2004-12-02

A Biomechanical Analysis of Sprinters vs. Distance Runners at Equal and Maximal Speeds

Tyler D. Bushnell
Brigham Young University - Provo

A BIOMECHANICAL ANALYSIS OF SPRINTERS VS. DISTANCE RUNNERS AT EQUAL AND MAXIMAL SPEEDS

by

Tyler D. Bushnell

A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Master of Science

Department of Exercise Sciences

Brigham Young University

December 2004

BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

Tyler D. Bushnell

This thesis has been read by each member of the following graduate committee and by a majority vote has been found to be satisfactory.

Date	Iain Hunter, Chair
Date	Ron Hager
Date	Allen Parcell

BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Tyler D. Bushnell in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

Date

Iain Hunter
Chair, Graduate Committee

Accepted for the Department

Ruel Barker
Chair, Department of Exercise Sciences

Accepted for the College

Gordon B. Lindsay
Associate Dean, College of Health and Human Performance

ABSTRACT

A BIOMECHANICAL ANALYSIS OF SPRINTERS VS. DISTANCE

RUNNERS AT EQUAL AND MAXIMAL SPEEDS

Tyler D. Bushnell

Department of Exercise Sciences

Master of Science

In the sport of track and field, sprinting and distance running represent two major categories of athletes. Sprinting is associated with power and speed, whereas distance running focuses on the economy of movement. With distance running there are elements of sprint technique that overlap. With distance events, there comes a time near the end of the race where economy gives way to speed. If the distance runners knew how to alter their technique in a way to become more sprint-like, this process could possibly be more successful. **PURPOSE:** This study compared the differences in technique between sprinters and distance runners while running at equal and maximal speeds. **METHODS:** Subjects for the study consisted of 10 Division I collegiate distance runners, 10 Division I collegiate sprinters, and 10 healthy non-runners. The subjects performed two tests, with each consisting of a 60 meter run completed on the track. Test 1 was run at a pace of 5.81 m/s (4:37 min/mile), while Test 2 was completed at maximal speed. Video footage of each trial was collected at 180 Hz, monitoring hip, knee, thigh, and shank positions, as well as stride length, and contact time. **RESULTS:** Significant differences ($p < .05$) between the sprint and distance groups at maximal speed were found in the following areas: speed, minimum hip angle, knee extension at toe-off, stride length, contact time, and the position of the recovery knee at touchdown. Sprinters and distance runners exhibited a significantly lower minimum knee angle than those in the control group. Significant differences between the sprint and control group existed at the minimum hip angle, speed, stride length, contact time, and the position of the recovery knee at touchdown. Regarding the paced trial, the sprinters and distance runners showed significant difference concerning the minimum hip angle, center of mass at touchdown, and recovery knee at touchdown. Sprinters differed significantly from the control group in contact time, the center of mass at touchdown and the position of the recovery knee at touchdown. **CONCLUSION:** As distance runners attempt to sprint, the desired adaptations do not necessarily occur. The development of economical distance form is a fairly natural process that occurs with the miles of training. Sprinting, however, is a separate, learned technique that often requires specific feedback. When attempting maximal speed, distance runners may benefit by focusing on one characteristic of technique. If knee extension at toe-off could be trained to become more sprint-like, the other characteristics unique to sprinters may follow.

ACKNOWLEDGMENTS

Special thanks to Dr. Hunter for his expertise, time, and enthusiasm in the development and completion of this thesis. I would also like to thank Mark Robison, Edward Eyestone, Leonard Myles-Mills, and the BYU Men's Track and Field team for their assistance and willingness to be a part of this study. Additionally, I would like to thank my Mom and brother Tanner for their continued interest and support throughout the entire project. Finally, extra thanks to Sandy Alger and her uncanny editing ability.

Table of Contents

List of Tables

List of Figures

A Biomechanical Analysis of Sprinters vs. Distance Runners at

Equal and Maximal Speeds

Tyler D. Bushnell, MS, Exercise Sciences, Brigham Young University

Iain Hunter, PhD, Exercise Sciences, Brigham Young University

Ron Hager, PhD, Exercise Sciences, Brigham Young University

Allen Parcell, PhD, Exercise Sciences, Brigham Young University

Correspondence: Tyler D. Bushnell, 1933 Wooded Knolls Dr, Philomath, OR 97370,

(541) 929-5032.

Email: tdb34@email.byu.edu

Abstract

In the sport of track and field, sprinting and distance running represent two major categories of athletes. Sprinting is associated with power and speed, whereas distance running focuses on the economy of movement. With distance running there are elements of sprint technique that overlap. With distance events, there comes a time near the end of the race where economy gives way to speed. If the distance runners knew how to alter their technique in a way to become more sprint-like, this process could possibly be more successful. **PURPOSE:** This study compared the differences in technique between sprinters and distance runners while running at equal and maximal speeds. **METHODS:** Subjects for the study consisted of 10 Division I collegiate distance runners, 10 Division I collegiate sprinters, and 10 healthy non-runners. The subjects performed two tests, with each consisting of a 60 meter run completed on the track. Test 1 was run at a pace of 5.81 m/s (4:37 min/mile), while Test 2 was completed at maximal speed. Video footage of each trial was collected at 180 Hz, monitoring hip, knee, thigh, and shank positions, as well as stride length, and contact time. **RESULTS:** Significant differences ($p < .05$) between the sprint and distance groups at maximal speed were found in the following areas: speed, minimum hip angle, knee extension at toe-off, stride length, contact time, and the position of the recovery knee at touchdown. Sprinters and distance runners exhibited a significantly lower minimum knee angle than those in the control group. Significant differences between the sprint and control group existed at the minimum hip angle, speed, stride length, contact time, and the position of the recovery knee at touchdown. Regarding the paced trial, the sprinters and distance runners showed

significant difference concerning the minimum hip angle, center of mass at touchdown, and recovery knee at touchdown. Sprinters differed significantly from the control group in contact time, the center of mass at touchdown and the position of the recovery knee at touchdown. **CONCLUSION:** As distance runners attempt to sprint, the desired adaptations do not necessarily occur. The development of economical distance form is a fairly natural process that occurs with the miles of training. Sprinting, however, is a separate, learned technique that often requires specific feedback. When attempting maximal speed, distance runners may benefit by focusing on one characteristic of technique. If knee extension at toe-off could be trained to become more sprint-like, the other characteristics unique to sprinters may follow.

Introduction

In the sport of track and field, two major categories of athletes are sprinters and distance runners. As they compete in their respective events, there are many differences between the two groups. Sprinting is not simply running fast, just as distance running is not simply running long. There are distinct variations in technique and form that separate the two styles of running.

Sprinting is associated primarily with power and speed, whereas distance running is focused on efficiency and smoothness of movement. This major difference is easily observed at a track meet or practice where both groups are competing. As the distance team runs lap after lap, their ease of movement and smoothness of stride is apparent. They appear collected and controlled in their actions, delaying the onset of fatigue with their methods of minimizing the energy expenditure. The sprinters, on the other hand, demonstrate high speed and explosive movement. They showcase their power with quick, forceful motion as they speed down the track.

Distance runners represent efficiency in a way that is rarely seen in sports. Their form is fluid and economical with little wasted motion. The foot-strike is often near the heel in an effort to absorb impact, and the feet are lifted no higher than necessary to complete each stride. Little vertical oscillation is found among distance runners, while arm motion is primarily for proper counterbalance (Williams and Cavanagh, 1987). Internally, it is even more dramatic with lungs, muscles, and a heart that are incredibly adapted to handle long periods of stress (Brandon and Boileau, 1992).

Sprinting focuses on power, explosiveness and top speed. The use of the body centers on the development of force, and the effort is highly intense. The body type of sprinters is also dramatically different from their sinewy distance counterparts. Sprinters exhibit a much larger muscle mass, more capable of high speed and rapid acceleration. Biomechanically, they are trained to display elevated thigh amplitude and a higher range of motion at both the hip and the knee.

With distance running, however, there are elements of sprint technique that overlap. In the course of a distance event, there comes a time near the end of the race where economy of movement gives way to speed. The runners become less concerned with their economy and more concerned with crossing the finish line as soon as possible. When this happens, many runners simply lengthen their stride to increase the pace, showing very little change in their overall form (Cavanagh and Kram, 1989). If they knew how to alter their technique in a way to become more sprint-like, this process could possibly be more successful. The majority of the race is still controlled by the issue of efficiency, but as the finish nears, changes may need to be made to improve performance.

Some of these changes involve positioning the body for a foot contact that minimizes braking and maximizes forward acceleration. Braking forces and the hip flexion angular velocity are connected by an inverse relationship. By increasing the angular velocity at the hip, showing a quicker recovery of the leg, the braking force will be reduced (Kivi, Marai and Gervais, 2002). Knee flexion comes into play with the leg recovery as well. By utilizing a higher degree of flexion, the runner is able to shorten the lever arm of the leg as it is pulled from behind the body to the front (Williams *et al*., 1987).

