2010-07-08

The Effects of Indoor Track Curve Radius on Sprint Speed and Ground Reaction Forces

Jesse Tipasa Tukuafu
Brigham Young University - Provo

The Effects of Indoor Track Curve Radius on

Sprint Speed and Ground Reaction Forces

Jesse Tukuafu

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

Iain Hunter, Chair
J. Brent Feland
Matt Seeley

Department of Exercise Sciences

Brigham Young University

August 2010

ABSTRACT

The Effects of Indoor Track Curve Radius on

Sprint Speed and Ground Reaction Forces

Jesse Tukuafu

Department of Exercise Sciences

Master of Science

Sprinting on a curve is significantly slower than on a straightaway. Although the dimensions vary from track to track, indoor track curves are among the tightest curves that athletes will sprint at maximal speed. Previous studies have provided theories for how speed attenuation occurs when running on a curve. Yet, no previous research has determined how the variability of indoor track curve radii affects trained sprinters at maximal speeds. **Purpose:** To determine the differences in running speeds, ground time (GT), and medio-lateral (ML) impulse, with different indoor track radii. A secondary purpose was to understand the between-leg differences in GT and ML impulse during maximal sprinting on a curve. **Methods:** 10 male intercollegiate sprinters performed 45-m maximal sprints on a straightaway, 15-m track curve and 21-m track curve. A force platform embedded under an indoor track surface measured ground reaction forces while timing lights measured running speed. **Analysis:** A mixed models analysis of variance blocking on subjects was performed testing the main effects of the track curve on sprinting speed, GT and ML impulse ($p<0.01$). **Results:** Sprinting speed was significantly slower when running on a curve. GT increased for inside leg on both curved path conditions compared to straight. ML impulses increased as the radius of the track curve decreased. **Discussion:** If a 200m race were performed on both our track curves, the track with 21m curve would be 0.12s faster than the track with the 15m curve. GT and ML impulse results support leading explanations that the inside leg is the limiting factor during curve running. Tighter track curves require greater ML forces, but for a shorter period of time compared to larger track turns. Coaches and athletes should consider the radius of the track curve as they prepare for training and performance and consider injury risk. The speed differences observed due to the track curve radius may provide the first step to understanding how the radius of the indoor track curve affects sprinting speed and ultimately, performance.

Keywords: running, kinetics, biomechanics, sport

Word Count: 329

ACKNOWLEDGEMENTS

Thank you to Dr. Hunter for your guidance, friendship and patience. Thanks to the BYU Men's Track Team for letting me take two weeks of practice to conduct this study. Big thanks to my family for all their support, especially my wife, Megan, for always encouraging me to do what I love and thanks to my inspiration, my son, Nathan.

Table of Contents

List of Tables

List of Figures

The Effects of Indoor Track Curve Radius on Sprint Speed and Ground Reaction Forces

Jesse Tukuafu, MS, Exercise Sciences, Brigham Young University

Iain Hunter, PhD, Exercise Sciences, Brigham Young University

J. Brent Feland, PT, PhD, Exercise Sciences, Brigham Young University

Matthew Seeley, PhD, ATC, Exercise Sciences, Brigham Young University

Correspondence: Jesse Tukuafu

(801) 836-2696.

Email: tukuafu22@yahoo.com

Abstract

Sprinting on a curve is significantly slower than on a straightaway. Although the dimensions vary from track to track, indoor track curves are among the tightest curves that athletes will sprint at maximal speed. Previous studies have provided theories for how speed attenuation occurs when running on a curve. Yet, no previous research has determined how the variability of indoor track curve radii affects trained sprinters at maximal speeds. **Purpose:** To determine the differences in running speeds, ground time (GT), and medio-lateral (ML) impulse, with different indoor track radii. A secondary purpose was to understand the between-leg differences in GT and ML impulse during maximal sprinting on a curve. **Methods:** 10 male intercollegiate sprinters performed 45-m maximal sprints on a straightaway, 15-m track curve and 21-m track curve. A force platform embedded under an indoor track surface measured ground reaction forces while timing lights measured running speed. **Analysis:** A mixed models analysis of variance blocking on subjects was performed testing the main effects of the track curve on sprinting speed, GT, and ML impulse ($p<0.01$). **Results:** Sprinting speed was significantly slower when running on a curve. GT increased for inside leg on both curved path conditions compared to straight. ML impulses increased as the radius of the track curve decreased. **Discussion:** If a 200m race was performed on both our track curves, the track with 21m curve radius would be 0.12s faster than the track with the 15m curve radius. GT and ML impulse results support leading explanations that the inside leg is the limiting factor during curve running. Tighter track curves require greater ML forces, but for a shorter period of time compared to larger track turns. Coaches and athletes should consider the radius of the track curve as they prepare for training and performance and consider injury risk. The speed differences

observed due to the track curve radius may provide the first step to understanding how the radius of the indoor track curve affects sprinting speed and ultimately, performance.

Introduction

Running on a curved path is an integral part of track and field events. However, running on a curved path compared to a straight path is significantly slower (Y. Chang & Kram, 2007; P. R. Greene, 1985; Hamill, Murphy, & Sussman, 1987). This decrease in speed may be most apparent when considering indoor track designs. Indoor tracks are generally much smaller than outdoor tracks resulting in tighter curves. The International Association of Athletic Federations (IAAF) specifies that that a 200m indoor track can have a radius ranging from 15m to 19m with 17.20m being the "200-m standard indoor track" (Wilson, 2008). In the United States, the National Collegiate Athletic Association (NCAA) specifies for indoor track championships that "the inside radius of the curves on a 200-meter track should be not less than 18m and not more than 21m" (Podkaminer & Danehy, 2008). Depending on the level of competition, an athlete could compete on a track with curve radii ranging from 15m to 21m.

