Treadmill vs. Overground Sprint Training

Doug Schweigert, MS, CSCS
Rory Beil, MS, CSCS

Treadmill sprint training has become very popular in certain areas lately. Unfortunately, this rise in popularity has come about without scientific justification or validation of the treadmill as a superior training tool. The purpose of this article is to review the literature currently available specific to training on a treadmill while also discussing the variables associated with speed and its development.

WHAT IS SPEED

The definition of speed is much more complex than how fast you can run. In the simplest terms, it can be described as the product of stride length and stride frequency (Stride Length X Stride Frequency = Speed). While it is often assumed that an increase in either, or both, of these components will result in speed improvement, this isn't always the case. The ability to effectively increase speed through increased stride length and/or rate is determined by the ability to apply productive forces during ground contact (Mann, 1984). It is possible to increase stride length or stride frequency without altering the ground force applied, but it will typically create a decrease in the other component resulting in no effective change in speed. This would indicate that effective increase in stride length or stride frequency can only come from improving the ability to apply force to the ground. In reviewing research investigating the relation between stride pattern and running speed, Schmolinsky (1992) also concluded that too much emphasis on the increase of stride length and stride frequency in training would be a mistake. More emphasis should be placed on developing the explosive strength of the muscles which will then allow the athlete to take longer strides in a shorter time.

When analyzing speed we must take into consideration the three primary components: acceleration, maximum speed and speed endurance (McFarlane, 1994).

1. Acceleration can be defined as the ability to reach maximum speed in the least amount of time
2. Maximum speed is the maximum velocity an athlete is able to run
3. Speed endurance is the ability to maintain speed with minimal deceleration.

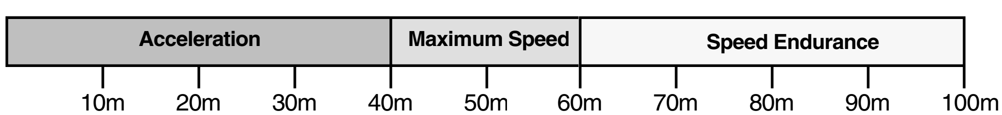

Figure 1

In analyzing these three components as applied to a linear 100m sprint, a typical high school athlete will have an acceleration phase of approximately 30-40 meters. At this point the athlete will be running at maximal velocity and this can be maintained for up to 20 meters. For the remainder of the race, the effects of fatigue will begin to set in resulting in a decreased stride frequency and an increased stride length with a gradual deceleration (Schmolinsky, 1992, Mero et al, 1992). This would be considered the speed endurance phase. In this paper, we will explore the efficacy of treadmill versus overground sprint training within these three components of speed.

ACCELERATION

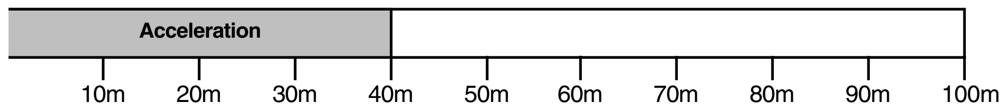

Figure 2

Acceleration is the ability to reach maximum speed in the least amount of time. In analyzing split times of 20 sprinters who competed at the Olympic Games and the World Championships, Letzelter (2000) was able to conclude that the largest difference in top sprinters and their slower counterparts was in the acceleration phase. Based on the results, it was recommended that the main goal of training should be the development of sprint strength, in particular the improvement of starting and pick-up acceleration.

Effective acceleration requires the application of force in a predominantly horizontal direction to project the body forward. The horizontal forces generated during this phase come primarily from muscular contraction rather than elastic response (Seagrave, 1989). This would indicate that to be effective in this phase requires high levels of strength and power (Maximum Rate of Force Development or max RFD) to accelerate the body to maximum speed quickly and efficiently. While accelerating, the horizontal force produced during the contact phase is 46% greater than that found during maximal speed running and the force is produced over a longer period of time (Mero, 1988). Mero (1988) emphasizes that this demonstrates the importance of strength during the acceleration phase.

On a treadmill, once the foot is supporting the athlete's weight the speed of the tread will actually pull the foot underneath the body so the only pushing action taking place is what is needed to support the body. In other words, there is minimal force being applied to the tread. The speed the tread is pulling the foot underneath the body is dependent on the speed the tread is set at. There is no acceleration taking place or you would run off the front of the treadmill.

