (21,25,31).

The medial-lateral component (F_y), describing a side-to-side motion, is created as the result of shifting body weight from one limb to another during the stance portion of the running cycle (32). This component is smaller in magnitude than the anterior-posterior components, never becoming more than 10% of BW, and posing even greater amounts of variability (18). (Figure 2).

In essence, the vertical component (F_z) is the element of impact force that is used most frequently to represent GRF. For one, it has the greatest magnitude, to the extent that the resultant force is almost equal to the resultant force of all three component forces together. Likewise, the vertical component has a clear force-time history that is straightforward and easy to quantify, with very small variability (27). The magnitude of the F_z is affected by changes in body weight and running speed. A decrease in body weight from one session to another kept at the same running speed shows as a decrease in the magnitude of F_z , while an increase in running speed results in an increase in the magnitude of F_z (19,29).

Impact phase. Impact phase is the time the heel contacts the ground to the time when the center of mass of the support leg stops decelerating. This phase corresponds to the peak of the vertical component, F_z (Figure 1). The stance phase (how long the support limb remains on the ground), includes the impact phase, and is the time from when F_z becomes greater than zero, then returns back to zero and remains there (after toe off) (27). The stance phase lasts about 30% to 40% of the gait cycle (13,24). In heel strikers, the stance time has two peaks, the initial F_z (F_{z1}) peak denoting impact and a second peak F_z (F_{z2}). The second peak is greater than the first and is associated with propulsion. The impact force peak usually appears within 50 ms into the support phase (3,10,36). The time of this cycle is important when estimating the impact phase in midfoot running, where an absence of the F_{z1} peak makes it difficult to determine when the impact phase ends. In midfoot and forefoot strikers this initial impact force peak is either absent or barely present, as the vertical component rises directly towards the propulsion or thrust peak (27) (Figure 2).

Stride length. Stride length, also characterized as step length in some literature, is the distance between successive ground contacts of each foot. Research in this area has provided evidence that runners, given the option to run at a self-selected stride length, tended to choose a stride close to their most metabolically efficient running length.

Cavanagh and Williams (12) found that the self-selected stride length on average to be within 4.2 cm of the stride that is metabolically, most efficient for that runner. Does this optimal stride guarantee a stride that impacts the musculoskeletal system least? This question was aptly answered by Derrick et al. (15). They looked at five different stride length conditions at a speed of 3.83 m/sec and measured the energy absorption at the different joints, including the knee joint. The five stride lengths consisted of the preferred stride length (PSL), +10% of PSL, -10% of PSL, +20% of PSL and -20% of PSL. They concluded that a stride length that was 20% less than the preferred stride was the stride length with the least stress at the knee joint during the impact phase. Greater vertical thrusts corresponded with longer stride lengths, where these greater thrusts, or push-offs, were indicative of the subjects leaving the ground.

The implications of these studies support the contention that the knee joint acted as a shock absorber to handle the stress moving through the system. The data indicated that the longer the stride length, the greater the impact loads, the more the knee must act to attenuate the shock moving through the system (15). In essence, the longer the stride length, the greater the impact.

Stride rate. Stride rate can be defined as the frequency of each successive right and left foot ground contact over a period of time. In some literature it is referred to as step frequency or also as cadence. Similar to stride length, a runner selects a stride rate

that optimizes metabolic cost as evidenced by the Cavagna and Franzetti (6) study on human walking.

What determines stride rate has been addressed in a number of other studies. Cavagna, Franzetti, Heglund, and Willems found that the body's search for balance results in a self-selected step frequency matching the body's natural rhythm (7). At speeds that produce a step frequency other than ideal to the runner, the vertical oscillation would develop an amplitude and duration that would be dissonant with the step frequency (7).

In a subsequent study by Cavagna, Willems, Franzetti, and Detrembleur (8), the investigators noted that at a higher step frequency, where the time of support became shorter, the average vertical force F_z and the vertical displacement both decreased. The power necessary to move the center of mass decreased as the period of rest between strides (support time) decreased.

Farley and González (17) also found similar results with respect to a decrease in vertical displacement. In their research, they determined that animals adjusted their "leg spring" system by increasing the angle of the support limb (stiffening), thus bouncing off the ground in less time. Like Cavagna et al. (8), they found the vertical displacement of the center of mass and the time on support decreased at a higher stride rate. The Farley and González study concluded that stiffening of the spring limb would permit a runner to maintain a flexed knee stance as they move forward through the gait cycle, requiring less power to move the body's center of mass over the support limb (17).

From the above examination of the existing literature on joints, forces, stride length, and stride rate, it is clear that a runner, when given the option to run at different

stride lengths and frequency, will unconsciously select a stride length and frequency that is more metabolically efficient. One can speculate that by manipulating running by reducing stride length and increasing stride rate, the decrease in VGRF would potentially result in a decrease in the impact forces at the knee joint.

Knee Joint Biomechanics

The body can be viewed as being composed of various rigid structures, and connecting those various structures are joints (31). These joints act as bearings that allow for different types of movements in different directions. The knee can be characterized as such a joint, specifically a hinge joint that essentially allows flexion and extension with small amounts of rotation and gliding (13).

Knee Injury Etiology. Up to the early 1970's, a common perception was that joint degeneration was initially a result of lubrication failure in the absence of synovial fluid. Radin, Parker, Pugh, and Steinberg (33) concluded that joints do not wear out even when the lubrication from the synovial fluid has been removed. In investigations involving subjecting rabbits to large amounts of impact loading, the investigators determined that the repetitive nature of the impact loading was a direct cause of articular degeneration (33). This conclusion was supported later by James et al. (21) and by Bobbert, Yeadon and Nigg (3). When the knee joint is subjected to repetitive impacts from running, high amounts of stress can develop affecting the structure of the joint. As people strive to do longer events with higher training mileage's, coupled with inefficient running mechanics and inadequate rest, this leads to an accrual of stress within the knee joint structure. In response, the knee joint's ability to handle this stress intensification

decreases in the face of the load accumulation. The self-defeating condition persists until the structure fails and and/or injury develops (2).

Knee angle at impact. The basic run gait cycle consists of two phases, the swing phase, when the leg is in the air, and the stance, or support phase, when the leg is on the ground (20). The stance phase of the gait cycle was determined to be 31% for runners and 22% for sprinters (24). Landing or the impact phase occurred as the foot strikes the ground. At this point the landing limb has its knee slightly flexed at a relative angle measured to be between 10° and 25° (5,28,36). The support limb then sustains the body as the contralateral limb swings forward past the support limb in preparation for landing. The support limb flexes until the body's center of gravity goes past the midstance point, then starts to extend preparing for take off. The support foot then pushes off and the swing leg lands, repeating the cycle. These movements take place in the sagittal plane (24).

Derrick et al. (15), observed that the knee joint is the only joint flexing during the entire impact phase of running. They detected that, during the stance phase, energy is mainly absorbed at the knee joint. The degree of energy absorption at the knee joint was directly related to the length of the stride, and this stride length was directly related to the angle of knee flexion. Mann and Hagy (24) determined as the speed of gait increased, flexion at the knee joint increased and extension decreased. This was thought to be a reaction whereby the knee increases flexion as a method to absorb the increasing impact forces (10).

At this point it is useful to describe the different knee joint angles at landing between runners of varying ability and running style. Experienced runners

displayed a knee flexion angle at foot strike between 10° and 20° (28) when measured at slower speeds (<4.0 m/sec) and an angle of 25° at faster speeds (> 4.0 m/sec) (5,11). The more the runner's tibia and foot land forward of a vertical line from the hip, the more the runner initiates contact with the ground at the heel. The closer the foot lands to the vertical line from the hip (knee joint is at an increased angle), the more the runner contacts the ground with the ball of the foot midfoot style (33). Midfoot striking is closely associated with more elite runners and faster speeds. Training a heel striking runner to emulating the landing style of more elite runners requires an increase in the knee flexion angle during the landing phase which facilitates the midfoot type of landing.

Conclusion In studies with sprinters (11,24), it was noted that while running, their knee joints remained in a state of flexion and their legs never fully extended. These biomechanics allowed them to maintain progressive flexion starting from the point of landing through the support phase. It follows that as the runner moves away from heel striking and closer to midfoot striking, the knee flexion angle at landing increases and promotes a greater ability to absorb the impact force at the knee joint (9).

Pose Method of Running

The Pose Method looks at running as an ideal system, where running should be like a wheel. While constantly changing support, the wheel shows no vertical oscillation of its center of gravity, maintaining a truly continuous system (34). The legs of a runner should be like the spokes on a wheel only staying on the ground as necessary to support the body as it moves forward (24).

The Pose Method is a running technique developed by Nicholas Romanov that has as its primary components a higher stride rate, shorter stride length, greater knee

flexion angle, and reducing the amplitude of the vertical oscillation of the center of gravity during the gait cycle. This running style promotes a deeper knee flexion angle so as to derive a shorter stride length. The higher stride rate promotes a smoother run by decreasing the vertical oscillation of the body (34). In support of a higher stride rate, Cavanagh and Kram (9) in their assessment of muscular and mechanical factors and elastic energy, detected that energy can be elastically stored in continuous motion, whereas stored energy would be lost during the brief relaxation found on an extended support time. In keeping with the above literature, the effect of the Pose Method should be to lower the force of impact at the knee joint.

Conclusion

In conclusion, running is an activity that has consistently produced a high incidence of knee related injuries. The majority of knee injuries are a consequence of the stress associated with overuse and overload. Running style does contribute to the stress accumulation in the knee joint. The musculoskeletal system can withstand a limited amount of stress before it reaches its limits and an injury occurs. Options to extend the life of these systems and decrease the possibility of injury must be explored. Changing the biomechanical variables that influence a running style is such an option, specifically when directed to heel strikers. By virtue of their biomechanics, these runners stress their musculoskeletal systems and their knee joints over and above the other types of runners.

The Pose Method of running provides a focus to change ones landing style by altering running biomechanics. The shortening of the running stride and the increase in stride frequency help to provide a greater knee flexion angle which is thought to decrease

the GRF at impact and potentially reduce the load on their musculoskeletal system and injuries of the knee.

The purpose of this investigation was to determine if changes in the kinematic of

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running could be made in recreational runner and how these changes might contributed to

Subject Selection

the stress at the knee joint. Specific study objectives included: 1) the measurement of the

Seventeen subjects volunteered from the local population of recreational runners

kinematic variables, stance phase (SP), stride rate (SR), stride length (SL), and knee

and triathletes. Subjects were all heel strikers, representing the majority of the running

flexion angle at foot strike (KFA@FAS); 2) the measurement of the maximal vertical

population (31). All participants signed an Informed Consent approved by the

ground reaction forces at the ground (MVGRF) and at the knee joint (MVF@K); and 3)

Institutional Review Boards of Florida Atlantic University and Good Samaritan Medical

how the changes in these kinematic variables affected the force measurements. A

Center. They were all apparently healthy as per the ACSM Guidelines (1), and free of

significant decrease in the impact forces at the knee joint could have a positive

any injuries that may have precluded them from running within the last 6 months.

implication on knee-related injuries in running.

Individuals not available for weekly training sessions or not willing to change their

running style were placed in the control group. The training or treatment group (T-group)

totaled eight runners, 5 male and 3 female, while the control group (C-group) included 9

runners, 6 male and 3 female. Both groups were similar in age, height, weight, $\dot{V}O_{2max}$,

and $\dot{V}O_{2peak}$ (Table 1).