Understanding speed attenuation when running on a curved path has been a primary focus of previous research (Y. Chang & Kram, 2007; P. R. Greene, 1985; P. R. Greene, 1987; Hamill et al., 1987; Jindrich, Besier, & Lloyd, 2006; Stoner & Ben-Sira, 1978). Running on the curve is often compared to an object moving in circular motion in classical physics (Y. Chang & Kram, 2007; P. R. Greene, 1985; Hamill et al., 1987). In order to be continuously changing direction around the curve, a runner must generate centripetal forces with the ground. This requires athletes to put some of their efforts into generating ground reaction forces that accelerate them towards the axis of rotation of the curve. As the medio-lateral (ML) ground reaction forces increase to generate centripetal forces, the vertical forces are decreased which results in a loss of running speed (Y. Chang & Kram, 2007). Linear sprint speed increases with increased vertical ground reaction forces and decreased ground contact time (Weyand, Sternlight, Bellizzi, & Wright, 2000).

Researchers who have studied running on the curve have identified the major causes of speed attenuation as decreased vertical ground reaction forces due to the altered body positioning required to generate increased horizontal ground reaction forces due to altered body positioning (Y. Chang & Kram, 2007; P. R. Greene, 1985; Hamill et al., 1987; Jindrich et al., 2006). Sprinting at maximum velocity around extreme curves of 6m or less radii shows that the inside leg will perform much differently than the outside leg (Y. Chang & Kram, 2007; Smith, Dyson, Hale, & Janaway, 2006). The inside leg is limited in its ability to produce peak vertical ground reactions forces due to the generation of centripetal forces. Extremely small curve radii cause a runner to make extreme alterations in foot positioning (Y. Chang & Kram, 2007). Even on a curve of 31.5 m the inside foot usually strikes the ground in a more pronated position than the outside foot (Hamill et al., 1987). The inside leg is responsible for braking and changing direction. The outside leg is primarily responsible for propulsion and also plays a role in changing direction (Smith et al., 2006). Therefore, the differences in ground reaction forces between inside and outside legs can help identify the changes made by a sprinter to different track curve radii and may also account for changes in speed.

Previous studies did not quantify differences in sprint performance that can be attributed specifically to indoor track radius. Combining the guidelines set forth by the IAAF and the NCAA, a US sprinter could compete on a track with a radius between 15m and 21m. No researchers have determined how a range of track radii from 15m to 21m affects performance in sprinting events. Some researchers studied maximal sprinting on radii that were not comparable for 200m track design (Y. Chang & Kram, 2007) and others studied maximal sprinting performed by recreational runners on a banked turn (P. R. Greene, 1987). Other studies that analyzed running on a curve used running speeds that were submaximal (P. R. Greene, 1987; Hamill et al., 1987; Jindrich et al., 2006; Kawamoto, Ishige, Watarai, & Fukashiro, 2002; Stoner & Ben-Sira, 1978).

The primary purpose of this study was to determine the effect of indoor track radii on running speeds, ground time (GT), and ML impulse. A secondary purpose was to identify potential between-leg differences for GT and ML impulse during maximal sprinting on curves of different track radii. At maximal running speed, the longest GT, greatest ML impulse and slowest sprinting speed were expected to be on a 15-m track curve. For each track curve condition, we hypothesized that the inside leg will experience longer GT and ML impulse compared to the outside leg.

Methods

Subjects

Ten NCAA Division I male sprinters (age 22 ± 3 yr) participated in this study. Sprinters were defined as competitors in track events 400m or less. Age, height, mass, and best performance times were recorded at the time of data collection. Each subject signed a consent form approved by the Institutional Review Board prior to any testing. All subjects had been free from injury for at least 2 months prior to testing.

Running Protocol

Subjects were asked to perform their traditional warm up before a workout or race. Following this warm up, the subjects performed 45m sprints at a maximal speed. Each subject was given five minutes rest between sprints to avoid fatigue and ensure maximal effort. The study consisted of three days of testing. Testing days were separated by a minimum of two days and a maximum of seven days. For each testing day, a maximum of eight sprinting trials were performed to avoid injury and fatigue.

On each testing day, each subject was assigned one of three sprint condition using a randomized block design (Figure 1).

1) 45-m straight sprint
2) 45-m sprint with a 21-m track curve beginning at the 30-m mark
3) 45-m sprint with a 15-m track curve beginning at the 30-m mark

To assess differences between right and left legs, sprinters were asked to start the sprints alternating between right and left feet every sprint. A valid sprint consisted of full-foot contact with a force plate embedded in the track at the 35-m mark of each sprint. Full-foot contact was determined by a research assistant who visually confirmed contact within a marked box on the track. For the eight sprint trials, a minimum of one valid contact with left leg and one with the right leg were required per trial day. All subjects ran with their own training shoes.

Sprinting speed was assessed using two sets of photoelectric timing systems aimed at shoulder height of shortest subject. The first set was placed at the 20-m and 30-m mark. The first 10-m split was used to ensure that each subject exerted maximal effort on each trial since the first 30m for each trial were on a straight path. It was assumed that with maximal effort the 10-m splits would be within 2% of the average straightaway split. Trials that were below the maximal effort range were left out. A second set was used starting at the 30-m and 40-m mark to assess differences in speed based on the assigned sprint condition.

Force Plate

A Kistler force plate (Type 9287BA, 900 mm x 600 mm, Amherst, New York, USA) was used to collect ground reaction force data. The force place was located 35m from the beginning of each run and was embedded under a Mondo indoor track with an asphalt foundation. The force plate was covered with the same texture and surface as the rest of the track as well as the practice area inside the track curve. The calibration of the force plate took place during manufacturing by the company.

A customized computer program (Microsoft Visual Basic.NET) determined the ML impulses and GT among the different sprint conditions. Recorded forces were normalized to body weight. Mathematically, we rotated the axis of rotation of the force plate to account for the curved paths. Axial rotations for the 21-m and 15-m track curves were 21.6 and 28.6 deg, respectively. GT was determined from vertical ground reaction forces with a threshold of 100N.

Statistical Analysis

We performed a mixed models analysis of variance blocking on subjects to test the main effects of the track curve conditions on sprinting speed, GT, and ML impulse. When we detected a significant effect, we performed a Tukey-adjusted post hoc test (p=0.01). Between-leg differences were tested with the same model. All statistical analysis was performed using Statistical Analysis Software.