Another area of focus, concerning the differences between sprinting and distance running involves the contact or stance time with each step. As speed increases, the foot-to-ground contact times dramatically decrease. In a study by Weyand et al. (2001) findings showed that when comparing slow vs. fast sprinters, the greatest differences between the two groups involved the support forces and contact times.

The inclusion of a control group in the comparison of the trained distance and sprint groups is essential in determining if the distance and sprint technique is a learned skill or natural process. This element of the study allows for a comparison of differences between healthy non-runners and those who have been specifically trained in either distance running or sprinting.

In order to understand these variations, with an eye towards improving distance running performance near the finish line, an analysis of sprinters and distance runners, while running at an equal pace, is necessary. The present study determines whether the technique of sprinters, distance runners, and a control group is different at equal and maximal speeds.

Methods

Subjects

Twenty members of the Brigham Young University Track and Field team were recruited on a volunteer basis to participate in this study. In order to create an even distribution of sprinters and distance runners, ten from each category were selected.

Those chosen for the sprint group were athletes who specialized in the 100m, 200m, or 110m hurdle races. Those chosen for the distance group were athletes who specialized in the 10,000 m, 5000 m, or 3000 m steeplechase races, averaging 55-90 miles of running a week.

A control group of ten additional subjects was selected. Members of this group consisted of healthy males who had no previous background or structured training in distance running or sprinting.

Testing Procedures

Each subject completed two tests. The first involved a run on the track at a pace of 5.81 m/s (4:37 min/mile). This speed was selected because it is currently the NCAA Division I regional qualifying pace for the men’s 5000 m run -- which represents the pace of many of the selected distance runners. After a five-minute warm-up and stretching, each subject ran approximately 60 m at the above mentioned pace. Timing lights, placed at the 40 m and 50 m marks, were used to monitor the speed. Video footage was also collected between the timing lights. If the recorded time was within 2% of the required pace, the sample was saved. If not, the subject was allowed to recover, then run again. All subjects ran in spiked shoes designed for track athletes.

A 2-D analysis was completed using the Peak Motus System, measuring: Knee extension at toe-off, minimum knee angle, position of recovery knee at touchdown, center of mass position at touchdown, minimum hip angle, shank angle at touchdown, stride length, and contact time (Figures 1, 2 & 3) (Peak Motus 8.0, Colorado Springs, CO). Calibration was performed using Peak's projective scaling method. A Basler 602F (Basler, Germany), running at 180 Hz, recorded each run.

The second trial involved a maximal speed test completed on the track. Subjects began with at least a ten-minute warm-up, followed by a few short sprints close to their maximal speed. The test was very similar to the first, except that it was run at maximal speed. Each subject sprinted approximately 60 m, with the timing lights and camera set between the 40 m and 50 m marks. This allowed each subject adequate time to reach their top speed (Hirvonen, Rusko, Rehunen, and Harkonen, 1987).

The Peak Motus System was again used to calculate data concerning top speed, contact time, stride length, and other body position variables during this portion of the test.

Statistical Analysis

Differences in the dependent variables between groups were tested using ANOVA with Bonferroni post hoc tests for each condition – maximal speed and pace. Concerning the maximal speed condition, the top running speed for each subject served as a co-variate. Alpha was set at 0.05.

Results

Maximal speed trial

Results from the maximal speed trial depicted six significant differences between the sprinters and distance runners, even after accounting for speed. Measurements concerning speed, minimum hip angle, trail-leg knee extension at toe-off, contact time, stride length, and the recovery knee position at touchdown were significantly different

(Table 1). Sprinters and distance runners also exhibited a significantly smaller minimum knee angle than those in the control group.

The sprinters and control group differed significantly concerning the measurements for speed, minimum hip angle, stride length, contact time, and the position of the recovery knee at touchdown (Table 1).

In looking at the location of the center of mass at touchdown, there appears to be a trend toward significant difference between the sprinters and distance runners (Table 1).

Pace trial

Results from the pace trial depicted three significant differences between the sprinters and distance runners. Minimum hip angle, center of mass at touchdown, and the position of the recovery knee at touchdown were all significantly different in comparing the two groups (Table 2).

Sprinters also differed significantly from the control group concerning contact time, the center of mass at touchdown and the position of the recovery knee at touchdown while running at pace (Table 2).

The values for shank angle at touchdown, contact time, and the minimum knee angle appear to present a trend toward significant difference between the sprint group and distance runners ($p = .06$, Table 2).

Discussion

This study was designed with the premise that there are distinct variations in technique and form that separate sprinters from distance runners. Additionally, it was hypothesized that these differences between the two groups would exist at both equal and maximal speeds. This is to say that even when slowed down, sprinters would still run with sprint technique, and distance runners, when attempting to sprint, would still run with distance form. The results in the present study show that many of the measured aspects of technique differ significantly concerning sprinters and distance runners at both speeds.

An interesting difference between distance running and sprinting is illustrated at the hip joint, involving the degree of flexion and extension. When sprinting, most of the increased motion at the hip involves flexion. Prior research has stated that sprinters display approximately 10 to 15 degrees more flexion at the hip joint than distance runners (Mann and Hagy, 1980). The present study supports this, finding that even when the distance runners attempt to sprint, there is still an 11 degree difference regarding the minimum hip angle (Table 1). The sprint group displayed significantly more acute hip angles in both trials. This increased flexion at the hip exhibits a quicker recovery of the leg, as less time is spent with it behind the body (Mann *et al*., 1980).

The more acute hip angle is also related to the reduction of the braking forces during ground contact. When the leg is recovered faster, the athlete is in a better position to initiate the backward acceleration upon foot-to-ground contact (Kivi *et al*., 2002) Higher thigh amplitude, as displayed by the sprint group in this study, is crucial in making this movement possible. Many distance runners, in an effort to cushion the foot-strike, develop a rear-foot landing that allows footwear and skeletal structures to absorb more of the load. This also, however, increases the braking force (Williams *et al*., 1987).

So while this heel-strike may be important when logging high mileage, it is certainly not beneficial when it comes to sprinting.

The degree of thigh amplitude may also be closely related to stride length. While running at maximal speed, the sprint group in the present study produced a significantly longer stride than those of the distance and control groups. In connecting this with the above described thigh amplitude, one can see that with a higher level of hip flexion the leg will be positioned further in front of the body, allowing for a longer stride (Mero, Komi and Gregor, 1992).

Another area of significant difference involved the position of the recovery knee at touchdown. In both trials, the sprint group, at touchdown, exhibited a more forward position of the trailing knee, indicating a quicker recovery of the leg. This positioning can be partially attributed to the degree of knee extension at toe-off, which was also found to be significantly different between the sprint and distance groups during the maximal speed trial. Sprinters exhibited a lower degree of extension, allowing a more powerful push-off with the foot, and a faster turnover of the trail-leg.

This result, regarding the knee extension at toe-off, endorses past research by Kivi *et al*. (2002) in which high speed treadmills were used in sprint development. As the treadmill increased in pace towards 95% of the subject's maximal speed, knee extension at the push-off phase decreased. The straighter the leg becomes, the less power it is able to generate. With a fully extended knee, the push-off phase essentially becomes a flick of the ankle. Elite sprinters, however, begin the recovery phase before the trail-leg straightens out, allowing the muscle groups of the upper leg to assist in the push-off process.

The above-described stance regarding the more forward position of the recovery knee is also highly connected to the knee flexion of the trail leg. During the maximal speed trial, both the sprint and distance groups exhibited a significantly higher degree of flexion in comparison to the normal group. The more acute knee angle shortens the lever arm, allowing a quicker recovery of the trail leg (Williams et al., 1987). With the faster recovery, it is understandable how the trailing knee, at touchdown, is found more forward in its positioning.

In comparing the sprint and pace trials for all three groups, a positive relationship was found to exist between velocity and the range of motion at the hip and knee joints. As the subjects attempted to sprint, more movement at these joints was observed. This increase in range allows for longer strides and shorter lever arms – both of which lead to an increase in speed (Cavanagh and Williams, 1982).

A prior study by Mann *et al*. (1987) demonstrated that as subjects increased their speed, from walking to running to sprinting, their stance time decreased dramatically from one stage to the next. Walking and running registered as .620 s and .220 s, respectively. When the subjects sprinted, their contact time dropped to .140 s. The present study reinforces these results by showcasing several areas of significance concerning contact time. In both the pace and maximal speed trials, the sprint group exhibited a significantly quicker contact time than the control group. The sprinters also differed significantly from the distance runners while running at maximal speed.