Data Collection

The data collection occurred during two sessions both at the beginning and at the

end of the study. One session consisted of first measuring the physiological variables of

body fat (1,30), flexibility (Sit & Reach test) (1,30), and leg power (Sargent Jump-Reach

test) (35). These tests were then followed by an assessment of running economy, $\dot{V}O_{2max}$,

and $\dot{V}O_{2peak}$ (1). This session was conducted at the Florida Atlantic University Human

Performance Laboratory, Davie, Florida. The second session consisted of the kinetics

and kinematic measurements and took place at the Good Samaritan Medical Center's Orthopaedic Research Laboratory, West Palm Beach, Florida. The kinematic variables measured included stance phase, stride rate, stride length, knee flexion angle at foot

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strike, and knee flexion angle at maximum force at the knee joint. The kinetic variables

Subject Selection

were maximum loading rate, maximum ground reaction force during impact phase, and maximum force at the knee joint during the impact phase.

Seventeen subjects volunteered from the local population of recreational runners

and triathletes. Subjects were all heel strikers, representing the majority of the running

Physiological Measurements

population (31). All participants signed an Informed Consent approved by the Institutional Review Boards of Florida Atlantic University and Good Samaritan Medical Center. They were all apparently healthy as per the ACSM Guidelines (1), and free of standardized procedures (1) measurements were taken and placed into the Lie seated any injuries that may have precluded them from running within the last 6 months.

Body Composition Equation 7-Site Formula to determine the body density (30). The Individuals not available for weekly training sessions or not willing to change their percentage of body fat was then estimated by utilizing the body density with the Siri running style were placed in the control group. The training or treatment group (T-group)

equation (30). Leg power was measured by using a Sargent Jump-Reach test, accepting the best of three attempts. Low back and hamstring flexibility was assessed with the Sit runners, 6 male and 3 female. Both groups were similar in age, height, weight, HR_{max} , and Reach (trunk flexion) test, also accepting the best of three attempts (1,30) and VO_{2peak} (Table 1).

Throughout this session participants were encouraged to stretch for about 5 minutes

Data Collection

before each test.

The data collection occurred during two sessions both at the beginning and at the

During treadmill running all the participants had their VO_{2peak} assessed using a end of the study. One session consisted of first measuring the physiological variables of Medgraphics Cardio O₂ Metabolic Cart (Cardiopulmonary Diagnostic Systems, St. Paul, body fat (1,30), flexibility (Sit & Reach test) (1,30), and leg power (Sargent Jump-Reach Minnesota). Additional equipment used for this portion of the testing were a Quinton Q test) (35). These tests were then followed by an assessment of running economy, HR_{max} ,

65 treadmill and a Q4500 ECG Stress Test Monitor (Quinton Instrument Co., Seattle, and VO_{2peak} (1). This session was conducted at the Florida Atlantic University Human Washington), and a Polar Trainer NV Heart Rate Monitor (Polar OJC, Inc., Port Performance Laboratory, Davie, Florida. The second session consisted of the kinetics Washington, New York). The speed of the max test was established individually for each

and kinematic measurements and took place at the Good Samaritan Medical Center's Orthopaedic Research Laboratory, West Palm Beach, Florida. The kinematic variables measured included stance phase, stride rate, stride length, knee flexion angle at foot strike, and knee flexion angle at maximum force at the knee joint. The kinetic variables were maximum loading rate, maximum ground reaction force during impact phase, and maximum force at the knee joint during the impact phase.

Physiological Measurements

Lange Skinfold Calipers (Beta Technologies, Inc. Cambridge, Maryland) were used to acquire the skinfold measurement from seven sites (30). Following ACSM standardized procedures (1) measurements were taken and placed into the Generalized Body Composition Equation 7-Site Formula to determine the body density (30). The percentage of body fat was then estimated by utilizing the body density with the Siri equation (30). Leg power was measured by using a Sargent Jump-Reach test, accepting the best of three attempts. Low back and hamstring flexibility was assessed with the Sit and Reach (trunk flexion) test, also accepting the best of three attempts (1,30). Throughout this session participants were encouraged to stretch for about 5 minutes before each test. During treadmill running all the participants had their VO_2 peak assessed using a Medgraphics Cardio O_2 Metabolic Cart (Cardiopulmonary Diagnostic Systems, St. Paul, Minnesota). Additional equipment used for this portion of the testing were a Quinton Q65 treadmill and a Q4500 ECG Stress Test Monitor (Quinton Instrument Co., Seattle, Washington), and a Polar Trainer NV Heart Rate Monitor (Polar CIC, Inc., Port Washington, New York). The speed of the max test was established individually for each

subject, as that subject's normal training pace. Each stage of the max test consisted of increasing the grade by 1% per minute while maintaining that same speed until volitional exhaustion. The heart rate (HR) and rate of perceived exertion (RPE) using the Borg scale (6-20) were recorded at the end of each minute during the max test. The heart rate for each stage was determined from the average of the last 10 heartbeats recorded at the end of each minute. The same testing procedures were used during the post-testing sessions.

Kinetics and Kinematic Measurements

The kinetics and kinematics measurement session at the Good Samaritan Medical Center Orthopaedic Research Laboratory utilized six Motion Analysis Corporation ((MAC), Santa Rosa, California) cameras at 180 Hz, plus a video kinematic measurement system. This system included an SGI Indy Workstation, 2 video processing units, 64 channel A/D, and MAC capture and analysis software. The force plates for ground reaction force determination were two Advanced Mechanical Technology Inc. ((AMTI) Newton, Massachusetts) LG-6 Component Force Platforms with a 2' x 4' surface. Data editing, tracking, and analysis was accomplished using the MAC EVa 5.11 version motion analysis software and the MAC OrthoTrak 4.1.2 motion analysis software. The software calculated all the kinetic and kinematic variables for each subject. During the session at the Orthopaedic Lab all subjects ran for a few minutes to warm up and then stretched prior to all testing trials. Twenty-nine reflective markers were placed on the subject to acquire the static positional data based on the Cleveland Clinic arrangement protocol developed by the Human Performance Lab, Department of Musculoskeletal Research, Cleveland Clinic Foundation with the Motion Analysis

Corporation and the University of Florida Human Motion Laboratory Department of Orthopaedics (Figure 4). Upon acquiring a positive static trial, the lateral and medial knee and lateral and medial malleoli markers were removed and the bilateral heel and toe markers added. For the purpose of capturing vertical oscillation data an additional marker at the base of the neck was added by investigators.

While warming up during the pre-test, each subject was encouraged to self-select a speed to be used for testing. During the test trials the subjects were required to maintain a speed that did not vary more than 10% . In the process of each run trial, the subject was filmed for a minimum of a complete stride. A complete stride meant two successive strikes of the same foot that landed on the force plate. For example, a complete right side stride meant a right foot strike landing squarely on force plate, then the left foot strike, then the right foot strike again to complete the stride. A successful trial had three components: 1) one complete stride, 2) a definite ground reaction force detection from the force plate and, 3) same approximate speed as previous trial. The testing session concluded when a minimum of three good trials were collected by the MAC system. The post testing session utilized the same protocols and speeds used in the pre-test.

Kinematic and Kinetics Variables

Stride Rate (SR). An objective of the Pose Method training was to increase the stride rate, expressed in $\text{steps} \cdot \text{min}^{-1}$. Stride rate was used to see if the subjects had actually changed their running style. Pose Method runners generally have average frequencies of about $180 \text{ steps} \cdot \text{min}^{-1}$ (34).

Stride Length (SL). Stride length was defined as the length between two successive foot strikes of the same foot and it was measured in centimeters. A shorter

stride length was another Pose Method training objective, where decreasing the stride length permits the support leg to land under the body and allows for a higher stride rate (34). This variable was also measured to evaluate if the subjects had actually changed their running style to the Pose Method style.

Stance phase (SP). Stance phase was defined as the time the support foot spends on the ground (also known in the Pose Method as “period of support”) (34). It was measured from the point of initial contact with the ground at foot strike to the time the foot ceased contact with the ground. The stance phase of the stride cycle for each subject was measured, in milliseconds, to determine if there was any change in the time on support.

Maximum Vertical Ground Reaction Force During Initial Impact Phase (MVGRF). Three types of ground reaction force are at work during the gait cycle, vertical, anterior-posterior and medial-lateral (Figure 3). The force type measured in this investigation was the maximum vertical ground reaction force (MVGRF) or the maximum point of the F_{z1} peak (Figure 1). The MVGRF variable was intended to determine the changes in impact at the ground level. While with heel strikers the presence of the F_{z1} peak, defined the impact phase, the peak’s absence in midfoot strikers (Figure 2) made it necessary to find an alternative method to calculate the impact phase. In the absence of an initial impact peak in the post-test results of the T-group, the pre-test MVGRF was matched to the corresponding post-test MVGRF at the same percentage of stance phase. By normalizing the stance phase to 100 frames (100 frames=100%), the frame that contained the MVGRF was identified and then matched to the corresponding frame. The procedure was tested against those subjects still demonstrating an F_{z1} peak in

their post-test results and the frame of the max force in the pre-test matched the frame of the max force in their post-test.

Knee Flexion Angle at Foot strike (KFA@FS). Knee flexion angle (KFA) during the running gait cycle is an important kinematic variable. Measuring the angle of the knee joint as the foot strikes the ground (knee flexion angle at foot strike) allowed for the determination of the participants' running styles (24). A change to a greater KFA@FS established the subject had adopted one of the biomechanical objectives of the Pose Method of running. The objective was a greater knee flexion angle at landing to increase shock absorption (22,34). In the pre-test, KFA@FS was identified by first determining the MVGRF in the F_{z1} peak. The procedure was the same as with the MVGRF. After the MVGRF was identified in the normalized stance phase, that frame was then matched to the same frame in the KFA progression of the landing leg. The process was repeated for the post-test, once the MVGRF was identified.

Maximum Vertical GRF at the Knee Joint during Initial Impact Phase (MV@K). The MAC motion analysis software allowed for the measurement of the vertical ground reaction forces measured at the ground and specifically at the knee joint, which was the key variable in the investigation. Calculation of this force variable allowed the identification of the impact force felt at the knee joint. It was then possible to examine if kinematic changes occurred due to the training program and if they resulted in a reduction of the impact force load at the knee joint.

Knee Flexion Angle at MVGRF at the Knee Joint (KFA@MVFK). Measurement of the MVGRF at the knee joint during impact would be determined if there were any changes in the knee flexion angle measured at the point of maximum impact.

By normalizing the stance phase to 100 frames, the frame that contained the MVF@K was identified and matched to the corresponding frame containing the knee flexion angle at that same point in the stance phase. The process of identifying this variable in the pre- and post-test was the same process utilized in MVGRF and KFA@FS.

Maximum Loading Rate (MLR). The main characteristic in a classic midfoot impact curve is the disappearance of the F_{z1} peak. The post-test results for the training group, as they changed their running style, denoted similar midfoot VGRF curves without any initial impact peaks. To interpret the results it became necessary to follow the recommendations of Miller (27) and Munro, Miller, and Fuglerand (29). In these studies, impact was calculated as the force over time or the loading rate. Since the present investigation involved self-selected speeds, there was a need to make an additional adjustment to account for the speed variability within the test subjects. This was accomplished by calculating the loading rate based on force over percentage of stance phase as opposed to force over time. By normalizing everyone's stance phase into 100 frames, which were then expressed as a percentage (100 frames = 100%), the MLR for all individuals could now be compared.