Newton's law of Action/Reaction also lends itself to understanding the involvement of the moving treadmill in reducing force output. This law tells us that for every action there is an equal and opposite reaction. To say this another way, whenever two objects come into contact with each other, they exert the same amount of force on each other, but in opposite directions. This relationship means that the acceleration of a body is directly equal to the external force applied to the body by the ground and is in the same direction as that applied force. If the acceleration of the body is directly equal to the applied force, then the greater the force applied to the body, the greater the acceleration. On a treadmill the external force applied to the body is greatly reduced since the tread is moving backward. Figure 3 will help explain this concept where F = action force and RF = reaction force. With the backward tread movement, the forward ground friction is reduced which reduces the reaction force needed to propel the body forward, proportionally reducing the action force output required by the muscular system.

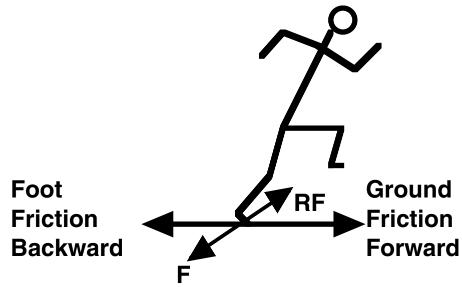

Figure 3

One study by Kram, et al. (1998) looked at horizontal and vertical ground reaction forces when walking and running on a treadmill. A treadmill with a built in force plate was designed to measure the forces in question. Based on the results obtained the researchers were able to determine that steady speed walking or running on a treadmill is identical to overground walking and running. However, the speed used when running on the treadmill was 6.7 mph which is equivalent to a moderate jogging speed. The force requirements and biomechanics for jogging are far different than those required for sprinting. When asked how the results of this study would apply to sprinting Kram concluded that the results of the original study were based on steady state jogging which does not describe sprinting. Consequently, Kram feels the treadmill is a poor simulator for sprinting since it does not mimic the inertial forces present in sprinting or more specifically, the braking and propulsion phases that are present every foot strike when sprinting (Kram, 2000). Mero, et al. (1992) support this concept finding that when sprinting, all foot contacts have both braking and propulsion phases, although the ratios will vary through the different sprint phases.

We also need to consider the neuromuscular recruitment patterns involved with the acceleration movement. In the acceleration phase there is a distinct increase in both stride length and stride frequency as the athlete attempts to reach maximal speed. The large application of horizontal forces into the ground is assisted by longer foot contact which gradually decreases as the athlete gets closer to top running speed. The principle of specificity must be considered when trying to optimize these neuromuscular recruitment patterns. Treadmill protocols require the athlete to mount the treadmill while it is already moving at a high rate of speed. In other words, there is no acceleration. The mounting of a treadmill at high rates of speed does not allow the recruitment patterns necessary for learning the motor skills for optimal acceleration development.

Biomechanically, the acceleration phase is characterized by a forward body position with an approximate 45 degree angle at the shin as compared to ground (Mann, 1994). Foot contact is made directly or slightly behind the hips to create the "pushing" position which is necessary for optimal acceleration. Common treadmill sprinting protocols require running up a steep incline. Empirical evidence demonstrates that this produces a biomechanical position where foot contact with the tread is far ahead of the hips. This creates a significant variation from the "pushing" position one strives for during an acceleration movement. An athlete who would actually place their foot in this position while trying to accelerate on the ground would prematurely stand upright and take themselves out of the optimal accelerating position. Most discussion regarding incline training suggests a maximum incline of 3 degrees because beyond this angle, sprinting technique is negatively effected.

Without <u>published</u> research to verify otherwise, it appears fairly evident that the treadmill is not an effective tool for developing acceleration as compared to more specific ground based methods already used to develop this component of speed.