Results

Sprinting Speed

Runners were 2.4% and 4.5% slower for the 21m and 15m track curves, respectively, compared to straight (Table 1).

Ground Time

Longer ground times were observed for the curved paths (Table 1). However, when differentiating by contact foot, the outside foot showed no significant differences among sprint conditions (Table 2). The inside foot had longer GT for the curve conditions compared with the straightaway (Table 2).

For the 15 and 21m track curves, differences in contact time between legs were significant (Table 3). For each track condition, the inside leg was on the ground longer than the outside leg. Sprinters on a 15m track curve and a 21m track curve spent more time on the ground with the inside leg compared to the outside leg.

ML Impulse

ML impulse was significantly different between the three conditions (Table 1). As the track curve radius decreased, ML impulse increased. There were between-condition differences for the right and left leg (Table 2). Between-leg differences existed only for the 15m track curve (Table 3). The outside leg on the 15m track curve had a lower ML impulse compared to the inside leg.

Discussion

The main goal of this study was to identify how indoor track curve radii affect maximal sprint speed, GT, and ML impulse. As expected, maximal sprint speed decreased as the radius of the track curve decreased. The results for GT and ML impulse helped in understanding the speed differences and provided insight into how track design affects indoor sprinters. A secondary goal of this study was to evaluate between-leg differences of GT and ML impulse during maximal sprinting on the track curve. These differences confirmed the roles of the inside and outside legs during running on a curve.

Our results agreed with previous research that shows that running on a curve is slower than running a straight path (Y. Chang & Kram, 2007; P. R. Greene, 1985; P. R. Greene, 1987; Hamill et al., 1987; Jindrich et al., 2006). However, our study was unique since the sprinting speeds in our study were higher than these other studies. Also, the subjects were well-trained collegiate sprinters who ran on a track surface. Even with the higher speeds, the decreases in maximal sprint speed between the 15m and 21m track curves agree with Greene's predictions (Greene, 1985) for the relationship between maximum sprint speed and radius.

Based on speed alone, if the average sprinter from our study was to run 200m at maximum speed on the 21m radius curve track in lane 1 the time would be 22.14s. The same situation on a 15m radius curve track would take 22.26s. Sharper track turns result in slower maximum sprint speeds while in the turn but give sprinters a high percentage of distance spent on straightaways where maximum speed is higher.

Decreases in curve running speed are primarily attributed to decreases in maximum vertical leg extension force due to the additional ML forces that are required due to the curved path of the turn (Y. Chang & Kram, 2007; P. R. Greene, 1985; P. R. Greene, 1987; Hamill et al., 1987; Jindrich et al., 2006). We expected to see continuous increases in GT and ML impulse as the radius of the track curved decreased. Our results were consistent with previous research that showed an increase in GT and ML impulse as the radius of the turn decreased (Y. Chang & Kram, 2007).

The inside leg on the track turn has been characterized as "the weakest link in the chain" during maximal sprinting around the curve (Y. Chang & Kram, 2007). During our study, the GT for the inside leg was almost 0.1s longer when sprinting on the curve for both curve conditions. The outside leg maintained a GT equal to maximal sprinting on a straight path, even though the ML impulse increased for the right leg at each condition. The ML impulse was not a factor on the straight. The ML impulse on 15m and 21m track curves were significantly higher, but the largest value was seen on the 15m track curve. Even with the increased ML impulse, the outside leg is able to maintain GT equal to maximal straight sprinting. This could be due to greater extension at touchdown leading to a stiffer stance phase. However, without kinematic data, this cannot be proven.

Based on the GT, we assumed that higher vertical ground reaction forces were maintained thus allowing the outside leg to maintain speed and perform similarly to the straight path. This assumption agrees with previous research that characterizes the outside leg as being primarily responsible for maintaining speed throughout the turn (Y. Chang & Kram, 2007; P. R. Greene, 1987; Hamill et al., 1987).

The ML impulses for the right and left legs on the 21m track curve were not significantly different. However, the significant ML impulse differences found on the 15m track curve are indicative of the greater decreases in sprinting speed. A major factor in speed losses on a curved path is that as the radius of the curve decreases, foot positioning for both feet becomes extremely pronated (Y. Chang & Kram, 2007). The inside foot has been found to have the most extreme alterations in foot position especially curve radius decreases to 6m or less (Y. Chang & Kram, 2007; Hamill et al., 1987). Kinematic data were not collected. However, differences in ML impulse on the smallest curve may signify that on a track with a 15m curve radius the inside foot position is beginning to pronate more indicative of the larger differences in ML ground reaction forces observed by Chang & Kram (2006).

Tighter curves require greater ML forces, but allow straighter running overall for one lap. Additionally, our results show that as the radius of the curve tightens more stress is placed on the inside leg but for a shorter period of time. These findings should be considered by coaches and athletes in relation to training, performance, and injury risk.

In 2004, the IAAF discontinued the 200-m indoor sprint competition. The findings of this study are most applicable to a 200-m indoor sprint competition due to the length of the race. However, our results are still relevant for indoor 400m competitions. Competitors are not allowed to race out of their starting lanes until after the first 200m. The radius of the track curve will provide advantages or disadvantages to individuals based on the radius of the track curve and lane assignment. Our results may be a first step in developing time adjustments based on track design. In 200-m or 400-m events, 0.12s can mean the difference between a gold medal or no medal at all. Appropriate adjustments for indoor tracks will ensure fairness of competition and further enhance the appeal of sprint events.

Limitations

The population of interest for this study was limited to male collegiate sprinters. Any possible adjustments suggested by this study can only be applied to trained male sprinters. During this study we were unable to use banked turns, which is the typical, but not found in all indoor tracks (Wilson, 2008). Creating a banked track with a force plate embedded would be extremely costly. A similar problem would still exist though since various degrees of banking exist between tracks.