Training Sessions

The training sessions were held at a running track and consisted of a number of running drills (Fig. 5)(34). Sessions were once a week for 12 weeks and lasted approximately 1.5 hours. Each training session had two major goals: 1) to make the runners cognizant of their own foot strike and gait mechanics and 2) to change the runner's biomechanics to enable the runners to change their running style from heel to midfoot striking using the Pose Method of running. The drills were designed to promote

increasing the stride rate, by shortening the stride length and reducing the vertical oscillation of the center of mass of the body. Each session consisted of 7 to 8 core drills.

Each drill focused on a specific biomechanical component, which was practiced

STATISTICAL ANALYSIS

repeatedly for about 50 meters. Subjects were then encouraged to be cognizant of the

The statistical analysis of the data for the study was performed using SigmaStat 2.03 (SPSS Inc., Chicago, Illinois). For all of the kinematic and kinetic variables, the distance of up to 400 meters. In addition to the core drills, a drill of increasing difficulty average of three good trials were used for determination of the value for each of variables was added each time the group met. At the end of each session, participants were analyzed. The kinematic variables were stride rate (SR), stride length (SL), stance phase encouraged to incorporate the drills and new style into their weekly training. Compliance (SP), and knee flexion angle at foot strike (KFA@FS), and at maximum impact at the rate for the training sessions was 94%.

The control group was also encouraged to maintain their current training levels at reaction forces during impact measured at the ground (MVGRF) and at the knee joint which they pre-tested and to avoid any changes to their running style. All subjects (MVF@K), and the maximum loading rate as a percentage of stance phase (MLK), performed pre and post-testing with the same type of shoes.

Ground reaction force data was normalized to percentage body weight (% BW) for comparative purposes. All data presented as means \pm SE.

The acquired data for the groups was then submitted to Two-Way Repeated Measures ANOVA. The alpha level was set at 0.05, using, when appropriate a Tukey Post Hoc test to identify any significant differences (23).

The physiological variables of weight (WT), percentage body fat (BF), Sit-and-Reach (S&R), Jump-Reach (Jump), HR_{max} , and VO_{2peak} were submitted to a matched pair t-test analysis with the alpha level set at 0.05 (23). Data presented as means \pm SE.

STATISTICAL ANALYSIS

The statistical analysis of the data for the study was performed utilizing SigmaStat 2.03 (SPSS Inc., Chicago, Illinois). For all of the kinematic and kinetic variables, the average of three good trials were used for determination of the value for each of variables analyzed. The kinematic variables were stride rate (SR), stride length (SL), stance phase (SP), and knee flexion angle at foot strike (KFA@FS), and at maximum impact at the knee joint (KFA@MVFK). The kinetic variables were: maximum vertical ground reaction forces during impact measured at the ground (MVGRF) and at the knee joint (MVF@K), and the maximum loading rate as a percentage of stance phase (MLR). Ground reaction force data was normalized to percentage body weight (%BW) for comparative purposes. All data presented as means \pm SE.

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Figures 7 to 12 show the outcome of the Pose Method of running on the kinematic and kinetic variables.

RESULTS

Physiological variables. The results for the physiological variables are listed in Table 1. No significant changes or differences in the physiological variables were found between the groups or between the testing sessions. The fact that no significant changes in weight were found is important. The magnitude of the peak ground reaction forces is known to be affected by changes in body mass (19) as force is equal to mass times acceleration ($f=m \cdot a$), making it critical to take notice of any weight changes (mass) in the subjects. Since there was no significant change in weight, any changes in the GRF would reflect changes in the kinematic variables rather than changes influenced by a weight change. During the course of the study, three C-group subjects incurred running related injuries, dropped out of the study, and their data excluded, leaving the C-group sample size at $N=6$.

Kinematic and kinetic variables. The overall pre and post mean values for the kinematic and kinetic variables can be found in Table 2, while the P value results for the same variables are detailed in Table 3. In the final analysis of data, results for one subject in the T-group had to be eliminated. The elimination was due to the subject's inability to maintain the same pre and post speed in the running trials, leaving the T-group sample size at $N=7$. In addition, a second subject in the T-group had to have their data with respect to the forces at the knee dismissed due to partial force plate saturation affecting the shear component of the force equation. No other data for this subject was affected.

Figures 7 to 12 show the outcome of the Pose Method of running on the kinematic and kinetic variables.

Significant interaction at the level of treatment was found, noting a training effect in the running mechanics of the T-group. There was a significant increase in the SR from 168 ± 3.5 to 181 ± 2.9 steps \cdot min⁻¹ (Figure 8), and there was a significant decrease in SL from 270 ± 13.6 cm \cdot sec⁻¹ to 247 ± 11.2 cm \cdot sec⁻¹. The decrease in SL was enough to influence the ability of the runners to increase their stride rate. The resultant increase in SR and decrease in SL led to a significant decrease in the SP, as SP is a function of SR and SL. The trained runners reduced their average time on support from 242 ± 11.0 ms to 222 ± 9.4 ms.

With respect to the KFA@FS, the trained group showed a noticeable deeper knee flexion in the post-test over the controls of approximately 24% (Figure 9), from $17.4^\circ \pm 1.2^\circ$ to $20.9^\circ \pm 1.5^\circ$. However, while this modification translated to a knee flexion increase of 20% over the same-subject pre-test results, and while it approached having a significant training effect ($P=0.051$) statistically the change was not significant.

The T-group demonstrated a significant training effect by demonstrating a reduction in all three force variables, MVGRF, MVF@K (Fig. 10,11) and MLR, (expressed as maximum load, ML, in Fig. 12). The % BW in the MVGRF was reduced from 1.96 ± 0.12 to 1.39 ± 0.12 , the %BW in the MVF@K was reduced from 1.52 ± 0.1 to 1.4 ± 0.1 and the force (N) in the MLR was reduced 223.2 ± 39.2 to 141.7 ± 21.5 (a 36% reduction).

A visual cue as to a successful changeover from heel to midfoot striking was the representative GRF curves for the subjects. All the subjects in the T-group displayed a change in their GRF curves from pre- to post-testing. The pre-to post-test modifications in the GRF curves of the T-group are well represented by Figure 6a and Figure 6c, actual pre and post GRF curves of a T-group subject. The same applies to the MLR, with Figures 6b and 6d depicting the changes in the loading rate of that same individual. The percent changes for these variables ranged from 29% to 36 %, and these changes were associated with the changes contributed by the Pose Method of running in these kinematic variables.

Acceptable strategy for reducing the incidence and prevalence of running related knee injuries.

Specifically, our results reveal a statistically significant increase in stride rate (SR) for the Trained Group (T) (Pose Method of running) compared to the Control Group (C). This finding coupled with the significant decrease in stride length (SL) in the T-group, produced a significant reduction in the length of the support phase (SP), a variable thought to be very important to the overall force dynamics present in running.

The average stance phase times in this study were comparable to those reported in Munro *et al.* (29) signifying that both groups were representative of normal running populations. During post-testing, the stance phase of the T-group at a speed of $3.71 \text{ m}\cdot\text{s}^{-1}$ was only 222 ms ($\text{SE}\pm 25$), which was comparable to the normal stance phase of runners at a faster speed of $4.25 \text{ m}\cdot\text{s}^{-1}$ ($21 \text{ SD}\pm 13$) (29). In essence, the T-group decreased their

support time significantly, while maintaining the same running velocity. The changes in the SP, SL, and the resultant SP supported the integration of the Pose Method of running.

Both groups in the pre-test exhibited average ground reaction force curves

DISCUSSION

The results of this preliminary study indicate that the Pose Method of running moderates important biomechanical variables in a manner that reduces the ground reaction force (GRF) at the knee joint. Specifically, the Pose Method of running requires all the T subjects exhibited a change in the shape of their VGRF curve and significant runners to reduce stride length, while increasing stride frequency, and knee joint flexion changes in all the force variables measured. The majority of T-group participants during the support phase of the running cycle. Data from this study suggests that by displaying an impact curve consistent with midfoot landing, that is, with a complete adopting the Pose Method of running, the serious recreational runner might find an absence of the initial impact phase (Fig.6c).

acceptable strategy for reducing the incidence and prevalence of running related knee injuries.

In order to characterize the initial part of the VGRF curve (the impact phase) as indicated above, Miller (27) and Munro et al. (29) recommended utilizing the loading rate as the descriptor for the $F_{0.1}$ peak. The loading rate can then be calculated regardless of the (SR) for the Trained Group (T) (Pose Method of running) compared to the Control Group (C). This finding coupled with the significant decrease in stride length (SL) in the T-group, produced a significant reduction in the length of the support phase (SP), a variable presence of an impact peak at landing. Our kinetic analysis disclosed from the referenced literature in two aspects. While Miller and Munro et al. utilized the loading rate expressed as %BW per unit of time (27,29), the present analysis expressed the loading rate in Newtons (N) as a percentage of stance phase (%SP), similar to the Huczek et al. study on thought to be very important to the overall force dynamics present in running.

The average stance phase times in this study were comparable to those reported in knee and ankle kinematics and kinetics (5). Every runner had a different self-selected speed; therefore, there was a necessity to express the data in a format relative to one another to facilitate comparison between the subjects. Each runner's stance phase data was only 222 ms (SE±25), which was comparable to the normal stance phase of runners was normalized to 100 frames, aiding the investigators in comparing subjects in terms of at a faster speed of 4.25 m•s⁻¹ (21 SD±13) (29). In essence, the T-group decreased their percentage of stance. With this normalization of the data, the investigators were able to examine the application of the forces with respect to loading. Specifically, the M.R.R.

support time significantly, while maintaining the same running velocity. The changes in the SP, SL, and the resultant SP supported the integration of the Pose Method of running. Both groups in the pre-test exhibited average ground reaction force curves consistent with heel striking (10,40). The curve consisted of a very visible initial F_{z1} peak signaling impact with the heel, followed by a valley as the foot rolled through support, then an increase in the VGRF as the runner prepared to take off (Fig.6a). Results showed all the T subjects exhibited a change in the shape of their VGRF curve and significant changes in all the force variables measured. The majority of T-group participants displayed an impact curve consistent with midfoot landing, that is, with a complete absence of the initial impact phase (Fig.6c).

In order to characterize the initial part of the VGRF curve (the impact phase) as indicated above, Miller (27) and Munro et al. (29) recommended utilizing the loading rate as the descriptor for the F_{z1} peak. The loading rate can then be calculated regardless of the presence of an impact peak at landing. Our kinetic analysis digressed from the referenced literature in two aspects. While Miller and Munro et al. utilized the loading rate expressed as %BW per unit of time (27,29), the present analysis expressed the loading rate in Newtons (N) as a percentage of stance phase (%SP), similar to the Buczek et al. study on knee and ankle kinematics and kinetics (5). Every runner had a different self-selected speed; therefore, there was a necessity to express the data in a format relative to one another to facilitate comparison between the subjects. Each runner's stance phase data was normalized to 100 frames, aiding the investigators in comparing subjects in terms of percentage of stance. With this normalization of the data, the investigators were able to examine the application of the forces with respect to loading. Specifically, the MLR

exhibited the most dramatic change of all the force measurement variables. The training effect for the T-group was a decrease in the average loading rate by over 36% from its pre-test value. An example of changes in the loading rate as force (N) per % SP in a pre- and post-test of a trained subject is detailed in Figures 6b (pre-) and 6d (post-). The change in the MLR is an important indicator that a change in running style is able to change the application of forces experienced by the body.