MAXIMAL SPEED

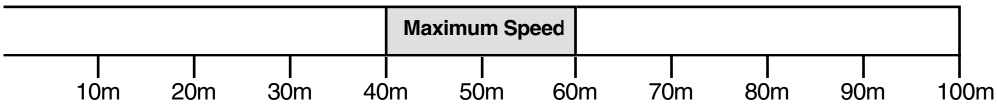

Figure 4

Maximal speed is the maximal velocity an individual is able to attain. Since the athlete cannot accelerate beyond individual maximal speed capabilities, the biomechanics of the sprinting action changes in this phase. The trunk assumes a near vertical position and foot contact adjusts from a “pushing” action to more of a “pulling” action with contact being made slightly ahead of the center of gravity. At maximal speed, horizontal forces are at their peak so the focus is on maintaining maximal velocity, not accelerating. The primary forces to deal with in this phase are the vertical forces created by the effects of gravity trying to pull the body back to the ground each stride. Mann (1994) demonstrated vertical forces of approximately 350 lbs per running stride for a 160 lb runner during maximal speed sprinting. A sprinters training should be designed to develop the physical abilities to not only control the vertical forces developed but to effectively utilize these forces through the stretch shortening cycle to minimize energy loss. Running mechanics should also reinforce optimal foot placement to create the “pulling” action.

A study by Nelson et al. (1972) concluded that the biomechanics of treadmill running differ significantly from overground running. High speed video identified reduced vertical velocities, longer periods of support, and less variation between horizontal and vertical velocities for running on a treadmill compared with overground running. The foot is placed further in front of the center of gravity than when running on ground (which would lead to a reduction in velocity in overground running because of the braking action it would cause) and is returned underneath the body by the moving belt. This eliminates the “pulling” of the leg under the body as required in effective overground sprinting and as demonstrated so well by high level sprinters. Additionally, it was found that the legs spend more time behind the body and less time in front in the desirable “high knee” position. Dal Monte, et al. (1973) also found less vertical movement of the center of mass when running on a treadmill. These studies would seem to demonstrate that treadmills are less effective at developing the ability to control and effectively utilize the vertical forces involved in maximal speed running.

It is also important that when training for Maximal Velocity, time spent at maximal speed should not exceed 2-4 seconds since neural fatigue will not allow further gains past this time (Seagrave, 1989). This also makes it absolutely necessary for the recovery periods to allow for full recovery. Common treadmill protocols utilize repetitions of 6-30 seconds in length with less than optimal recovery periods.

As stated previously, a high school athlete or developmental athlete will be able to maintain the maximal speed phase for up to 20 meters. In a linear sprint (that requires no change of direction) an athlete will require 30-50 meters to accelerate to this maximum speed. When conducting a needs analysis on any of the sports participated in today, it becomes readily apparent that the only sport that allows an all out linear acceleration to reach maximal velocity is track and field. In other words, no other sport (with the exception of football on very rare occasions) ever involves the maximal speed component so there is little need to train for it. This time can be better spent working on more specific training for the sport in question (acceleration, agility, power, etc.).

Without published research to verify otherwise, it appears fairly evident that the treadmill is not an effective tool for developing maximal speed, as compared to more specific methods already used to develop this component of speed, since the vertical forces are reduced when running on a treadmill and the biomechanics are different.

SPEED ENDURANCE

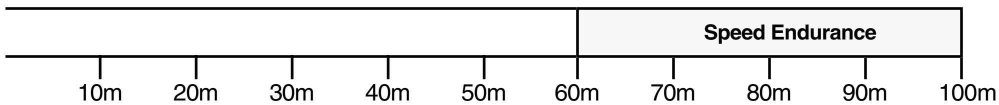

Figure 5

Speed endurance is the ability to maintain speed beyond the maximal speed phase with minimal deceleration. Again, this component would only have application to limited sports since most sports do not have the opportunity to sprint all out through the maximal speed phase (i.e. beyond 60 meters).

A 100 meter race is characterized by a rapid increase of both stride length and stride frequency during the acceleration phase, a plateau of both components during the maximal speed phase and then an increase in stride length with a decrease in stride frequency in the speed endurance phase as the athlete fatigues (Plisk, 1995). Goals for enhancing the speed endurance phase would be to delay the onset of fatigue to allow for maintenance of similar stride patterns found in the maximal speed phase for as long as possible. Frishberg (1983) analyzed college varsity sprinters with treadmill experience running in both overground and high speed treadmill running conditions. He concluded that overground and treadmill locomotion at high speeds are biomechanically and physiologically different. Data showed oxygen debt was 36% greater for overground sprinting. This is partially caused by the moving treadmill belt reducing the propulsive forces necessary on a treadmill, thereby reducing energy requirements. While running on a treadmill may elicit a metabolic response, it would appear it is not as effective as overground running in placing a demand on the metabolic systems at the same speeds.