The ideal adjustments based on track design would need to consider both the radius and the banking of the track turn. Our experiment only accounted for the radius, independent of the bank. The banking of turns helps reduce speed losses on the curve and decreases ML forces that act upon the lower extremity by minimizing pronation of the foot (P. R. Greene, 1987). The decreased ML forces allow for greater vertical forces and faster sprint speeds closer to maximal linear sprint speeds. However, further research is needed to understand the appropriate amount of banking based on the radius of the track curve. The results of our study combined with further research on banked turns could help to provide accurate time adjustments for tracks throughout the United States based on individual design.

Lastly, we did not collect kinematic data during the testing such as 3D motion analysis. The time to prepare subjects for kinematic measurements and have them continue in their prescribed training was impractical for the scope of this study. Further analysis looking at the alterations in foot position would be extremely useful to further understand how the design of indoor track curve affects sprint performance. The lack of kinematical data was appropriate for this study because the main focus was on the speed losses due to alterations in track design.

Conclusion

Coaches and athletes agree that design of the track makes a difference. The findings of our study show that sprinting speed decreases, GT increases for the inside leg, and ML impulses when the radius of the indoor track curve decreases. The radius of the track curve can cost a runner 0.12s in a 200m race between different certified tracks. The results of this study may increase understanding of how track design affects performance. This study may also provide coaches and athletes an increased understanding of how to better train for competition based on the design of the track.

References

Chang, Y., & Kram, R. (2007). Limitations to maximum running speed on flat curves. *The Journal of Experimental Biology, 210*, 971-982.

Greene, P. R. (1985). Running on flat turns: Experiments, theory, and applications. *Journal of Biomechanical Engineering, 107*(2), 96-103.

Greene, P. R. (1987). Sprinting with banked turns. *Journal of Biomechanics, 20*(7), 667-680.

Hamill, J., Murphy, M., & Sussman, D. (1987). The effects of track turns on lower extremity function. *International Journal of Sport Biomechanics, 3*(3), 276-286.

Jindrich, D. L., Besier, T. F., & Lloyd, D. G. (2006). A hypothesis for the function of braking forces during running turns. *Journal of Biomechanics, 39*(9), 1611-1620.

Kawamoto, R., Ishige, Y., Watarai, K., & Fukashiro, S. (2002). Influence of curve sharpness on torsional loading of the tibia in running. *Journal of Applied Biomechanics, 18*(3), 218-230.

Podkaminer, B., & Danehy, L. (Eds.). (2008). *2009/2010 NCAA men's and women's track and field and cross country rules*. Indianapolis, Indiana: The National Collegiate Athletic Assoication, 130-132.

Smith, N., Dyson, R., Hale, T., & Janaway, L. (2006). Contributions of the inside and outside leg to maintenance of curvilinear motion on a natural turf surface. *Gait & Posture, 24*(4), 453-458.

Stoner, L. J., & Ben-Sira, D. (1978). Sprinting on the curve. *In terauds, J. and dales, G.G. (ed.), science in athletics, p. 167-173.*

Weyand, P. G., Sternlight, D. B., Bellizzi, M. J., & Wright, S. (2000). Faster top running speeds are achieved with greater ground forces not more rapid leg movements.*89*, 1991-1999.

Wilson, D. (Eds.). (2008). *IAAF track and field facilities manual 2008.* Editions EGC. Monte Carlo, 266-273.

Table 1: Means and Standard Deviations for all 3 sprint conditions.

	Straight (A)	**21-m radius (B)**	**15-m radius (C)**
Speed (m/s)	9.18±.400^{BC}	8.96±.068^{AC}	8.78±.290^{AB}
Ground Time (s)	0.122±.008^{BC}	0.128±.009^{A}	0.128±.011^{A}
ML Impulse (BWs)	0.001±.006^{BC}	-0.045±.015 ^{AC}	-0.079±.022^{AB}

Superscripts denote a significant difference (p<0.01) between groups. Numbers are mean±SD.

Table 2: Means and Standard Deviations based on contact foot for all 3 sprint conditions.

	Straight (A)	**21-m radius (B)**	**15-m radius (C)**
Ground Time-RF (s)	0.122±.009	0.124±.009	0.122±.008
Ground Time-LF (s)	$0.123 \pm .007^{BC}$	$0.132 \pm .008^{A}$	$0.133 \pm .011^{A}$
ML Impulse-RF (BWs)	$-0.002 \pm .005^{BC}$	$-0.047 \pm .011^{AC}$	$-0.073 \pm .023^{AB}$
ML Impulse-LF (BWs)	$0.004 \pm .006^{BC}$	$-0.043 \pm .019^{AC}$	$-0.084 \pm .022^{AB}$

Superscripts denote a significant difference (p<0.01) between groups. Numbers are mean±SD.

Table 3: Means and Standard Deviations comparing differences between contact feet for track curve conditions only.

	21m (B)		**15m (C)**	
	Left	Right	Left	Right
Ground Time (s)	0.132±.008*	0.124±.009*	0.133±.011*	0.122±.008 *
ML Impulse (BWs)	-0.043±.019	-0.047±.011	-0.084±.022*	-0.073±.023*

* denote a significant difference (p<0.01) between left and right. Numbers are mean±SD.