A second force variable to show a discernible training effect was the MVGRF, which decreased by approximately 29% from the pre to the post-test. Figures 6a and 6c depicting a trained subject's pre and post vertical GRF curve normalized to N as a %SP, is a representative response of the whole T-group.

The impact phase of the running gait cycle, on average, shows a maximum impact peak within the first 50 ms, with the initial impact occurring at about 25 ms (3,10,16,19). The VGRF data for the heel strikers collected in the pre-test was consistent with the gait literature. The F_{z1} peak in all the subjects appeared within the first 50 ms of the stance phase, allowing an assumption applicable to the quantification of the GRF during the post-test data analysis. After the post-test force plate data was collected, a time calculation was done to extract the maximum force at about 50 ms into the landing phase. This assumption was tested against post-test data of subjects still showing a slight impact peak. The results confirmed that a landing phase containing a maximum force occurred within that time frame.

A decrease in the MVGRF demonstrated a successful change in the third and most important force variable in the study, the MVF@K. The significant decrease validated the research hypothesis that changes in the foot strike would decrease the stress

at the knee joint. The MVGRF at the knee joint decreased about 30% over the same subject pre-test results and, furthermore, decreased by 24% over the control group in the post-test.

The KFA@FS was measured to establish the position of the knee at the moment of landing. As was previously discussed in the Results section, increases in the KFA@FS resulted in this angle being about 20% in the T-group. Previous studies such as that by Lafortune et al. (22) determined that an increased knee flexion angle at foot strike was found to improve shock attenuation. Derrick et al. (15) also ascertained that the length of the stride was directly related to the knee flexion and extension cycle, and Cavanagh and LaFortune (10) agreed that this was a strategy to absorb the impact shock wave traveling through the system. The adoption of the Pose running style, promoting an increase in the flexion angle at landing, resulted in the T-group developing a shorter stride length, in addition to force variables that decreased dramatically. The training effect on knee flexion, following the Pose sessions, showed the greatest kinematic between-groups and same-subject differences, and was as close to statistical significance as could possibly be with $P=0.051$.

Finally, the subjective results from the investigation must be noted. First of all, none of the participants in the training group developed any new running related injuries during the 3 months of sessions while three control subjects dropped out due to running related injuries incurred while training. Second, of the group that trained with the Pose Method, five subjects ran a marathon within two weeks of the study ending. All five reported no knee pain at the end of the marathon (which they had experienced in past marathons). The sixth subject did an Ironman triathlon (included a 13 mile run),

improved his run time and did not report any knee pain (which he had experienced previously in similar events).

CONCLUSION

The results of this preliminary investigation were very positive with respect to decreasing VGRF by changing a heel striking style of running to a mid foot striking style of running as taught by the Pose Method. Altering the running styles of recreational runners can decrease the impact forces at the knee joint. Running related injuries at the knee joint as a result of heel striking play a large part in the life of these runners.

Decreasing these forces can increase the joint's ability to handle the stress accumulation that comes from running. As a group, the trained subjects successfully assimilated the Pose biomechanics as demonstrated by a higher stride rate, a shorter stride length and a deeper knee flexion angle at foot strike. These changes were expressed kinetically by all the trained subjects depicting a post-test absence, or close to, of the initial impact curve, defining the landing as a classic midfoot.

The study was successful in changing the running styles of the training group. By doing so, the series of objectives set at the beginning were met. Significant changes in the kinematic variables, expressed by SL, SR, SP, and KFA@FA, plus significant changes in the force variables as expressed by MVGRF, MVI@K, and MLR were determined. Furthermore, the study also assessed how changing the running kinematics affected the force measurements. Probably the most compelling argument for a Pose style mid foot strike is the fact that not only were the VGRF measured at the knee joint significantly decreased but that all three force indicators had meaningful decreases in the range of 29% to 36%. This known fact provides a strong argument for further study with an increased

CONCLUSION

The results of this preliminary investigation were very positive with respect to decreasing VGRF by changing a heel striking style of running to a mid foot striking style of running as taught by the Pose Method. Altering the running styles of recreational runners can decrease the impact forces at the knee joint. Running related injuries at the knee joint as a result of heel striking play a large part in the life of these runners. Decreasing these forces can increase the joint's ability to handle the stress accumulation that comes from running. As a group, the trained subjects successfully assimilated the Pose biomechanics as demonstrated by a higher stride rate, a shorter stride length and a deeper knee flexion angle at foot strike. These changes were expressed kinetically by all the trained subjects depicting a post-test absence, or close to, of the initial impact curve, defining the landing as a classic midfoot.

The study was successful in changing the running styles of the training group. By doing so, the series of objectives set at the beginning were met. Significant changes in the kinematic variables, expressed by SL, SR, SP, and KFA@FA, plus significant changes in the force variables as expressed by MVGRF, MVF@K, and MLR were determined. Furthermore, the study also assessed how changing the running kinematics affected the force measurements. Probably the most compelling argument for a Pose style mid foot strike is the fact that not only were the VGRF measured at the knee joint significantly decreased but that all three force indicators had meaningful decreases in the range of 29% to 36%. This known fact provides a strong argument for further study with an increased

sample size and a controlled training schedule. Following the contention that increased and accumulated loads at the knee joint is cause for injuries in the heel striking

population, these results provide compelling arguments for further examination into this foot striking style and its potential for reduced loading at the knee in this population.

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APPENDIX
TABLES

Table 1

Physiological Variables - Mean & S.E.

Variable	Treatment N=7		TABLES N=6	
	Pre	Post	Pre	Post
Age	34.9±2.4		38.8±1.4	
HT	56.9±7.4		65.7±2.0	
WT	138.7±10.5	138.3±10.5	149.5±13.3	142±12.4
HRmax	184.9±4.8	183.9±3.0	181.3±1.9	181.8±4.1
VO ₂ peak	45.4±4.5	47.4±5.1	40.7±2.9	46.4±5.2
BF	20.2±3.5	20.7±3.3	25.7±2.3	27.2±2.1
S&R	15.2±2.2	16.7±1.5	19.4±1.8	19.4±1.2
Jump(cm)	38.9±4.3	39.6±4.0	33.6±4.0	32.0±5.0

HT-Height (in.) WT-Weight (lbs) HR - Heart Rate (bpm)

BF - Body Fat % S&R - Sit & Reach (in.)

Table 2

Kinetic and Kinematic Variables - MEAN & SE

T= Treatment Group C = Control Group

Variable	Pre-T	Post - T	Pre - C	Post - C
MVGRF(%BW)	1.96±0.12	1.39±0.12*	1.72±0.13	1.86±0.17
MVF@K(%BW)	1.52±0.1	1.06±0.1*	1.37±0.1	1.50±0.1
KFA@MVFK(deg)	24.6°±0.8	27.1°±1.2	22.9°±2.5	26.0°±1.4
SP (ms)	242.2±11.0	222.4±9.4*	224.6±10.0	232.2±5.3
MLR (N)	223.2±39.2	141.7±21.5*	152.9±28.1	152.2±23.8
SR (steps/min)	168 ± 3.5	181 ± 2.9*	179 ± 6.5	180 ± 6.1
SL (cm/s)	270 ± 13.6	247 ± 11.2	257 ± 22.0	246 ± 19.7
KFA@FS(deg)	17.4°±1.2	20.9°±1.5	15.5°±1.9	16.8°±1.4

*Variables showing significance at the level of Treatment within subjects

N=7 for Treatment (except at MFK N=6)

N=6 for Control

Table 1

Physiological Variables - Mean & S E

Variable	Treatment	N=7	Control	N=6
	Pre	Post	Pre	Post
Age	34.9±2.4		38.8±1.4	
HT	56.9±7.4		65.7±2.0	
WT	158.7±10.5	158.3±10.5	149.5±13.3	142±12.8
HRmax	184.9±4.8	183.9±3.0	181.3±1.9	183.8±4.1
VO ₂ peak	45.4±4.5	47.4±5.1	40.7±2.9	40.4± 3.9
BF	20.2±3.5	20.7±3.3	25.2± 2.3	27.2±2.1
S&R	15.2±2.2	16.7±1.5	19.4±0.8	19.4±1.2
Jump(cm)	38.9±4.3	39.6±4.0	33.6±4.9	32.0±5.0

HT-Height (in.) WT-Weight (lbs) HR – Heart Rate (bpm)

BF – Body Fat % S&R – Sit & Reach (in.)

SL (cm/s)

KFA@FS(deg)

N=7 for Treatment (except at MVF@K N=6)

N= 6 for Control

Table 2

Kinetic and Kinematic Variables - MEAN & SE

T= Treatment Group C = Control Group

Variable	Pre-T	Post – T	Pre – C	Post – C
MVGRF(%BW)	1.96±0.12	1.39±0.12*	1.72±0.13	1.66±0.17
MVF@K(%BW)	1.52 ± 0.1	1.06 ± 0.1*	1.37 ± 0.1	1.40 ± 0.1
KFA@MVFK(deg)	24.6° ± 0.8	27.1°± 1.2	22.9°± 2.5	26.0°±1.4
SP (ms)	242.2±11.0	222.4±9.4*	224.6±10.0	232.2±5.3
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SL (cm/s)	270 ± 13.6	247 ± 11.2	257 ± 22.0	246 ± 19.7
KFA@FS(deg)	17.4°± 1.2	20.9°± 1.5	15.5°± 1.9	16.8°± 1.4

*Variables showing significance at the level of Treatment within subjects

N=7 for Treatment (except at MFK N=6)

N= 6 for Control

Table 3

Kinetic and Kinematic Variables			
P Values		T= T-group	C= C-group
	Training Effect	T- Post	C-Post
MVGRF(%BW)	0.004	<0.001	0.655
MVF@K(%BW)	0.003	<0.001	0.701
KFA@MVFK(deg)	0.159	0.160	0.430
SP (ms)	0.006	0.005	0.182
MLR (N)	0.045	0.007	0.979
SR (steps/min)	0.012	0.001	0.894
SL (cm/s)	0.004	0.004	0.122
KFA@FS(deg)	0.145	0.051	0.665

N=7 for Treatment (except at MVF@K N=6)