Of further interest on this subject is the anecdotal evidence regarding vomiting while participating in some treadmill based training programs. Dr. William Kraemer, Director of Research, Center for Sports Medicine at Penn State University has summarized this philosophy as follows in a recent presentation (1995), “Just because you vomit at the end of a workout doesn’t mean it was a good workout, it means it was a bad workout. Guys that run around saying it was a good workout because you vomit don’t know anything about basic physiology.” Vomiting would be an indication of insufficient recovery times between exercise bouts or exercise bouts of too high an intensity for an individuals current fitness level. When trying to develop components of speed, power, and maximum rate of force development (all critical components to the acceleration phase or the maximal speed phase) it is critical that the rest periods allow for full recovery. This will ensure that fatigue doesn’t become a limiting factor in performing maximal work bouts. If metabolic training is the goal, decreasing recovery time is necessary to challenge the metabolic systems but to the point of vomiting is excessive and is indicative of a program poorly designed for an individuals’ current ability.

CONCLUSION

While the research that has been conducted on the similarities of treadmill sprinting to overground running is limited, those studies which have been completed would suggest that the differences can be significant. Frishberg (1983) concluded that treadmill sprinting is not as physiologically stressful as overground running and probably will not result in the same physiological improvement that can be attained with overground training and that certain aspects of an individual's treadmill running technique do differ from the technique used by the same individual during overground running. Dal Monte et al (1973) found less vertical movement of the center of mass, and decreased period of nonsupport and stride length during treadmill running. Nigg et al (1994) found that subjects adapt their running style to the demands of the treadmill and individual assessment of running kinematics on a treadmill may possibly lead to inadequate conclusions about overground running. Nelson et al (1971) concluded that the biomechanics of treadmill running differ significantly from those associated with overground running. Elliott and Blanksby (1976) found that significant differences did occur between overground and treadmill running at faster speeds (4.82 - 6.20 m/s for males and 4.85 - 5.76 m/s for females). Kram (2000) believes that the treadmill does not mimic the inertial forces found in sprinting so it is a poor simulator for sprinting.

One unpublished document in support of treadmill running (Swanson, 1997) argues that, "When running overground, the body's center of mass has a horizontal velocity at foot strike which is equivalent to forward running velocity and any mass with velocity has momentum, which causes a reduction on the total amount of energy needed at toe off to propel the body forward and maintain its horizontal velocity. Since the horizontal velocity of the center of mass is basically zero at foot strike on a treadmill, the energy transferred to the lower extremity by the treadmill belt is similar in magnitude to that due to the forward momentum of the center of mass in the overground case." Thus, the author suggests that overground running must be the same as treadmill running. The key to understanding the inaccuracies of this conclusion is that the comparison is to that aspect of sprinting where the goal is to "maintain horizontal velocity" so consequently, force application to the ground is irrelevant. This, of course, is the maximal velocity phase which has little to no application in most sports. As we have discussed, the acceleration phase of sprinting is intensely concerned with force application to the ground and development of this phase (which has application to nearly every land based sport) is fully dependent on increasing the ability to apply these effective ground forces. In the maximal velocity phase, the objective is to develop the ability to effectively control and utilize the vertical forces involved which research has demonstrated (Nelson, et al 1972 & Dal Monte, 1973) is minimized on a treadmill. This article also argues that any energy differences between overground and treadmill running, which have been found by researchers, is due to air resistance, the subjects' treadmill experience and the construction of the treadmill. This may very well be true. However, the point is there is a difference. This tells us overground training will elicit a greater metabolic response and is consequently more effective.

There has been some argument that the biomechanical differences found when comparing overground to treadmill running were due to the quality of the treadmill (Ingen Schenau, 1980, Swanson, 1997, Frappier, 2000). Primarily, the argument revolves around the treadmills being inadequately powered and lacking adequately weighted flywheels. Nigg et al (1995) specifically addressed this issue when conducting a kinematic comparison of overground and treadmill running. The effect of quality of a treadmill was addressed by comparing overground running to a small treadmill, a midsize treadmill and a large research treadmill. Interestingly, the most significant differences were found between overground running and the large research treadmill as compared to the small treadmill. It was concluded that the results of the study did not support the speculation that the size and power of the treadmill would decrease the biomechanic differences found between overground and treadmill running.