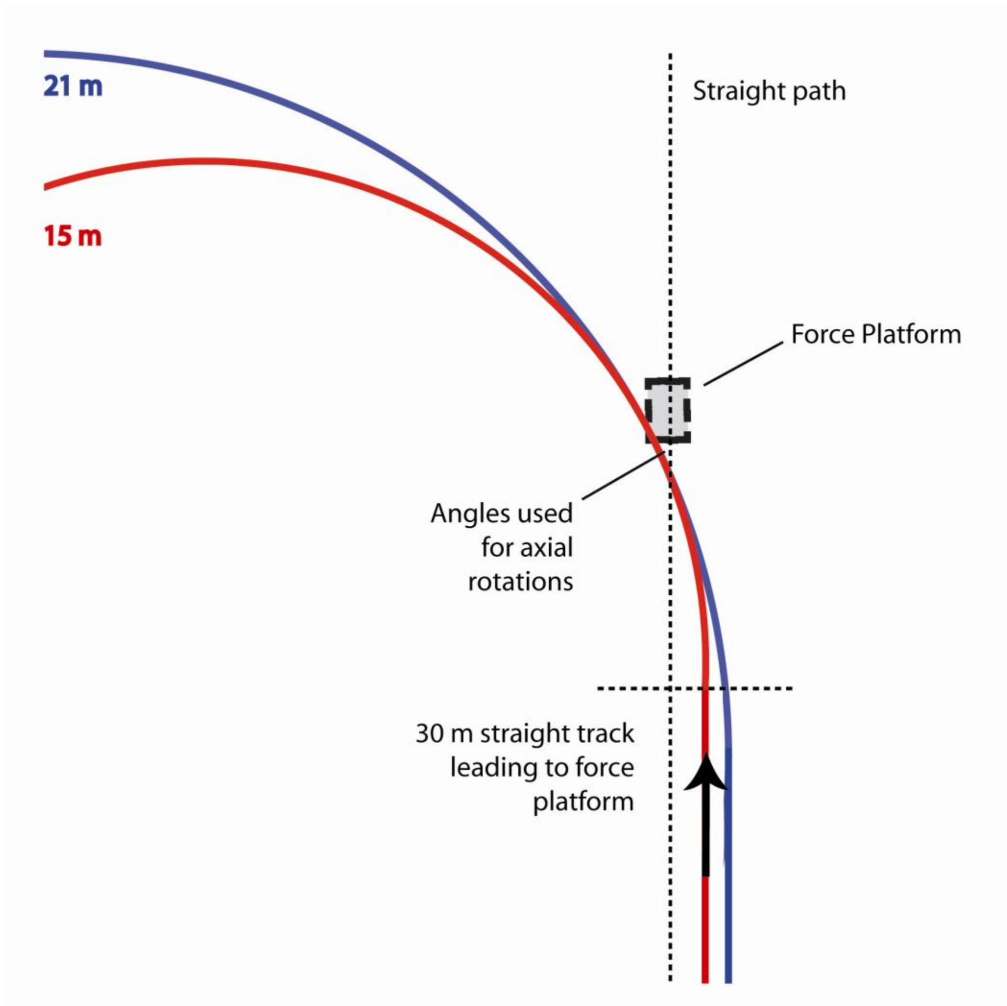

Figure 1: Diagram of the testing setup.

Appendix A

Prospectus

Chapter 1

Introduction

In the sport of Track and Field, performance in sprinting events of the 100 m and 200 m are commonly used as the measuring stick for the "world's fastest man." Sprint events are generally classified as events of 400 m or less. Sprinting events of 200 m-400 m require some alterations in form and technique as athletes compete on an oval track where they must run on curves and straights. Track designs are generally based upon guidelines that are determined by athletic federations or associations that organize track and field championships. Professional track and field athletes compete on tracks that meet guidelines set forth by the International Association of Athletic Federations (IAAF). In the United States, collegiate athletes are governed by the National Collegiate Athletic Association (NCAA). The IAAF and NCAA provide the specifications for designs of both indoor and outdoor tracks.

Indoor tracks play an important role in track and field as parts of the world experiences weather that prohibits outdoor competitions. For sanctioned championship competitions the IAAF specifies that a 200m indoor track can have a radius ranging from 15m to19m with 17.20m being the "200m standard indoor track" (Wilson, 2008). The NCAA specifies for indoor track championships that "the inside radius of the curves on a 200-meter track should be not less than 18 meters and not more than 21 meters" (Podkaminer & Danehy, 2008). Collegiate and professional athletes may compete on an indoor track that could have a curve radius ranging from 15m to 21m.

For the purpose of this study, speed is the primary consideration when evaluating sprint performance for events of 400m or less. Previous studies have attempted to identify the main contributing factors that lead to speed attenuation when running along a curved path compared to a straight (Y. Chang & Kram, 2007; P. R. Greene, 1985; P. R. Greene, 1987; Hamill et al., 1987; Jindrich et al., 2006; Stoner & Ben-Sira, 1978). Running on the curve is often compared to an object moving in circular motion in classical physics (Y. Chang & Kram, 2007; P. R. Greene, 1985; Hamill et al., 1987). In order to be continuously changing direction around the curve, a runner must generate centripetal forces. Track athletes always run counter-clockwise during competition turning left. This requires athletes to put some of their efforts into generating force that accelerate them towards the axis of rotation of the curve. Previous studies have defined the horizontal ground reaction force directed toward the center of the axis of rotation as the medial ground reaction force and lateral ground reaction force as the opposite (Y. Chang & Kram, 2007; Hamill et al., 1987; Smith et al., 2006). For the purpose of this study, we define medial ground reaction force as the horizontal ground reaction force directed toward the center of the axis of rotation for both legs and the lateral ground reaction force being the opposite for both legs. As the medial and lateral ground reaction forces increase, the vertical forces are decreased which results in a loss of running speed. Increased vertical ground reaction forces and decreased ground contact time are the result of increasing sprint speed to maximal (Weyand et al., 2000).

Studies looking at running on the curve have identified the causes of speed attenuation. However, previous studies did not quantify differences in sprint performance that can be attributed specifically to indoor track radius. Combining the guidelines set forth by the IAAF and the NCAA, a US sprinter could compete on a track with a radius between 15m and 21m. No previous studies have been able to clearly identify how a range of track radii from 15m to 21m affects performance in sprinting events. The two studies that used maximal sprinting either used radii that were not comparable for 200 m track design (Y. Chang & Kram, 2007) or the maximal sprinting was performed by recreational runners on a banked turn (P. R. Greene, 1987). The other studies that analyzed running on a curve used running speeds that were submaximal (P. R. Greene, 1987; Hamill et al., 1987; Jindrich et al., 2006; Kawamoto et al., 2002; Stoner & Ben-Sira, 1978). Further research is needed to identify the effects of the track radii on sprinting speed.