N= 6 for Control

Figure 1. Heel Strike

FIGURES

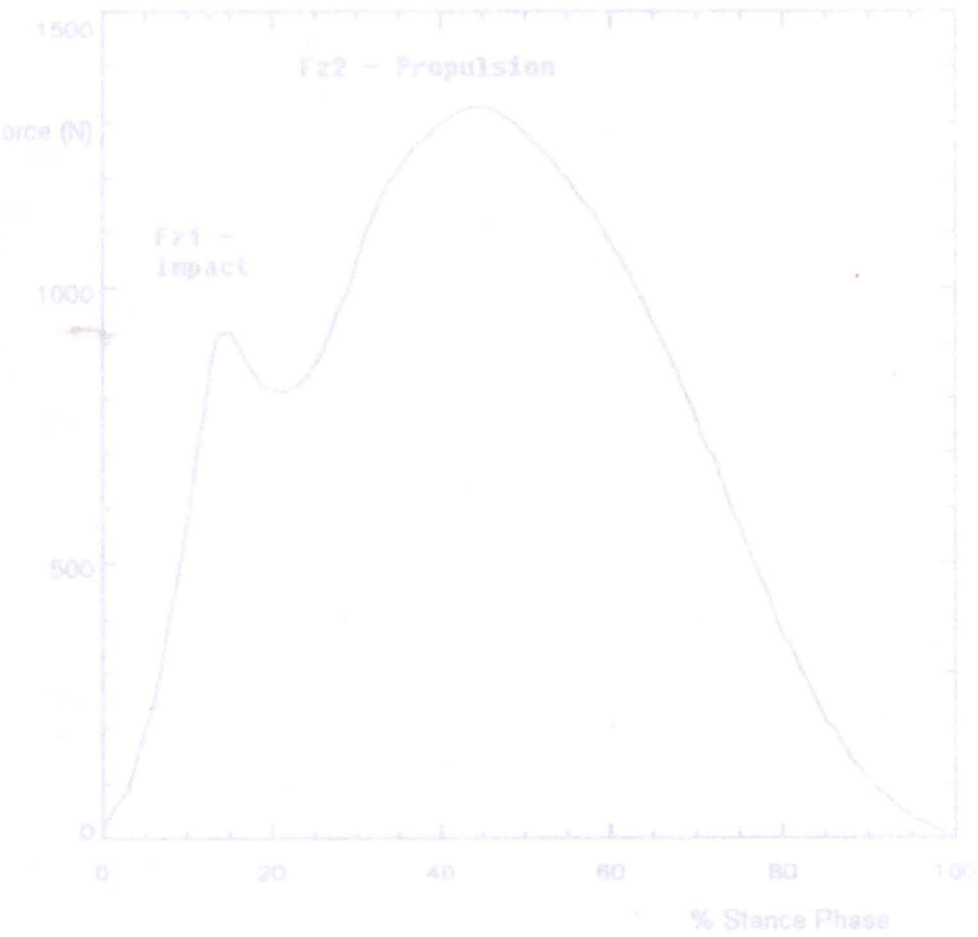


Figure 1. Heel Strike

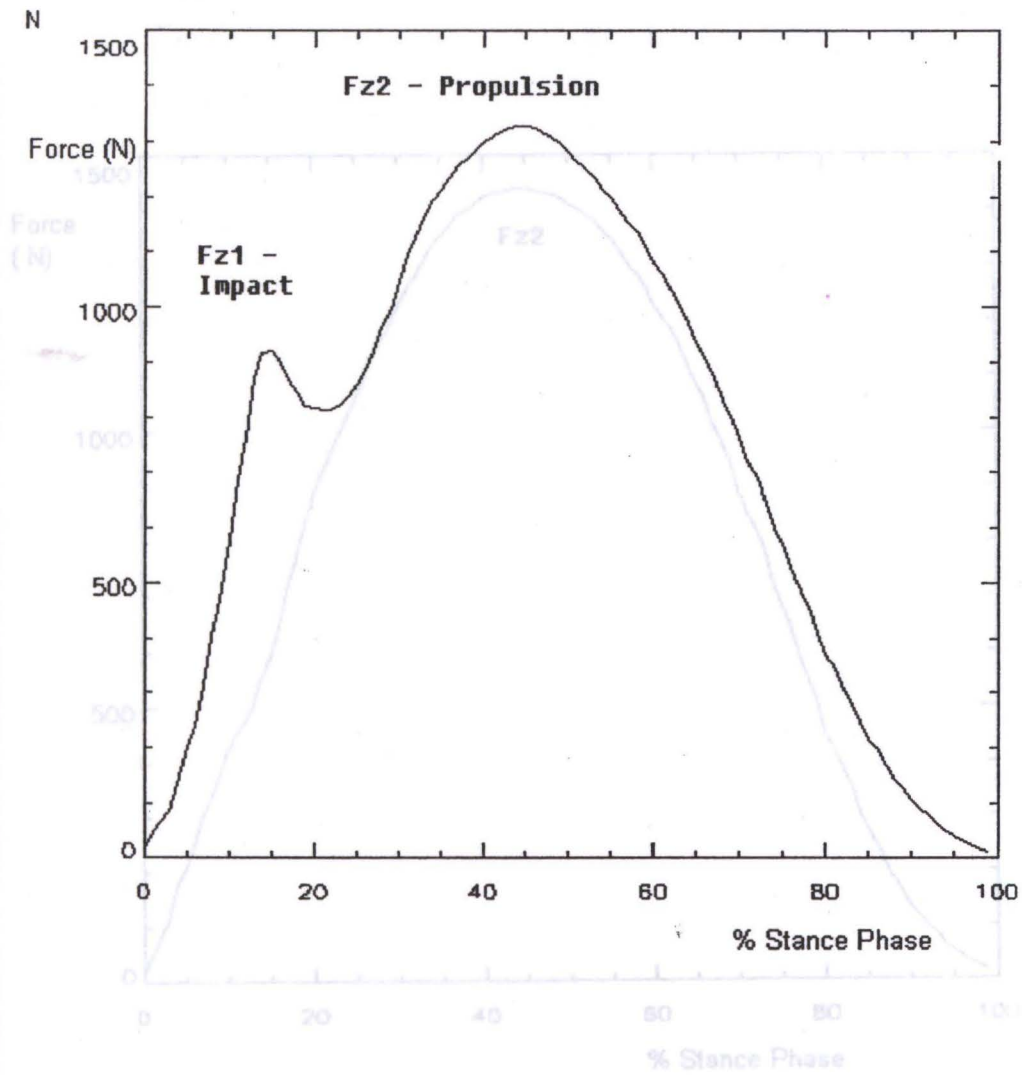


Figure 2. Midfoot Strike on Force

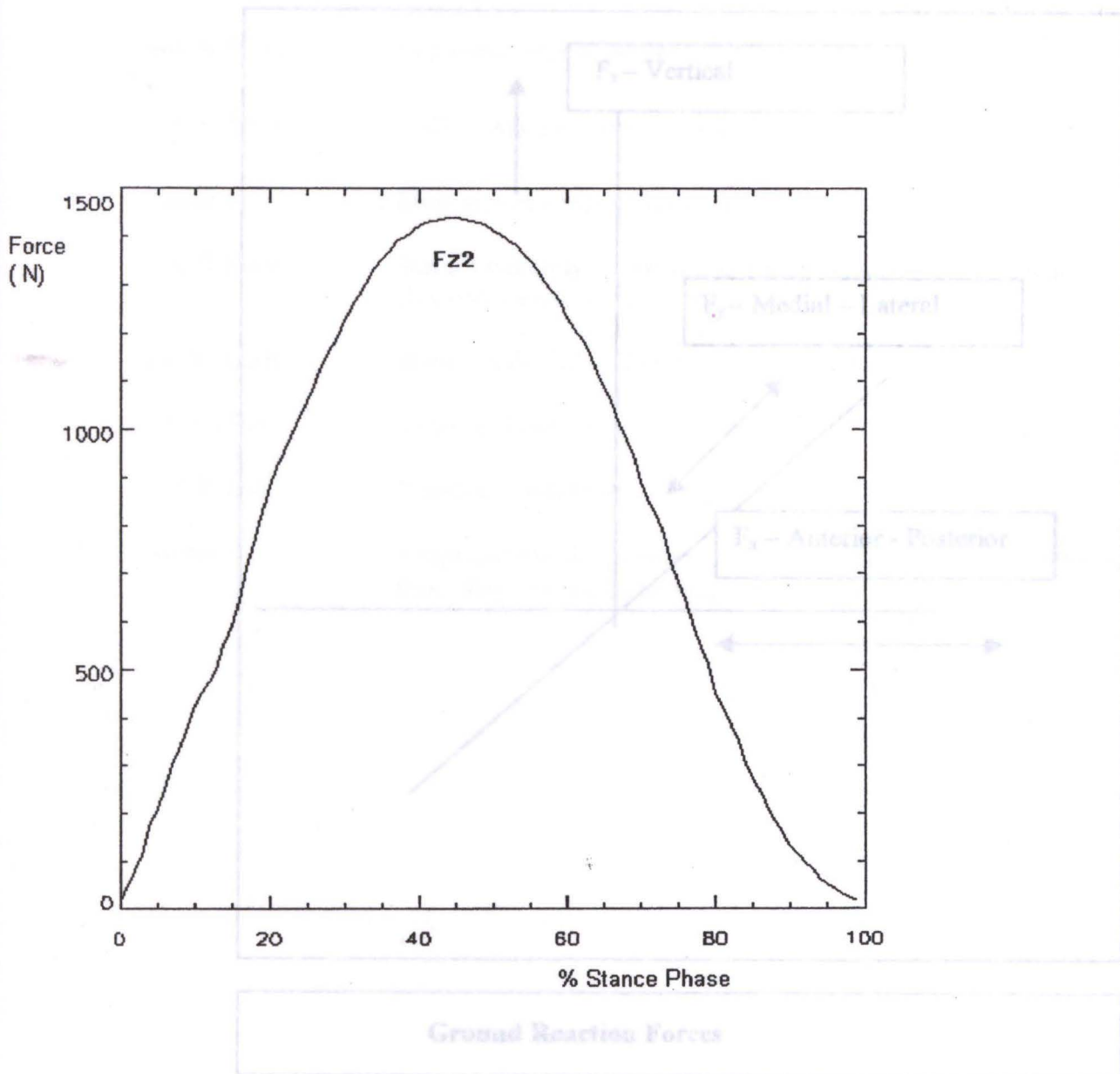


Figure 3. Ground Reaction Forces

Figure 4. Orthopaedic Research Laboratory Running Marker Placement

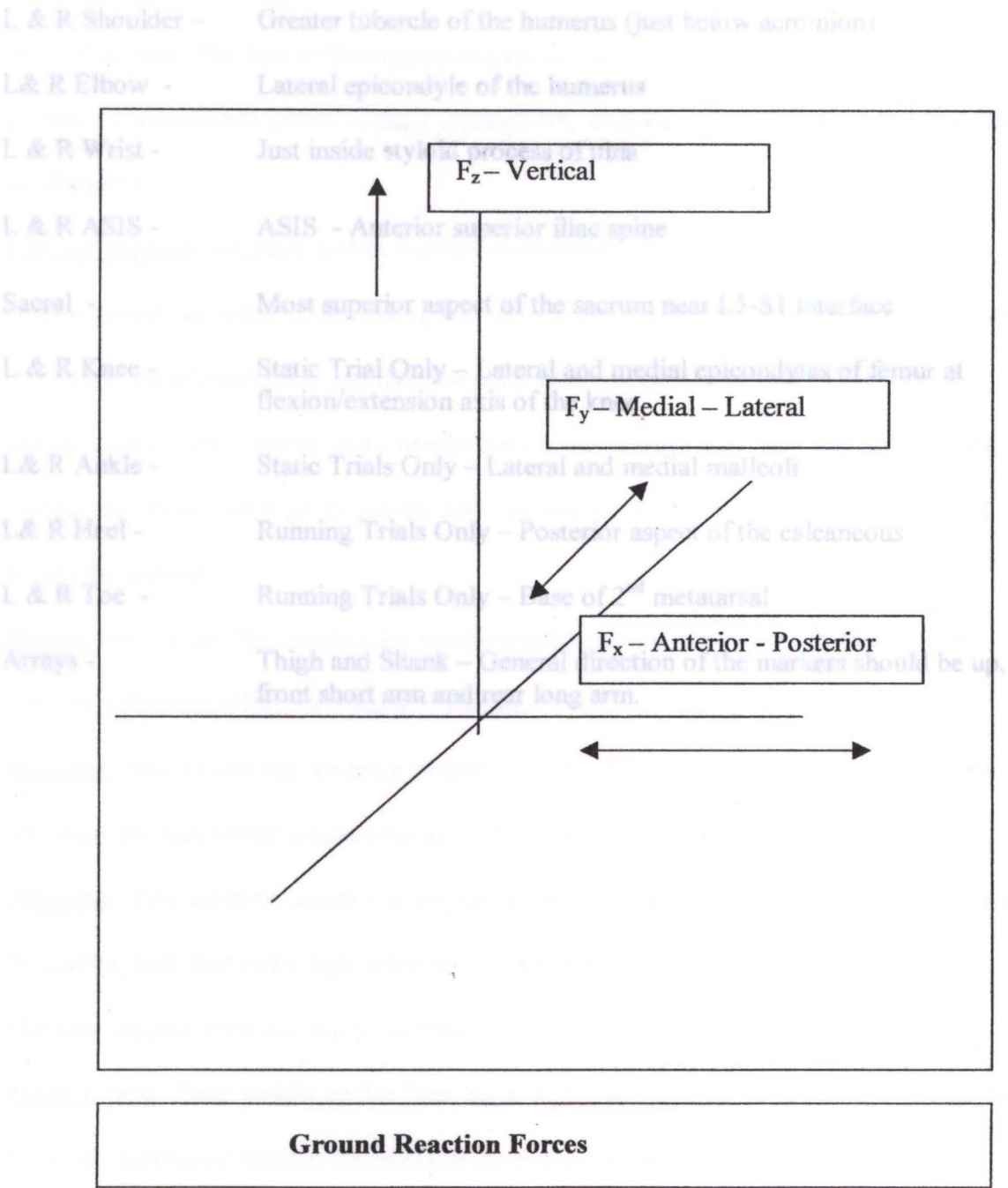


Figure 4. Orthopaedic Research Laboratory Running Marker Placement

<u>S-like Stance</u> (running pose). The knee is bent. The general center of mass is on the balls of the feet. The heel of the support leg doesn't touch the ground (is a bit of the ground). The three key points along a vertical line: shoulder, hip and balls of the foot (leg on support.)	
L & R Shoulder –	Greater tubercle of the humerus (just below acromion)
L& R Elbow -	Lateral epicondyle of the humerus
L & R Wrist -	Just inside styloid process of ulna
L & R ASIS -	ASIS - Anterior superior iliac spine
Sacral -	Most superior aspect of the sacrum near L5-S1 interface
L & R Knee -	Static Trial Only – Lateral and medial epicondyles of femur at flexion/extension axis of the knee
L& R Ankle -	Static Trials Only – Lateral and medial malleoli
L& R Heel -	Running Trials Only – Posterior aspect of the calcaneus
L & R Toe -	Running Trials Only – Base of 2 nd metatarsal
Arrays -	Thigh and Shank – General direction of the markers should be up, front short arm and rear long arm.

Hopping. Hop on one leg, keeping weight on it (on balls of the foot). Pull another ankle up, when the foot barely touches the ground. Let it land by itself.

Skipping. Two variants: single and double skipping. Single - keep weight on one leg and by landing both feet make light jump on one and pull up another ankle. Double - alternate support from one leg to another.