To date, no peer reviewed research has been published that would support the use of a treadmill as a superior method to developing speed capacities (acceleration, maximal speed, and speed endurance) as compared to existing methods. If such research is ever produced it is critical that the research design evaluates a comparison of common treadmill protocols to current methods of developing speed and that trained, conditioned athletes were used in the study. A study that would simply indicate improvement in speed in an untrained and unconditioned population could not justify the treadmill as a superior method of training. We also need to consider that the research completed to date (Elliott, et al, 1976, Frishberg, 1983, and Nelson, et al, 1973, Dal Monte, et al, 1973, Nigg, et al 1994) has concluded that the biomechanics of treadmill running, especially at higher speeds, is significantly different than those associated with overground running. Whether continued exposure to sprinting on a treadmill will negatively effect sprinting mechanics on the ground has not been concluded and needs to be further researched. From a motor learning perspective however, it does seem logical that this would be the case.

References

Dal Monte, A., Fucci, S., and Manoni, A. (1973). The treadmill used as a training and simulator instrument in middle- and long-distance running. Medicine and Sport, Vol 8: Biomechanics III, Basel:Karger, pp. 359-363.

Elliott, B.C., and Blanksby, B. A. (1976). A cinematographic analysis of overground and treadmill running by males and females. Medicine and Science in Sports and Exercise, 18:84-87.

Frappier J (2000). Q&A with John Frappier. Acceleration Magazine. 1(July):4.

Frishberg, B. (1983). An analysis of overground and treadmill sprinting. Medicine and Science in Sports and Exercise, 15:478-485.

Ingen Schenau Van GJ (1980). Some fundamental aspects of the biomechanics of overground versus treadmill locomotion. Med. Sci. Sports Exerc. 12:257-261.

Kraemer, W.J. (1995). Anaerobic exercise prescription guidelines. Essential Principles of Strength and Conditioning Symposium.

Kram R, Griffin T, Donelan JM, and Chang YH (1998). Force treadmill for measuring vertical and horizontal ground reaction forces. J. Applied Physiology, 85:764-769.

Kram R, (2000) Personal correspondence.

Letzelter, M. (2000). Sprint strength as the main training aim in short distance. Sprints and Relays: Contemporary Theory, Technique and Training. Tafnews Press:Mountain View.

Mann, R., Hart, C., Yessis, M., Hay, J.G., Wilt, F., & Brittenham, D.R. (1984). Coaches Round Table: Speed Development. NSCA Journal, January:12-22, 72-73.

Mann, Ralph (1994). The Mechanics of Sprinting and Hurdling, Compusport at Grand Cypress, Orlando.

McFarlane, Brent (1994). Speed...a basic model. Track Technique, #126, Winter 1994.

Mero A (1988). Force-time characteristics and running velocity of male sprinters during the acceleration phase of sprinting. Research Quarterly for Exercise and Sport. 59(2). 94-98.

Maro A, Komi PV, Gregor RJ (1992). Biomechanics of sprint running: a review. Sports Medicine. 13(6):376-92.

Nelson, R.C., Dillman, C.J., Lagasse, P., and Bickett, P. (1972) Biomechanics of overground versus treadmill running. Medicine and Science in Sports and Exercise, 4:233-240.

Nigg, B. M., Ruud, W., & Fisher, V. (1995). A kinematic comparison of overground and treadmill running. Medicine and Science in Sports and Exercise, 27(1):98-105.

Piscopo, J. & Baley, J. (1981). Kinesiology: The science of movement. Wiley: New York.

Plisk, S. (1995). Theories, concepts and methodology of speed development as they relate to sport performance. Essential Principles of Strength and Conditioning Symposium.

Schmolinsky, G. (1992). Track and Field: The East German Textbook of Athletics. Sport Books Publisher: Toronto.

Seagrave, L. (1989). The development of drug free elite sprinters and hurdlers. 1989 Track and Field Symposium, Las Vegas, Nevada.

Swanson, S. (1997). Comments on the biomechanics of incline and level treadmill running vs. overground running. Unpublished manuscript. Acceleration Products.