100-METER SPRINT RUNNING: EVENT ANALYSIS AND PROGRAMMING OF TRAINING AND COACHING

Miro Enroth

Coaching Seminar
Science of Sport Coaching and Fitness Testing
Biology of Physical Activity
Faculty of Sport and Health Sciences
University of Jyväskylä
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Supervisor: Antti Mero

ABSTRACT

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This work consists of biomechanics and technique of sprint running in all four phases of the 100-meter event: block phase, acceleration phase, maximum running phase and deceleration phase. Regarding physiology, the role of neuromuscular system and energy metabolism will be described. The programming of an annual coaching plan will be presented. In the plan sprint running methods, resistance training, nutrition, recovery, and other special concerns of coaching are described according to the current literature. At the end, international sprinting standards and the current state of coaching system in Finland will be discussed.

Biomechanics and technique. Running velocity (V) can be calculated by multiplying the length of the stride (SL) with the rate of the stride (SR): V = SL x SR. One stride consists of ground contact phase and flight phase. The ground contact phase can be divided into braking and propulsion phases. Braking phase occurs prior to propulsion phase starting from the initial ground contact point that occurs no more than 20 cm ahead of the total body center of gravity. The propulsion phase begins after the total body center of gravity crosses the ground contact point and allows the propulsive force production to begin. The force should be directed as vertical as possible in the braking phase and as horizontal as possible during the propulsion phase. The ratio between ground contact time and flight time varies across the different phases of the 100-meter sprint. During the powerful acceleration phase ground contact durations vary from 140 to 200 milliseconds and decrease down to 80–90 milliseconds, when the maximal velocity is attained. The duration of the braking phase is slightly shorter compared to propulsion phase during maximum running.

Neuromuscular system and energy metabolism. It is advantageous for a sprinter to have proportionally more fast (F) motor units rather than slow (S) motor units in their leg muscles. The genetics will determine 47–78 % of the muscle fiber type distribution (motor nerve and muscle fibers are always the same type within one motor unit). During the maximal 100-meter sprint performance energy production occurs through immediately available adenosine triphosphate (ATP) and phosphocreatine (PC) over the first 50–60 meters. Later, additional energy is produced via anaerobic glycolysis. The portion of producing ATP via PC and anaerobic glycolysis is approximately 50 % / 50 % during maximal 100-meter running. Both energy pathways can be enhanced with training and optimal nutrition.

Elite sprinter. **Velocity:** The most important physical feature of an elite sprinter is velocity. During the 100-meter sprint elite male sprinters reach peak velocities of over 11.5 m/s (i.e. running flying 20-meter <1.74 s) whereas elite female sprinters reach velocities of over 10.5 m/s (i.e. running flying 20-meter <1.92 s). The maximal velocity usually occurs between 50–70 m among both male and female elite sprinters.

Sprint specific strength: Sprint specific strength (i.e. force applied to the track during a rapid ground contact) is the most valid value of strength measures. Elite sprinters can apply higher reaction forces to the track with shorter ground contact time compared to their lower performing

counterparts. During the sprint both vertical and horizontal force is produced, while mediolateral force remains minor. During the acceleration phase horizontal force contributes to the motion acceleration (braking force < propulsive force). During the acceleration vertical force allows the lift of the total body center of gravity, consequently enabling the sprinter to advance running in an upright position. In the maximum running phase, as the velocity is constant, the importance of horizontal force is less significant (braking force = propulsion force). Therefore, vertical force is more important, as it is working against gravity and enabling the sprinter to retain a long stride length by large resultant force produced at propulsion. Stride length is approximately 1.4 x body height among elite male sprinters and 1.3 x body height among elite females, respectively.

Strength test values: Elite male sprinters can deep squat approximately 2.5 x their body mass (BM) and lift 1.8 x BM in power clean. The coefficients of the same bar tests for elite female sprinters are 2.0 and 1.5, respectively. In power and plyometric tests elite male sprinters reach 65–75 cm in a countermovement jump (no arm swing) and 17–19 m from standing 5-jump, while elite female sprinters reach 55–60 cm and 15–16 m, respectively.

Programming of training. The annual training plan in athletics (i.e. sprint running) usually consists a bicycle periodization model, where competing occurs in two phases: indoor and outdoor. Programming is used to direct training progressively throughout the subsequent phases, to stimulate physiological adaptations, manage fatigue and to optimize peak performance to occur in main competitions. Furthermore, training should not occur in a linear fashion, but it must be alternated with the volume and intensity of training and with respect to the individual necessities of the sprinter. The most common microcycle rhythm is 2:1 -cycle, where two weeks of high training load entitles one week of rest and recovery associated with a lower training load. Certainly, also other similar versions can be programmed. The number of races during the competitive phases determines the cycling of training load. Annually, the total number of races varies from 20 to 30 among elite sprinters. The average number of training within a microcycle varies distinctly across different season phases. During a preparatory phase, a microcycle may consist of five sessions of high load and additional five of preparative- or restorative sessions. While approaching competitions the quantity of sessions decreases significantly.

Sprint training. Sprint training consists of speed and speed endurance training. Maximal (96–100 %) and submaximal (90–95 %) speed training include the acceleration and maximum running phase within distances of 30–60 meters. Speed endurance (80–100 %) consists distances mainly from 70 to 150 meters, where the stimulation of anaerobic glycolysis is achieved. The sprint distance of speed endurance training may reach up to 300 meters in case the sprinter competes both in 100 and 200-meter events. Furthermore, aerobic tempo running (50–70 %) is often used during the preparatory phase in distances between 100–300 meters, whereas high intensity intervals (70–80 %) are used to cause more intense stimuli. All running intensities above are expressed in percent of maximal velocity/personal best of the distance. Sprint technique can be trained via coordination exercises and by highlighting correct sprint mechanics in each exercise. More sprint training should always occur compared to strength training, usually the ratio is 3:2 in favor of sprint running in intense sessions.

Strength and power training. Strength training should include characteristics of all areas of strength: speed-strength (i.e. power), maximal strength, and endurance strength. Maximal strength (both neural and hypertrophic) underlies all other areas of strength, such as power, later through which sprint specific force can be attained. Endurance strength is usually trained during the preparatory phase (e.g. resisted sprints, plyometrics). Strength training should occur in such fashion that the transition effect from weight room to sprint running is achieved each competitive season.

Recovery and nutrition. Optimal adaptations during training are gained by consistently ensuring appropriate rest and regeneration, where quality of sleep (8–9 hours) and appropriate nutrition are preserved. For both male and female sprinters the daily carbohydrate intakes of 4–6 g/kg body mass and 1.5–2.0 g/kg body mass intakes of protein are recommended. During high intensity training and competitions additional recovery modalities and dietary supplements may be beneficial. The most used supplements among sprinters are amino acids, whey protein, creatine monohydrate, sodium bicarbonate and β-Alanine.

Coaching systems. There is variation in the fashion of sprint training programming according to differences in background, gender, age, level, assets, constrains and other inter-individual variables. Still, the principles of annual training plan are very much the same in different countries. In Finland the emphasis seems to be on small training groups and individualized coaching that is organized by athletic clubs, whereas, for instance in Poland the emphasis is set on national team events such as training camps that recur more frequently compared to Finland. Furthermore, in the United States the college and university-based programs are partially more developed with their grant systems.

Conclusions and challenges of Finnish coaching system. According to research and practical experiences the following challenges and propositions should be taken into consideration by executive practitioners in the Finnish sprint training and system:

1. in order to succeed in the 100-meter event finals in Olympic Games, World Championships and European Championships requires exceptional genetics and first-class training and coaching
2. in age group 7–13 years track and field training should focus on diverse skill development and to speed, since that is when the “sensitivity period” occurs for characteristics in question
3. a new goal in Finnish track and field club training in ages of 7-13 should be 2–5 sessions track and field weekly, with progression and with instructions by experienced and educated coaches
4. in ages between 13–19 years athletes may begin to advance towards peak performance phase, after a broad skill base (i.e. trainability) is achieved along with high quantities of quality sprint training
5. the peak performance phase, especially ages of 19–25 years are important. The sprinter should understand what it takes to achieve success in elite sprinting. National and international training centers that offer advanced training circumstances should be utilized as much as possible. A well-experienced and educated full-time coach is required in coaching work, to maintain the required high standards for reaching success in sprinting.

TIIVISTELMÄ

Enroth Miro. 2020. 100 metrin pikajuoksun lajianalyysi sekä harjoittelun että valmennuksen ohjelmointi. Valmentajaseminaari. Valmennus- ja testausoppi. Liikuntabiologia. Liikuntatieteellinen tiedekunta. Jyväskylä. Suomi. 107 s.

Tässä työssä esitetään ensiksi 100 metrin pikajuoksun lajianalyysin biomekaniikkaa sekä tekniikkaa suorituksen jokaisessa neljässä vaiheessa: telinelähtövaihe, kiihdytysvaihe, maksimaalisen nopeuden vaihe ja nopeuden hidastumisvaihe. Fysiologian osalta työssä kuvataan hermolihasjärjestelmän ja energiantuoton toimintaa pikajuoksusuorituksessa. Valmennuksen ohjelmointiosiossa esitetään pikajuoksun vuosisuunnitelma ja eri valmennusjärjestelmiä. Harjoittelun jaksottamisessa käsitellään pikajuoksu- ja voimaharjoittelua, palautumisen kokonaisuudessa ravintoa ja unta, sekä harjoittelun erityispiirteitä kuten harjoittelun seurantaa, testaamista ja kunnon huipentamista. Työn lopussa lyhyt yhteenveto lajin tasosta maailmalla ja Suomessa sekä pohdintaan haasteista suomalaisessa pikajuoksuvalmennusjärjestelmässä.

Biomekaniikka ja tekniikka. Juoksunopeus (V=velocity) voidaan laskea kertomalla askelpituus (SL=stride length) askeltiheydellä (SR=stride rate): V = SL x SR. Yksi askel koostuu ratakontaktista sekä lentovaiheesta. Ratakontakti voidaan jakaa jarrutus- ja työntövaiheeseen. Jarrutusvaihe alkaa siitä hetkestä, jolloin piikkari ensiksi koskettaa rataa, joka tulisi tapahtua aikuisella juoksijalla vähemmän kuin 20 cm juoksijan kehon painopisteen pystylinjan edessä. Työntövaihe alkaa siitä hetkestä, kun kehon painopiste siirtyy ko. pystylinjan etupuolelle. Jarrutusvaiheessa juoksunopeus hidastuu ja työntövaiheessa kiihtyy. Jarrutusvaiheessa voimantuotto tulisi tapahtua mahdollisimman pystysuuntaisesti ja työntövaiheessa mahdollisimman vaakasuuntaisesti. Kontakti- ja lentoaikojen suhde vaihtelee juoksun erivaiheissa siten, että kiihdytysvaiheessa kontaktiajat ovat pisimpiä (140–200 millisekuntia), josta ne lyhenevät huippupikajuoksijoilla maksimaalisen nopeudenvaiheessa 80–90 millisekuntiin. Maksimaalisen nopeudenvaiheessa jarrutuksen kesto on hieman lyhyempi kuin työnnön kesto.

Hermolihasjärjestelmä ja energiantuotto. Pikajuoksijalle on eduksi lihassolujakauma, jossa nopeiden motoristen yksiköiden suhteellinen määrä alaraajoissa on suurempi kuin hitaiden motoristen yksiköiden. Perimä määrittää eri tutkimusten mukaan 47–78 % lihassolutyyppien jakaumasta (motorinen yksikkö koostuu aina saman tyypin hermosto-osasta ja lihassoluista). Maksimaalisessa 100 metrin juoksussa rekrytoidaan mahdollisimman voittopuolisesti nopeita motorisia yksiköitä (nopeita lihassoluja). Energiantuotollisesti maksimaalisen 100 metrin pikajuoksusuorituksen aikana energiaa tuotetaan ensimmäisten 50–60 metrin aikana välittömien energialähteiden adenosiinitrifosfaatin (ATP) ja fosfokreatiinin (FK) avulla. Juoksun loppuosassa myös anaerobinen glyykolyysi aktivoituu voimakkaasti. FK:n ja anaerobisen glykolyysin osuus ATP:n tuottamisessa on maksimaalisessa 100 metrin suorituksessa noin 50 % / 50 %. Kaikkia energiantuottotapoja voidaan edistää harjoittelulla ja optimaalisella ravinnolla.

Urheilija-analyysi**.** **Nopeus:** Pikajuoksussa ratkaisevin fyysinen ominaisuus on nopeus. Huippumiespikajuoksija voi ylittää 100 metrin kilpailun aikana yli 11,5 m/s nopeuden (lentävä 20 m < 1,74 s) ja huippunaispikajuoksija yli 10,5 m/s nopeuden (lentävä 20 m < 1,92 s). Huipuilla sekä miehillä että naisilla maksiminopeus ajoittuu 50–70 metrin kohdalle. **Lajivoima:** Pikajuoksussa voimaominaisuuksista ratkaisevin on lajivoima eli se kuinka tehokkaasti juoksija kykenee tuottamaan voimaa rataan lyhyen askelkontaktin aikana. Huippupikajuoksijat kykenevät tuottamaan rataan suuremmat reaktiovoimat lyhemmällä kontaktiajalla verrattuna hitaampiin juoksijoihin. 100 metrin juoksun aikana voimaa tuotetaan pääasiassa vain pysty- ja vaakasuuntaan (sivusuuntaan tuotettu voima on hyvin vähäistä). Kiihdytysvaiheessa vaakavoiman seurauksena nopeuden on mahdollista kiihtyä (jarrutusvoima < työntövoima). Kiihdytysvaiheessa pystyvoimaa tarvitaan nostamaan juoksijan painopistettä ylöspäin valmiit -asennon tasosta pystyjuoksun tasoon. Maksiminopeudenvaiheessa vaakavoiman rooli on vähäisempi, koska etenemisnopeus on vakio (jarrutusvoima = työntövoima). Näin ollen, pystyvoiman merkitys on suurempi, koska sen avulla pyritään vastustamaan maan vetovoiman vaikutusta juoksijaan sekä mahdollistamaan pitkä juoksuaskel suurella työntövaiheen resultanttivoimalla. Huippumiespikajuoksijoilla askelpituus on 1,4 x juoksijan oma pituus ja huippunaispikajuoksijoilla 1,3 x juoksijan oma pituus. **Voimatestien arvoja:** Huippumiespikajuoksijoilla syväkyykkytulos on noin 2,5 x oma paino ja raaka rinnallevetotulos noin 1,8 x oma paino. Huippunaispikajuoksijoilla vastaavat kertoimet ovat 2,0 ja 1,5. Nopeusvoimaa mittaavissa hyppytesteissä miesten tulokset vaihtelevat vauhdittomassa 5-loikassa 17–19 m:n ja kevennyshypyssä 65–75 cm:n välillä. Naisilla vastaavat tulokset ovat 15–16 m ja 55–60 cm.