In observing the differences in contact time among the groups, one can see that sprinters, in the course of their training, develop the ability to spend less time on the ground with each step. Previous work by Weyand *et al*. (2001) found that one of the major differences between average and great sprinters involved the contact time. The study showed that quicker foot-to-ground contact was more important than even stride frequency or length.

What is of interest with the contact time results is that even at pace, when the speeds are completely equalized, sprinters still exhibit a smaller time spent in contact with the ground. It is understandable to estimate that with all of the high-speed training they complete, sprinters are ingrained to recover their steps as quickly as possible – even when the pace is slowed. If distance runners developed this ability, perhaps the final stage of their race could be more successful.

In the attempt to more accurately measure an event such as contact time, the use of force plates could provide stronger, more correct results (Weyand *et al*., 2001) The high speed camera produces respectable estimates, but it is felt that even at 180 Hz, there is room for inaccuracy when trying to measure an event of this nature.

A result that created some questions involved the shank angle figures. While neither trial produced a significant difference between the groups, there appeared to be a trend towards a difference in the pace runs, separating the sprinters from the distance and control groups. This motion, in showing the direction of the foot at landing to be more negative, exhibits a clawing effect upon foot-to-ground contact (Mero et al., 1992). The hypothesis concerning these figures estimated a difference between the sprint and distance groups in both trials. Additional research regarding this measurement would be beneficial in the attempt to understand the variety of results obtained in the present study.

The results obtained from the maximal speed test concerning the shank angle present an interesting connection with stride length. At maximal speed, the sprint group produced a significantly longer stride length than their distance counterparts, while still exhibiting an equal shank angle at touchdown. Prior research suggests that an increased stride length is normally accompanied by a larger shank angle (Challis, 2001). As the runner over-strides, the lower leg reaches out further in front of the body, leading to a heel-strike and a high braking effect. The present study, however, reveals that sprint technique allows the runner to produce a longer stride and still position the shank nearly vertical upon touchdown.

A possible explanation for this action involves the timing of each stride. As the sprinter demonstrates a more powerful push-off, followed by a quicker recovery of the leg, as well as higher thigh amplitude, there is more time to initiate the clawing effect upon ground contact. Research looking at the velocity of the shank might better explore this relationship.

Considering the control group, most of the measured aspects of technique were found to be comparable to those displayed by the distance group. The only result showing a significant difference between the distance and control groups involved the minimum knee angle. With this information it is suggested that sprint technique is more of a learned skill, different in many ways from the natural process of running.

Conclusion

Considering the above described variation between distance runners and sprinters at maximal speeds, specific changes in technique could be made in an effort to improve performance. Great distance runners are some of the most efficient athletes in all of sport, rarely showing wasted effort or motion. Near the finish, however, economy of movement gives way to top speed. There is a transformation that takes place as they attempt to change from distance runner to sprinter. Results from the present study, however, indicate that this desired adaptation does not necessarily occur. In several of the measured areas concerning leg positioning and stride length at maximal speed, the distance runners exhibited significantly different technique than that of the sprinters. The distance runners, due to their necessary training that emphasizes high levels of efficiency, do not truly know how to sprint. The development of economical distance form is a fairly natural process that occurs with the miles of training. Whatever wasteful motion the runners may begin with is usually phased out as fatigue sets in (Jerome, 1997). Sprinting, however, is a separate, learned technique that often requires specific feedback.

With this being understood, it is suggested that the inclusion of biomechanical intervention into the training programs of both sprinting and competitive distance running would be beneficial. Both efficiency and sprinting power can be monitored and evaluated with the help of biomechanical analysis. As great as it would be to possess elite ability in both the sprints and the distance events, everyone is limited in their range. Biomechanical analysis can help the long-distance runners develop their sprinting form, but it will never make them a world-class sprinter. Physiological differences, such as muscle fiber type, limit the overall capacity for speed development. In working with an eye towards the elite distance runners, however, it is not a matter of making sprinters out of the milers and 5000 m runners. They are simply looking to slightly adapt their form in the later stages of the race in order to increase their speed and finish with the competition.

When attempting maximal speed, distance runners may benefit by focusing on one characteristic of technique. If knee extension at toe-off could be trained to become more sprint-like, the other characteristics unique to sprinters may follow. To further explain this example, one can see that a smaller degree of knee extension at toe-off could lead to a more explosive push-off, followed by a more acute angle of knee flexion during the recovery phase. With a shorter, quicker lever arm, a more forward position of the recovery knee at touchdown would be possible. The center of mass would also be more forwardly positioned, found closer to the point of foot-to-ground contact. From this stance, the athlete could then produce higher thigh amplitude, leading to a longer stride, higher support force, and quicker contact time. (Kivi *et al*., 2002). Whether this type of flow would actually occur stride after stride is still a question to be answered, but the connections between each phase of the step are certainly observable.

References

Brandon, L.J., and Boileau, R.A. (1992). Influence of metabolic, mechanical and physique variables on middle distance running. *Journal of Sports Medicine Physical Fitness*, **32**(1), 1-9.

Cavanagh, P.R., and Kram, R. (1989). Stride length in distance running: velocity, body dimensions, and added mass effects. *Medicine Science Sports Exercise*, **21**(4), 467-479.

Cavanagh, P.R., and Williams, K.R. (1982). The effect of stride length variation on oxygen uptake during distance running. *Medicine Science Sports Exercise*, **14**(1), 30-35.

Challis, J.H. (2001). The variability in running gait caused by force plate targeting. *Journal of Applied Biomechanics*, **17**(1), 47-54.

Hirvonen, J., Rusko, H., Rehunen, S., and Harkonen, M. (1987). Breakdown of high-energy phosphate compounds and lactate accumulation during short supramaximal exercise. *European Journal of Applied Physiology*, **56**, 253-259.

Jerome J. (1997). The elements of effort. New York, NY: Simon & Schuster Inc.Williams, K.R., and Cavanagh, P.R. (1987). Relationship between distance running mechanics, running economy, and performance. *Journal of Applied Physiology*, **63**(3), 1236-1245.

Kivi, D.M.R., Marai, B.K., and Gervais, P. (2002). A kinematic analysis of high-speed treadmill sprinting over a range of velocities. *Medicine Science Sports Exercise*, **34**(4), 662-666.

Mann, R.A., and Hagy, J. (1980). Biomechanics of walking, running, and sprinting. *The American Journal of Sports Medicine*, **8**, 345-350.

Mann, R.A., Moran, G.T., and Dougherty, S.E. (1986). Comparative electromyography of the lower extremity in jogging, running, and sprinting. *The American Journal of Sports Medicine*, **14**(6), 501-510.

Mero, A., Komi, P.V., and Gregor, R.J. (1992). Biomechanics of sprint running. A review. *Sports Medicine*, **13**(6), 276-292.

Weyand, P.G., Sternlight, D.B., Bellizzi, M.J., and Wright, S. (2001). Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *Journal of Applied Physiology*, **89**(5), 1991-1999.

Williams K.R., Cavanagh P.R. (1987). Relationship between distance running mechanics, running economy, and performance. *Journal of Applied Physiology*, **63**(3), 1236-1245.

Table 1: Maximal Speed Trial Results

	Sprinter (A)		Distance (B)		Control (C)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Speed (m/s)	9.35 ^{BC}	.059	8.40	.059	8.26	.073
Min. Knee Angle (deg)	32 ^{C}	7.531	33 ^{C}	4.391	41	6.455
Min. Hip Angle (deg)	101 ^{BC}	8.418	112	5.564	112	5.008
Knee Ext. at toe-off (deg)	151 ^{B}	7.470	163	6.262	156	7.047
Contact Time (s)	.109 ^{BC}	.009	.124	.017	.131	.012
Stride Length (m)	4.447 ^{BC}	.219	4.035	.313	3.862	.453
Shank Angle at touchdown (deg)	2	2.394	1	2.601	1	5.164
Center of mass at touchdown (m)	.377	.043	.406	.054	.410	.048
Recovery knee at touchdown (m)	.395 ^{BC}	.069	.539	.107	.514	.113

Note. Superscripts (A,B,C) denote differences between groups at $p < .05$ in the Bonferroni post hoc comparison (i.e. a variable with a superscript means the variable is significantly different from the subsequent variables superscripted).

Table 2: Pace Trial Results

	Sprinter (A)		Distance (B)		Control (C)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Speed (m/s)	5.81	.033	5.81	.025	5.78	.020
Min. Knee Angle (deg)	39	8.536	45	7.128	48	8.469
Min. Hip Angle (deg)	117 ^{B}	10.696	126	5.837	125	4.017
Knee Ext. at toe-off	163	4.342	161	3.351	161	4.868
Contact Time (s)	.168 ^{C}	.012	.177	.018	.187	.012
Stride Length (m)	3.88	.233	3.66	.175	3.72	.360
Shank Angle at touchdown (deg)	5	3.225	7	2.530	8	3.348
Center of mass at touchdown (m)	.408 ^{BC}	.053	.457	.033	.462	.038
Recovery knee at touchdown (m)	.460 ^{BC}	.112	.587	.076	.618	.089

Note. Superscripts (A,B,C) denote differences between groups at $p < .05$ in the Bonferroni post hoc comparison (i.e. a variable with a superscript means the variable is significantly different from the subsequent variables superscripted).