Front Lunge. Keep weight on the front leg and pull up ankle of the same leg. Second leg does only additional support and stays in the rear position.

*Extracted with permission from – *The Pose Method of Teaching Running Technique* by Nicholas Romanov, Ph.D.

Figure 5. Pose Running Technique Drills

S- like Stance (running pose). The knee is bent. The general center of mass is on the balls of the feet. The heel of the support leg doesn't touch the ground (is a bit of the ground). The three key points along a vertical line: shoulder, hip and balls of the foot (leg on support.)

Change support. (in place and in forward movement). Pull ankle of the support leg up (with a hamstring, ankle or heel along the vertical line under the hip). Pulling a hamstring is only the initial movement and then the shin, ankle and thigh move by themselves by inertia, momentum, reactive and Coriolis forces. Never force and move the airborne leg (swing leg) down. Let it go by gravity and reactive forces and only after the support leg leaves the ground.

Ponny. Stay on one leg, another leg barely touches ground with toes. Change support with the minimum effort and range of motion.

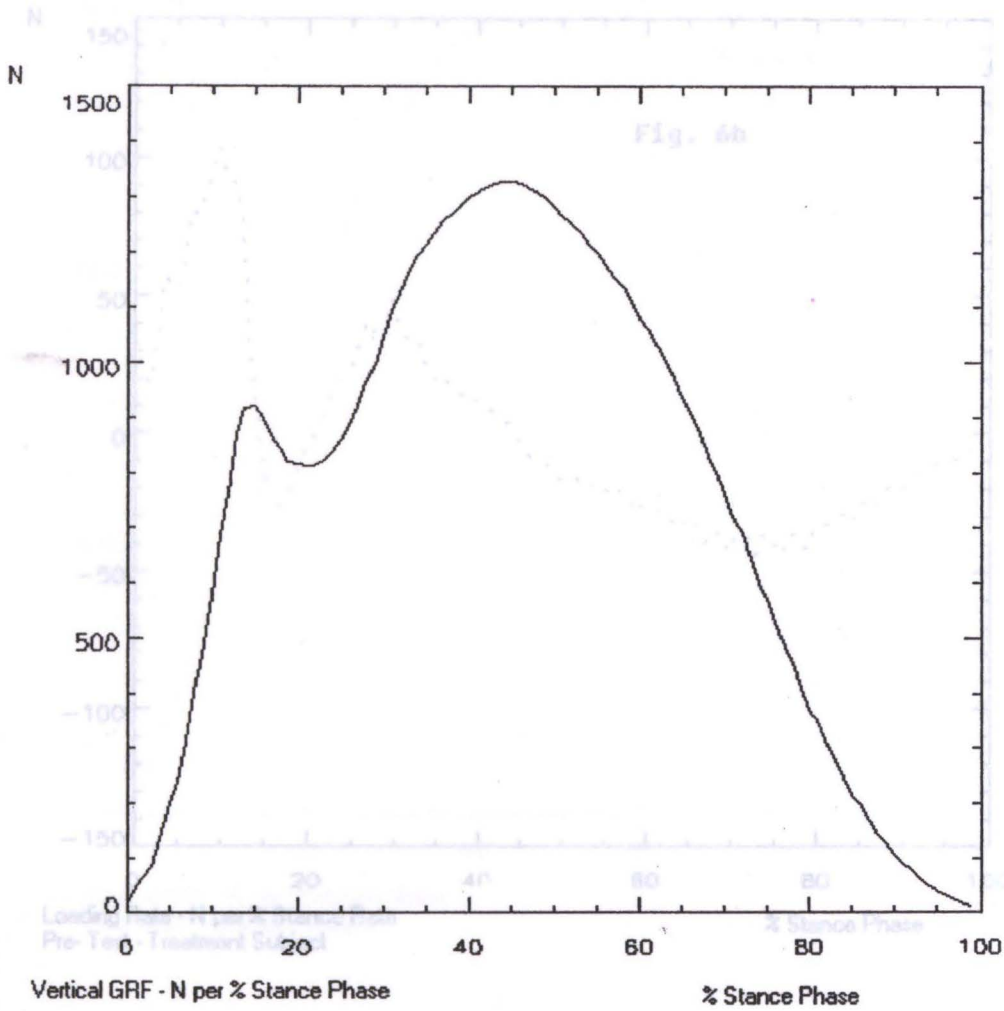
Hopping. Hop on one leg, keeping weight on it (on balls of the foot). Pull another ankle up, when the foot barely touches the ground. Let it land by itself.

Skipping. Two variants: single and double skipping. Single – keep weight on one leg and by landing both feet make light jump on one and pull up another ankle. Double – alternate support from one leg to another.

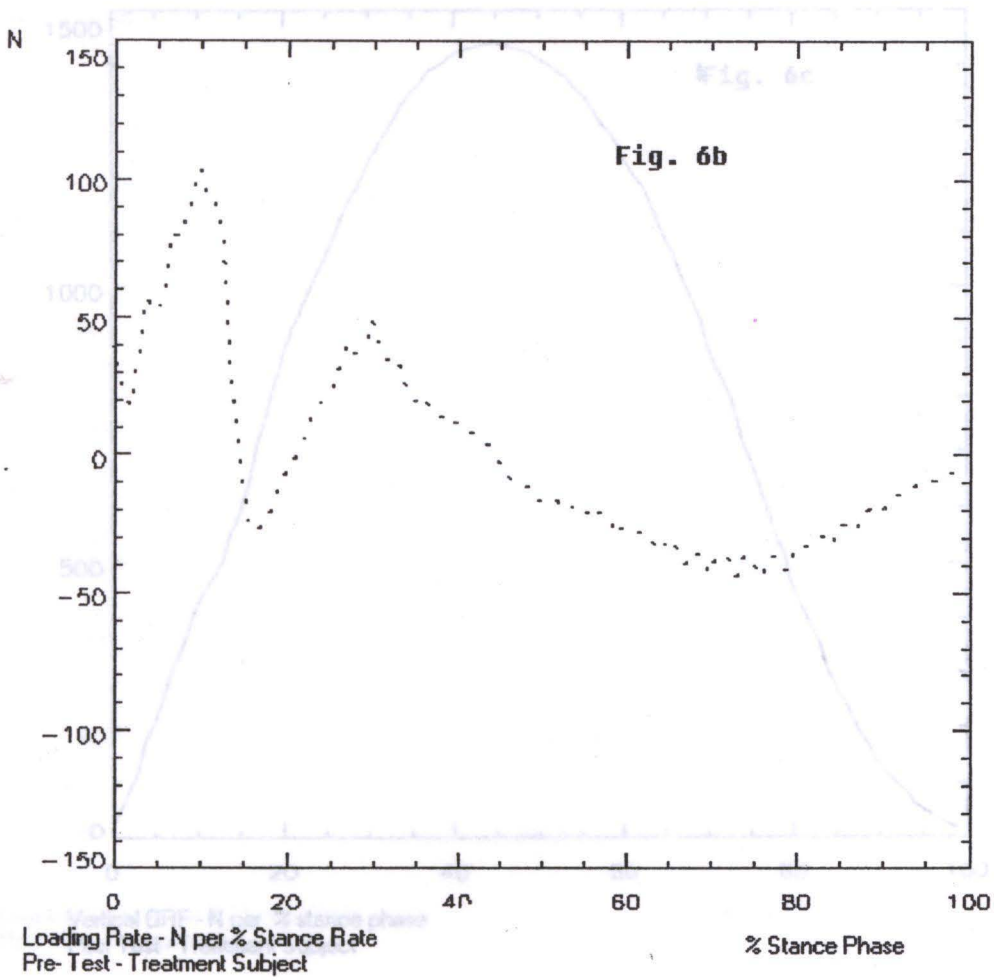
Front Lunge. Keep weight on the front leg and pull up ankle of the same leg. Second leg does only additional support and stays in the rear position.