Harjoittelun ohjelmointi**.** Yleisurheilussa harjoittelun vuosisuunnitelma rakennetaan yleensä kahteen toisiaan mukailevaan sykliin (halli- ja ulkoratakausi). Harjoitussuunnitelma tehdään johdonmukaisen ja edistävän harjoittelun takaamiseksi. Harjoitussuunnitelman tulee sisältää johdonmukaisesti toisiaan seuraavia vaiheita alkaen peruskuntokaudesta ja edeten kilpailuihin valmistavaan kauteen ja itse kilpailukauteen. Harjoittelun kuormittavuutta tulee säädellä ensisijaisesti harjoittelun intensiteetin ja volyymin muutoksilla. Kilpailukaudella palautumisen lisäksi on tärkeää onnistunut kunnon huipentaminen (”piikkaus”) pääkilpailujen kohdalla. Ennen kaikkea harjoittelun tulee olla yksilöityä ja progressiivista. Viikkorytminä harjoittelukaudella käytetään eniten 2:1-jaksoa eli kaksi kovaa viikkoa ja yksi kevyt palautumisviikko. Luonnollisesti myös muita versioita lähellä tuota käytetään. Kilpailukaudella kilpailujen määrä vaikuttaa eniten jaksotteluun. Kilpailuja tulee olla koko vuonna halli- ja ulkoratakilpailut huomioiden 20–30 huippu-urheilussa. Viikon keskimäärinen harjoitusten määrä vaihtelee paljon. Tyypillinen tehoharjoitusten määrä on harjoittelukaudella viisi ja valmistavia ja palauttavia harjoituksia voi olla sama viisi. Kilpailukaudella määrä putoaa selvästi mentäessä kohti pääkilpailua.

Juoksuharjoittelu**.** Pikajuoksijan juoksuharjoittelu sisältää nopeusharjoittelun ja nopeuskestävyysharjoittelun. Maksimaalinen (96–100 %) ja submaksimaalinen (90–95 %) nopeusharjoittelu sisältävät kiihdytys- ja maksimaalisen nopeuden vaiheen harjoittelun 30–60 metrin vetomatkoilla. Nopeuskestävyysharjoittelu tapahtuu pääasiassa 70–150 metrin vetomatkoilla, joissa anaerobinen glykolyysi toimii suhteellisen aktiivisesti tuottaen happamuutta lihaksiin. Juoksujen nopeudet vaihtelevat 80–100 %:iin. Jos pikajuoksija kilpailee sekä 100 että 200 metrin matkoilla, niin nopeuskestävyyden vetomatkat laajenevat aina 300 metriin asti. Nopeuskestävyyden tukiharjoituksina käytetään peruskuntokaudella aerobisia harjoituksia yleensä 100–300 metrin matkoilla: määräintervallit (50–70 %) ja tehointervallit (70–80 %). Harjoituksen intensiteetti (%) ilmoitetaan prosentteina maksimijuoksunopeudesta tai ko. matkan ennätyksestä. Juoksutekniikan harjoittelussa käytetään juoksukoordinaatioita ja tekniikan korostamista kaikessa juoksuharjoittelussa. Harjoittelussa on aina pyrittävä pikajuoksunomaiseen juoksemiseen. Juoksuharjoittelun osuus viikkojaksoissa on aina suurempi kuin voimaharjoittelun, yleensä tehoharjoituksina 3:2 juoksun eduksi.

Voimaharjoittelu. Pikajuoksijan voimaharjoittelun tulee sisältää kaikkia voiman lajeja: nopeusvoimaa, maksimivoimaa ja kestovoimaa. Maksimivoima (ns. hermostollinen ja hypertrofinen) on perusta kaikelle muulle voimaharjoittelulle. Se antaa pohjan nopeusvoimalle ja sitä kautta lajinomaisen juoksuaskeleen voimantuottoon. Kestovoimaa harjoitellaan jonkin verran peruskuntokaudella - tavallisesti lajinomaisesti eli juoksemalla ylämäkeen tai hyppelysarjoilla. Voimaharjoittelun eteneminen tulee tehdä juoksijan uralla siten, että hankittu voima onnistutaan siirtämään lajisuoritukseen joka vuosi.

Ravinto ja uni palautumisessa. Kovasta harjoittelusta palautuminen onnistuu optimaalisella ravinnolla, riittävällä 8–9 tunnin unella ja muiden arjen asioiden huomioimisella. Sekä mies- että naispikajuoksijalle päivittäisen energiasaannin on hyvä sisältää 4–6 g/kg (kehonpaino) hiilihydraattia ja vastaavasti 1,5–2,0 g/kg proteiinia. Ravintovalmennuksessa tulee suosia normaalia kotimaista ruokaa. Kovien harjoittelujaksojen aikana ja kilpailukaudella lisäravinteista voi olla hyötyä. Käytetyimpiä ovat aminohappo- ja proteiinivalmisteet, kreatiini, natriumbikarbonaatti ja β-alaniini.

Valmennusjärjestelmät. Valmennuksen ohjelmointitavoissa on järjestelmäeroja, jotka johtuvat useista taustatekijöistä kuten kyseisen maan harjoittelukulttuurista, urheilijan sukupuolesta, iästä, tasosta, vahvuuksista, kehityskohteista sekä muista yksilöllisistä tekijöistä. Siitä huolimatta pikajuoksuvalmennuksen ohjelmoinnissa eri maissa on enemmän samankaltaisuuksia kuin eroavaisuuksia. Suomessa valmennus painottuu pienryhmä- ja yksilövalmennukseen, josta vastaavat urheiluseurat ja joissa pätevien valmentajien rooli on erittäin tärkeä. Esimerkiksi Puolassa huippuvalmennuksen painopiste on kyseisen maan yleisurheiluliiton organisoimassa maajoukkueen leiriharjoittelussa, jota tapahtuu saman tasoisilla juoksijoilla enemmän kuin Suomessa. Yhdysvalloissa yliopisto-ohjelmien valmennus- ja harjoitteluolosuhteet ovat mm. urheilun stipendijärjestelyiden myötä joiltain osin edistyksellisemmällä tasolla verrattuna Suomeen.

Johtopäätöksiä ja suomalaisen pikajuoksun haasteita. Käytännön kokemusten ja tutkimustulosten mukaan seuraavia haasteita ja toimenpiteitä olisi hyvä tarkastella suomalaisessa pikajuoksuvalmennuksessa.

1. suomalaisen menestyminen miesten ja naisten 100 metrin matkalla Olympia, MM- tai EM-finaalissa vaatii poikkeuksellista perimän osuutta ja erinomaista harjoittelua
2. ikävaiheessa 7–13 vuotta tulisi keskittyä monipuolisten yleisurheilun lajitaitojen ja nopeuden kehittämiseen, koska tuolloin ovat ko. ominaisuuksien herkkyysvaiheet

3. uusi koventunut tavoite suomalaisessa urheiluseuravalmennuksessa ikävaiheessa 7–13 vuotta tulisi olla 2–5 harjoituskertaa yleisurheilua viikossa nousujohteisesti kokeneiden ja koulutettujen valmentajien ohjaamana
4. huippuvaiheeseen voidaan edetä ikävaiheessa 13–19 vuotta hankittujen monipuolisten yleisurheilun lajitaitojen sekä riittävän aikaisin aloitetun pikajuoksun laadukkaan ja määrällisen harjoittelun kautta
5. huippuvaiheessa erityisesti ikävaihe 19–25 vuotta on tärkeä. Juoksijan tulee ymmärtää mitä huipulle pääseminen tarkoittaa käytännössä. Huippu-urheilijaksi pyrkivän tulisi hyödyntää harjoittelussaan sekä kansallisia että kansainvälisiä harjoittelukeskuksia mahdollisimman useasti. Huippuvaiheessa kokeneen ja koulutetun valmentajan tulee ylläpitää sitä vaatimustasoa, jota huipulle pääseminen vaatii.

ABBREVIATIONS

ATP	adenosine triphosphate
BM	body mass
BOS	base of support
EMG	electromyography
IEMG	integrated electromyography
GRF	ground reaction force
MVC	maximum voluntary contraction
RFD	rate of force development
SL	stride length
SR	stride rate
SSC	stretch-shortening cycle
TBCG	total body center of gravity
TRT	total reaction time
WA	World Athletics
1RM	one repetition maximum

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ABSTRACT

TIIVISTELMÄ

1 INTRODUCTION

The development of sprint training demands both scientific research and practical experience (e.g. Mero et al. 1992; Jouste & Mero 2016; Haugen et al. 2019a and Haugen et al. 2019b), that all show that the 100-meter sprint includes four distinct phases: block phase, acceleration phase, maximum running phase and deceleration phase. In the block phase, the sprinter must find optimal block obliquity and spacing and overall start position (i.e. body posture) that will allow the sprinter to proceed to a powerful acceleration along with a minimum reaction time from the gun signal. A commonly used fashion by sprinters is to set block spacing into a bunched start position that is two footsteps from the start line to the front block and three footsteps to rear block. The challenge in the block start is whether to produce force over the blocks longer (i.e. maximize horizontal force) on a detriment of later first ground contact or to produce less force to blocks and to recover the rear limb sooner, to commence acceleration earlier. In either case the angle of force should be directed horizontally, and the thrust angle should be as low as possible. After the blocks there are usually 2 to 3 post block ground contacts, before the total body center of gravity is set behind the initial ground contact point (i.e. body alignment is vertical and a braking phase is formed) and to remain there throughout the sprint. Maximum running velocity is achieved in 5–6 seconds and is between 50 to 70 meters among male and between 40–60 meters among elite female sprinters. Similarly, to the block start in the maximum running phase there are optimal biomechanical variants that will allow the most efficient and powerful running to occur. Matters such as the ratio between stride rate and stride length, ground contact (braking phase and propulsion phase), optimal initial ground contact point and joint angles will be discussed closely later. Lastly, the aim is to maintain the achieved maximum running velocity until the end of the race. However, high absolute velocities are difficult to maintain, therefore the deceleration percent varies from 2 to 10 %.

The next chapters concerning physiology discuss action in the neuromuscular system and energy metabolism. After this, a review of a cyclic annual training plan for sprint training is presented with attention to program each training phase. Across the training year beginning with preparatory phase, followed by two competitive phases (e.g. indoor, outdoor) and fulfilled by transition phases all have their unique characteristics and special concerns such as tapering,

recovery strategies, variation, testing and monitoring within the training practices. Programming is fulfilled with guidelines for sprint and resistance training methods. Finally, at the end of this work conclusions are made and the most important characteristics of biomechanics and physiology in the 100-meter sprint are highlighted. In addition, international standards and the current state of coaching system in Finland will be briefly discussed.

JOHDANTO

Pikajuoksun kehitys vaatii sekä tieteellistä tutkimusta että käytännön kokemuksia (esim. Mero ym. 1992, Jouste ja Mero 2016, Haugen et al. 2019a ja Haugen et al. 2019b) ja ne osoittavat lajianalyysistä, että 100 metrin pikajuoksu voidaan jakaa neljään vaiheeseen: telinelähtövaihe, kiihdytysvaihe, maksimaalisen nopeudenvaihe ja nopeuden hidastumisvaihe. Telinelähdössä pikajuoksijan on tärkeää löytää itselleen optimaalinen lähtöasento, josta tehokas kiihdytys lyhyellä reaktioajalla on mahdollista. Ensisijaisesti lähtöasentoa muokataan lähtötelineen ja jalustojen etäisyyksien säädöillä sekä muuttamalla jalustojen kaltevuutta. Yleinen nyrkkisääntö hyvän lähtöasennon löytämiseksi on kaksi piikkarinmittaa lähtöviivasta etujalan jalustaan ja kolme piikkarinmittaa takajalan jalustaan. Haaste telinelähdössä on, että halutaanko kohdistaa voimaa telineisiin pidempään (vaakavoiman maksimoimiseksi) tai pyrkiä takajalan nopeaan ensimmäiseen askelkontaktiin. Molemmissa tapauksissa voimantuotto tulee tapahtua vaakasuunnassa ja vartalokulma tulee olla mahdollisimman matala. Telinelähdön jälkeen yleensä kaksi tai kolme ensimmäistä askelkontaktia tapahtuu kehonpainopisteen takana, jonka jälkeen juoksu muuttuu pystyasentoiseksi ja askelkontaktin alkuun muodostuu selkeä jarrutusvaihe. Huippunopeudenvaihe saavutetaan tavallisesti 5–6 sekuntia lähtölaukauksen jälkeen. Huippumiespikajuoksijoilla huippunopeuden vaihe sijoittuu yleensä 50–70 metrin välille ja huippunaispikajuoksijoilla noin 40–60 metrin välille. Huippunopeuden vaiheessa tulee huomioida useita biomekaanisia osatekijöitä, joiden esiintyessä tehokas ja taloudellinen juoksu on mahdollista. Muun muassa askeltiheyden ja askelpituuden suhdetta, askelkontaktia (jarrutus- ja työntövaihe), askelkontaktin sijaintia (suhteessa kehon painopisteeseen) ja pikajuoksulle optimaalisia nivelkulmia käsitellään tulevassa tekstissä. Edellä mainittujen tekijöiden lisäksi tavoitteena on säilyttää huippunopeudenvaihe suorituksen loppuun saakka, mutta tavallisesti nopeuden hidastumisen suuruus on 2–10 % huippunopeudesta.

Pikajuoksun biomekaniikka osion jälkeen työssä käsitellään hermolihasjärjestelmän ja energiantuoton pääkohtia huippupikajuoksusuorituksen kannalta. Viimeisessä osiossa käsitellään mm. juoksu- ja voimaharjoittelu metodeja, joista erityisesti plyometrinen, voima- ja nopeusvoima harjoittelu ovat merkittävässä asemassa pikajuoksussa, itse juoksuharjoittelun lisäksi. Valmennuksen ohjelmointiosiossa esitetään ensiksi vuosisuunnitelma, jonka jälkeen kauden jokainen vaihe käsitellään erillisesti. Vuosisuunnitelma sisältää peruskuntokauden I, kisaan valmistavankauden I, hallikauden, peruskuntokauden II, kisaan valmistavankauden II, ulkoratakauden sekä ylimenokauden, jonka toimii myös siirtymäjaksona seuraavaan kauteen. Valmennuksen ohjelmoinnissa huomioidaan myös sovellustapoja harjoittelun yksilöimiseen ja vaihtuvuuteen, pikajuoksijan ravintoon, palautumismenetelmiin ja suorituskyvyn huipentamiseen pääkilpailuun sekä testaamiseen. Lopuksi lajintasoa Suomessa tarkastellaan suhteessa maailman ja Euroopan kärkeen sekä pohditaan Suomen pikajuoksun ongelmakohtia.

2 BIOMECHANICS

The 100-meter sprint includes four distinct phases: block phase, acceleration phase, maximum running phase and deceleration phase. Although, succeeding in each phase is premised on the same result of high stride length and stride frequency (V = SL x SR), sprint biomechanics and the running technique transform over the four phases, thus all the phases have their own special concerns to focus on. In the following subheadings the block- and acceleration phase will be discussed jointly, while maximum running phase and deceleration phase are discussed separately.

2.1 Block- and acceleration phase

Mero & Komi (1992) reported that the acceleration phase lasts commonly for approximately 30–50 meters. However, later Mero (2016) stated that acceleration phase may last up to 50–70 meters, as it was observed that some elite sprinters require more time to reach their peak velocity. Still, the aim is to reach maximal running velocity as fast as possible. Acceleration is improved by increasing maximal velocity, decreasing time taken to reach the maximal velocity or ideally by combination of both increased velocity and decreased time. Block acceleration values for sprinters (personal best 10.2–10.8) have been reported to range from 8.68 to 11.77 m/s^2 (Mero et al. 1992).