Figure 1: Picture Exhibiting Minimum Hip Angle

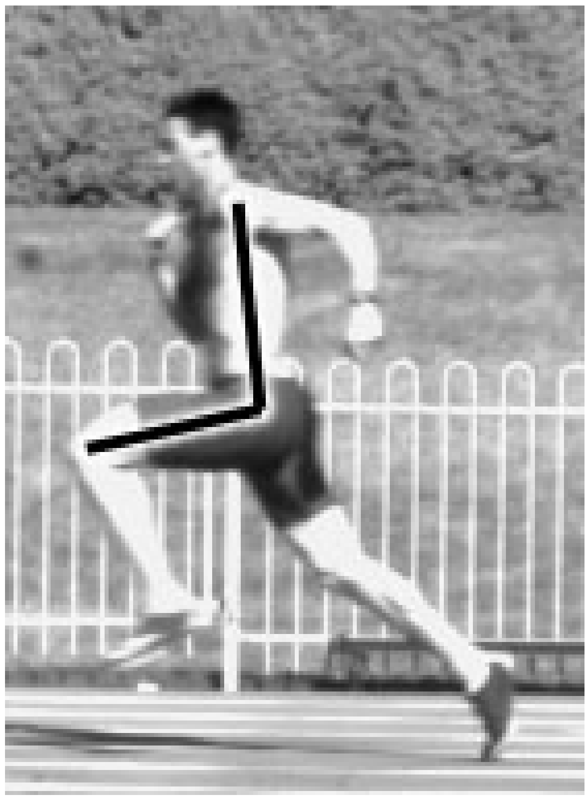


Figure 2: Picture Exhibiting Minimum Knee Angle

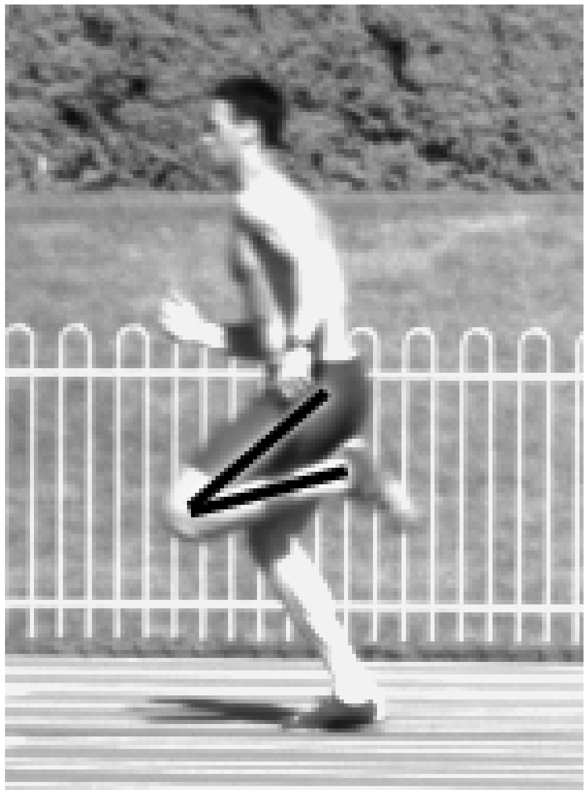
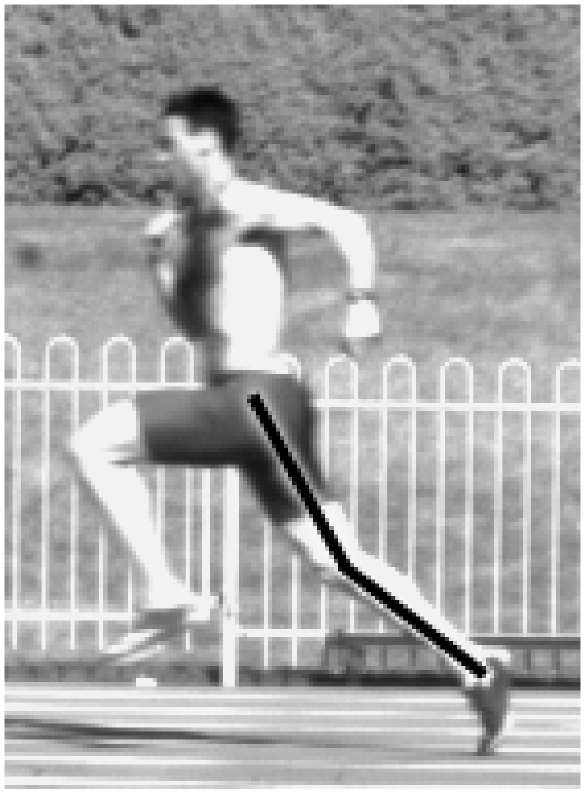


Figure 3: Picture Exhibiting Knee Extension at Toe-off



Appendix A

Prospectus

Chapter 1

Introduction

In the sport of track and field, two major categories of athletes are sprinters and distance runners. As they compete in their respective events, there are many differences between the two groups. Sprinting is not simply running fast, just as distance running is not just running long. There are distinct variations in technique and form that separate the two styles of running.

Sprinting is associated primarily with power and speed, whereas distance running is focused on efficiency and smoothness of movement. This major difference is easily observed at a track meet or practice where both groups are competing. As the distance team runs lap after lap, their ease of movement and smoothness of stride is apparent. They show little wasted movement, and appear collected and controlled in their actions. The sprinters represent the other end of the spectrum with their high speed and explosive movement. They showcase their power with quick, violent motion as they speed down the track.

Within each race, however, there are elements from each that overlap. With distance events, there comes a time near the end of the race where economy of movement gives way to speed. The runners become less concerned with their economy and more concerned with crossing the finish line as soon as possible. When this happens, many runners simply continue with their same form, attempting to increase the pace. If they knew how to alter their technique in a way to become more like a sprinter, this process could possibly be more successful. The majority of the race is still controlled by the issue of efficiency, but as the finish nears, changes may be made to improve performance.

Some of these changes involve positioning the body for a foot contact that minimizes braking and maximizes forward acceleration. Braking forces and the hip flexion angular velocity are connected by an inverse relationship. By increasing the angular velocity at the hip, showing a quicker recovery of the leg, the braking force will be reduced.[1] Knee flexion comes into play with the leg recovery as well. By showcasing a higher degree of flexion, the runner is able to shorten the lever arm of the leg as it is pulled from behind the body to the front.[2]

Another area of focus, concerning the differences between sprinting and distance running involves the contact or stance time with each step. As speed increases, the foot-to-ground contact times dramatically decrease. In a study by Weyand, Sternlight, Bellizzi, and Wright findings showed that when comparing slow vs. fast sprinters, the greatest differences between the two groups involved the support forces and contact times.[3]

In order to understand these variations, with an eye towards improving distance running performance near the finish line, an analysis of sprinters and distance runners, while running at an equal pace, needs to be completed. This study will determine whether the technique of sprinters and distance runners is different at equal and maximal speeds.

Purpose Statement

The purpose of this study is to compare the differences in technique between sprinters and distance runners while running at equal and maximal speeds.

Hypotheses

When running at a pace of four minutes per mile, in comparison to distance runners, sprinters will:

1. exhibit a longer stride length;
2. exhibit a shorter contact time;
3. exhibit a slower stride rate;
4. produce a more acute angle of knee flexion in the recovery leg;
5. position their foot, at touchdown, closer to their center of mass in the A/P direction;
6. exhibit a smaller angle of knee extension at take-off;
7. produce higher thigh amplitude;
8. exhibit a more forward position of the recovery knee at touchdown; and
9. show the direction of the foot at landing to be more negative.

When running at maximal speed, sprinters will exhibit all of the above, minus the slower stride rate. At maximal speed, sprinter will produce a faster stride rate than their distance counterparts.

The measurements of the control group are expected to be similar to the distance runners, but more variable.

Limitations

1. Subjects will be recruited on a volunteer basis, rather than using a random sample.
2. The majority of the subjects' racial status will be Caucasian.
3. The subjects involved will be male.

Delimitations

1. The sample will include 20 members of the BYU men's track and field team.
2. The subjects will be divided into three categories -- sprinters, distance runners, and a control group with no prior structured experience in sprinting or distance running.

Definition of Terms

Step -- Foot contact of one foot until contact of the opposite foot.

