

BIOMECHANICAL FACTORS IN SPRINT TRAINING- WHERE SCIENCE MEETS COACHING.

Andrew J. Harrison

Biomechanics Research Unit, University of Limerick, Ireland.

This paper examines the biomechanics of sprinting and sprint training. Various biomechanical models of sprint performance are considered with respect to the start, acceleration and speed maintenance phases of the 100 m sprint event together with the research that underpins those models. The impact of research on strength and conditioning training is discussed with special reference to the control of leg-spring stiffness and the applications of resistance and complex training modalities. Training practises for sprinting are discussed with respect to scientific evidence. The relevance of commonly used sprint and running drills is evaluated in relation to the kinematics and muscle activation patterns in sprinting. Finally, a simple coaching related model for the development of sprinting is presented which is consistent with scientific evidence.

KEY WORDS: Running, leg spring stiffness, complex training, reactive strength

INTRODUCTION: The mission of ISBS emphasises the importance of ‘bridging the gap between scientists and practitioners’. Sprint running is fundamental to successful performance of many sports activities and athletics events. Consequently, the biomechanics of sprinting has been researched in great detail over many years. Despite the considerable body of scientific knowledge currently available on the biomechanics of sprinting and sprint training, Jones et al, (2009) found a dearth of knowledge amongst expert coaches on the technical constructs which govern the successful completion of each phase of the 100m sprint event. It is therefore apparent that much more work is required to bridge the gap between scientists, sprint coaches and their athletes. It is intuitively obvious that the quality of performance in sprinting or any other activity must be related to the quality of the training experience and preparation of the athlete. Therefore, consideration must be paid to the biomechanical factors that improve sprint training as well as those that affect sprint performance. This paper summarises the evolution of biomechanical “technical knowledge” of sprinting and sprint training. It examines the biomechanical and technical models of sprinting and considers biomechanics factors in sprint training. These factors focus on how research in biomechanics has underpinned improvements in strength and conditioning training as well as improvements in running technique. Finally, a simple technical model of sprinting is presented which is underpinned by scientific evidence from biomechanical investigations and reviews. The paper and accompanying presentation examines in detail, how practises should be structured and developed to achieve optimal sprinting technique.

BIOMECHANICAL MODELS OF SPRINTING: Biomechanical models of sprinting have been presented in various forms and each model contributes to our understanding of the biomechanics and performance of the activity. The Deterministic Models of Hay and Reid, (1988) show the factors that affect performance of sprinting and the relationships between those factors using simple mathematical relationships. The advantage of this approach lies in the ability of the models to identify the biomechanical factors that truly limit performance. The disadvantage is that many of the factors may not be readily observable in field situations and therefore alternative coaching models are presented in the form of picture sequences and descriptions of critical features, (see figure 1). Graham and Harrison, (2006) have provided a typical deterministic model for the start and first 5 m of the sprint event, (see figure 2). While this model was derived to identify factors limiting performance of the start to 5 m, the right side of the flowchart identifies the deterministic factors that act throughout the race after block clearance.

Maximum Velocity Models: When the athlete has accelerated to maximum running velocity, (which is attained after 25 to 50 m depending on performance level), then performance is limited by the ability of the athlete to maintain speed.



Figure 1: Picture sequence for sprint running. (From Dyson, 1973)

Research has shown that in maximum speed running, the leg action can be effectively modelled as a simple linear spring-mass model, (Farley et al, 1991; Farley et al, 1996; McMahon et al, 1987). The stiffness of the leg spring, K_{leg} can be determined by dividing the peak ground reaction force by the change in leg length, ΔL and the vertical stiffness, K_{vert} equals the peak vertical ground reaction force divided by the vertical displacement of the centre of mass, Δy . In vertical hopping $K_{vert}=K_{leg}$. Over the last 20 years, various researchers have demonstrated the importance of leg-spring and vertical stiffness in fast running. Arampatzis et al, (1999) found that leg stiffness increased with increasing running speed and Farley et al, (1991) found that the stiffness of the leg-spring can change as much as twofold to accommodate different hopping frequencies.

Chelly and Denis, (2001) showed that leg stiffness values are correlated to maximal running velocity ($r = 0.68$, $P < 0.05$). Similarly, experimental research on well trained athletes has also shown that sprinters have significantly higher leg spring stiffness compared with distance runners (Harrison et al., 2004). It is therefore clear that the ability to interact with the ground using a stiff spring-like action of the lower limb, is critical in encouraging a fast cadence and running speed in the speed maintenance phase of sprinting.