The start block phase prior to the actual acceleration phase includes a stationary set position in the blocks before gun signal, short reaction to the gun signal and a powerful clearance of the blocks. Block clearance is continued with a powerful acceleration with an aim of proceeding to an upright running position after few accelerative post block strides. Several variables influence to the block start, such as block- spacing and obliquity, reaction time, force production on the blocks, block clearance time and vertical alignment of the body in contrast to the post block steps (a braking phase occurs). Note, that there is some inter-individual variability with all measures presented due to the unique features (e.g. strength, anthropometrics) of each individual sprinter.

2.1.1 Block spacing

By rule, the blocks can be placed to any distance behind the start line, however in the literature there are usually three type of block spacings outlined with different anteroposterior inter-block spacings: bunched start (<30 cm) medium start (30 to 50 cm) and elongated start (>50 cm). Most used fashion by sprinters is to measure two footsteps from the start line to the front block and three footsteps to rear block. This is alike bunched start as the average adult feet size in centimeters is under 30. Schot & Knutzen (1992) were at side with this fashion as they presented measures of bunched block spacing to be superior in achieving the fastest time to 2.29 meters compared to medium and elongated positioning. Bunched block spacing was also superior in terms of shortest time to detach from blocks. However, bunched block spacing was not superior either on producing force to blocks nor when measuring time taken to reach 46.72 meters when compared to medium and elongated spacing. As medium block spacing produced the fastest acceleration, it was theorized that medium block spacing enables more complete utilization of extensor reflex of lower extremities due to high raised hips, along with powerful thrust and quick recovery of the rear lower extremity (Schot & Knutzen 1992).

2.1.2 Block obliquity and block velocity

To achieve maximum block velocity with minimum block clearance time, it seems favorable to set the obliquity of the blocks rather decreased than increased. According to Mero et al. (2006) block velocity was higher with block obliquity of 40 degrees than 65 degrees. The results indicated a differential of 3.39 versus 3.30 m/s between the obliquity angle in use. Similar findings were made earlier by Guissard et al. (1992) by using angles of 70, 50 and 30 degrees. The results showed increasing velocities from 2.37 to 2.80 and 2.94 m/s as block obliquity was lowered. However, some start block manufacturers may not produce blocks that can be adjusted with a range of 70 to 30 degrees, thus the sprinter should adjust to few different obliquities. It may be that the reason for the improvement in block velocity is due to increased contribution of both gastrocnemius and soleus muscle of the calf during the eccentric and concentric phases of muscle contraction. Since, if the muscle-joint complex length is higher at the beginning of force production, it provides the ankle with extended range of motion and improves the subsequent stretch-shortening cycle (SSC) to contribute more effectively as an elastic component to muscle shortening, consequently generating higher power (Mero et al. 2006; Guissard et al. 1992). Despite the fact that high block velocity is the aim Mendoza and Schollhorn (1993) reported that horizontal block velocity is not a reliable predictor of a successful block start with respect to time to 20 m, while also Tellez & Doolittle (1984) reported that block clearance time accounts for only approximately 5 % of the total time in 100-meter sprint.

2.1.3 Knee-, hip angle and body alignment

After optimal block settings are adopted the sprinter sets to a position in which hands are placed just behind the start line with index finger and thumb being closest to the line. Head is facing down in line with the spinal column, elbow joints are usually straightened, triceps contracted, shoulders and back muscles fixed, and abdominal muscles contracted to create stability and to load more weight over the legs compared to arms, while hips are lifted moderately high. More closely, according to Mero et al. (1992) and Mann (2013) in the set position, the joint angle of the front knee is set between 83–105 degrees and rear knee somewhere between 115–138 degrees, on average. Hip joint angle of front lower extremity varies from 50 to 60 degrees and with rear lower extremity from 80 to 100 degrees. Ankle joint angles are highly dependent of the block obliquity in use, but usually vary from 90 to 110 degrees with both feet. Setting the knee- and hip angles in the mentioned ranges allows a slight lean of trunk, usually between 8 to 22 degrees.

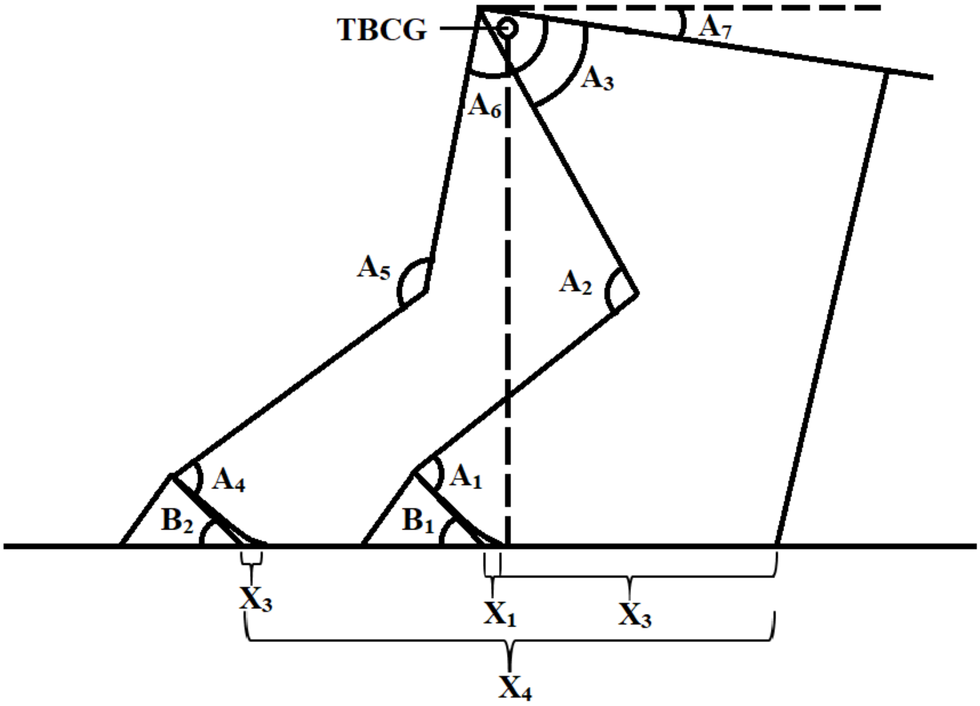
It is hypothesized that more acute joint angles are beneficial to gain higher block velocity, due to a greater range of motion at joint extension, presuming that the sprinter is strong enough to produce such high force. Still, there are no significant difference of knee joint angles and trunk lean between elite- and mediocre sprinters, while the hip joint angle appears to be more acute among better performing sprinters (Jouste & Mero 2016; Harland & Steele 1997). This may be partly related to short block spacings. In addition, more acute hip joint angle places the extensor muscles of the hip under a greater stretch, therefore gaining higher force output because of the length-tension relationship (Francis 1991). However, it has been reported that vertebral flexion and reduced pelvis-femur angle will proportionally increase the length of the hip extensor muscle load arm by moving the total body center of gravity (TBCG) in relation to the joint axis (Hoster et al. 1979). Thus, excessively acute hip joint angle can be disadvantageous, as increased load arm distances can reduce the efficiency of hip extensor muscles (Hoster et al. 1979).

2.1.4 TBCG and upper body

Total body center of gravity (TBCG) in the set position is preferred to be vertically high and horizontally as close to the start line as possible. The vertical height of the TBCG is often between 0.61–0.66 m, while the horizontal distance of TBCG varies from 0.16 to 0.19 m (Mero et al. 1987; Baumann 1976). With regards to arm positioning there is a strong inter-individual variation in the width between arms. Placing arms to a wider position will lower the shoulder-line and set lower back, gluteus, and hamstring muscles under a greater stretch, assuming that the spinal column is positioned correctly. Stronger arms allow the TBCG to be closer to the start line which is considered advantageous. Sandstrom (1983) advocated that TBCG should be positioned as close as possible to the forward edge of the base of support (BOS), meaning hands in this case. This is done with intention to allow TBCG to move outside of the BOS in a minimum time. However, Harland and Steele (1997) pointed out that the hands of the sprinter leave the track first, no longer making them part of the BOS. For instance, as the reaction times of well-performing sprinters may vary from 0.12 to 0.18 seconds and the hands leave the track approximately after 0.15 to 0.20 seconds, hands contribute as BOS only for very short period. Therefore, during the time when force is applied to the blocks, majorly only feet are forming the BOS, thus unnecessary load over hands has no benefit (Harland & Steele 1997).

Schot & Knutzen (1992) studied variables of four different sprint start positionings: bunched-forward (BF), bunched-perpendicular (BP), elongated-forward (EF) and elongated-perpendicular (EP). The measures of arm orientation differed between forward leaned arms where arms are angled forward (i.e. shoulder over hand) roughly in 10-degree angle, and perpendicular arms where arms are positioned perpendicularly relative to the ground (i.e. shoulder and hand vertically inline). Arm orientation produced differences in horizontal position of the TBCG at clearance, in both bunched and elongated conditions, as the forward lean placed the TBCG 3 % further ahead compared to perpendicular arm orientation. In contrast, TBCG was vertically 5 % higher in EP in contrast to EF. Forward lean tended to result in greater vertical velocity at block clearance and horizontal velocity at first step toe-off, although perpendicular arm orientation resulted a greater velocity at 2 meters. Forward lean resulted a 4 % shorter first step compared to the step length from perpendicular arm orientation conditions. However, longer step length may not always be beneficial as excessive step length may incur higher horizontal braking forces. In addition, there was also a significant delay of 3 % in relative time to second max force with perpendicular arm positioning compared to forward lean (Schot & Knutzen 1992).

Majority of literature agrees that the characteristics of a successful block start includes a powerful thrust against the blocks with both feet, while keeping the angle of drive low to maximize the horizontal component of force. Sprinter should clear the blocks at a low angle of 40 to 45 degree relative to the ground. After this, the following two post-block steps need to occur with the TBCG ahead of the foot that is in contact to the track, to minimize potential horizontal braking forces (Harland & Steele 1997).



PICTURE 1. Optimal start position. Adapted with permission from Jouste & Mero (2016).

TABLE 1. Average joint angle degrees, block spacing distances and the range at which they vary in the optimal start position (Jouste & Mero 2016).

	Average degree	**Range of the degree**
A_1	100	90–110
A_2	100	92–105
A_3	55	50–60
A_4	100	90–110
A_5	129	115–138
A_6	89	80–100
A_7	14	8–22
B_1	40	30–50
B_2	50	40–60
	Distances	
$X_{1,2}$	6 cm	4–8 cm
X_3		23–63 cm
X_4		65–90 cm

2.1.5 Reaction time

Reaction time can be measured by the time taken from the gun signal until a certain amount of pressure is exerted against the blocks, that is the beginning of force production. Total reaction time (TRT) can be separated into two parts: pre-motor time (PMT) and motor time (MT). PMT signifies the delay from the gun signal until the beginning of muscle activity (i.e. EMG-signal). Respectively, MT is the time from onset of EMG-signal until beginning of force production of a skeletal muscle (Mero et al. 1992). In competition conditions only the total reaction time is measured. Among both male and female elite sprinters, the reaction times vary from 0.100 to 0.160 seconds (Jouste & Mero 2016). Starting from 1990 IAAF has considered a reaction time under 0.100 seconds as a false start. However, Pain and Hibbs (2007) reported that the neuromuscular-physiological component of simple auditory reaction times can reach under 100 ms, probably even under 85 ms, and that EMG latencies can have values of about 65 ms. Similarly, Brown et al. (2008) and Komi et al. (2009) have reported that the neuromuscular response of the auditory reaction time during a sprint start can be under 100 ms. According to Komi et al. (2009), the auditory evoked reaction consists of the sequence as follows: 3–6 ms for the start signal discharge to travel to the ear of sprinter, 10–15 ms for travelling through the brain stem and approximately 50 ms to reach the auditory cortex, which after 20–30 ms lapse to cross over the motor cortex to the spinal cord and to the leg muscles (Komi et al. 2009). Therefore, the total auditory reaction time is 93–106 ms, when the mechanical delay of 5–10 ms is included. In the research of Komi et al. (2009) the results indicated that average reaction time in seven sprinters to reach a force detection level of 25 kilograms was generally longer than 100 ms, however three sprinters were able to reach a reaction time under 100 ms, repeatedly. The time to the onset of muscle activation in the fastest start reaction condition of these three sprinters was 60–80 ms. Their conclusion was that reaction times have strong inter-individual variation, body segments have different reaction times (e.g. lower limbs have longer reaction times compared to upper limbs) and that the reaction time can be under 100 ms and even under 80 ms. Therefore, Komi et al. (2009) suggested the WA (former IAAF) to lower the level of false start regulation to 80 or 85 ms with the current used force production devices in the blocks. After all, even if the good reaction time is important, it does not have a strong and significant correlation to the overall performance level measured in several major championships.

2.1.6 EMG activity

In the block start electromyography (EMG) measures can be done to examine electrical activity changes of skeletal muscles. Measuring muscles of both rear and front lower extremities and pelvic muscles are relevant to the block start. Commonly in literature the measured muscles include: gluteus maximus (GM), quadriceps femoris (GF), bicep femoris (BF), rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM) and gastrocnemius (GA). However, all the mentioned muscles are not always elected to the study. A reliable threshold for detecting change in EMG activity is often set to 10 % of maximal horizontal force after the end of TRT (Mero & Komi 1990). Furthermore, Mero & Komi (1990) clarified that TRT in EMG monitoring can be divided into premotor and motor time. However, in some muscles the electrical activity may start to increase after the TRT, that is believed to occur because of multi-joint characteristics of the block start. Note, it needs to be acknowledged that majority of the research, such as EMG measures, in sprinting do not include elite sprinters and only a small proportion may be sub-10 second runners. Therefore, there may be some variation to the ratios of EMG patterning of elite sprinters. In addition, there is always the inter-individual variation.

After the gun signal, most muscles begin to work concentrically to push off from the blocks. To reach great block velocity the leg extensor muscles must contribute rapidly and maximally to the force production. More closely, neural components such as maximal number of motor units recruited, motor neuron excitability and the type of motor units affect to a successful block start (Sale et al. 1983). The sooner the EMG activity begins in each muscle, the faster the neuromuscular performance can be maximized. For improving the block start it is found beneficial to create pretension to all extensor muscles before any dynamic force is exerted against the blocks (Mero & Komi 1990). Guissard & Duchateau (1990) found a relative consistency among sprinters with their mono-articular muscles displaying greater consistency than biarticular muscles in EMG pattering. However, Mero & Komi (1990) reported that EMG pattering had evident inter-individual variations. This is partly due to technique.

Front leg is contributing to the force production longer, nearly throughout the whole duration of force production at the block phase since the rear leg is prior to leave the blocks. Mero and Komi (1990) reported that GM of the rear limb had the shortest pre-motor time (74 ms) and the earliest peak integrated electromyography (IEMG) was (50 ms) of all rear leg muscles during the block start. In addition, Coh et al. (2007) reported that GM reaches its highest activity in the beginning of the block phase. Activity of the front leg GM was slightly higher compared to the rear leg. This underlines the importance of GM muscle during the early force production. The GM of the front leg reached also a second activity peak at the end of block phase. During the first two post block steps GM remains active. Guissard and Duchateau (1990) reported that the general sequence of muscle activation, when gluteus maximus was not analyzed begins with biceps femoris, is followed by the quadriceps muscles and then the calf muscles. In contradict, Mero & Komi (1990) reported that the gastrocnemius muscle activated first of the five muscles studied. Gastrocnemius of both rear and front leg generates two notable peaks during the block phase, from which the higher occurs at the end of contact with the blocks. However, the activity levels of GA relate partially to the feet positioning in the blocks. If the spikes are on the track, GA has a higher pretension thus the muscle activity begins earlier. Note, if the pretension occurs then GA is activated with an eccentric contraction, whereas in the push off the activity appears due to concentric contraction.