Stride -- Two steps in a row. A stride is completed when the feet regain the initial relative positions.

Stride Index -- The distance from the heel to the center of the pressure point as a percentage of shoe length, measured at the time that the increasing vertical ground reaction force curve reaches 10% of maximal vertical force.

Thigh amplitude -- During flight, the minimum angle between the trunk and the thigh of the lead leg.

Significance of Study

The significance of this study involves two main areas. The first deals with the technique differences between the two groups of track athletes. We know that variations exist between sprinters and distance runners, but do they still exist when everyone is running at the same speed? If they do, what are the specific differences? Once these questions are better understood, we can then begin handling the second area of significance, which involves possible training adaptations for distance runners. At the end of each distance race, there is a moment when the emphasis changes from economy of movement to raw speed. The runner is no longer concerned with fluid efficiency, but rather becomes completely focused on crossing the finish line as fast as possible. It is at this moment when the distance runner needs to become a sprinter. They need to know what technique differences they should make in order to create more power and speed. With the results of this study, we can hopefully provide understanding in this area.

Chapter 2

Review of Literature

In comparing sprint vs. distance form, a few basic differences should be understood. Sprinting focuses on power, explosiveness and top speed. The use of the body centers on the development of force, and the effort is highly intense. Distance running is focused more on the economy of movement, with form that is fluid and efficient, exhibiting little wasted motion. "The body is quiet, the head still, the arms pump only enough to provide adequate counterbalance. There's no excessive or violent motion anywhere, no bobbing up and down, the feet lifted no higher than required to get the job done. Everything is smooth".[4] As distance runners develop their form through miles of training, whatever wasteful motion they may begin with is usually fazed out as fatigue sets in. In studying the two forms of running, they are found at opposite ends of the spectrum. One is strictly power and speed, whereas the other relies on high levels of efficiency.

Over the years there have been several methods employed concerning the examination of different running technique. Electromyographic timing, center of mass measurements, raw force-plate data, joint movements, and joint powers are just a few of the means that have been used.[5] The impacts of changes in velocity, as well as the characteristics of the gait cycle are other areas that have been opened up and looked at. To better understand the present study, an examination of these methods, and their usefulness, is important.

To explore the motion of sprinting vs. running, Mann, Moran, and Dougherty conducted an electromyographic (EMG) study of the lower extremity muscles that involved a comparison of jogging, running, and sprinting.[6] Results showed that as the subjects increased their speed, their stance time decreased dramatically from one stage to the next. Stance time involves the moment in which their foot was on the ground with each step. For walking, this phase was recorded as 620 msec. Jogging and running registered as 260 msec and 220 msec, respectively. When the subjects sprinted, their stance time dropped to 140 msec. This lowered support phase is one factor that separates sprinting from simply running fast. From the EMG readings, this study also showed that the primary muscle group associated with the increase of speed is the hip flexor.[6] A separate, yet similar study by Mann and Hagy also showed an increase in quadricep and hamstring activity with a rise in speed.[7]

Mann and Hagy also looked at the hip and knee motion of runners and sprinters. A positive relationship exists between velocity and the range of motion in these two joints.[7] An interesting difference between distance running and sprinting is illustrated at the hip joint, involving the degree of flexion and extension. When sprinting, most of the increased motion at the hip involves flexion. The sprinter displays approximately 10 to 15 degrees more flexion at the hip joint than the runner. The degree of extension in the hip, at sprint speed, is actually decreased slightly in comparison to distance running.[7] This increase in flexion, and decrease in extension yields a quicker recovery of the leg, as less time is spent with the leg behind the body. In discussing the motion at the knee at sprint velocity, it is actually similar to the hip in that the degree of flexion rises, while extension slightly drops. This motion, in both the hip and knee, creates a lower center of gravity for the body.[7]

Mann and Hagy also touched on the electromyographic activity of the anterior muscles of the calf.[7] With running and sprinting, these muscles experience a concentric contraction at the time of contact. When the subject is walking, the contraction is eccentric.[7] This is connected with the increased plantar-flexion associated with higher speeds. As you move from a jog to a sprint, the heel-strike will disappear. Elite sprinters are striking with their fore-foot, leading quickly to the explosive concentric contraction of the calf muscles, and plantar flexion of the foot.

As high-speed treadmills have progressed in quality, they have become more popular as tools for speed development. Specific training programs can be followed, and all conditions can be closely monitored. A recent study included a biomechanical analysis of six elite sprinters as they completed four trials on a treadmill at differing intensities.[1] The emphasis was on sprinting, as the participants ran at 70%, 80%, 90%, and 95% of their individual maximum velocity. Camera footage was collected as each trial lasted 3-5 seconds, enough to analyze three successive strides. Stride frequency, stance time, and flight time were all recorded, as well as hip and knee kinematics. As speed increased, stance time and flight time both decreased. The stride frequency increased with the higher velocities.[1] This is to be expected as one sprints. Their legs move more rapidly, and their feet spend less time on the ground with each step. The kinematic analysis of the knee measured flexion, extension, and the angular velocity of both flexion and extension. As the speed increased towards 95%, knee extension at the push-off phase decreased. The straighter the leg is at this point in time, the less power it is able to generate. With the lower degree of extension, higher speeds are possible. The angular velocities at the knee, in both flexion and extension, showed significantly higher values at the 95% trial in comparison to the 70% trial. The importance of this increase from a sprinter's point of view is explained in the following statement. "Knee extension angular velocity is important in allowing the lower leg enough time to be able to produce sufficient knee flexion angular velocity at touchdown, which will reduce the forward braking force during the initial portion of ground contact."[1] Additionally, the values obtained from the kinematic analysis of the hip show that flexion at the hip increases significantly as the velocity mounts; and the same goes for the hip flexion angular velocity. This leads us to understand that the "ability of a sprinter to reduce braking forces during ground contact may be related to the ability to recover the leg forward. If the leg is recovered faster, the athlete will be in a better position to initiate the backward acceleration of the leg to ground contact."[1] Other observed differences involved the increase in hip extension angular velocity. One of the acknowledged advantages of treadmill sprint training is that this extension velocity is dramatically increased due to the help provided from the moving belt.

Kivi, Marai, and Gervais, in showing the differences that occur at each stage of velocity, have helped in exploring some key variations between runners and sprinters.[1] With the above information concerning hip and knee angles, as well as the angular velocities of both, one can see how they differ as speed increases. Sprinters, since they regularly train at high speeds, are likely to produce more acute angles at the hip and knee.

Their overall higher speed also leads to the regular production of an increased angular velocity at the hip. Whether this still occurs, compared to distance runners, when they are running slower has yet to be looked at.

Elite sprinters, as discussed earlier, strike fore-foot first, which leads to a shortened stance time. Past research has established that contact or stance time is negatively related to running speed.[8] A rear foot strike, as exhibited by many distance runners, will certainly lengthen the phase of contact at each step. Weyand, Sternlight, Bellizzi, and Wright conducted a study that explored what influences the top sprint speeds in human runners.[3] Their hypothesis suggested that top speed is more heavily effected by the amount of force applied to the ground rather than how quickly our legs are repositioned in the air. Their research fought against the more common idea that stride length and frequency are most responsible for greater forward velocity. As part of the study, their subjects completed several rounds of short, increasingly faster sprints on a high-speed treadmill. Perpendicular forces applied to the running surface, as well as contact times for each step, were recorded throughout the test. Stride length, frequency, and contact length were also collected. As speed increased, so did the support forces applied to the running surface. Additionally, the foot-ground contact times were dramatically reduced.[3] When comparing slow vs. fast runners, Weyand found that the greatest differences between the two groups involved the support forces and contact times. Utilizing stride frequency for top speed was found to be somewhat limited in that the slowest subject, with a top speed of only 6.2 m/s, exhibited a nearly equal time of repositioning the leg for the next step as the fastest 100m sprinter in the world.[3] This subject is running half as fast as the world record holder, yet the stride frequency is nearly the same. This concept exhibits once again how sprinting differs from running fast.

The research discussed above should not discount earlier studies focusing on the issue of stride frequency. If one moves his legs faster, and maintains his stride length, he will increase his speed. That is not debatable. What Weyand, Sternlight, Bellizzi and Wright added to the discussion is the comparison between a recreational runner, and a highly trained sprinter.[3] When this is looked at, and you are able to evaluate their support force and contact time, stride frequency is not going to be the answer for the difference in speed. Stride frequency, when increased, will certainly contribute to a higher velocity, but the differences between a fast and slow runner are going to come primarily from the increase in support force and the decrease in contact time.

One aspect this study hopes to explore is whether this difference in contact time between sprinters and runners is present when they are both running at the same velocity. Are the sprinters, who train at higher speeds and possess more fast-twitch muscle fibers, programmed to consistently produce higher ground force and lower contact time even when running at slower speeds? We aim to answer this.