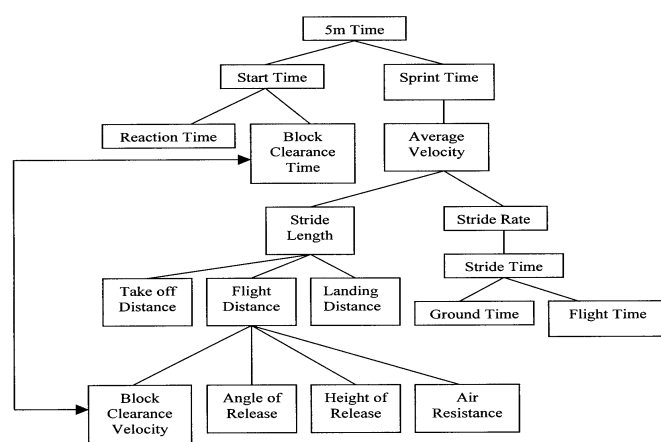


Figure 2: Deterministic model for sprinting based on the guidelines of Hay and Reid (1988).

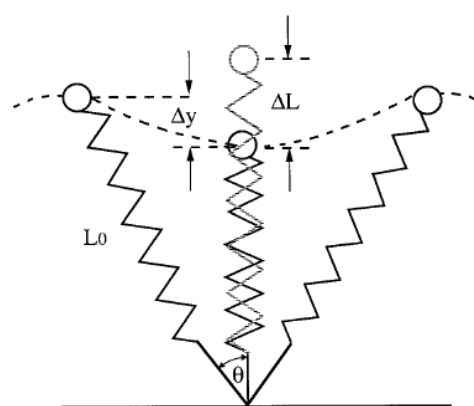


Figure 3: Diagram of the spring-mass model during running L_0 , ΔL , Δy , and θ represent the initial length of the leg spring, the maximum compression of the initial length of the leg spring, the maximum vertical displacement of the centre of mass, and the half of the angle swept by the leg spring during the stance phase, respectively. The spring-mass model drawn with a discontinuous line represents the uncompressed leg spring. The arc drawn with a discontinuous line represents the path of the mass (centre of gravity of the subject) during the stance phase. (From, Chelly and Denis, 2001)

BIOMECHANICAL FACTORS IN SPRINT TRAINING: Research in biomechanics points to the importance of strength development in the early acceleration phase and the development reactive strength or leg stiffness for maximum speed running. The use of sledge towing and resistance running has been found to benefit the early acceleration phase of sprinting. Cronin et al, (2008) established that sledge towing was an appropriate training modality for the early acceleration phase in sprinting, provided the amount of resistance was moderate and did not result in major changes in the joint kinematics of the sprinting action. Harrison and Bourke, (2009) found that sledge training with a load of approximately 13% of body mass, significantly improved 5 m and 10 m movement times in field tests and improved starting strength in laboratory-based tests. It appears then, that resistance running exercises are a valuable training modality for developing the early to mid-acceleration phase. The transition between early acceleration and the attainment of maximum velocity, which is commonly referred to as the 'pick-up' or 'drive phase' is an important aspect of sprinting but to date there is little scientific work on the biomechanics of this phase. However, logic points to the use training exercises where resistance is applied during running and then released and this is borne out by observation of coaching practices.

In recent years, several studies have examined the application of complex training (which alternates heavy resistance and plyometric exercises) to improve performance in sprinting and jumping activities. The outcome of complex training studies have been somewhat conflicting with some authors finding clear benefits (Robbins, 2005; Comyns et al, 2006; Chatzopoulos, 2007) and others observing no perceptible benefits (Ebben and Watts, 1998; Jones and Lees, 2003; Scott and Docherty, 2004). Close inspection of the research in complex training reveals wide variations between studies on how data are analysed and this may account for the inconsistency in findings. Comyns et al, (2006 and 2007) showed that complex training could be used to induce acute changes in the leg-spring stiffness response during rebound jumps. Comyns et al (2007) indicated that the optimal load for the heavy resistance component of complex training was >90% of a 1 repetition maximum. The optimal recovery interval for inducing a post activation potentiation response appeared to be highly individualised (Comyns et al 2006). Comyns et al (2010) found that the benefits of using complex training to improve sprinting performance were highly variable and that athletes probably required sustained and repeated exposure to this training modality to gain significant benefits. In summary, it appears that a major benefit of complex training is in improving the leg-spring stiffness response and reducing contact times during running and jumping.