The bi-articular rectus femoris (RF) has been recorded to display abnormal activation patterns compared to the other mono-articular quadriceps. Both the front and rear leg RF act as a knee extensor in the block start. RF is not very active at the beginning of the block phase, rather it increases its activity until the very end of block phase and reaches its peak EMG value in the last third of the block phase (Coh et al. 2007). Similarly, during the first two post block steps the EMG value of RF peaks at the end of ground contact and during the first half of the following flight phase, until it is reciprocally inhibited by activation of the biceps femoris (Mero & Komi 1990). In addition, some EMG activity appears during the contralateral ground contact where RF acts as a hip flexor in the flight phase.

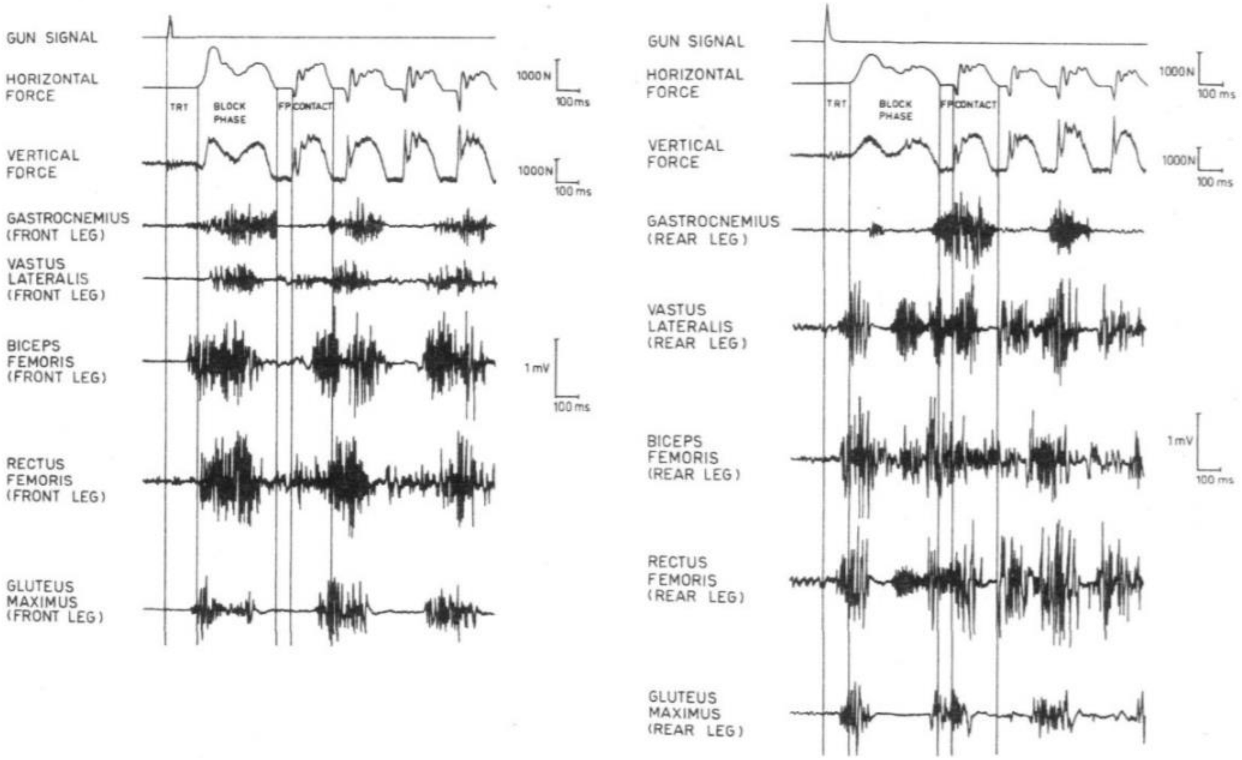
The one joint muscles vastus lateralis (VL) and vastus medialis (VM) EMG activities appear throughout the block phase within the front leg, yet the VL and VM of the rear leg are only active at the beginning of the push off. VL displays a slightly higher degree of activation compared to VM at the blocks, whereas VM reaches its maximal degree of activation at the first ipsilateral ground contact. VM pre-activation begins already during the flight phase, that is extremely important in ensuring the rigidity of those muscles that are responsible for transferring elastic energy from the eccentric contraction to concentric contraction (Coh et al. 2007). VL is more active during the concentric motion at propulsion phase, whereas VM is more active during the braking phase that creates an impact and eccentric contraction. Therefore, both VL and VM are active during the whole ground contact, however the activity decreases between the first and second post block steps. In addition, Mero & Komi (1990) found that the IEMG for VM was greater during the first strides compared to maximum velocity running. This result indicates a greater use of the single joint knee extensors early in the sprint.

The two-joint muscle biceps femoris (BF) has been found to co-activate with RF prior to ground contact. By stiffening the extremity at ipsilateral ground contact BF and RF resist the impact that occurs at the initial ground contact and therefore lowers the braking force. BF of the rear leg is active nearly throughout the push off during block phase, whereas the front leg BF is distinctly active throughout the whole duration of the block phase and reaches its peak EMG value at the beginning of the force production (Mero & Komi 1990). However, according to Coh et al. (2007) EMG peak of the front leg BF occurred during the second third of the push off. After block phase BF works actively by moving the leg backwards prior to ground contact and during the propulsion phase of the ground contact. BF reaches its peak in the second third of the contact phase. The activation of the BF is similar during the first two post block steps. However, the activation occurs higher during the first ground contact compared to the second.

Gastrocnemius (GA) is one of the most important muscles that influence to a great block velocity and successful acceleration. GA of both front and rear leg reaches its peak EMG activity at the end of push off from the blocks, yet the peak activity of the GA of front leg is higher and influences the block velocity more directly. The activity of the rear leg GA begins slightly later compared to other muscles studied, yet again the activity of GA depends also on the pre-activity level that relate partially to the feet positioning in the blocks. During the first two post block steps GA is active throughout the whole duration of the ground contact and reaches its peak in the propulsion phase.

Especially gluteus maximus, vastus medialis, vastus lateralis and biceps femoris are pre-active before the first and the second ground contact (Coh et al. 2007). Pre-activity of the muscles is essential as it decreases ground contact time, enhances the use of elastic energy, and lowers the braking force impact. The use of elastic energy is enhanced due to pre-activation since muscle tension increases joint stiffness that consequently will better counter to forces during the ground contact. The magnitude of the EMG peaks appears similar between the first strides and maximum velocity running, however the timing of the peaks occurs 10–20 % earlier in the start (Wiemann & Tidow 1995). From the point of biomechanics, it is essential how the first contact after the block start is performed to have an efficient transition from the blocks to acceleration (Mero et al. 1992; Korchemny 1992).

Altogether, a high integrated EMG activity of the lower extremities is reported to occur during acceleration phase. In the acceleration phase there was a 4.8 % higher IEMG activity compared to the EMG values of the maximum running phase (Mero & Peltola 1989). The difference implies that neural activity in 100-meter sprint is highest during the acceleration phase. EMG during strides at the maximum running phase is discussed in chapter 2.2.4



PICTURE 2. Ground reaction force and raw EMG of five selected muscles of one random subject in the measurements of Mero et al. (1992).

2.1.7 Force production

A successful block clearance requires powerful force production at the blocks combined with a skilled technique. Both vertical and horizontal force is produced to the blocks by the whole body. Major amount of the concentric force is produced by the lower extremities, such as hip extensors (i.e. gluteus muscles) and large muscles of the thigh (i.e. rectus-, bicep femoris). During the block start there occurs a 1–2 % lengthening of the muscle-tendon complex in gastrocnemius and soleus muscles, that is also contributing to the force production. This lengthening is also referred to as pre-tension. Pre-tension can be achieved by actively pressing against the blocks, thus eccentrically preloading the extensor muscles of the lower extremities prior to concentric action. This allows a wider range of motion and more powerful concentric contraction. Furthermore, the lengthening can be extended (i.e. enhance pre-tension) by placing the first spikes of both feet on the track. Pre-tension force values of 20–88 N for the front leg and 80–102 N for the rear leg have been reported (Van Coppenolle 1989). In addition, some force is generated at the push off by the upper body extension and the pendulum movement of the upper extremities.

Mann (2013) reported that among elite sprinters force is produced for 0.28–0.30 seconds over the blocks, during which time force values of 1600 N for the front leg maximal vertical force and 1400 N of rear legs maximal vertical force were measured. Mero (1988) reported lower force values that varied between 1185–1224 N (maximal horizontal), 766–958 N (maximal vertical force) and 1426–1555 N (maximal resultant force). On average, the rear leg produces 45 % of the force in block phase (Mero & Komi 1990). Successful force production to the blocks have resulted horizontal block velocity of 4.18 m/s for males and 3.71 m/s for females (Mann 2013). After block clearance, between the first and second step, an elite sprinter may have reached vertical velocity of 0.75–0.80 m/s from where it will decrease down to 0.35–0.37 m/s by the end of the acceleration phase. Concurrently, as the vertical velocity decreases horizontal velocity will increase and gain a velocity of 7 m/s by the end of second step. This is already over 50 % of the horizontal velocity at the maximum running phase.

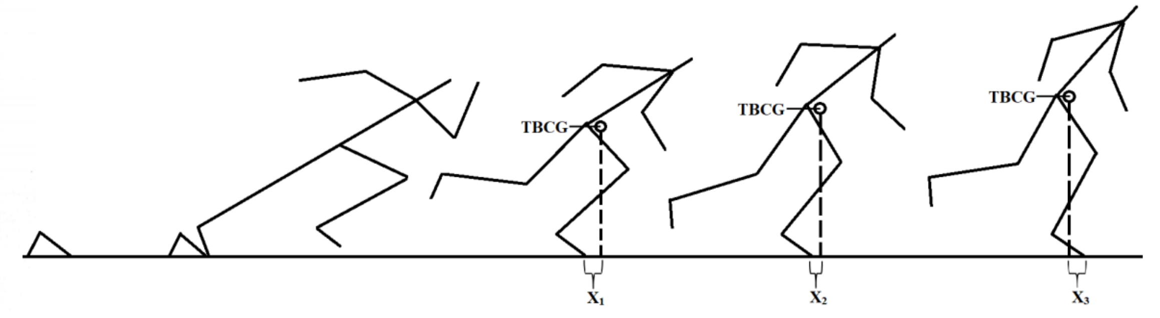
The amount of force exerted against the blocks (from optimal angle; see chapter 2.1.10) correlated directly to the increase of block velocity. While this is important, achieving short block clearance time is also important, as it will allow a high stride rate to be achieved immediately. Therefore, whether to invest more on the duration of force production or to early first ground contact (i.e. quick recovery of the rear leg) needs to be considered.

2.1.8 Post block technique

After clearing the blocks, a sprinter must advance explosively from the stationary set position into an asymmetrical running action. Apart from overcoming the effects of gravity with vertical force the sprinter must produce maximal horizontal force in order to travel forward, allow the propulsive rear limb to be recovered and to commence running on the first ground contact. Unlike during maximum running phase, over the first post block strides feet are preferred to be lifted only slightly from the ground or even to be dragged on the track. Seeing, that the feet will travel a shorter distance between two contacts when it remains close to the track. As discussed earlier, the challenge on the blocks is whether to produce force over the blocks longer (i.e. maximize horizontal force) on a detriment of later first ground contact or to produce less force to blocks and to recover the rear limb sooner, to commence running earlier. A compromise between the duration of force production and recovery of the rear lower extremity appears to be the best option. A medium start block spacing could provide this. Mann (2013) stated that a shuffle start with a high stride rate is superior to a jump start, seeing that force is only produced at ground contact and not from the air. Therefore, due an immediate high stride rate more force can be produced in a short period of time. For elite male sprinters first stride length has been reported to range from 0.98 to 1.20 m (mean: 1.02; Atwater 1982). Later, Mann (2013) reported that optimal first stride length should be approximately 1.09 m to obtain a high stride rate immediately and to obviate excessive braking force. On that account, it seems that while block clearance time is important, optimal first steps and high acceleration are even more pivotal to the result.

Mann (2013) claimed that a short stride allows the sprinter to reach a high stride rate (5.0 Hz) already during the first contacts, although the vertical displacement of the TBCG during the first post block strides will work against it by increasing ground contact time, thus reducing stride rate as well. Eventually, the stride rate will decrease down to 4.7–4.8 Hz over the total 100-meter sprint (Jouste & Mero 2016). Schot and Knutzen (1992) reported that in bunched starts the first step occurred 6 % shorter compared to elongated starts. Also, the degree of forward lean in the set position effected the first step length. In bunched start forward lean increased first step length by 3 % and decreased it in elongated by 2 %. In contrast to what is mentioned earlier about an overly long first step retarding the force production due to higher braking force, Schot and Knutzen (1992) stated that the anterior braking forces created with shorter steps are not significantly lower than those associated with a long step.

Furthermore, TBCG moves with respect to the ground contact points over the first few post block strides. As presented in picture 3, during the first ground contact (X_1) TBCG is distinctly ahead of the contact point but usually starting from the third ground contact (X_3) TBCG is set behind the initial ground contact point and will remain there throughout the sprint forming a braking phase (Mero et al. 1992). Some elite sprinters may retain TBCG in front of the contact point until the fourth or the fifth ground contact. TBCG expresses vertical fluctuation starting from the first ipsilateral contact as the TBCG falls during the first part of the ground contact (i.e. braking phase) and rises during the second part (i.e. propulsion phase). The vertical fall reduces stride rate due to increased ground contact time, which will consequently reduce running velocity. The braking phase and propulsion phase can be segregated either by defining the location of TBCG in relation to the initial ground contact point or by the negative and positive horizontal reaction forces (Mero et al. 1992; Luhtanen & Komi 1978). Among elite sprinters the TBCG vertical fall has been exhibited to appear as low as 0.017 ± 0.016 m (Harland & Steele 1997).



PICTURE 3. Post block technique and initial ground contact point in relation to TBCG.

2.1.9 Ground contact-, flight times and force

Despite the position of TBCG with respect to the ground contact point negative horizontal force is always produced, even during the first strides after the blocks (very small at the beginning). This indicates that all contacts are similar in terms of the braking- and propulsion phase, although the ratios vary. Among elite sprinters ground contact time decreases evenly during the acceleration phase from approximately first contact of 0.130 s to approximately 0.080 s (Jouste & Mero 2016). In contrast, flight times increase from 0.080 s of beginning to 0.130 s by the end of acceleration. Also, stride length and velocity increase evenly throughout the acceleration phase.

Ground contact times during the first two steps are reported to alter between 160–194 ms for the first contact and from 150 to 181 ms for the second contact. Respectively, flight times of the first two steps have been reported to alter between 60–70 ms for the first flight and from 44 to 90 ms for the second flight (Harland & Steele 1997). Atwater (1982) reported that of the total stride, that includes the ground contact and flight time, the time at ground contact accounted for 82 and 76 % of the total time, over first two strides. This indicates that during the first two post-block steps there is considerably more time spent in the contact phase than in flight phase.