Sprinting at maximum velocity around extreme curves of 6m or less radii show that the inside leg will perform much differently than the outside leg (Y. Chang & Kram, 2007; Smith et al., 2006). The inside leg is limited in its ability to produce peak vertical ground reactions forces due to the generation of centripetal forces. Extremely small curve radii cause a runner to make extreme alterations in foot positioning (Y. Chang & Kram, 2007). Even on a curve of 31.5m the inside foot usually strikes the ground in a more pronated position than the outside foot (Hamill et al., 1987). The right and left legs do not act uniformly during running on the curve. The inside leg is responsible for braking and changing direction (Smith et al., 2006). The outside leg is primarily responsible for propulsion and also plays a role in changing direction. Therefore, the differences in ground reaction forces between inside and outside legs can help to identify the changes made by a sprinter to different track curve radii and may also account for changes in speed.

The significance of this study is in providing information on how the radius of an indoor track curve affects performance in trained sprinters. Studies have shown that running on a curve is slower compared to a straight run (Y. H. Chang, Huang, Hamerski, & Kram, 2000; P. R. Greene, 1987; Hamill et al., 1987). However, they have not appropriately categorized the effects of the indoor track curve on collegiate sprinters or elite sprinters.

The primary purpose of this study is to determine the differences in running speeds, ground contact time, and medio-lateral impulse, with different track radii. A secondary purpose is to understand the differences in ground reaction forces between legs during maximal sprinting. This study may help coaches to train their athletes to be better prepared for different track designs. It may help track designers have a better understanding of how indoor track curves affect athletes and improve indoor tracks in the future. Also, the results of this study may be a first step in developing a mathematical model that could account for differences between existing tracks.

Hypotheses

At maximal running speed, the greatest ground contact time, the most medio-lateral impulse and slowest sprinting speed will be seen on a 15m track curve. On a 21m track curve ground contact time and medio-lateral impulse will decrease and sprinting speed will increase compared to a 15m track curve. A straight path will have minimal ground contact time and medio-lateral impulse and the fastest sprinting speed compared to the aforementioned track conditions. For each track curve condition, the inside leg will experience higher ground contact time and medio-lateral impulse compared to the outside leg.

The null hypothesis is that there is no difference in the variables of sprinting speed, ground contact time, and medio-lateral impulse among sprinting on a straight-away, a 15m track curve and 21m track curve. Also, there will be no differences between the inside leg and outside leg.

Limitations

1. Trials will be performed on a flat track curve rather than a banked track curve.
2. Ground reaction forces will be slightly dampened by the track surface.

Delimitations

1. The sample will consist of 12 male sprinters from the BYU men’s track and field team.

2. Trials will only be performed at maximal speeds to evaluate performance variables on the track curve.

Operational Definitions

Ground Contact Time—the amount of time the foot is in contact with the ground during running.

Medio-lateral Impulse—the force versus time integral in the transverse plane during ground contact time.

Chapter 2

Review of Literature

The biomechanics of running continue to be examined and reexamined as scientists strive to improve running performance and understand the etiology of injuries (Hamill et al., 1987). A few studies have investigated the differences between linear running and curvilinear running as well as the effects of banked turns on a track (Y. Chang & Kram, 2007; P. R. Greene, 1985; Hamill et al., 1987; Smith et al., 2006). Most running events in track and field will require athletes to run one or more turns on the track. The standard for indoor tracks provide for a bank of 10 degrees (Wilson, 2008). Sprint events such as the 200m or 400m require runners to sustain maximal sprint velocities throughout the curves. Depending upon the track, athletes may spend up to 60% of the race on the turn (P. R. Greene & Monheit, 1990).

The purpose of this review is to determine the extent of research that has been performed on sprint performance with differing track radii. Scientists have studied running on the curve by looking at ground reaction forces (GRF) on flat and banked turns (Y. Chang & Kram, 2007; P. R. Greene, 1987; Hamill et al., 1987; Kawamoto et al., 2002; Smith et al., 2006). They have analyzed the biomechanics of running as they alter the radius of the curve on flat and banked turns (Y. Chang & Kram, 2007; P. R. Greene, 1987; Hamill et al., 1987; Smith et al., 2006).

Studies have also looked to mathematical models to predict sprint times based on the biomechanics of running on the curve and to identify optimal radius for the track turns (P. R. Greene & Monheit, 1990; Mureika, 1997; Usherwood & Wilson, 2006). The mathematical models have been able to account for the loss of speed when sprinters enter the track curve (Mureika; Usherwood & Wilson). This review catalogs the biomechanics of runners along a curved pathway focusing on GRFs, lower body position and a combination of running speed and track design.

Ground Reaction Forces

Ground reaction forces vary significantly between legs as runners sprint along a curve. As the radius of the curve decreases on a flat surface the inside leg is unable to produce the peak vertical GRF compared to straight running (Y. Chang & Kram, 2007). Another component of GRF is the time to peak force. As the radius tightens below 6m, the time to peak GRF will increase (Y. Chang & Kram, 2007). The lateral forces also increase as the radius decreases. These factors must be considered when looking at sprint performance around the curve because they provide the limiting factors on very small curves and may still be the major contributing factors when looking at indoor track radii that range from 15m to 21m.

Compared to the smaller radii used in the Chang and Kram study, Hamillet al. (1987) reported differences in the GRFs that were less significant using a flat track curve with a radius of 31.5m and submaximal running (Hamill et al., 1987). The significant values were found in the medio-lateral force component. The medio-lateral forces will change considerably compared to straight running as the runner must compensate for the continuous change in direction (Hamill et al., 1987). The medio-lateral forces become very important in sprint performance as the athletes will have to deal with increased forces as they try to generate and maintain maximal speed throughout the race.

Ground reaction forces can be useful in identifying torsional moments that act upon the lower body during running. In distance running, tibiae stress fractures are very common. Scientists used GRFs and kinematic data to determine torsional loading of the tibia while running on flat curves with radii of 5m and 15m (Kawamoto et al., 2002). They found that the tibia did experience higher torsional loading as the radius of the curve increased. The determination of torsonial loading is important to sprint performance because proper training can help to strengthen the runner's ability to handle increased torsional loading with increases in sprinting speed.