USE OF ISOLATION DRILLS: An important feature of sprint coaching is the establishment of optimal movement and coordination patterns. The predominant coaching model for this derives mainly from descriptive movement sequences and critical features. Coaches and athletes often use a variety of running drills (sometimes called isolation drills) to encourage the development of optimal movement and coordination patterns. These isolation drills are designed to help the athlete to practise specific parts of the running skill and it is therefore assumed that the drills are the parts of a whole-part-whole learning strategy. For this approach to be successful, it is important that the part practises relate well to the correct sprinting techniques and activate the muscles in patterns that are consistent with sprinting. From a pedagogical perspective, the use of varied part practices is well justified provided the movement parts relate well to the whole skill. The use of such drills is widespread but close inspection of some of the drills reveals they have questionable relevance to sprinting. A typical example of inappropriate practise is the use of the heel flick drill which is assumed to mimic the knee flexion action during the early swing phase of sprinting.

Figure 1 shows a typical picture sequence for sprinting and it is clear that soon after toe off the knee and hip joints appear to flex as the leg moves through the swing (or recovery) phase. Dyson, (1973) even implied that this knee flexion occurred to decrease the load on the hip flexors and increase the speed of the swing phase.

"In this way the mass of the leg is brought closer to the hip axis, reducing

the leg's moment of inertia and increasing angular velocity.” (Dyson, 1973)

Harrison and Warden, (2003) have pointed out that this exercise may be of dubious benefit in sprint training because careful observation of the sprinting shows the heel flick action is not consistent with the pattern of movement of sprinting. In the swing phase of sprinting, the knee does not flex before the thigh is flexed. In reality the knee flexion occurs simultaneously with hip flexion or slightly after the initiation of hip flexion. Furthermore, various authors have shown that the hamstrings do NOT actively contract to facilitate knee flexion immediately after toe off. Weimann and Tidow (1995), Thelen et al (2005a) and Thelen et al (2005b) provided EMG data that demonstrated the hamstring muscles remain relatively inactive during the early part of the swing phase, (see figure 5).

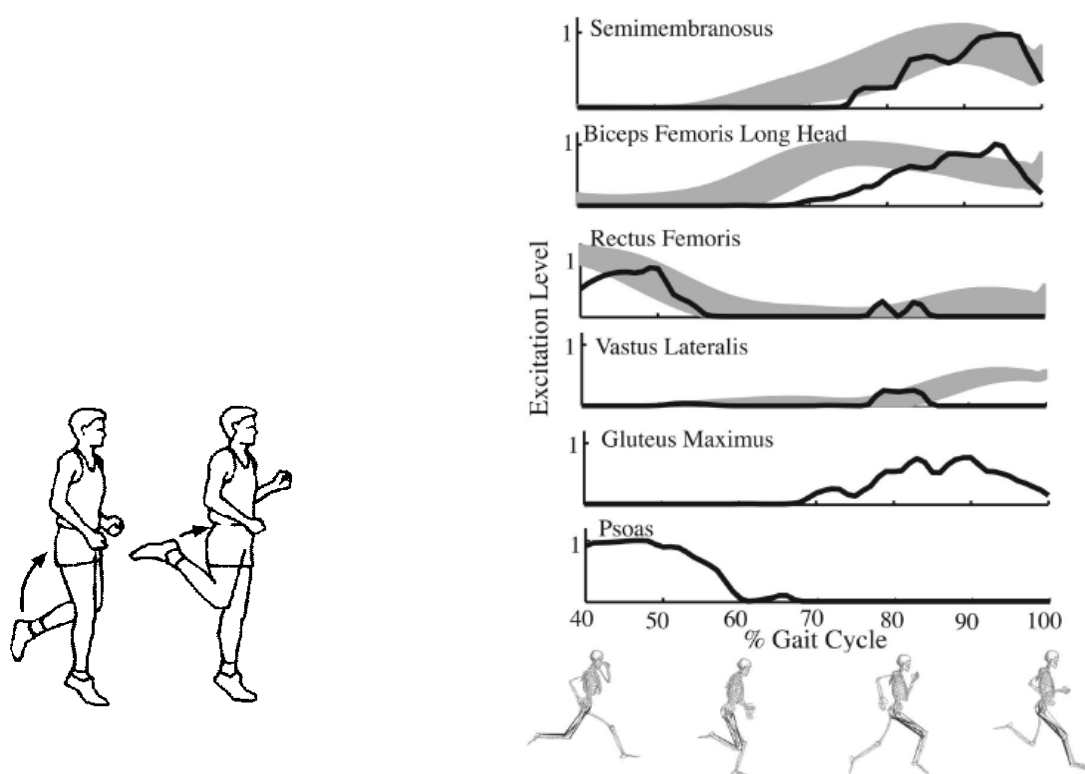


Figure 4: The heel flick drill commonly used in sprint training. (From Carr, 1999).