A previous study approached a portion of the above topic by examining the differences found between knee extensor and flexor muscles with sprint vs. endurance training.[9] After an eight week training program of either sprint work or distance running, the subjects involved completed a number of tests concerning their knee extension and flexion strength. Endurance, concerning these muscle groups, was also measured. The results were interesting in that the sprint group showed an increase in extensor capabilities, and a slight decrease in flexor torque. The endurance group also exhibited an increase in extensor strength, but showed no change in flexor torque. Further analysis involving the flexor/extensor ratio showed that sprint training can possibly encourage a greater difference in strength between the knee flexors and extensors in comparison with the distance runners.[9] A focus of the study involved how this imbalance between the two muscle groups may possibly lead to higher levels of injury. It also, however, showcases some additional variation between sprinters and distance runners, and how their different training and techique produces different adaptations.

When examining a sprint in three separate stages, we look at the start or acceleration phase, the constant-speed phase, and the braking phase. To begin with, fast sprinting speeds are achieved by those who are able to produce the greatest amount of force and power possible. The sprinter is looking to create the highest velocity as soon as he can. From that acceleration, the sprinter then moves into the constant-speed phase where the focus shifts towards maintaining that high velocity to the finish. Once across the line, the sprinter moves into the braking phase, which involves a biomechanical shift that slows the body down.

In order to enhance the acceleration and constant-speed phases, Mero, Komi, and Gregor have stated that, "efficient sprint running requires an optimal combination between the examined biomechanical variables and external factors such as footwear, ground and air resistance."[10] These factors, along with the continued study of the nervous system, muscle force, and power production will allow for continued progress in the future concerning the most favorable form of sprinting.

As discussed earlier, distance running focuses on economy. In thinking mechanically, angles, attachment points and lines of force come together to aid in the understanding of economy of movement. John Jerome explains it in the following way: "The more economical you can make your stride, the farther, faster, and safer you can run. A deeper understanding of the mechanics of running can improve your performance."[4] A study conducted by Williams and Cavanagh looks into the realm of distance running efficiency.[2] Biomechanical measures were recorded as the subjects completed runs on the track and the treadmill. Stride length, velocity, and the angles of several joints were analyzed. The 55 subjects involved in the study were all accomplished runners, and were broken into three groups based on their VO_2submax values. The more skillful runners made up the low VO_2submax group, while the medium and high groups were slightly less proficient. The test was run at 3.57 m/s; therefore, distance form was the primary variable of interest. The results obtained concerning the joint angles showed interesting differences between those exhibiting a high level of economy vs. those who did not. Many of them differed significantly from one VO_2submax group to the next. The shank angle, described as the angle of the lower leg as you step forward, showed further extension for those in the low VO_2submax group. They also exhibited more of a forward lean with the trunk – 5.9º for the low VO_2submax group compared to 2.4º for the high VO_2submax group.[2] Arm and wrist movement was also quite different between the two categories. Those with the higher VO_2submax had a much less efficient motion concerning their arm carry. Another difference was observed with the amount of vertical oscillation during the run trials. Those who are more efficient in their running will show less up and down movement. This was seen in the study with the low VO_2submax group exhibiting 9.1 cm of oscillation, compared to the high VO_2submax group, who registered at 9.6 cm.

In looking at the knee flexion of the trail leg, Williams and Cavanagh again found a difference between the high and low VO_2submax groups.[2] A more efficient runner will shorten the lever arm by showing more flexion at the knee as the hip flexors pull the leg forward from behind the body to the front. This was observed in the study as those who ran more economically produced a higher knee flexion during this support phase – 43.1º for the low VO_2submax group, compared to 39.4º for the high VO_2submax group.[2]

Although there are numerous variations in stride kinematics, analysis such as the above described study has shown that subtle changes can lower the metabolic energy costs. For example, those in the low VO_2submax group "showed a lower stride index, longer contact time, a lower maximal vertical force peak, and a more extended lower leg at foot strike, all characteristics of a foot strike back toward the heel. Lower energy costs might be related to the cushioning that takes place immediately following contact."[2] Whatever portion of the body you decide to analyze, from the heel to the hip to the trunk, it is theoretically possible that by tweaking a certain aspect of a runner's style, a lowered VO_2submax could result.

Having stated the above, it should also be noted that other studies have showed most distance runners self-select their optimal stride length to minimize oxygen uptake.[11]

Therefore, concerning economy, one should be careful in looking to alter the length of their stride.

In further discussion of stride length, a study by Cavanagh and Kram produced results which showed a linear relationship between stride length and velocity.[12] Stride frequency, on the other hand, was found to remain fairly constant. During the testing portion of the study, which involved a treadmill run, as the speed increased from 3.15 m·¯1 to 4.12 m·¯1 the subjects increased their stride frequency by only 4% while lengthening their stride length by 28%.[12]

When looking back at our analysis of a sprinter, we can see the components of economical running differing greatly from those of sprinters. Therefore, why would we even look to incorporate the two at the conclusion of a distance race? Great milers are some of the most efficiently smooth runners in the world. As they progress through their race, there is rarely a wasted effort or motion. Near the finish, however, economy of movement gives way to top speed. There is a transformation that takes place as they attempt to change from distance runner to sprinter. It is believed by some that the U.S. distance track team has struggled with this adaptation. Now, rather than leaving this process to self-optimization, biomechanical observation is attempting to intervene with feed back and the fine-tuning of certain movement.[2]

A study conducted by Brandon and Boileau looked at the differences among three groups of middle distance runners – 800m, 1500m, and 3000m.[13] The variables of VO_2max, stride length, anaerobic capacity, peak velocity, thigh length, and percent body fat were all examined among the three distance categories.[13] The results showed that there were strong differences between the preferable type of training for one running the 1500m or 3000m, and one running the 800m. The data showed that 800m runners would benefit from an emphasis on anaerobic speed work, aerobic conditioning, and maintaining muscle mass. Those who race the 1500m or 3000m are better suited to train for the enhancement of VO_2max, stride length, and a large anaerobic capacity.[13]

With the results of this study being known and understood, it is also suggested that biomechanical intervention be added to the training regimen, as well. As explained through much of the above-described experiments, both efficiency and sprinting power can be monitored and evaluated with the help of biomechanical analysis. As great as it would be to possess elite ability in both the sprints and the distance events, everyone is limited in their range. Biomechanical analysis can help the long-distance runners develop their sprinting form, but it will never make them a world-class sprinter. Physiological differences, such as muscle fiber type, limit the overall capacity for speed development. In working with an eye towards the U.S. distance team, however, it is not a matter of making sprinters out of the milers and 5000m runners. They are simply looking to slightly adapt their form in the later stages of the race in order to increase their speed and race with the competition.

Due to past research concerning over-ground vs. treadmill running, it is understood that there are consistent biomechanical differences in the running form of the two methods.[14] The significant differences are most commonly found in the support phase of each step. One such distinction involves an over-extension of the landing leg in the treadmill mode of running. This leads to a higher braking force, as well as a center of mass that is further back from the touchdown position of the foot in comparison to over-ground running. Another difference in the support phase involves a greater range of angular motion concerning the supporting leg. Research attributes these differences to the moving treadmill belt, and its ability to bring the supporting foot back under the body on its own.[14] Due to the biomechanical variations between the two modes of running, this study will conduct all tests on the track.

In discussing what we expect to find through our testing, we feel that several differences between the sprinters and distance runners will be discovered and more fully understood. One such distinction involves the contact time. Even as we equalize the pace, we feel that sprinters, due to their training and increased ability for speed, will exhibit a shorter contact time than the distance runners. We also expect them to produce a more acute angle of knee flexion and thigh amplitude when compared to their distance counterparts. We feel this will lead to a more forward position of the recovery knee, and a more negative direction of the lead foot, at touchdown. Finally, due to their technique and form development, we feel the sprinters will also showcase a longer stride length than the distance runners.

Chapter 3

Methods

Subjects

Twenty members of the Brigham Young University Track and Field team will be recruited on a volunteer basis to participate in this study. In order to create an even distribution of sprinters and distance runners, ten from each category will be selected. Those chosen for the sprinter group will be athletes who specialized in the 100m, 200m, or 110m hurdle races. Those chosen for the distance group will be athletes who specialized in the 5000m, 10,000m, or 3000m steeplechase races.

A control group of ten additional subjects will also be selected. Members of this group will consist of healthy males who have no previous background or structured training in distance running or sprinting.