To reduce torsional forces during running, the body implements braking forces in order to prevent excessive body rotation (Jindrich et al., 2006). However, the braking forces have not been found to decrease speed in submaximal curve running. The braking forces deal mostly with the inside leg in the curve rather than the outside leg (Smith et al., 2006). Scientists believe the braking impulse is due to the foot position of the inside foot which must adjust the direction of the center of mass to effectively lead the body around the turn (Kawamoto et al., 2002; Smith et al., 2006).

Another constraint to curve sprinting that has been looked at is limb force. Limb force is the increase in body weight due to the ground reaction forces that are required to overcome gravity and centripetal forces around the curve (Usherwood & Wilson, 2006). Limb forces and braking forces may provide the major limitations on sprint performance, but more research is needed to identify the contribution to speed deceleration around the curve.

Body Positioning

Sprinting at maximum velocity around curves at different radii show that the inside leg will perform much differently than the outside leg (Y. Chang & Kram, 2007; Smith et al., 2006). The inside leg is considered the weakest link in the chain of curvilinear locomotion. When sprinting on flat turns with a small radii, the inside leg generates more varus moments and external rotations compared to the outside leg. These adjustments are necessary to keep the center of mass moving along the curved path. Chang and Kram (2007) highlighted that curve sprinting is a complex three-dimensional movement that can have several coupled biomechanical constraints. The constraints are that during curved running the body has to position itself to provide maximum vertical GRFs and lateral GRFs to maintain speed around the curve. The body also has to balance forward acceleration while controlling body rotation in the transverse plane. Depending on the sprinting speed and the radius of the curve these constraints will begin to dictate the performance of an athlete.

Scientists have compared a runner sprinting around a curve to an inverse pendulum (Hamill et al., 1987). A runner's center of gravity continually changes as they round the curve due to the centripetal forces they must overcome. The inside leg usually strikes the ground in a pronated position and outside leg is in a slightly more supinated position. In order to overcome the centripetal forces the body will compensate by leaning into the turn and altering the foot position to change the center of mass in the direction of the turn. Hamill et al. (1987) identified the possible cause of injuries of running on the curve as a result of the asymmetry caused by the lean. They also concluded that more studies could be done to examine the etiology of track running analyzing GRF and kinematics at faster running speeds and at a smaller track radius such as an indoor track (Hamill et al., 1987).

Running Speed and Track Design

The International Association for Athletic Federations is the governing body that regulates oval track specifications for track and field competitions. They provide guidelines for both outdoor and indoor tracks. To optimize space, oval tracks are usually built around another sporting venue such as soccer or American football. Indoor tracks are notably much smaller than outdoor tracks, and IAAF approved tracks can have a curve radius from 15m to 19m. Studies looking into the effects of running on the curve have also placed emphasis on analyzing the biomechanical differences at different radii (Y. Chang & Kram, 2007; Hamill et al., 1987).

Chang and Kram (2007) had runners perform their sprinting tests at maximal velocity around a 6m, 4m, 3m, 2m and 1m curve. The speeds were normalized to maximal velocity on a straight path (Y. Chang & Kram, 2007). A limitation to the study is that the running speeds were performed by recreational athletes and not elite sprinters. In order to qualify the results as performance enhancing the study needed to incorporate trained sprinters and analyze the different running velocities at different radii. Also the different radii are extremely small compared to the track curve radii on an indoor track.

A study of a slightly larger curve was able to design a track turn experiment with radius of 11 m and 19 m and the ability to create a bank of 0°-30° (P. R. Greene, 1987). Banking of turns on tracks is generally only performed on indoor tracks. The IAAF and the NCAA specify the bank degree as a function of track radius (Podkaminer & Danehy, 2008; Wilson, 2008). Banking of turns has been found to have a 10% effect on the speed of the runner (Greene, 1987). The banking of a turn would then have a huge effect on sprint performance as every millisecond counts in a 20 or 40 second race. A possible enhancement of the Greene study would be to identify the differences in GRFs comparing banked turns with flat turns.

Hamill et al. (1987) had runners perform trials on a 31.5m flat curve, the standard radius of the curve for an outdoor track (Hamill et al.). The runners' average velocity was 6.31 m/s, well below sprinting speed for elite male athletes. From a performance perspective the track conditions were very good. They simulated a standard track. The runners speed was slower than would be expected from a sprint race like the 200m or 400m but useful in analyzing longer events like the 800m or 1500m. An improvement to the study would be to increase the runner's velocity to around 8-9 m/s to simulate elite sprinter performance velocity.

In order to determine torsional loading of the tibia along a curved path, scientists used a straight path, a 15m radius flat curve, and a 5m radius flat curve. The runners performed their trials at 3.5m/s. The speed at which they performed the trials is very slow compared to the performance speeds of a 200m or 400m race. Another study is needed to identify the torsional loading of the tibia at sprint speeds around the curve of an indoor track.

Summary

Running on the curve is more complex movement than traditional linear running. Ground reaction forces differ significantly when running on the curve. Vertical GRF are lower for the inside leg as the runner must position the foot to change the direction of the center of mass to accomplish the turn. The medio-lateral GRFs also play a major role in maintaining velocity. Torsional loading, braking forces and limb forces are other components that have been studied to better understand the possible etiology of running on the curve.

An important part of curvilinear running is the curve itself. Studies that have been performed on curvilinear running have used curved radii as small as 1 m and as large as 32m. An important component of any curved running study is the radius of the curve. Indoor tracks provide the tightest curves for athletes to sprint on. The design of an indoor track must take into account the radius of the curve as the medio-lateral force should be significantly higher than an outdoor track. Scientists have also performed running studies at different speeds ranging from 3 m/s to 7 m/s. There is a lack of research looking at running on the curve at maximal sprint speeds around 8-9 m/s.

The research that has been done provides a wide array of track radii. Limiting this study to acceptable radii for an indoor track will identify the optimal radius for an indoor track. Few studies have used elite sprinters to better understand foot positioning and ground reaction forces at elite sprinting speeds around 8-9 m/s. This study would help to better understand the biomechanics of running on the curve at elite sprint speeds on indoor tracks.