Figure 5: Simulation of a $9.3 \text{ m}\cdot\text{s}^{-1}$ sprint running cycle showing that the model predicted hip and knee angle kinematics close to experimental values throughout swing phase. The predicted excitations of the Semimembranosus m. Biceps femoris m. Vastus lateralis m. and Rectus femoris m. are compared with measured EMG activities (*shaded curves* are the mean ± 1 SD of the rectified EMG activities for five subjects). The simulated activation sequences show that the hamstrings and gluteus medius m. are relatively inactive during the early swing phase. The Vastus lateralis m. and Psoas m. (hip flexors) are active in early swing phase. Note that the simulations also provide excitation estimates for muscles (e.g., psoas m.) that cannot be monitored using surface electrodes. (From Thelen et al, 2005b).

Johnson and Buckley (2001) examined hip and knee joint moments and powers during the mid-acceleration phase of sprinting and found that the knee flexion moments were relatively small just after toe-off. Considered together, these studies indicate that the hamstrings are not likely to be active immediately following toe off and therefore the practice

of heel flick drills is inappropriate. Thelen et al (2005b) also suggest that hamstring activity at this point in the running gait cycle could increase the risk of injury.

Science contributes significantly to our understanding of the technical aspects of sprint training and performance but ultimately coaches need to distil the findings of scientific research down to simple technical models that emphasise the correct or optimal movement, coordination and muscle activation patterns for sprint performance. Knowledge of such optimal patterns may allow the coach to select systematically appropriate drills and training practises. Based on many years of experience of coaching international level sprinters, the author has developed a simple model of sprinting which has important implications for training. This model assumes that the arms play a subordinate, counterbalancing role to the leg action in sprinting and therefore, little emphasis is placed on correction of arm actions unless they are demonstrably unbalancing or destabilising the overall movement of the sprinter. This is somewhat contrary to the views of many expert coaches but is consistent with the scientific literature (Jones et al 2009). The primary emphasis in sprinting should be on the action of the legs which involves moving each leg alternately from the positions of the right leg in figure 6A and 6B. The emphasis during ground contact should be on the production of a short, pawing movement with stiff spring-like rebounding action during the speed maintenance phase. The relevance or otherwise of various drills and practises will be explored during the presentation using video sequences.

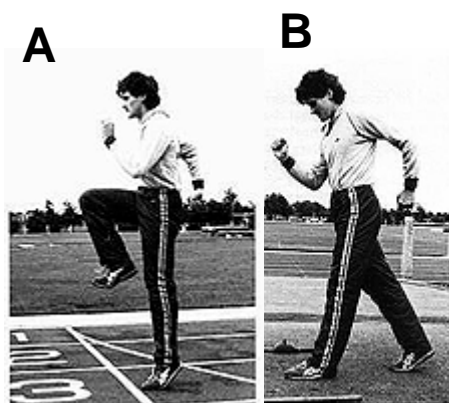


Figure 6: Two key positions in sprinting.

CONCLUSION: Effective coaching requires that coaches have a clear and valid model of sprinting technique that describes desired movement, coordination and muscle actions which are consistent with evidence from scientific investigations. It is concluded that in many instances, current coaching practise does not draw effectively on research findings on sprinting biomechanics. A simple technical model of sprinting is presented together with a series of relevant practises and drills.

REFERENCES:

- Arampatzis, A., Brüggeman, G.P., & Metzler, V. (1999). The effect of speed on leg stiffness and joint kinetics in human running. *Journal of Biomechanics*. 32, 1349-1353.
- Baker, D (2003). Acute effect of alternating heavy and light resistances on power output during upper-body complex power training. *Journal of Strength and Conditioning Research*. 17(3), 493 - 497.
- Carr, G. (1999) *Fundamentals of Track and Field*. 2nd Edition. Human Kinetics, Leeds.
- Chatzopoulos, D.E., C.J. Michailidis, A.K. Giannakos, K.C. Alexiou, D.A. Patikas, C.B. Antonopoulos, & CM. Kotzamanidis. (2007) Postactivation potentiation effects after heavy resistance exercise. *Journal of Strength Conditioning Research*. 21(4):1278-1281.
- Chelly, S. M., & C. Denis, C. (2001) Leg power and hopping stiffness: relationship with sprint running performance. *Med. Sci. Sports Exerc.*, 33, (2): 326–333.