Testing Procedures

Each subject will complete two tests. The first involves a run on the track at a pace of 5.81m/s (4:37min/mile). This speed has been selected because it is currently the NCAA regional qualifying pace for the men's 5000m run. After a five minute warm-up and stretching, each subject will run approximately 50m at the above mentioned pace. Timing lights, placed at the 30 and 40m marks, will be used to monitor the speed. Video footage will also be collected between the timing lights. If the recorded time is within 1% of the required pace, the sample will be saved. If not, the subject will be allowed to recover, and then run again. All subjects will run with their own or borrowed spiked shoes.

A 2-D analysis will be performed using the Peak Motus System, with sampling conducted at 120Hz, hip, knee and thigh positions will be monitored and recorded. Stride length and the center of mass will also be measured.

The second test, to be run on a separate day, involves a maximal speed test completed on the track. Subjects will begin with at least a ten-minute warm-up, followed by a few short sprints close to their maximal speed. The test will be very similar to the first, except that it will be run at maximal speed. Each subject will sprint approximately 80m, with the timing lights and camera set between the 60 and 70m marks. This allows each subject adequate time to reach their top speed.

The Peak Motus system will again be used to calculate data concerning top speed, contact time, stride length and rate, and other body position variables during this portion of the test.

Statistical Analysis

Differences in the dependent variables between groups will be tested using multiple t-tests. Concerning the maximal speed condition, the top running speed for each subject will serve as a co-variate. Alpha will be set at 0.05.

References

1. Kivi DMR, Marai BK, Gervais P. A kinematic analysis of high-speed treadmill sprinting over a range of velocities. Med Sci Sports Exerc. 2002; 34(4): 662-66.

2. Williams KR, Cavanagh PR. Relationship between distance running mechanics, running economy, and performance. J Appl Physiol. 1987; 63(3): 1236-45.

3. Weyand PG, Sternlight DB, Bellizzi MJ, Wright S. Faster top running speeds are achieved with greater ground forces not more rapid leg movements. J Appl Physiol. 200l; 89(5): 1991-9.

4. Jerome J. The elements of effort. New York, NY: Simon & Schuster Inc.; 1997.

5. Novacheck TF. The biomechanics of running. Gait Posture. 1998; 7(1): 77-95.

6. Mann RA, Moran GT, Dougherty SE. Comparative electromyography of the lower extremity in jogging, running, and sprinting. Am J of Sports Med. 1986; 14(6): 501-510.

7. Mann RA, Hagy J. Biomechanics of walking, running, and sprinting. Am J Sports Med. 1980; 8:345-50.

8. Munro CF, Miller DI, Fuglevand AJ. Ground reaction forces in running: a reexamination. J Biomech. 1987; 20(2):147-55.

9. Shealy MJ, Callister R, Dudley GA, Fleck SJ. Human Torque velocity adaptations to sprint, endurance, or combined modes of training. Am J Sports Med. 1992; 20(5): 581-86.

10. Mero A, Komi PV, Gregor RJ. Biomechanics of sprint running. A review. Sports Medicine. 1992; 13(6): 276-292.

11. Cavanagh PR, Williams KR. The effect of stride length variation on oxygen uptake during distance running. Med Sci Sports Exerc. 1982; 14(1): 30-35.

12. Cavanagh PR, Kram R. Stride length in distance running: velocity, body dimensions, and added mass effects. Med Sci Sports Exerc. 1989; 21(4): 467-79.

13. Brandon LJ, Boileau RA. Influence of metabolic, mechanical and physique variables on middle distance running. J Sports Med Phys Fitness. 1992; 32(1):1-9.

14. Frishberg BA. An analysis of overground and treadmill sprinting. Med Sci Sports Exerc. 1983; 15(6): 478-485.

Appendix B

Additional Results

Category: Sprinter

Subject 1

	Max Trial	Pace Trial
Speed (m/s)	9.52	5.95
Minimum Knee Angle (deg)	38	44
Minimum Hip Angle (deg)	96	116
Knee Extension at toe-off (deg)	149	158
Contact Time (s)	0.106	0.167
Stride Length (m)	4.313	3.74
Shank Angle at touchdown (deg)	0	0
Center of Mass at touchdown (m)	0.328	0.361
Recovery Knee at touchdown (m)	0.269	0.437

Subject 2

Speed (m/s)	9.52	5.95
Minimum Knee Angle (deg)	40	41
Minimum Hip Angle (deg)	100	92
Knee Extension at toe-off (deg)	160	157
Contact Time (s)	0.104	0.144
Stride Length (m)	4.116	3.303
Shank Angle at touchdown (deg)	0	6
Center of Mass at touchdown (m)	0.377	0.321
Recovery Knee at touchdown (m)	0.365	0.172

Subject 3

Speed (m/s)	8.7	5.81
Minimum Knee Angle (deg)	25	38
Minimum Hip Angle (deg)	101	110
Knee Extension at toe-off (deg)	158	167
Contact Time (s)	0.12	0.172
Stride Length (m)	4.725	4.04
Shank Angle at touchdown (deg)	4	6
Center of Mass at touchdown (m)	0.438	0.371
Recovery Knee at touchdown (m)	0.436	0.446

Subject 4

Speed (m/s)	9.26	5.92
Minimum Knee Angle (deg)	32	38
Minimum Hip Angle (deg)	111	117
Knee Extension at toe-off (deg)	146	168
Contact Time (s)	0.1	0.16
Stride Length (m)	4.352	4.069
Shank Angle at touchdown (deg)	2	5
Center of Mass at touchdown (m)	0.353	0.427
Recovery Knee at touchdown (m)	0.372	0.532

Category: Sprinter

	Max Trial	Pace Trial
Subject 5		
Speed (m/s)	9.35	5.78
Minimum Knee Angle (deg)	31	34
Minimum Hip Angle (deg)	98	122
Knee Extension at toe-off (deg)	138	167
Contact Time (s)	0.117	0.172
Stride Length (m)	4.418	3.88
Shank Angle at touchdown (deg)	3	5
Center of Mass at touchdown (m)	0.406	0.51
Recovery Knee at touchdown (m)	0.367	0.434

Subject 6

Speed (m/s)	10.1	5.68
Minimum Knee Angle (deg)	32	56
Minimum Hip Angle (deg)	89	126
Knee Extension at toe-off (deg)	155	163
Contact Time (s)	0.104	0.176
Stride Length (m)	4.612	4.051
Shank Angle at touchdown (deg)	1	4
Center of Mass at touchdown (m)	0.414	0.402
Recovery Knee at touchdown (m)	0.493	0.52

Subject 7

Speed (m/s)	9.62	5.95
Minimum Knee Angle (deg)	31	43
Minimum Hip Angle (deg)	101	123
Knee Extension at toe-off (deg)	159	168
Contact Time (s)	0.1	0.164
Stride Length (m)	4.178	3.836
Shank Angle at touchdown (deg)	-1	10
Center of Mass at touchdown (m)	0.303	0.443
Recovery Knee at touchdown (m)	0.355	0.572

Subject 8

Speed (m/s)	8.55	5.71
Minimum Knee Angle (deg)	16	41
Minimum Hip Angle (deg)	99	119
Knee Extension at toe-off (deg)	146	165
Contact Time (s)	0.122	0.178
Stride Length (m)	4.533	3.967
Shank Angle at touchdown (deg)	7	9
Center of Mass at touchdown (m)	0.359	0.401
Recovery Knee at touchdown (m)	0.388	0.463

Category: Sprinter

Subject 9

	Max Trial	**Pace Trial**
Speed (m/s)	9.26	5.81
Minimum Knee Angle (deg)	30	22
Minimum Hip Angle (deg)	101	130
Knee Extension at toe-off (deg)	142	161
Contact Time (s)	0.116	0.188
Stride Length (m)	4.777	4.072
Shank Angle at touchdown (deg)	0	1
Center of Mass at touchdown (m)	0.417	0.443
Recovery Knee at touchdown (m)	0.403	0.535

Subject 10

Speed (m/s)	10.1	5.68
Minimum Knee Angle (deg)	42	39
Minimum Hip Angle (deg)	120	118
Knee Extension at toe-off (deg)	154	159
Contact Time (s)	0.1	0.161
Stride Length (m)	4.441	3.861
Shank Angle at touchdown (deg)	2	6
Center of Mass at touchdown (m)	0.376	0.396
Recovery Knee at touchdown (m)	0.506	0.49

Category: Distance

Subject 11

	Max Trial	Pace Trial
Speed (m/s)	8.7	5.78
Minimum Knee Angle (deg)	40	46
Minimum Hip Angle (deg)	115	124
Knee Extension at toe-off (deg)	166	161
Contact Time (s)	0.111	0.172
Stride Length (m)	4.025	3.545
Shank Angle at touchdown (deg)	-1	8
Center of Mass at touchdown (m)	0.414	0.437
Recovery Knee at touchdown (m)	0.605	0.507