Mero (1988) studied acceleration of eight male sprinters (personal best 10.45–11.07 s) and reported that from the total average duration of the ground contact (193 ms) the braking phase was only 22 ms (12.9 %) in the first stride post the blocks. Whereas at maximum running phase Mero & Komi (1987) reported braking phase to account for 43 % of the total ground contact time. Meaning, that the proportion of the braking phase increases during the acceleration phase as part to the total ground contact time. Average braking forces during the first contact appeared very small in both horizontal (-153 N) and vertical (148 N; net force) directions, compared to the respective values of propulsion phase of 526 N (horizontal) and 431 N (vertical; Mero 1988). Mero et al. (1983) reported that the braking phase of the first stride after the blocks decreased horizontal velocity by 3.0 and by 3.7 % during the second stride at lowest. The average braking forces during maximum running phase were 56 % (horizontal) and 89 % (vertical) higher compared to the first braking phase after block clearance (Mero et al. 1987). However, Mero (1988) reported that during the first ground contact the horizontal propulsive force was 46 % greater compared to the same force produced during maximum running phase at ground contact. Therefore, a high level of concentric strength is required from the sprinter during the acceleration phase. The values above describe how force is produced over a long period of time and that the average propulsive force is large during the early acceleration phase. Whereas at maximum running phase the ground contact time is short and the impacts are high (Mero 1992). The vertical propulsive force was found to be approximately the same both during the acceleration phase and at maximum running phase (Mero 1988).

2.1.10 Toe-off and thrust angle

In addition to a high horizontal velocity the direction of force application is cited as a crucial component of fast sprint times. Mero (1988) reported the thrust angle that is the angle between a line joining the TBCG from the front toe at the loss of front block contact and the horizontal line ranges between 32 to 42° among elite sprinters. The angle of force application relative to horizontal at the first ground contact toe-off varies from 43 to 50° and from 43 to 53° at the toe-off of the second ground contact. Generally, during the block start the angle of force production should be directed horizontally and the thrust angle should be as low as possible if it does not interfere with the subsequent running.

2.2 Maximum running phase

A great running velocity is a product of high stride rate and long stride length. Developing both components concurrently can be somewhat challenging since usually as stride length is increased stride rate will decrease, and reciprocally increasing stride rate will reduce stride length. However, as we learned before, during the velocity increase at the acceleration phase both stride rate and stride length are increasing simultaneously. Nevertheless, according to Mero et al. (1992) the concurrent linear increase of these two components can be maintained only up to a velocity of 7 m/s. During maximum running there is a greater increase of stride rate compared to stride length for a given increase in velocity, therefore stride rate is a more decisive determinant in sprint running (Mann 2013; Mero et al. 1981). Yet, some elite sprinters (e.g. Bolt) may be an exception to this (Krzysztof & Mero 2013).

2.2.1 Velocity

High maximum velocity has a strong positive correlation to the result. As explained before, running velocity (V) can be calculated by multiplying the length of the stride (SL) with the frequency of the stride (SR): $V = SL \times SR$. In 100-meter sprint peak velocities are usually accomplished in 5–6 seconds and between 50 to 70 meters among males and between 40–60 meters among females (Jouste & Mero 2016). After two seconds from the start approximately

75 % of the maximum velocity is achieved, 95 % after three seconds and 99 % after four seconds (Mero 1987). The highest measured velocities for elite male sprinters have peaked at over 12 m/s and at over 10.5 m/s among females (Jouste & Mero 2016). The peak velocity can be maintained for only 10 to 20 meters. However, it has been reported (e.g. Jouste & Mero 2016; Krzysztof & Mero 2013), that Usain Bolt maintained his peak velocity for approximately 30 meters in his world record -run.

2.2.2 Stride rate and stride length

During the maximum running phase, the stride rate will decrease slightly down from the rates of the early acceleration and remain in a range of 4.5–5.0 Hz with both male and female elite sprinters (Mann 2013). Generally, sprinters of shorter height are benefiting from their anthropometrics regarding to stride rate. Ability to reach a long stride length however is easier for tall sprinters. Therefore, as there is no gender difference regarding stride rate, stride length helps to explain the difference in running velocity between male and female sprinters. Between genders there is the difference of over 10 % in stride length, benefiting men. On average, stride lengths vary at range of 2.35–2.60 m among male and between 2.05–2.25 m among female sprinters, during maximum running phase (Jouste & Mero 2016). In addition to optimal ratio of stride rate and stride length factors such as running technique, ground contact time, flight time and time for a maximum flexion of thigh (i.e. knee lift) are crucially contributing to a high velocity and the running result (Jouste & Mero 2016). In case, stride length is desired to be lengthened it is primarily achieved through strength development, together with an adequate technique modification. Meaning, that the stride is lengthened by pushing behind during the propulsion phase rather than leaping forward prior to the initial ground contact when the braking force would increase (Mero Jr 2020). The estimated optimal stride length usually sets between approximately 1.4 x body height among elite male sprinters and 1.3 x body height among elite females, respectively (Jouste & Mero 2016).

2.2.3 Ground contact- and flight times

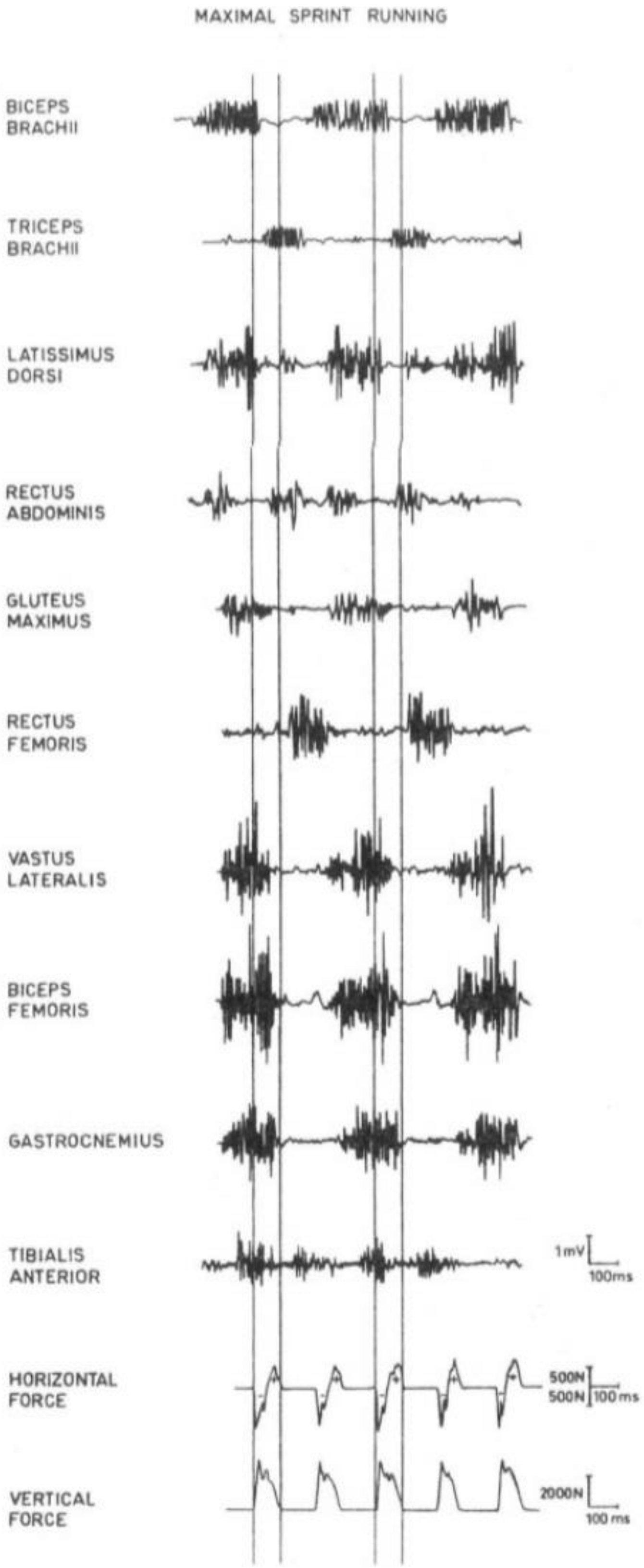
After the end of acceleration phase as the maximum velocity is attained the flight times have increased and now range from approximately 0.120 to 0.140 seconds. In addition, the ground contact times are decreasing significantly as running velocity increases (Mero et al. 1992). As discussed earlier, ground contact time can be separated into braking and propulsion phases that are defined by the vertical fluctuation of the TBCG either downward (braking) or upward (propulsion; Luhtanen & Komi 1978). During maximum running phase the braking phase appears to be slightly shorter compared to the propulsion phase (0.040 and 0.045; Jouste & Mero 2016).

2.2.4 EMG activity

Running at maximal velocity requires rapid sequenced muscle activation that appears complex but can be performed adequately with a correct order and timing. In the lower extremities, muscle activity (EMG) increases with increased running velocity (Mero & Komi 1986). EMG activity is lower during the propulsion phase compared to the braking phase. This is partly due to contribution of increased recoil of elastic energy during the propulsion phase (Williams & Cavanagh 1983). There appears to be a high pre-activity in the lower extremity musculature prior to ground contact, that resist the large impact forces that occur in the contact phase (Mero & Komi 1987). The relative EMG values of the muscle pre-activity (mean of five muscles) range from 50 to 70 % of maximum integrated muscle activity (IEMG; Mero et al. 1992). Therefore, it is necessary to have stiff leg extensor muscles prior and during the ground contact. In addition, the inevitable duration between a detectable electric activity in lower extremities and the following mechanical response (i.e. electromechanical delay), underlies the importance of the pre-activation, since the ground contact is more economical as it occurs after the electromechanical delay. The electromechanical delay ranges from 20 to 100 ms (Komi 1984). The ground reaction forces peak after 10–40 ms from the initial ground contact (Mero & Komi 1987). Yet, the stretch reflex system may not be fully active since the peak forces exist so soon after the initial ground contact (Dietz et al. 1979). However, both the high pre-activation and reflex-potential seem to be central components of increased muscle stiffness prior and during the ground contact. As the stiffness of muscles is maintained during the ground contact the energy can be transferred from the braking phase to the propulsion phase via the elastic elements. A proper utilization of elastic components results in increasing force production during ground contact (Komi & Bosco 1978).

During maximum running phase the peak EMG activities of the leg extensor muscles occur during the braking phase of the ipsilateral ground contact, from which after the activity decreases towards the end of propulsion phase (Mero et al. 1992). As the running velocity increases the EMG values, immediately after the ground contact, increase as well. However, the two-joint rectus femoris (RF) muscle displays a more complex EMG patterns since RF is required to work eccentrically due to the hip joint extension, at the propulsion phase of ipsilateral ground contact, and again during flexion at the knee joint after the ipsilateral ground contact. Towards the end of contralateral contact (i.e. flight phase) RF begins to act concentrically while flexing the thigh. However, RF is not very active in the extension of the leg prior to ipsilateral ground contact. Therefore, RF seems to be more important as a hip flexor rather than a knee extensor (Mero et al. 1992).

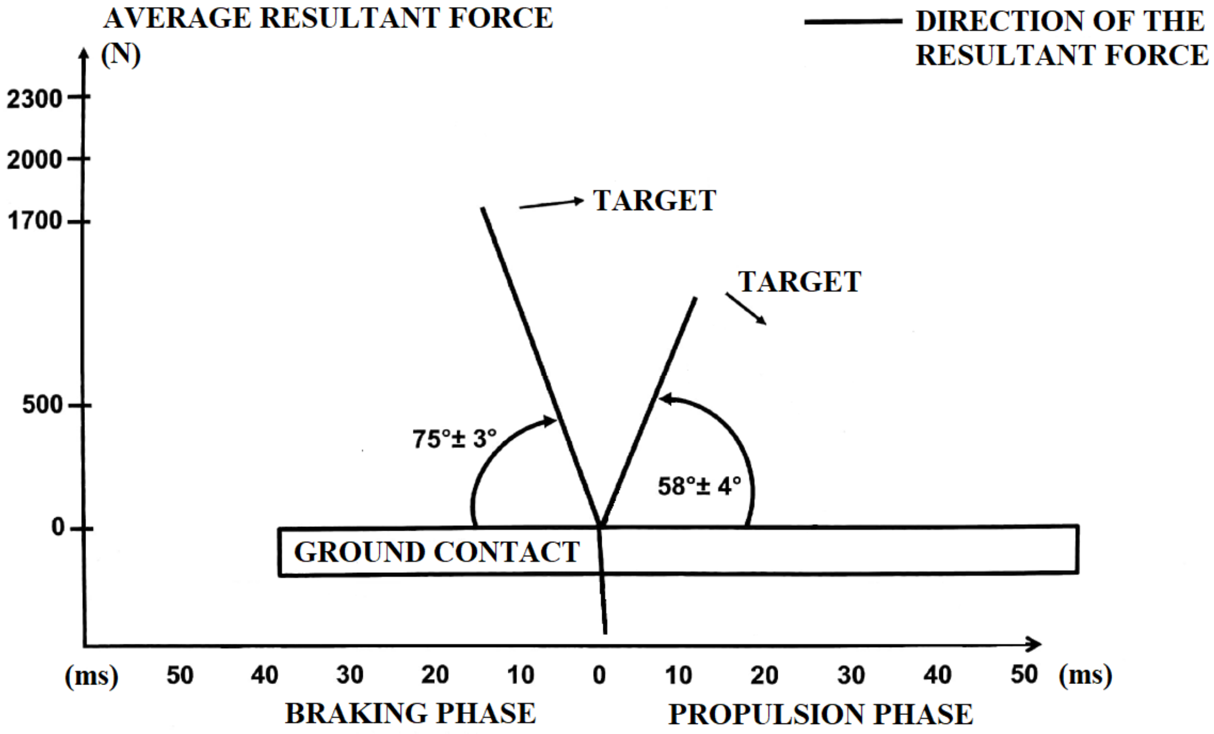
The muscle biceps femoris (BF) and gastrocnemius (GA) seem to be the major muscles working in the propulsion phase as they are fairly active during the ipsilateral ground contact (Mero & Komi 1987). However, after the block phase in maximal running the BF and GA are not very active while heel is moved under the pelvis. Therefore, the flexion of the leg is presumed to be caused by external forces, seemingly generated as reaction forces during the ground contact and by the residual muscle tension from the relaxation time of the muscles (Bigland-Ritchie et al. 1983). Minimal muscle activity of all lower extremities occurs during contralateral ground contact. This is an indication of well occurring relaxation of muscles that is beneficial for a powerful economical running.



PICTURE 4. EMG activities of five selected muscles during maximal sprint running (Mero et al. 1992).

2.2.5 Force production

Force production during the maximum running phase can be measured during ground contact with vertical-, horizontal- and mediolateral ground reaction force (GFR) values. Vertical and horizontal force production is known to increase in relation to increase in velocity (Mero & Komi 1986). Mann (2013) reported maximal net force values of 220 N (horizontal) and 1640 N (vertical: excluding BM) for elite male sprinters in the maximum running phase. However, data on mediolateral GRF have only been reported with slow submaximal velocities and only small changes (<0.3 x BM) are discovered with an increasing velocity (Cavanagh & LaFortune 1980). The average resultant braking and propulsion forces increase together with increasing velocity of the lowest submaximal velocity until the maximum velocity (Mero et al. 1992). In the maximum running both horizontal and vertical forces are higher in the braking phase compared to propulsion phase, making the resultant forces lower for propulsion as well. Mero et al. (1988) found a strong correlation between average net resultant force and stride length in the propulsion phase. The direction of the resultant forces affects both the economy of the running and the running velocity. The principal aim is to direct resultant force as vertical as possible in the braking phase and as horizontal as possible in the propulsion phase, however a realistic angle for the resultant force direction sets at 75° ± 3° in the braking phase and at 58° ± 4° in the propulsion phase (Jouste & Mero 2016; Mero et al. 1987). The horizontal force component of propulsion is often highlighted, as it clearly is the only component that creates acceleration in the targeted direction (i.e. horizontal). However, Haugen et al. (2019a) pointed out that this should not be misinterpreted as avoiding the vertical force component completely, since without any or with low vertical GRF a sprinter could not retain the upright body alignment nor reach adequate stride length. Furthermore, as work is a scalar it has no direction itself even if it may be initially associated with movement in a particular vector, thus the vertical movement may also be reutilized to the horizontal direction (Haugen et al. 2019a).