Chapter 3

Methods

Subjects

Twelve current intercollegiate male sprinters ages 18-25 will be recruited as volunteers from the Brigham Young University Track team. Sprinters will be defined as competitors in track events 400m or less. Each subject will complete a short questionnaire about current injury status prior to participating in the study. All of the subjects will be free of injury at the time of testing. Age, height, mass, and best performance times will be recorded at the time of data collection. Each subject will sign a consent form approved by the IRB prior to any testing.

Running Protocol

Subject will be asked to perform their traditional warm up before a workout or race. They will start 35 meters before the force plate from a standing start to allow time to reach maximal sprinting speed. They will continue to sprint at maximal speed 10 meters after the force plate contact. Each subject will be given five minutes rest between sprints to avoid fatigue and ensure maximal effort. The study will consist three days of testing. The testing days will be separated by a minimum of two days and a maximum of seven days. For each testing day a maximum of eight sprinting trials will be performed to avoid injury and fatigue.

Each subject will be assigned a sprint condition using a randomized block design. The three different sprint conditions that will be used are the following:

4) 45-m straight sprint
5) 45-m sprint with a 21-m track curve beginning at the 30-m mark
6) 45-m sprint with a 15-m track curve beginning at the 30-m mark

To assess differences between right and left legs, sprinters will be asked to make contact with the left leg during the initial four sprints. During the last four sprints the sprinter will alter starting legs to make contact with the right foot. A valid sprint will consist of full-foot contact with the force plate determined by a research assistant who visually confirms contact within a marked box on the track. For the eight sprint trials, a minimum of one valid contact with left leg and one with the right leg is required per trial day. All subjects will run with their own spiked shoes.

Sprinting speed will be assessed using two sets of photoelectric timing systems. The first set of timing lights will be placed at the 20-m mark and 30-m mark. The 10-m split will be used to ensure that each subject is exerting maximal effort on each trial since the first 30 meters for each trial are on a straight path. It is assumed with maximal effort the 10-m splits will all be within ±2%. Trials that are below the maximal effort range will be left out. A second set of timing lights will be used starting at the 30-m mark and 40-m mark to assess differences in speed based on the assigned sprint condition.

Force Plate

A Kistler force plate (Type 9287BA, 900 mm x 600 mm , serial number 1440145, Amherst, New York, USA) will be used for the collecting the ground reaction force data. The forces place will be located 35m from the beginning of each run and is imbedded into a Mondo indoor track with an asphalt foundation. The force plate is covered with the same texture and surface as the rest of the track as well as the practice area inside the track curve. The calibration of the force plate took place during manufacturing by the company. The force plate produces horizontal measurements of force (x and y) and vertical measurements of force (z), as well as the corresponding moments of force.

At the beginning of each testing session, a few practice trials will be done to verify the proper functioning of all instruments. A laptop computer will convert the force plate signal from voltage to force. A customized program created with Microsoft Visual Basic.NET will determine the horizontal impulses and ground contact times among the different sprint conditions. Recorded forces will be normalized to the body weights of the subjects by dividing force by weight in Newtons.

Statistical Analysis

Differences in the ground contact times, sprinting speed, horizontal impulse between legs for the three sprint conditions will measured using a mixed model statistical analysis.

References

Chang, Y. , Huang, H. W. C., Hamerski, C. M., & Kram, R. (2000). The independent effects of gravity and inertia on running mechanics. *Journal of Experimental Biology, 203*(2), 229-238.

Chang, Y., & Kram, R. (2007). Limitations to maximum running speed on flat curves. *Journal of Experimental Biology, 210*, 971-982.

Greene, P. R. (1985). Running on flat turns: Experiments, theory, and applications. *Journal of Biomechanical Engineering, 107*(2), 96-103.

Greene, P. R. (1987). Sprinting with banked turns. *Journal of Biomechanics, 20*(7), 667-680.

Greene, P. R., & Monheit, M. A. (1990). Optimal geometry for oval sprint tracks. *Journal of Biomechanics, 23*(5), 447-452.

Hamill, J., Murphy, M., & Sussman, D. (1987). The effects of track turns on lower extremity function. *International Journal of Sport Biomechanics, 3*(3), 276-286.

Jindrich, D. L., Besier, T. F., & Lloyd, D. G. (2006). A hypothesis for the function of braking forces during running turns. *Journal of Biomechanics, 39*(9), 1611-1620.

Kawamoto, R., Ishige, Y., Watarai, K., & Fukashiro, S. (2002). Influence of curve sharpness on torsional loading of the tibia in running. / influence du raccourci du virage sur la charge en torsion du tibia lors de la course sur piste. *Journal of Applied Biomechanics, 18*(3), 218-230.

Mureika, J. R. (1997). A simple model for predicting sprint-race times accounting for energy loss on the curve. *Canadian Journal of Physics, 75*(11), 837-851.

Podkaminer, B., & Danehy, L. (Eds.). (2008). *2009/2010 NCAA men's and women's track and field and cross country rules*. Indianapolis, Indiana: The National Collegiate Athletic Assoication, 130-132

Smith, N., Dyson, R., Hale, T., & Janaway, L. (2006). Contributions of the inside and outside leg to maintenance of curvilinear motion on a natural turf surface. *Gait & Posture, 24*(4), 453-458.

Stoner, L. J., & Ben-Sira, D. (1978). Sprinting on the curve. *In J. Teraud, & G.G. Dales, (eds.), Science in athletics, (pp. 167-173). Del Mar, CA: Academic Publ.*

Usherwood, J. R., & Wilson, A. M. (2006). Accounting for elite indoor 200 m sprint results. *Biology Letters, 2*(1), 47-50.

Weyand, P. G., Sternlight, D. B., Bellizzi, M. J., & Wright, S. (2000). Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *J. Appl. Physiol. 89*, 1991-1999.

Wilson, D. (Ed.). (2008). *IAAF track and field facilities manual 2008* Edition. Monaco; Editions EGC. Monte Carlo, 266-273.