Subject 12

Speed (m/s)	8.62	5.92
Minimum Knee Angle (deg)	35	48
Minimum Hip Angle (deg)	103	128
Knee Extension at toe-off (deg)	154	156
Contact Time (s)	0.124	0.18
Stride Length (m)	4.206	3.816
Shank Angle at touchdown (deg)	-2	4
Center of Mass at touchdown (m)	0.427	0.464
Recovery Knee at touchdown (m)	0.525	567

Subject 13

Speed (m/s)	8.55	5.75
Minimum Knee Angle (deg)	38	43
Minimum Hip Angle (deg)	120	133
Knee Extension at toe-off (deg)	159	164
Contact Time (s)	0.132	0.18
Stride Length (m)	3.953	3.866
Shank Angle at touchdown (deg)	-1	7
Center of Mass at touchdown (m)	0.384	0.488
Recovery Knee at touchdown (m)	0.521	0.721

Subject 14

Speed (m/s)	8.62	5.78
Minimum Knee Angle (deg)	30.4	42
Minimum Hip Angle (deg)	113	116
Knee Extension at toe-off (deg)	161	160
Contact Time (s)	0.111	0.161
Stride Length (m)	4.145	3.574
Shank Angle at touchdown (deg)	0	4
Center of Mass at touchdown (m)	0.367	0.4
Recovery Knee at touchdown (m)	0.401	0.504

Category: Distance

Subject 15

	Max Trial	Pace Trial
Speed (m/s)	7.52	5.75
Minimum Knee Angle (deg)	32	37
Minimum Hip Angle (deg)	120	128
Knee Extension at toe-off (deg)	156	160
Contact Time (s)	0.161	0.222
Stride Length (m)	3.785	3.701
Shank Angle at touchdown (deg)	5	7
Center of Mass at touchdown (m)	0.376	0.426
Recovery Knee at touchdown (m)	0.412	0.535

Subject 16

Speed (m/s)	8.77	5.85
Minimum Knee Angle (deg)	39	54
Minimum Hip Angle (deg)	106	122
Knee Extension at toe-off (deg)	157	162
Contact Time (s)	0.1	0.156
Stride Length (m)	4.007	3.62
Shank Angle at touchdown (deg)	-2	10
Center of Mass at touchdown (m)	0.302	0.424
Recovery Knee at touchdown (m)	0.393	0.536

Subject 17

Speed (m/s)	8.2	5.95
Minimum Knee Angle (deg)	29	38
Minimum Hip Angle (deg)	111	124
Knee Extension at toe-off (deg)	165	157
Contact Time (s)	0.12	0.168
Stride Length (m)	4.184	3.561
Shank Angle at touchdown (deg)	4	11
Center of Mass at touchdown (m)	0.47	0.496
Recovery Knee at touchdown (m)	0.649	0.673

Subject 18

Speed (m/s)	8.47	5.85
Minimum Knee Angle (deg)	32	45
Minimum Hip Angle (deg)	114	133
Knee Extension at toe-off (deg)	171	167
Contact Time (s)	0.122	0.178
Stride Length (m)	4.372	3.88
Shank Angle at touchdown (deg)	3	8
Center of Mass at touchdown (m)	0.391	0.463
Recovery Knee at touchdown (m)	0.592	0.555

Category: Distance

Subject 19

	Max Trial	Pace Trial
Speed (m/s)	8.77	5.75
Minimum Knee Angle (deg)	29	60
Minimum Hip Angle (deg)	113	133
Knee Extension at toe-off (deg)	168	164
Contact Time (s)	0.122	0.183
Stride Length (m)	4.367	3.706
Shank Angle at touchdown (deg)	0	5
Center of Mass at touchdown (m)	0.458	0.493
Recovery Knee at touchdown (m)	0.608	0.662

Subject 20

Speed (m/s)	8.13	5.68
Minimum Knee Angle (deg)	30	42
Minimum Hip Angle (deg)	107	121
Knee Extension at toe-off (deg)	171	162
Contact Time (s)	0.133	0.167
Stride Length (m)	3.309	3.309
Shank Angle at touchdown (deg)	3	4
Center of Mass at touchdown (m)	0.474	0.477
Recovery Knee at touchdown (m)	0.685	0.607

Category: Control

Subject 21

	Max Trial	Pace Trial
Speed (m/s)	8.93	5.85
Minimum Knee Angle (deg)	38	54
Minimum Hip Angle (deg)	111	128
Knee Extension at toe-off (deg)	161	162
Contact Time (s)	0.111	0.183
Stride Length (m)	4.363	2.872
Shank Angle at touchdown (deg)	1	7
Center of Mass at touchdown (m)	0.363	0.503
Recovery Knee at touchdown (m)	0.401	0.686

Subject 22

Speed (m/s)	8.55	5.75
Minimum Knee Angle (deg)	44	47
Minimum Hip Angle (deg)	114	121
Knee Extension at toe-off (deg)	163	169
Contact Time (s)	0.128	0.206
Stride Length (m)	3.99	3.952
Shank Angle at touchdown (deg)	-1	6
Center of Mass at touchdown (m)	0.383	0.457
Recovery Knee at touchdown (m)	0.36	0.605

Subject 23

Speed (m/s)	8.33	1.71
Minimum Knee Angle (deg)	26	33
Minimum Hip Angle (deg)	115	123
Knee Extension at toe-off (deg)	165	158
Contact Time (s)	0.133	0.167
Stride Length (m)	4.166	3.878
Shank Angle at touchdown (deg)	5	7
Center of Mass at touchdown (m)	0.443	0.438
Recovery Knee at touchdown (m)	0.559	0.53

Subject 24

Speed (m/s)	8.62	5.78
Minimum Knee Angle (deg)	44	45
Minimum Hip Angle (deg)	112	121
Knee Extension at toe-off (deg)	149	157
Contact Time (s)	0.128	0.189
Stride Length (m)	4.168	3.816
Shank Angle at touchdown (deg)	7	7
Center of Mass at touchdown (m)	0.432	0.469
Recovery Knee at touchdown (m)	0.517	0.618

Category: Control

Subject 25

	Max Trial	Pace Trial
Speed (m/s)	8.13	5.71
Minimum Knee Angle (deg)	38	42
Minimum Hip Angle (deg)	116	132
Knee Extension at toe-off (deg)	155	154
Contact Time (s)	0.133	0.183
Stride Length (m)	3.919	3.444
Shank Angle at touchdown (deg)	1	14
Center of Mass at touchdown (m)	0.428	0.442
Recovery Knee at touchdown (m)	0.56	0.541

Subject 26

Speed (m/s)	7.87	5.85
Minimum Knee Angle (deg)	40	46
Minimum Hip Angle (deg)	118	125
Knee Extension at toe-off (deg)	162	164
Contact Time (s)	0.15	0.2
Stride Length (m)	4.23	3.922
Shank Angle at touchdown (deg)	2	10
Center of Mass at touchdown (m)	0.45	0.516
Recovery Knee at touchdown (m)	0.646	0.753

Subject 27

Speed (m/s)	7.35	5.68
Minimum Knee Angle (deg)	43	50
Minimum Hip Angle (deg)	107	120
Knee Extension at toe-off (deg)	151	160
Contact Time (s)	0.133	0.194
Stride Length (m)	3.575	3.502
Shank Angle at touchdown (deg)	-1	10
Center of Mass at touchdown (m)	0.357	0.468
Recovery Knee at touchdown (m)	0.458	0.576

Subject 28

Speed (m/s)	7.87	5.78
Minimum Knee Angle (deg)	49	65
Minimum Hip Angle (deg)	102	130
Knee Extension at toe-off (deg)	149	165
Contact Time (s)	0.15	0.189
Stride Length (m)	3.748	4.135
Shank Angle at touchdown (deg)	8	12
Center of Mass at touchdown (m)	0.5	0.487
Recovery Knee at touchdown (m)	0.721	0.756

Category: Control

Subject 29

	Max Trial	Pace Trial
Speed (m/s)	8.62	5.88
Minimum Knee Angle (deg)	41	50
Minimum Hip Angle (deg)	110	123
Knee Extension at toe-off (deg)	155	154
Contact Time (s)	0.128	0.183
Stride Length (m)	2.805	3.771
Shank Angle at touchdown (deg)	-2	3
Center of Mass at touchdown (m)	0.38	0.381
Recovery Knee at touchdown (m)	0.501	0.499

Subject 30

Speed (m/s)	8.62	5.85
Minimum Knee Angle (deg)	48	51
Minimum Hip Angle (deg)	117	127
Knee Extension at toe-off (deg)	145	164
Contact Time (s)	0.117	0.172
Stride Length (m)	3.656	3.866
Shank Angle at touchdown (deg)	-10	5
Center of Mass at touchdown (m)	0.356	0.455
Recovery Knee at touchdown (m)	0.415	0.613