PICTURE 5. Amount of produced force and the optimal direction of the resultant force during a ground contact. Adapted with permission from Jouste & Mero (2016).

2.2.6 Technique

Components such as the ground contact time, angles of ankle-, knee- and hip joints, muscle activity, a whipping movement of the leg, maximum flexion of thigh, upper body and arm movement are contributing to sprint technique. Mero (1987) described an optimal sprint running technique in a technique analysis with regards to biomechanical measurements made from a group of sprint runners (n=9; personal best 10.58–11.00 s).

At the initial ground contact the distance between the TBCG and ground contact point is desired to be as short as possible yet keeping the foot slightly ahead (≤ 20 cm) of the body to utilize the elastic features of the body. The vertical peak-to-peak displacement of the TBCG during strides has been shown to decrease with increasing velocity (Gavagna et al. 1971; Luhtanen & Komi 1978). Due to a lesser vertical fluctuation of the TBCG, also the relative times of both braking-and propulsion phases (i.e. ground contact time) are reported to decrease across a running velocity range of 3.9 to 9.3 m/s (Mero et al. 1992). Coherently, the velocity of the TBCG is greater at toe-off than at touchdown. The measured velocities of TBCG decrease following the impact of the initial ground contact (i.e. touchdown) and increase during the subsequent propulsion phase. Mero et al. (1987) argued the primary reason for velocity decrease in running to be the horizontal distance between the initial ground contact point and the TBCG at touchdown. In addition, air resistance is known to decrease running velocity during the flight phase. Mann (2013) suggested that an optimal ground contact should initially occur less than 20 cm ahead of TBCG (PICTURE 6), thus the vertical fluctuation will be minor and the velocity decrease of TBCG will remain small (1–2 %). Among elite sprinters the vertical fluctuation during maximum running phase can be as small as 1–2 cm between the lowest point at ground contact and the highest at flight (Jouste & Mero 2016).

The leg needs to be positioned to a 90-degree angle in relation to the ground at the initial ground contact, in order to produce force perpendicularly to the ground. At angles less than 90 degrees the foot is positioned in a braking direction and at angles over 90 degrees the pre-activity of the muscles is defective and elastic components cannot be utilized (Jouste & Mero 2016). The hip joint angle grows across the ground contact after the touchdown, where the hip joint angle of 150 to 155 degrees is found desirable. The range of 150 to 155-degree hip angle will allow the sprinter with a strong posture and an upright vertical alignment of the upper body. In addition, a hip joint angle of 150 to 155 degrees reduces braking force at the ground contact since the support leg cannot be far ahead when the leg is positioned correctly. As the leg is approaching the track at the end of flight phase it is important to actively press down (i.e. striking movement) the foot prior to the ground contact. Vertical velocity of the leg indicates how well the down press is managed. As a result of a powerful down-/behind press of the foot prior to ground contact a better use of elastic energy and stretch reflex is established. Even though, the velocity of the leg is displayed as vertical the resultant force must be directed as horizontal as possible (PICTURE 5).

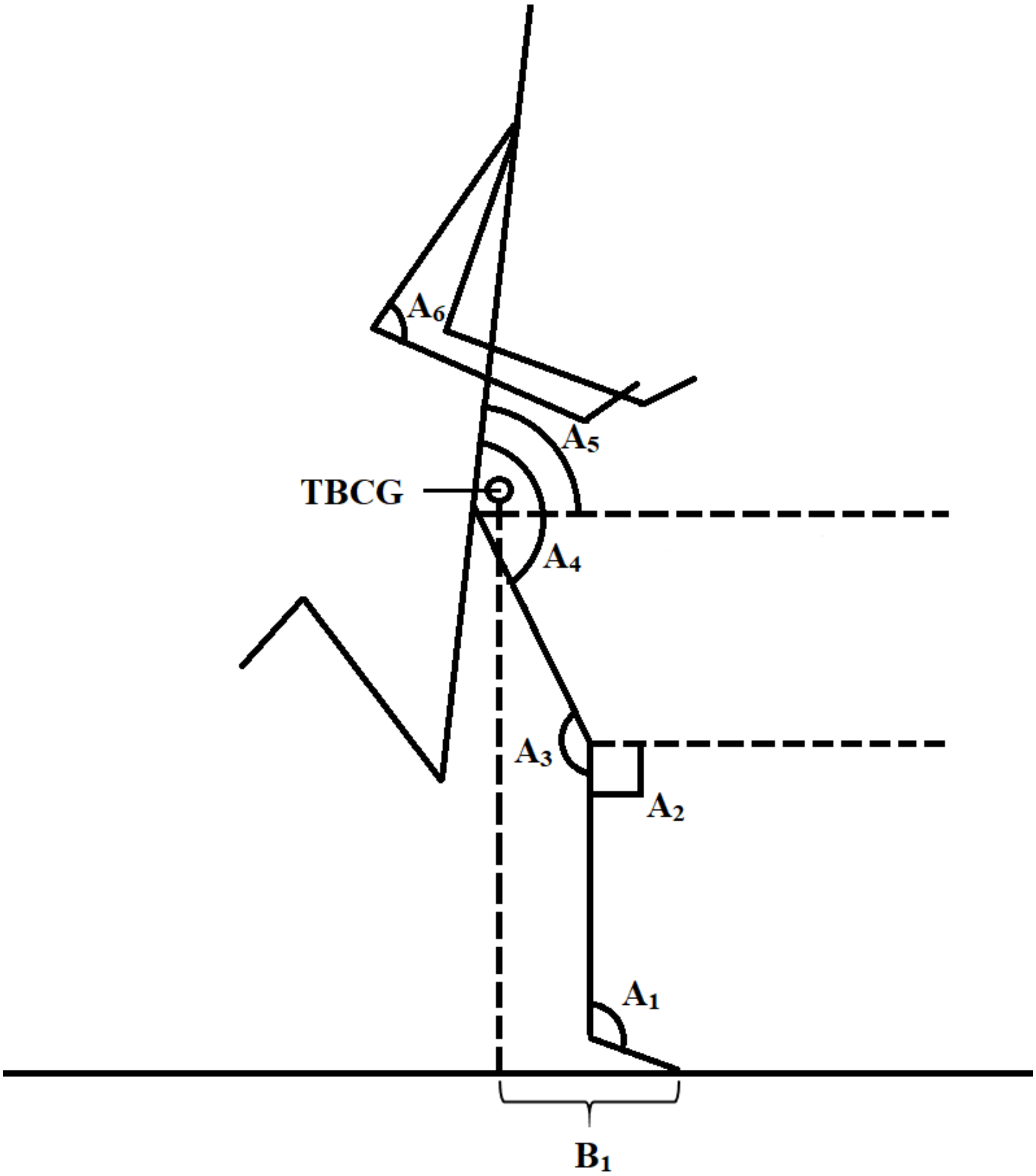
Energy is stored also during the flexion part of the flexion-extension cycle of the foot. The stored energy is immediately utilized in the extension. In a successful technique the movement of the prior to the ground contact is a revolving whip-like motion. The ground contact is executed with the ball of the foot. As the ground contact is initiated force is produced for a short period of time over the braking and propulsive phases of ground contact as explained in the abstract. The overall duration of the ground contact is desired to be short as possible since the velocity of one stride is determined by the time of both flight and ground contact.

Ankle joint angle in the ground contact phase is commonly found to decrease from its initial angle during the braking phase of the ground contact and to increase during the propulsive phase. The force production of the gastrocnemius and soleus muscles are greatest at ankle joint angles of 80–100 degrees. In fast movements the gastrocnemius appears to impact force production more than soleus. Gastrocnemius is usually strongest at ankle joint angle of 100 degrees. The lowest joint angle of the range, during ground contact, is desired to be attained at the initial ground contact. Mero (1987) reported that running velocity was higher in relation to how early the lowest ankle joint angle was attained after the start of ground contact. Therefore, leg stiffness is found beneficial for sprint running especially around the Achilles tendon, that stretches under the load of the braking force and stores elastic energy, that is reutilized in the propulsion. Both force production and the reutilization of stored elastic energy are significant mechanisms in sprint running. While concentric force production is most prominent during acceleration the elastic energy reutilization is extremely beneficial during maximum running phase. At high velocities, the use of elastic energy likely occurs due to the braking phase, therefore short ground contact time is the result of leg stiffness and not vice versa (Haugen et al. 2019a). As discussed earlier (chapter 2.2.5) the attempt to minimize braking excessively may lower the potential to produce force at the propulsion phase. Morin et al. (2015) indicated this with elite male sprinters (personal best 9.95–10.60 s) as sprint performance was more related to the ability of producing force at the propulsion than being able to minimize braking force. Therefore, while minimizing the braking phase is beneficial, ultimately, only the horizontal force component of the propulsion leads to the maintenance of running velocity, thus making it the primary concern of sprint mechanics. Furthermore, technique remarks are often divided to front- and backside mechanics (i.e. actions occurring at different sides the body's midline). By which Mann and Murphy (2015) theorized that, since the produced force during the very last part the propulsion at backside is minor, sprinters should focus on bringing the contralateral (i.e. swing) leg forward sooner, to move back on the productive front-side earlier, while also increasing stride rate, by reducing time spent at this "unproductive" part. However, Haugen et al. 2019a noted that at the end of propulsion force is (by laws of physics) bound to be low and must return to zero at toe-off, regardless of running technique.

In contrast to the changes in ankle joint angles the knee joint angle of the leg at the ipsilateral ground contact first decreases after the initial touchdown and continues to decrease until toe-off. In the measures of Mero (1987) the mean knee angle of the ipsilateral leg was 152 degrees and decreased down to a minimum of 140 degrees during the ground contact. An excessive decrease in joint angle can result in a waste of elastic energy, although the decrease in the knee joint cannot be avoided entirely due to high impact and braking forces at ground contact. High knee joint angles are beneficial considering the force production that can be created with big muscles of the thigh. High knee joint angles also allow a better hip alignment which appears high and in front. In addition, the revolving whip-like motion of the foot is often performed better from a high knee angle.

During the braking phase of the ground contact the pendulum of the contralateral leg is the only body part that is creating accelerative forces forward, while the contribution of the cross-side arm pendulum is minor. The heel of the leg in the flight phase first directs itself backwards under the pelvis and after an utmost knee flexion creates a small pendulum, in relation to the fulcrum of the pelvis, allowing the thigh to explosively recover in front of the body (i.e. knee lift, flexion of thigh). The horizontal velocity of the maximum flexion of thigh correlates strongly with running velocity. Therefore, the higher is the horizontal velocity (in forward direction) of the thigh during flight phase, the higher is the running velocity. In addition, the thighs of both legs are desired to be in line at the initial ground contact. When this is achieved the maximal velocity of the pendulum (i.e. knee lift) will occur at the same time with the initial ground contact of the ipsilateral leg and therefore reinforce the propulsion phase. Even though, the movement of the contralateral leg is referred to as “knee lift”, the raise of the knee must also be directed forward and may be accompanied with a slight rotation of the pelvis.

In order to minimize excessive muscle work the upper body should be aligned over the pelvis as vertical as possible and in line above the TBCG. Arm work should occur in the direction of running and with minor space between the elbow and the side. Arm work is desired to occur more on the front side of the body and the movement should occur across all joints of the arms (shoulder, elbow and wrist), in order to utilize all strength and elasticity of the arms and to compound to the total force production that is directed perpendicularly to the track. Often arms can be moved back and forth faster at smaller elbow joint angles, although low joint angles at range of 70 to 120 degrees are recommended for the elbow joint angle.



PICTURE 6. Joint angles at the initial ground contact point (i.e. touchdown). Adapted with permission from Jouste & Mero (2016).

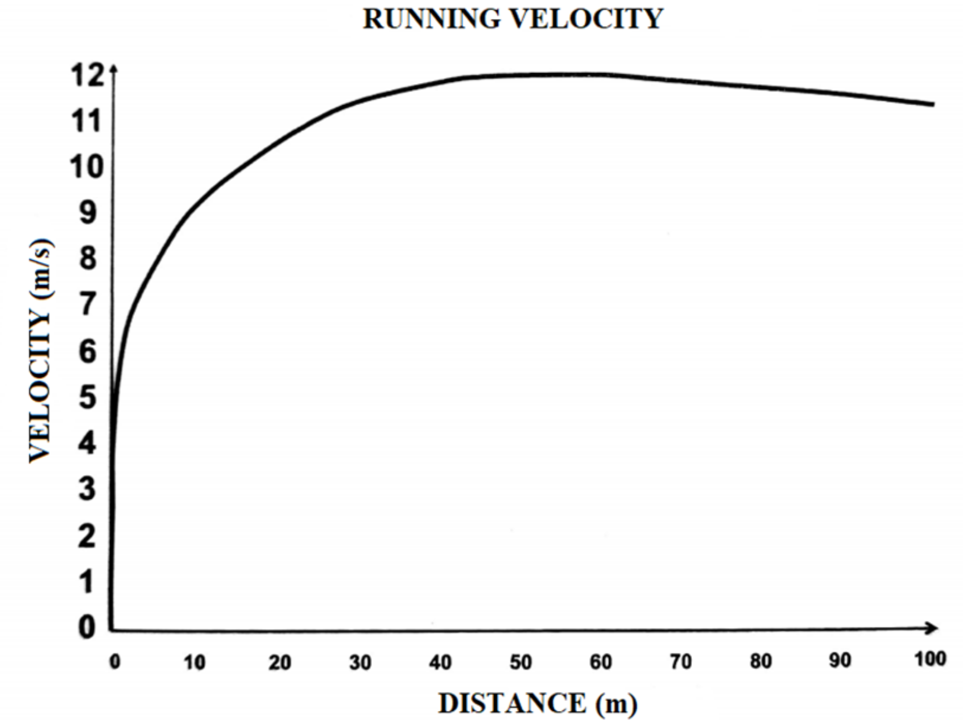
TABLE 2. Average joint angle degrees, the range at which they vary and the initial ground contact point. Adapted with permission from Jouste & Mero (2016).