- Chumanov, E.S., Heiderscheit, B.C., & Thelen, D.G. (2007) The effect of speed and influence of individual muscles on hamstring mechanics during the swing phase of sprinting. *Journal of Biomechanics*. 40: 3555–3562
- Comyns T.M., Harrison A.J., Liam K. Hennessy L.K. & Jensen R.L. (2010) The effect of squatting on sprinting performance and repeated exposure to complex training in male rugby players. *Journal of Strength and Conditioning Research*, 24(3): 610-618.
- Comyns T.M., Harrison A.J., Hennessy L. and Jensen R.L. (2006) The optimal complex training rest interval for athletes from anaerobic sports. *Journal of Strength and Conditioning Research*. 20 (3): 471- 476.
- Comyns T.M., Harrison A.J., Hennessy L. and Jensen R.L. (2007) Identifying the optimal complex training resistive load in male rugby players, *Sports Biomechanics*, 6 (1): 59-70.
- Cronin, J., Hansen, K., Kawamori, N., & McNair, P. (2008) Effects of weighted vests and sled towing on sprint kinematics *Sports Biomechanics*. 7(2): 160–172
- Dyson. G. (1973) *The Mechanics of Athletics*. 6th Edition. University of London Press.
- Ebben, W.P., & Watts, P.B. (1998). A review of combined weight training and plyometric training modes: Complex training. *Strength and Conditioning Journal*. 20(5), 18 - 27.
- Farley, C.T., Blickhan, R., Saito, J., & Taylor, C.R. (1991). Hopping frequency in humans: a test of how springs set stride frequency in bouncing gaits. *Journal of Applied Physiology*. 716, 2127-2132.
- Farley, C.T., & González, O. (1996). Leg stiffness and stride frequency in human running. *Journal of Biomechanics*. 29(2), 181-186.
- Graham, D. & Harrison, A.J. (2006) A biomechanical investigation of the application of schema theory in the sprint start. In: Schwameder, H. ed. *24th International Symposium on Biomechanics in Sport*. University Salzburg, Austria: 513-516.
- Harrison, A.J. & Bourke, G. (2009) The effect of resisted sprint training on speed and strength performance in male rugby players. *Journal of Strength and Conditioning Research*, 23 (1): 275-283.
- Harrison, A.J., Keane, S.P., & Coglán, J. (2004). Force-velocity relationship and stretch-shortening cycle function in sprint and endurance athletes. *Journal of Strength and Conditioning Research*. 18(3), 473-479.
- Harrison, A.J. & Warden, P. (2003) Isolation (Sprinting) Drills. *Coaches Information Service*, http://www.coachesinfo.com/index.php?option=com_content&view=article&id=355:sprintingdrill-article&catid=99:track-athletics&Itemid=184 accessed May 2009.
- Hay, J.G., & Reid J.G. (1988) *Anatomy Mechanics and Human Motion*. Englewood Cliffs, NJ. Prentice Hall.
- Jones, P., & Lees, A. (2003). A biomechanical analysis of the acute effects of complex training using lower limb exercises. *Journal of Strength and Conditioning Research*. 17(4), 694 - 700.
- Jones, R., Bezodis, I. & Thompson, A. (2009) Coaching Sprinting: Expert Coaches' Perception of Race Phases and Technical Constructs. *International Journal of Sports Science & Coaching*. 4(3): 385-396.
- Johnson, M.D., & Buckley, J.G. (2001) Muscle power patterns in the mid-acceleration phase of Sprinting. *Journal of Sports Sciences*, 19: 263- 272
- McMahon, T.A., Valiant, G., & Frederick, E.C. (1987). Groucho running. *Journal of Applied Physiology*. 62, 2326:2337.
- Robbins, D.W., (2005). Postactivation potentiation and its practical applicability: a brief review. *Journal of Strength and Conditioning Research*, 19(2): 453-458.
- Scott, S.L. & Docherty, D. (2004). Acute effects of heavy preloading on vertical and horizontal jump performance. *Journal of Strength and Conditioning Research*. 18(2), 201 – 205.
- Thelen, D. G., Chumanov, E.S., Best, T.M., Swanson, S.C., & Heiderscheit, B.C. (2005a) Hamstring Muscle Kinematics during Treadmill Sprinting. *Med. Sci. Sports Exerc.*, 37 (11): 1931-1938.
- Thelen, D. G., Chumanov, E.S., Hoerth, D.M., Best, T.M., Swanson, S.C., Li, L., Young, M., & Heiderscheit, B.C. (2005b) Hamstring Muscle Kinematics during Treadmill Sprinting. *Med. Sci. Sports Exerc.*, 37(1): 108–114.
- Wiemann, K., & Tidow, G. (1995) Relative activity of hip and knee extensors in sprinting - implications for training. *New Studies in Athletics*. 10 (1): 29-49