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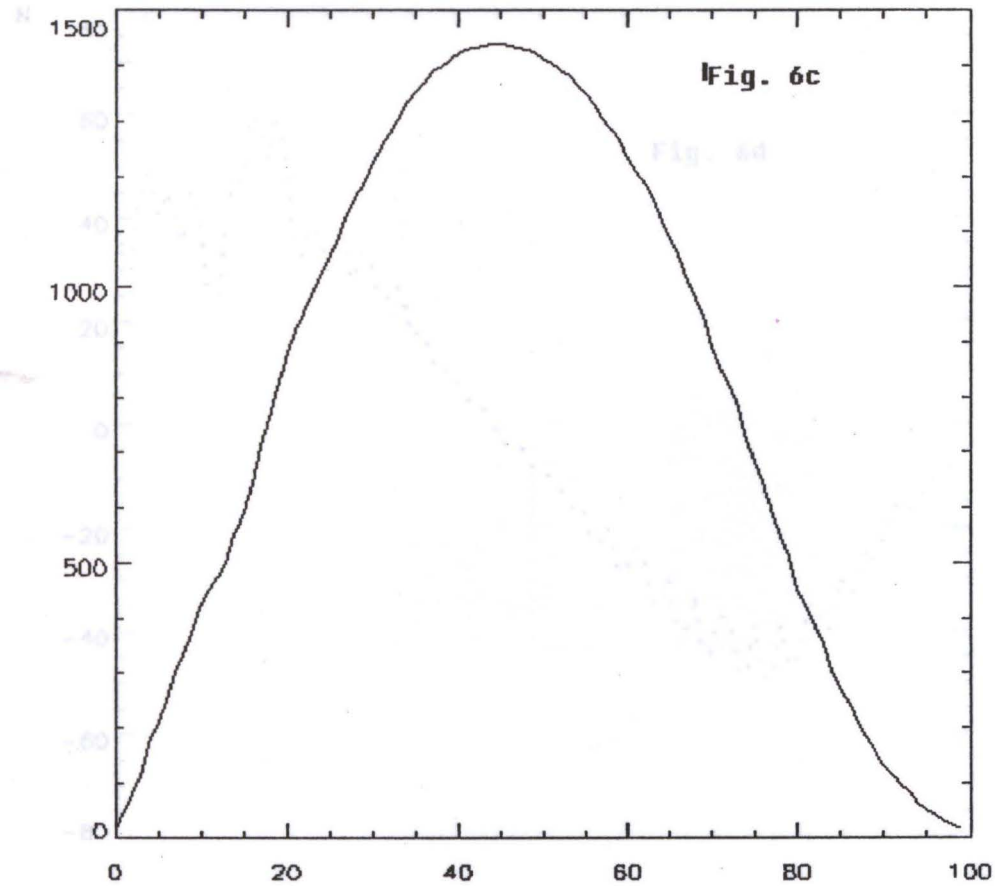
Figure 6a. Vertical GRF – Pre-test subject



6b. Loading Rate – Pre-test subject



6c. Vertical GRF – Post-test subject



Vertical GRF - N per % stance phase
Post Test - Treatment Subject

6d. Loading Rate – Post-test subject

Figure 7. Stance Phase (SP)

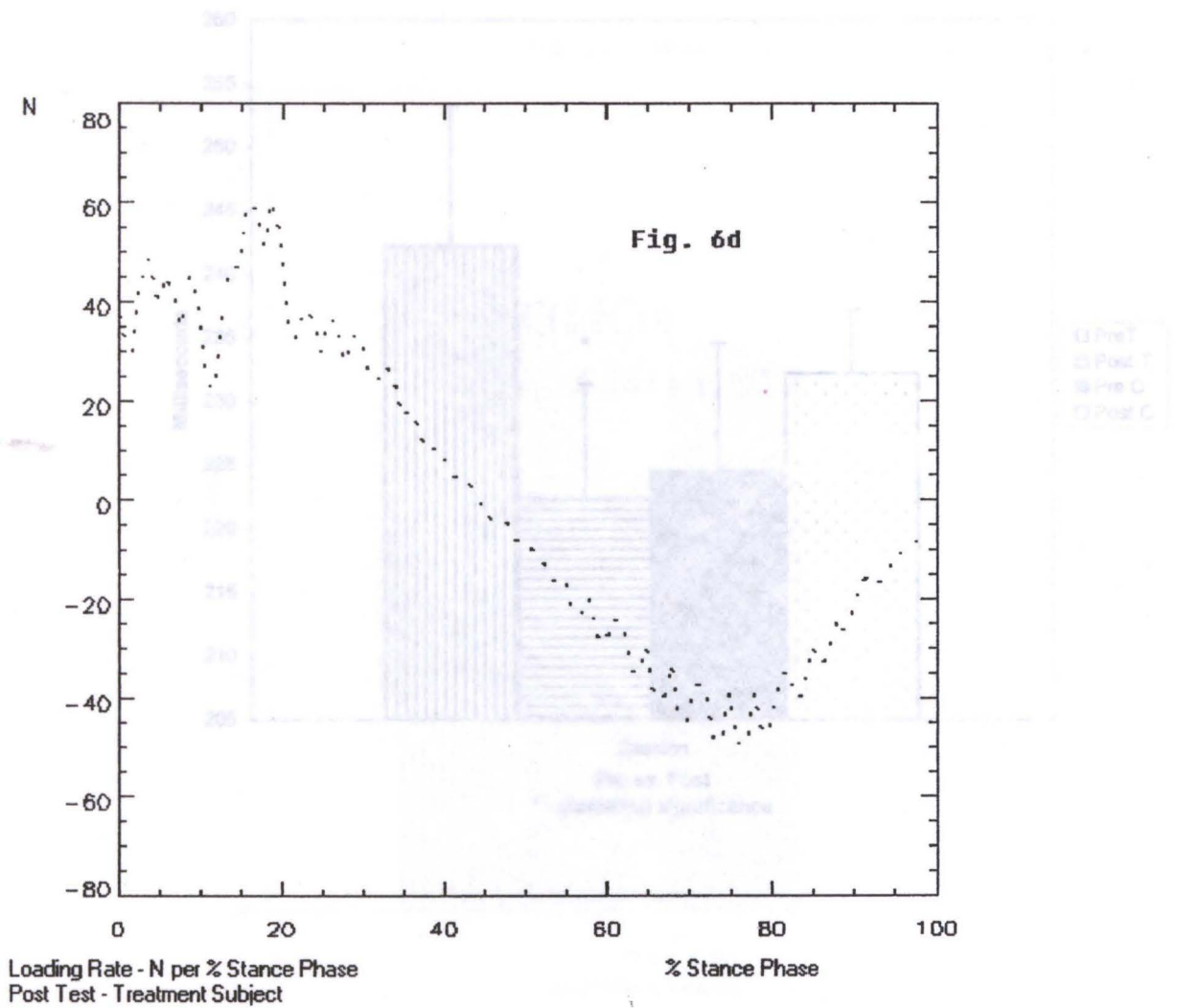


Figure 7. Stance Phase (SP)

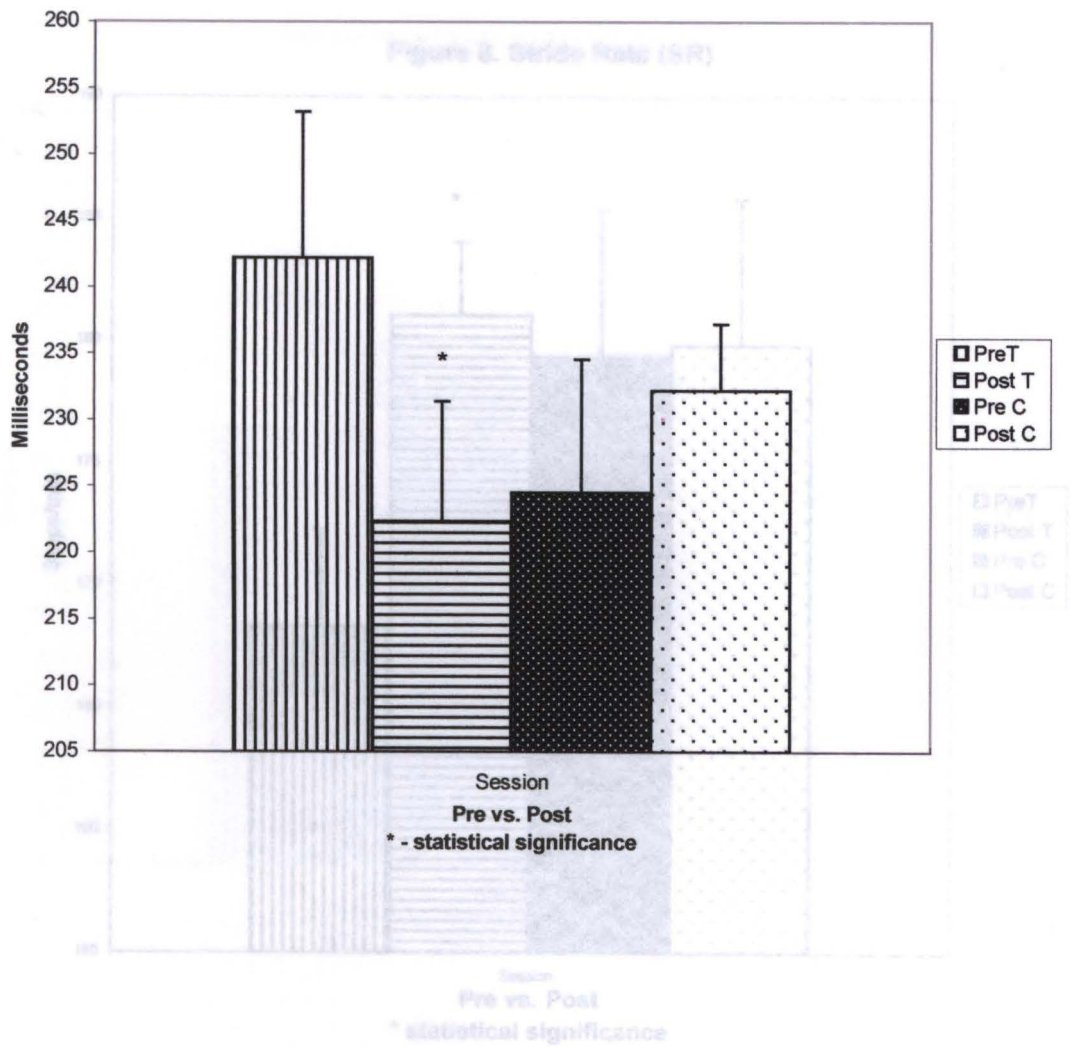


Figure 8. Stride Rate (SR)