	Average degree	**Range of the degree**
A_1	90	80–100
A_2	90	85–95
A_3	153	150–155
A_4	153	150–155
A_5	85	80–90
A_6	95	70–120
	Distance (cm)	
B_1	≤20	

2.3 Deceleration phase

In a 100-meter sprint the deceleration phase usually occurs between 60–100 meters and appears as deceleration of running velocity. In short sprint running that is the 100-meter sprint, the different phases of the performance can easily be distinguished by the velocity curve (PICTURE 7). Deceleration is the least studied phase in the 100-meter sprint for it is much as the running during maximum running phase. Deceleration percent is measured usually by the change from peak velocity over the best 10 m in contrast to the velocity over the last 10 m of the sprint. The interindividual range in the deceleration percent is great as it varies from approximately 2 to 10 %, indicating strong variation in performance capacity. Mero (1985) and Moravec et al. (1988) have reported the lowest loss of velocity from the peak as 0.9 %, measured from 100-meter race in the major championships. At Sevilla World Championships of 1999 the deceleration percent ranged from 2.3 to 5.6 % and from 1.8 to 8.1 % at Osaka World Championships of 2007, among male finalists (Jouste & Mero 2016). Mackala & Mero (2013) reported that at Berlin World Championships 2009 the average deceleration percent of male finalists was 3.1 % where Usain Bolt sustained at 2.4 % deceleration. The desired running mechanics and technique during the deceleration phase are much like in the maximum running phase. There is no difference in deceleration percent between genders.

The deceleration is due to changes in force production, muscle EMG, nervous system and energy production systems that appear as changes in technique (Mero 1987). The changes in technique are observable in the decrease of stride rate, which is believed to be more due to muscle fatigue rather than neural fatigue. Mero & Peltola (1987) reported a decrease of 2.0 % in muscle activation peak along with a decrease of 7.8 % in velocity (i.e. force production), indicating the deceleration being more due to muscle fatigue than neural fatigue. Stride length remains the same or might slightly increase during the deceleration phase. In addition, both the ground contact and flight times increase over the deceleration phase, jointly with increase in braking distance, velocity loss during braking and vertical descent of TBCG (Mero & Peltola 1989; Moravec et al 1988; Mero et al. 1988). Force production during the ground contact at deceleration phase is similar to the force production patterns at maximum velocity and only small declines in force occur along with velocity loss. The changes in muscle EMG and muscle activation models are associated with relaxedness of the muscles. At the end of race the sprinter strives to maintain the maximum velocity and resist the fatigue which results as additional muscle tension and pre-activation (Mero & Peltola 1987). Consequently, a more relaxed running is found better for the economy of the performance in sprint running.



PICTURE 7. Velocity curve during a 100-meter sprint.

2.3.1 Economy

The economy of sprint running is a key element to a successful sprint performance and for maintaining the maximum velocity (i.e. no deceleration). There are some detectable characteristics of a well-established economy in sprint running, although evaluating economy in sprint running is more difficult compared to long distance running or even to 200 and 400-meter sprints. The evaluation is hard for example due to the great contribution of anaerobic energy processes (Mero et al. 1992). In practice a widely used approach for estimating the contribution of the anaerobic energy production is to measure blood lactate concentration while performing sprints. With a lower blood lactate concentration, the blood pH decreases less, that is one component to perceived fatigue. Consequently, an athlete with greater economy in sprint running produces less blood lactate to perform the sprints at a given speed, thus uses more ATP and phosphocreatine stores.

Another, component to economy is the elasticity in sprint running. Especially, the use of elastic elements (e.g. muscle-tendon complex) via eccentric actions in stretch-shortening cycle is more economical to the mechanical efficiency compared to purely concentric work (Aura & Komi 1986). The Achilles tendon is commonly used for tendon force measurements by surgically implanting a special buckle transducer around the tendon (i.e. requires laboratory facilities; Finni 2020). The stretching phase (i.e. eccentric) in the stretch-shortening is characterized by a small change in length and high level of stiffness. This allows the muscles to resist the impact force at the braking phase of the ground contact and to modify the conditions for better performance potentiation in the subsequent concentric action at the propulsion phase. Mero et al. (1992) showed that the peak to peak Achilles tendon force increases along with the increase in running velocity up to 6 m/s. At increasing velocities over 6 m/s the tendon force stays the same or slightly decreases (Komi 1988). Among elite sprinters the peak Achilles tendon force may reach as high as 9000 N (12 to 13 times BM). The rate of force development of Achilles tendon at the braking phase increases linearly as running velocity increases.

Another parameter that can be detected to evaluate economy/efficiency of running is to observe vertical fluctuation of the TBCG (i.e. equilibrium). A minor vertical fluctuation of the TBCG is desired for an efficient running performance. In addition to this, a powerful but fluid and relaxed movement are found desirable in sprint running. The relaxation of muscles can be measured by comparing the maximum and minimum integrated EMG activity over one stride thus, to evaluate the economy of sprint running (Mero & Peltola 1989). Clearly, also the air resistance and possible headwind affects sprint economy.

2.4 Conclusion of sprint biomechanics

A well-formed block start position from which sprinter can output highest force, with best reaction time, that commence the acceleration is established when the blocks are positioned according to individual anthropometrics and features. Block spacing and block obliquity should be assessed first, followed by knee and hip angle and body alignment assessments. Chapter 2.1.1 provides guidelines for bunched, medium, and elongated start positions, whereas the block obliquity issue must be determined with the start block in use. Optimal start position is presented in picture 1. Stronger sprinters can use more acute angles compared to less trained counterparts. From the optimal start position the angle of force production should be directed horizontally and block clearance should occur at a low angle of 40 to 45 degree relative to the ground. After block clearance the sprinter must continue producing force horizontally in order to travel forward (apart from overcoming the effects of gravity with vertical force). The first few post-block steps need to occur with the TBCG ahead of the foot that is in contact to the track. The optimal first stride length is often found within the range of 0.98 to 1.20 m. Similarly to the block start, post block technique should be optimized to meet with the individual features (e.g. strength level, anthropometrics) of the sprinter to achieve best acceleration.

Sprinters with higher absolute running velocity usually require a longer distance to reach their maximum velocity (i.e. accelerate), thus maximum running phase may not take place until 50–70 meters. However, even before the maximum velocity is reached the biomechanical characteristics of maximum running apply as such. That is: an upright vertical alignment of upper body, active press down (i.e. striking-/whipping movement) of the foot prior to the ground contact, initial ground contact point of ≤ 20 cm (distance to TBCG), high knee joint angle and a hip joint angle of 150–155° at the initial ground contact, a short ground contact time

(<100 ms) performed with stiff ankle at joint angle of 80–100º throughout the ground contact, force directed vertically (75 ± 3º) at the braking phase and horizontally (58 ± 4º) at the propulsion phase, followed by a fast maximum flexion of thigh (i.e. knee lift) in the flight phase. Stride lengths usually vary at range of 2.35–2.60 m among male and between 2.05 and 2.25 m among elite females. Stride rates vary in a range of 4.5–5.0 Hz among both male and female elite sprinters. These components can result peak velocities for at over 12 m/s among elite male sprinters and at over 10.5 m/s among females. The deceleration percent varies from approximately 2 to 10 % regardless of gender.

3 NEUROMUSCULAR SYSTEM AND ENERGY METABOLISM

3.1 Neural factors and musculature

The 100-meter sprint requires rapid maximal force production over a relatively short period of time. Fundamentally, running movement and skeletal muscles are controlled by neural regulations through the central- and peripheral nervous system. The force exerted by skeletal muscle during a voluntary contraction depends on the number of recruited motor units and the rate at which action potentials are discharged (i.e. rate coding; Enoka 2015). It means that force production (i.e. output) can increase by inserting higher neural commands (i.e. input). Higher forces can be produced via additional recruitment of motor units or by increasing the firing rates of motoneurons. Enoka (2015) also explained that in the human neuromuscular system, there are three main groups of motor units known to exist: S (slow), FR (fast fatigue resistant) and FF (fast to fatigue). The motor units differ both morphologically (e.g. area covered, branching) and functionally (e.g. excitability) different kinds of motoneurons. Respectively, motor units also differ by the muscle fiber type that the motoneuron is innervating, since the innervated muscle fibers are always equivalent within a motor unit. Both of the fast type motor units are equally rapid to contract yet FF produces a higher force compared to FR, whereas FR endures more fatigue. Fast motor unit (FR and FF) are the most valid in sprint running because of their fast action.

The size of different motor units varies within their function in the body. Segments of the body that require small motoric functions are controlled by motor units of fewer neurons and muscle fibers. Respectively, the segments that account for higher force production are innervated with motor units that cover large areas and many muscle fibers (Avela et al. 2016). The quantity of innervated muscle fibers within a muscle unit varies from 5 to 2000 muscle fibers (McComas 1998). For instance, in the gastrocnemius muscle approximately 1900 muscle fibers are innervated per one motor unit (Feinstein et al. 1955). Therefore, in muscle such as gastrocnemius an addition of one new motor unit can increase the force production significantly.

Similarly, to the division of motor units also the muscle fibers share groups that are the slow-twitch (type I) and fast-twitch (type II) muscle fibers. Logically, the slow type motor unit S is only innervating the slow-twitch muscle fibers (type I) whereas fast type motor units FF and FR are innervating fast-twitch muscle fibers (type II). Fast-twitch muscle fibers are further divided into two subcategories IIa and IIx. In some literature type IIx may also be referred to as IIb. Both fast-twitch muscle fibers types share the same contraction features but differ metabolically as the type IIa functions as oxidative-glycolytic and IIx solely as glycolytic (Avela et al. 2016). IIa muscle fiber is reported of being capable to 6 times higher maximal power output compared to type I fibers and respectively type IIx to approximately 1.5 times higher maximal power output compared to IIa (Widrick et al. 2002). In addition, Type IIx contracts approximately 1.5 times faster than IIa that in turn contracts 3.0 times faster than type I (Malisoux et al 2006). Malisoux et al. (2006) also reported that the absolute force output of an singular muscle fiber is higher (25–40 %) among type II fibers compared to type I due to their larger cross-sectional area, consequently there seems to be no difference in force output of different muscle fibers in their proportional cross-sectional area.

For instance, the soleus muscle that is always active while standing and responsible for postural maintaining consists mainly of slow-twitch muscle fibers. Although the soleus muscle consists of slow-twitch muscle fibers it is relatively strong muscle with respect to its size. On that account soleus is crucial at enduring impact forces at ground contact and during the eccentric motion of muscles at braking- and propulsion phase of sprint running (Ishikawa et al. 2005). In turn, the gastrocnemius muscle mainly consists of fast-twitch muscle fibers that activate in fast movements, therefore making the role of gastrocnemius crucial at the propulsion phase of sprint running as it contributes to the force and velocity of the motion.

Among male sprinters (personal best 10.20–10.62s) the proportion of fast-twitch muscle fibers have been reported to vary from 50 to 79 % (e.g. Mero et al. 1987; Mero et al. 1981; Costill et al. 1976; Gollnick et al. 1972). The measures included muscle vastus lateralis, gastrocnemius and posterior deltoid, or only gastrocnemius. According to Komi et al. (1977) the distribution and relative quantity of muscle fiber types is inherited. Later, twin- and family research has indicated that 47–78 % of all physical attributes are received through genetics (Wackerhage Henning 2019, Silventoinen et al. 2008, Bouchard et al. 1999) Furthermore, it seems that attributes related to speed and power are near the top of the range. Distribution of fast type motor units is an important part of these inherited attributes and it can be measured with muscle biopsy sampling. However, while muscle biopsy sampling could provide more accurate information often speed- and power testing provides the information needed in sprint training (Mero 2020). Regardless of genetics with optimal strength training relative surface area of targeted muscle fiber type can be extended (hypertrophy) and according to Schoenfeld (2000) fast-twitch muscle fibers permit a greater hypertrophy compared to slow-twitch fibers. In addition, training-related fiber type transition is discovered in several studies (e.g. Bamman et al. 2007). Furthermore, with optimal power, speed and strength training the motor unit firing rates can be improved little (e.g. Avela et al. 2016).

As stated earlier in sprint running it is especially important to recruit fast motor units, however motor unit recruitment seems to follow a size principle (Enoka 2015). Meaning, that the small and slow motor units contribute to the force production first and later, according to needs, the larger and faster motor units begin to participate in force production. The currently available literature suggests that the upper limit (i.e. all are recruited) of motor unit recruitment stands at 65–85 % of maximal voluntary contraction (MVC) of the muscles (Avela et al. 2016). The upper limit of motor unit recruitment for lower extremities locates closer to 85 %. The remaining insertion to the force production is generated by increasing the firing rate of motor units. More research is needed in the question of what the percentage values are.

As a reference to the former chapter, the % MVC / firing force and the recruitment threshold have a positive correlation. Meaning, that strength and speed training enhance the recruitment of fast motor units. As mentioned earlier, motor unit recruitment follows a size principle, whereupon when pursuing to produce force rapidly fast motor units are later to activate. However, optimal power training lowers the threshold at which the fast motor units are recruited, consequently improving their recruitment. Concurrently both motor unit firing rates and double firing (e.g. MU fires twice within 10 ms) increase (Enoka 2015; Christie & Kamen 2006). Furthermore, a rapid discharge of motor units facilitates the alternations in rate coding that are required in a powerful and efficient timing of the sequential muscle activation of a great running technique. Discharge also (along with reciprocal inhibition) determines the relaxation of muscles during times that force in not required to be produced (i.e. flight phase).

3.2 Energy metabolism

All biological functions, muscle movement, force production and running require energy, that is mainly received from nutrition as chemical energy. In addition, to chemical energy there is mechanical energy to which there are references in the previous chapters. For cells to be able to use chemical energy, it first needs to be transferred to adenosine triphosphate (ATP) through a series of chemical reactions catalyzed by different enzymes (Enoka 2015). Consequently, the only energy suitable for muscle contraction appear as free energy that is bonded to ATP. Human body always consists a minor amount of ATP immediately available for use. After the immediately available energy is diminished new energy must be produced. There are various ways to produce ATP in the metabolic system, yet a first distinct division is drawn between aerobic (i.e. oxidative) and anaerobic (i.e. oxygen-free) mechanisms, from which the anaerobic mechanisms precede in the 100-meter sprint. Within a muscle there are three main pathways for energy production (i.e. to produce ATP): (1) phosphocreatine, (2) anaerobic glycolysis (i.e. break down of carbohydrates) and (3) aerobic- glycolysis, β-oxidation (i.e. break down of fats and lipids) and break down of proteins. More closely, in aerobic energy production mechanisms, ATP is generated in series of complex reactions where first carbohydrates, proteins, fats and lipids are broken down and later oxidized via respiratory air in citric acid cycle and electron transport chain/oxidative phosphorylation. Whereas in anaerobic energy production mechanisms ATP is generated directly from the muscle’s phosphocreatine and/or through glycolysis from carbohydrate stores, this happens faster compared to aerobic mechanisms due to fewer chemical reactions.

In the 100-meter sprint virtually only phosphocreatine (50 %) and anaerobically produced energy from glycogen (50 %) are contributing to energy production (Newsholme et al. 1992). Whereas aerobically produced energy from glycogen, blood glycose and triglycerides have a minor influence. Mero (1987) estimated that anaerobic energy production mechanisms accounted for approximately 85 % of the total energy production during a 100-meter sprint. Later, Duffield et al. (2005) reported that anaerobic energy expenditure accounted for 79.6 % (± 7.9) among male and for 75.0 % (± 7.4) among female sprinters. Due to this minor portion of triglyceride oxidation from total energy production, sprinters body fat percentage is desired to be low to enhance relative force production. However, it is difficult to precisely quantify the exact percentages of each mechanism with the current research practices (e.g. muscle biopsy), furthermore the knowledge on several mechanisms functioning concurrently complicates the quantification (Pullinen 2020). Regardless, from the standpoint of sprint specific training the understanding of phosphocreatine and anaerobic glycolysis usage covering 50 % / 50 % during a 100-meter sprint remains valid.