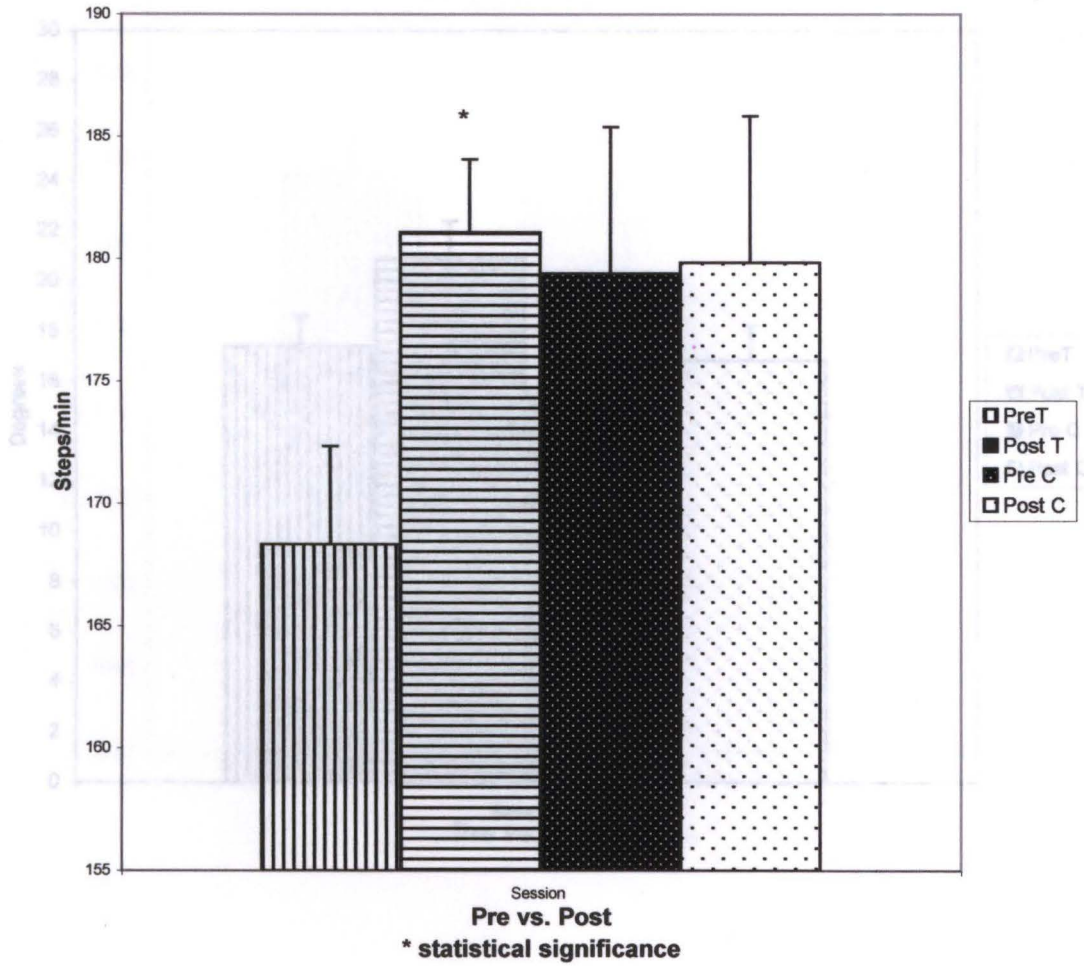


Figure 10. Maximum Vertical Ground Reaction Forces (N) 287

Figure 9. Knee Flexion Angle at Footstrike (KFA@FS)

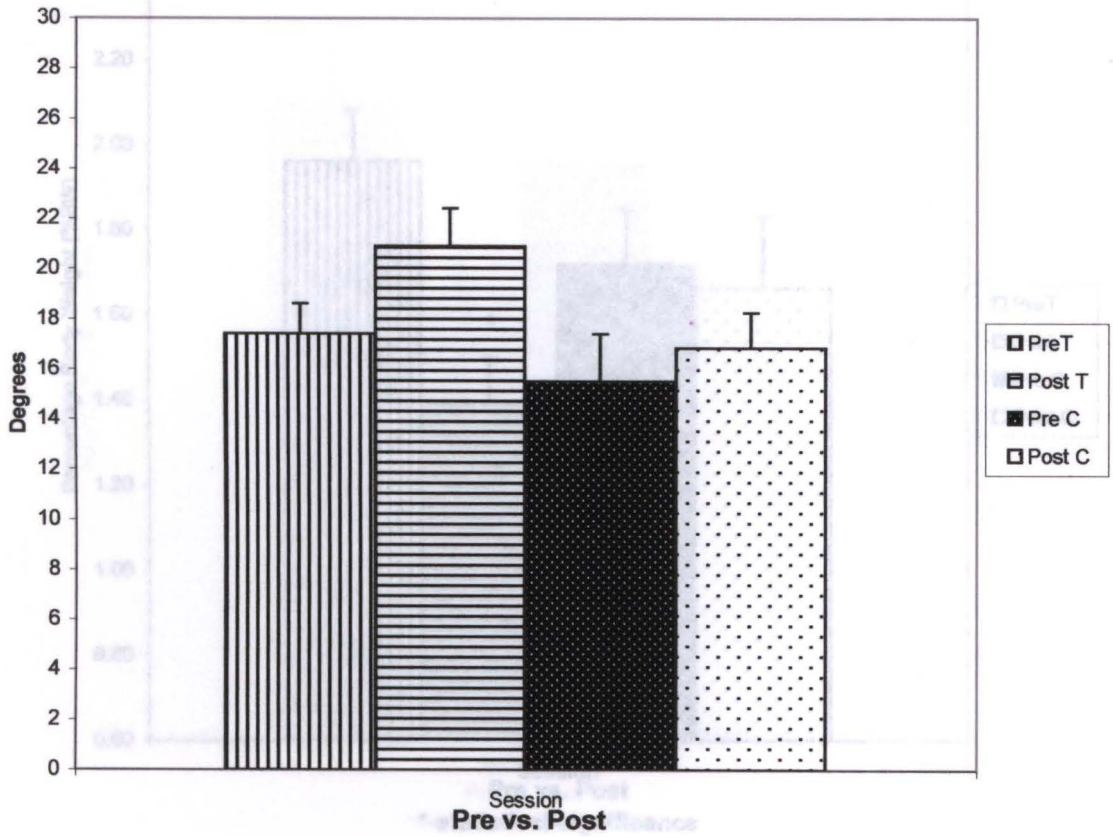


Figure 10. Maximum Vertical Ground Reaction Forces (MVGRF)

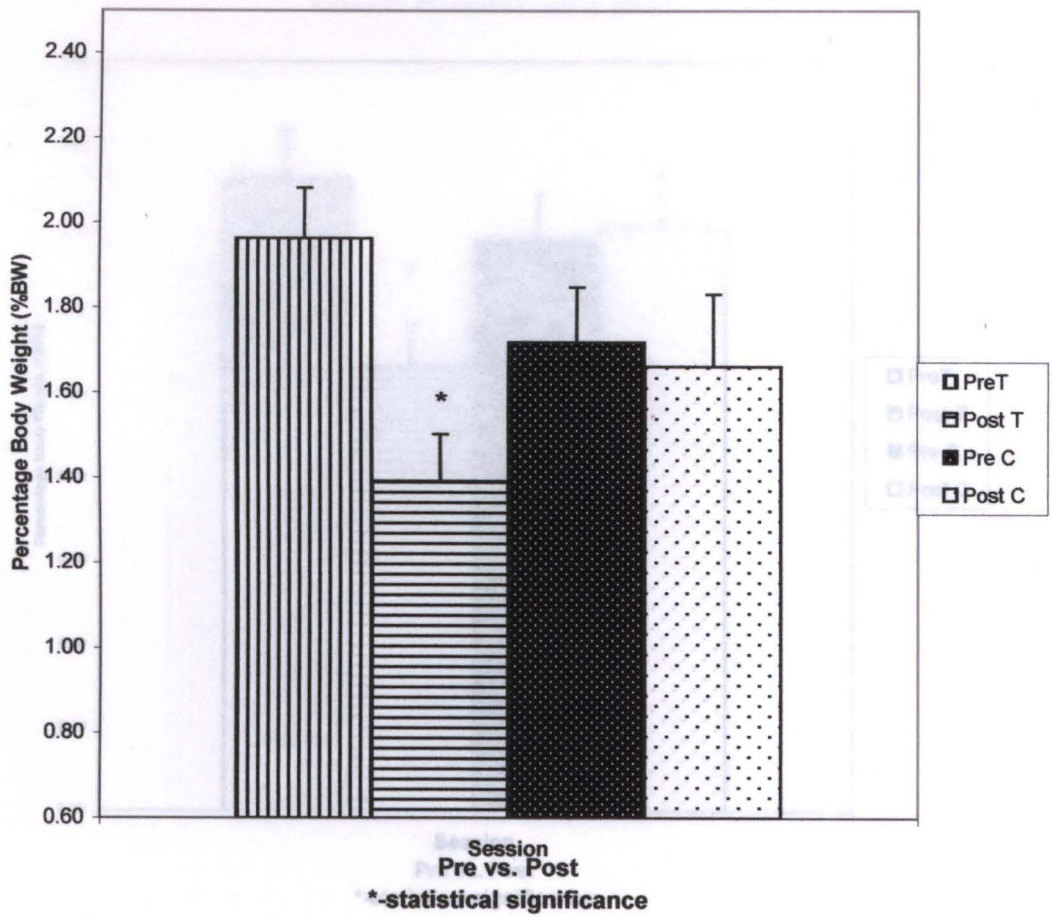


Figure 11. Maximum VGRF at Knee Joint (MVFK)

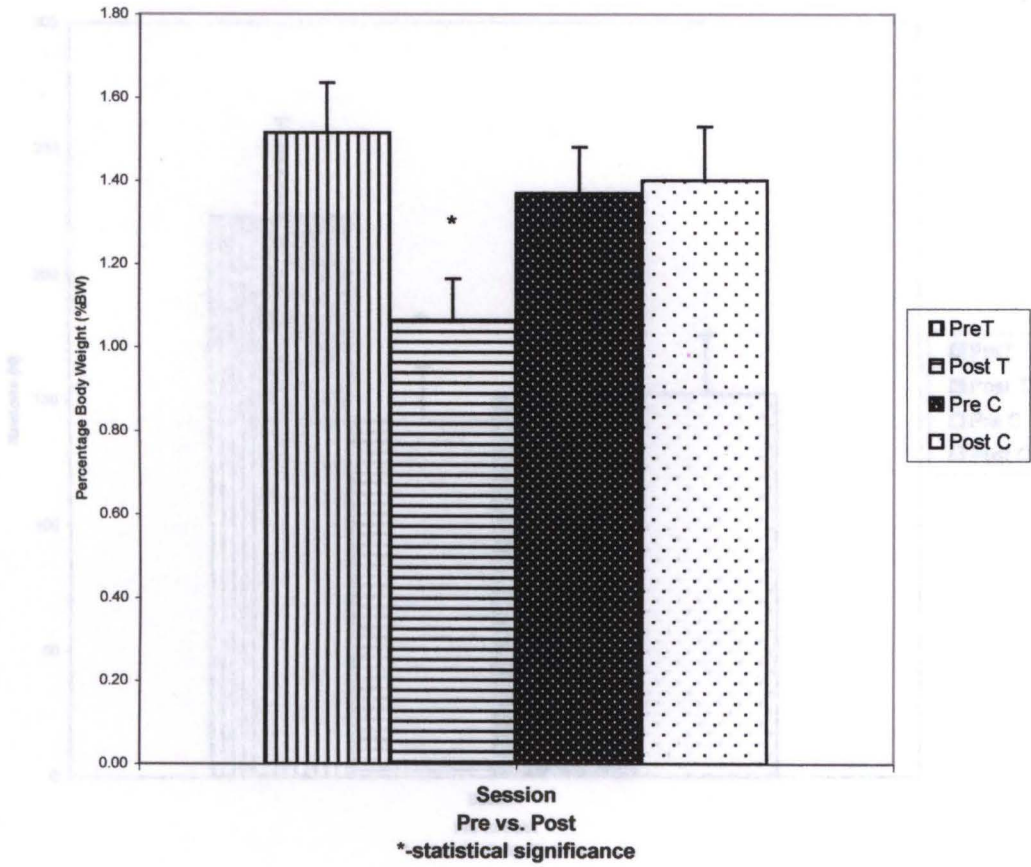


Figure 12. Maximum Loading (ML)