At performance of less than 10 seconds ATP is mainly (i.e. over 50 %) produced from the phosphocreatine stores of the muscles. Therefore, the energy production related challenge in a 100-meter sprint associate primarily with the energy production speed from phosphocreatine stores to ATP. However, according to Hirvonen et al. (1987) energy production speed from phosphocreatine stores is rarely a restrictive component to the performance, even though it has been reported that faster sprinters are able to exhaust their phosphocreatine stores faster compared to slower sprinters. Either, the energy production speed of glycolysis is not a strong determinant of a fast sprint performance since no significant distinction of blood lactate concentration is found between different level of sprinters after maximal performance. However, Nummela (2016) stated that alactic capacity (i.e. phosphocreatine) is found beneficial in short high intensity performance, such as sprint running. There is a 15–20 % difference in anaerobic capacity between males and females, in the favor of males. In addition, the power production of the muscle-nervous systems remains as one of the strong determinants.

Energy is produced concurrently by all energy production systems, however the necessity for energy production speed determines how ATP is primarily generated. At rest aerobic oxidation of fats and lipids are adequate for vital actions, but in a maximal sprint performance energy demand can be 120 times higher, consequently eliminating aerobic energy production to a fraction and making anaerobic mechanisms primarily responsible for energy production (e.g. Hulmi 2020). Anaerobic energy production mechanism act as the dominant system already after the energy demand is increased 10 to 40 times from rest. Consequently, the usage of aerobic energy production is restricted by its speed to generate ATP that is 75–80 % slower compared to alactic energy production (i.e. using phosphocreatine) and 50–60 % slower compared to lactic energy production (i.e. using glycolysis). ATP production in anaerobic glycolysis is 2–3 times faster, but only 5 % of the amount compared to aerobic break down of glycose. Glycolysis requires multiple seconds to reach the level and speed of any energy demand, that is determined by the muscles work power. For aerobic energy production mechanisms, it takes from multiple seconds to minutes to reach a similar energy production speed. Therefore, regardless of the intensity of the sprint running, the energy is always received primarily from the phosphocreatine stores of the muscles, during the first few seconds. Overall, anaerobic energy production is 10–12 times less economical compared to aerobic mechanisms. It means that when the energy demand is immediate / fast, anaerobic mechanism must be invoked at both low intensity and at high intensity (e.g. maximal running; Mero 1987).

The amount of available energy within the stores of muscles are approximately 1 kcal of ATP, 3.6 kcal of phosphocreatine and 1100 kcal of glycogen, among average males (Åstrand & Rodahl 2003). The size of the immediate ATP stores within the muscle are very small and vary between 0.2–0.3 kJ/kg (4–6 mmol/kg), whereas phosphocreatine and glycogen stores are larger 0.7–1.0 kJ/kg (15–22 mmol/kg) and 2.4–3.8 kJ/kg, respectively. ATP production speed from phosphocreatine stores is 2.2 mmol/kg/s and 1.2 mmol/kg/s via anaerobic glycolysis (McArdle 2014).

Phosphocreatine stores exhaust very fast but never empty fully. After a five second maximum running the phosphocreatine stores decrease approximately by 60 % (Mero 1987). Nevertheless, phosphocreatine stores also recover relatively fast. At rest 50 % of phosphocreatine stores is recover after 30 seconds and 85 % after two minutes, from starting level (Nummela 2016). Mero (1987) reported that phosphocreatine stores recover faster among type-II muscle fibers compared to type-I and that the phosphocreatine concentration (i.e. stores) grow along with the fiber type, to which the exercise is directed to. Therefore, energy production is exercised optimally by using the same motor units as during sprint competitions. However, due to the fast decrease in the phosphocreatine levels the proportion of anaerobic glycolysis increase in the energy production after the five seconds has passed (Newsholme et al. 1992). The downside of this transition is lactic acid that forms as an end-product of anaerobic glycolysis, when not enough oxygen is available. Lactic acid is split rapidly (probably in a few seconds) to hydrogen (H+) and lactate ions that transfer from muscle to other body parts via blood circulation. Hence, the acidity of both muscle and blood increases (i.e. pH decreases), thus impairing force production of the muscle. Acidity disturbs enzyme actions within the muscle that consequently weakens muscle contractions. As a result of this, force production is decreased as the muscle is no longer able to relax nor contract maximally and the performance cannot continue without fatigue for long. Even though, type-II (fast-twitch) muscle fibers are specialized to anaerobic energy production and account for most of the lactic acid production, they are especially exposed to fast fatigue, due to weaker ability (compared to type-I) to use lactate in ATP reformation (Nummela 2016).

Acidity is indicated as hydrogen ion concentration (pH). As the acidity increases pH value decreases. A linear correlation occurs between lactate multiplication and pH value decrease (Sahlin et al. 1975). A normal value of muscle cell pH is 7.0 from where it can decrease down to 6.4 in which case the fatigue is extreme. Equivalent values for blood pH are 7.4 (normal value) and 6.8 (extreme acidity). There is a direct relationship between blood lactate levels and the acidity, although there is inter-individual variation in the delay of substrate concentration changes in the blood (i.e. transfer from muscle to circulation). Elite sprinters may be able to raise their blood lactate levels up 13.2 mmol/l during a 100-meter sprint (Kinderman & Keul 1977). Note, there are also other minor bio-chemical contributors of fatigue, however they are more difficult to measure in practice, compared to main variables blood lactate and blood pH. It must be noticed that according to current understanding the main reason for muscle fatigue in short intensive anaerobic work is acidity (pH) not lactate. Blood lactate correlates strongly with blood pH and blood lactate is somewhat easier to measure in practical training circumstances. Furthermore, the human body can use lactate little to energy.

4 PROGRAMMING OF TRAINING AND COACHING

4.1 Annual periodization

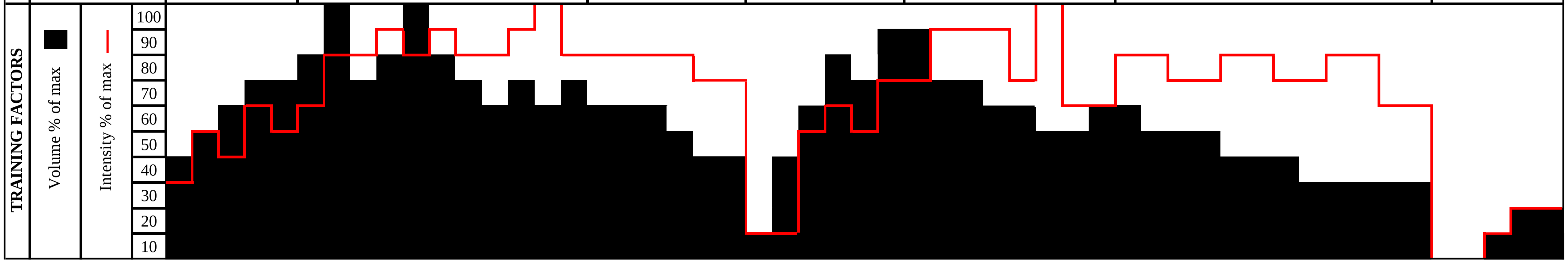
Annual plan covers 12-months of progressive and sequenced training. The plan is used to direct training, to stimulate and optimize physiological and psychological adaptations, manage fatigue, to ensure peak performance to occur at desired times and to manage recovery aspects as nutrition and sleep (e.g. Bompa & Buzzichelli 2018). Training should not occur in a linear fashion rather it must be alternated with the volume and intensity of training. Therefore, the annual plan is periodized into smaller segments that are also referred to as phases of training. Periodization is essential since it focuses different forms of training into distinct phases with specific objectives. A well planned periodization will consequently elevate and maximize sprint performance, together with the fatigue management that is applied with periods of recovery and regeneration, that allow the sprinter to avoid from excessive stress, overtraining and a decrease of performance capacity (e.g. Bompa & Buzzichelli 2018). Advanced long-term performance development can only be achieved by systematic training load increase over time, while ensuring sufficient recovery.

An adequate periodization requires consideration of the sprinters biomotor abilities, level of preparedness, psychological traits, management of fatigue, in other words, the capacity to perform and absorb training loads. As training is a complex interaction of different components and contributing factors, the annual plan must be subdivided logically into sequences of training phases, that are constructed according to individual needs, with appropriate volumes and intensities, realistic goals and options for modifications. The phases of training must be constructed to progressively develop specific components of sprint performance (physiological, technical, and psychological). In sprint training the annual plan is combined of two rather similar cycles (i.e. bicycle), from which the first is directed towards the indoor competitions and later towards outdoor competitions that is commonly considered more important. Both cycles are divided into main phases of preparatory, competitive and transition.

The phases of a bicycle annual sprint training plan are generally as follows: preparatory phase I, competitive phase I (i.e. indoor), transition phase I, preparatory phase II, competition phase II (i.e. outdoor) and transition phase II (see TABLE 3). Each of these subunits constitute to the objectives of the annual training plan. Every phase contains microcycles (e.g. a training week) and macrocycles (e.g. several weeks of training) that are altered via adjustment in volume and intensity. The duration of the phases depends on the time necessary to develop each separate performance component and to elevate sprinters overall training status and preparedness. The strongest determinant of the duration for each phase is the competition schedule since sprint performance must be peaked during competitions (e.g. Bompa & Buzzichelli 2018).

TABLE 3. Bi-cycle annual training plan in sprint training.

MONTH		1					2				3				4					5				6				7					8				9				10					11				12				
WEEK		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
Competition																		X	X			X	X															X		X	X			X	X			X	X					
Testing		X										X				X									X										X																			
PERIODIZATION	**PHASE**	**PREPARATORY I**												**COMPETITIVE II (INDOOR)**										**TRANSITION I**	**PREPARATORY II**										**COMPETITIVE II (OUTDOOR)**															**TRANSITION II**				
	SUBPHASE	**GENERAL PREPARATION**					**SPESIFIC PREPARATION**						**PRE COMPETITION**					**OFFICIAL COMPETITION**							**GENERAL PREP.**			**SPESIFIC PREPARATION**							**PRE COMPETITION**			**OFFICIAL COMPETITION**																
	OBJECTIVE	Construct strong physiological base, improve trainability					Transition to sprint-specific modalities						Elevating performance					Peak perfromance						Rest	Maximazing strength levels			Transition to sprint-specific modalities							Maximizing performance			Peak perfromance at major competitions												Full recovery and regeneration				
EMPHASIS	Sprint training	Technical, tempo					Accel., resisted sprints, speed end.					Acceleration, max velocity					Max velocity, assisted sprints							Technical, tempo					Max velocity, sprint spesific endurance								Max velocity, assisted sprints, sprint-spesific endurance													Off				
	Strenght training	Hypertrophy				Maximal strength and sprint spesifics						Power						Maintenance							Maximal strength					Power								Mainteinance												Off				
	Other training	Comprehensive overall					Aerobic-anaerobic,					Anaerobic lactic					Anaerobic alactic, plyometrics							Aerobic, upper body and mobility					Plyometrics								Anaerobic alactic													Diverse				
	Nutrition	Balanced					Protein and carbohydrates											High on carbohydrates						Balanced						Protein and carbohydrates								High on carbohydrates												Balanced				



4.2 Preparatory phase I

Preparatory phase I begins after the previous competitive season and recovery period (i.e. transition) in between the two annual seasons are finished. Preparatory phase I last approximately three months and is often subdivided into general and specific preparatory phases. The general preparatory phase is used to build a strong a physiological base for enduring high quantity of training (i.e. training capacity), to broaden the trainability of the sprinter for the upcoming season and to better tolerate the increase in training intensity that occurs later in the competitive phase. General preparatory phase along with the prior transition phase can be used for extended recovery, rehabilitation, and development of inadequacies (e.g. mobility) when necessary. In addition, preparatory phase is suitable for comprehensive overall conditioning, core strength and compensating disproportions between musculature segments (e.g. upper body). A high quantity of sprint training is executed at low intensities (e.g. tempo runs and speed endurance), with an initial target on to improve aerobic, anaerobic, and general endurance capacity. After first ensuring a gradual familiarization to high volume training the preparatory phase continues by rapidly increasing the quantity of exercises of high training volume. Additionally, over the course of the preparatory phase the intensities slowly increase towards nearly exclusively anaerobic training.

Resisted sprints and hill sprints are often applied in training during a preparatory phase. Strength training focuses mainly to hypertrophy and maximal strength during the early phase of the preparatory phase. Proportionally more vertical movements can be applied during the general preparation. High volume of training during the general preparation is also performed for psychological reasons such as determination, perseverance and willpower that are necessary for elite sprinters. If the preparatory phase is performed inadequately, the sprinters ability to tolerate training and maximize performance during the remainder of the season will be compromised.

During specific preparatory, the high training volume is remained while concurrently intensities still increase. Sprint-specific modalities are emphasized to develop the specific characteristics needed in a 100-meter sprint. These include biomechanically sprint alike movements in strength training, variety of coordination and technique exercises, and increasing use of horizontally directed movements in order to establish transition effects from vertical strength to power in sprinting. Strength training is accompanied with power training, while coherently sprint training proceeds towards intense short distance running (i.e. acceleration) and later to maximal velocity running and sprint specific endurance during pre-competition phase, whereupon, training volume may be lowered by as much as 40 % in remainder of this subphase. In addition, explosive strength and plyometrics are under attention. Specific preparatory subphase covers approximately 75–85 % of the whole preparatory phase.

Note, Haugen et al. (2019b) observed that among competitive sprinters two-thirds of all hamstring injuries occurred during the transition (i.e. pre competition) from specific preparatory phase to competitive phase. While this period is desired to have large reductions in training volume covered by increases in training intensity (i.e. sprint speed) sprinters require gradual mobilization of their maximal sprinting capacity (e.g. intensity, duration and repetitions) as the competitive phase approaches. It appears that if the difference between training speed and competition speed is too large, injury risk increases. Hence, the concept of progressive overload is envisioned to reduce the risk of injury, overtraining, and to stimulate long-term training adaptations.

TABLE 4. An example of a seven-day microcycle of high training load during the preparatory phase I.

DAY	MORNING	AFTERNOON
1	Rest	Rest
2	Running technique	Maximum strength
3	Circuit training + tempo	Hill + plyometrics
4	Rest	Body care + mobility
5	Speed	Hypertrophy
6	Rest	Mobility
7	Aerobic endurance + hill	Rest

4.3 Competitive phase I

In a bi-cycle plan competition phase I (i.e. indoor season) is the first of the two competition phases of an annual training season. It lasts approximately $2^{1/2}$ months at which time the sprinters sprint performance must be peaked. Competitive phase is often subdivided into pre-competition and official competition phases. Pre-competition phase may partly overlap the remainder of specific preparatory phase as the training is similar and transition (from training speed to competition speed) must be gradual. The peaking begins gradually during the specific preparatory/pre-competition phase where training volume is reduced distinctly and replaced with elevation of training intensity. Training volume may be reduced by 25 to 50 % compared to preparatory phase. The highest training intensities should occur two or three weeks prior to the main competition. During competition phase, maximal intensity training is not recommended to occur more than two or three times a week.

Over the early part of the competition phase performance is not peaked to its extreme, rather performance capacity is preserved as the first competitions are used partly as practice and as a testing ground regards to the major indoor competitions that are held at the end of competition phase. The 60-meter sprint event is often the primary focus of 100-meter sprinters during the indoor competitive season. One or two microcycles (e.g. 8 to 14 days) prior to the competition, a taper or unloading period is often used (see chapter 4.8.2). Peaking is the greatest challenge of a successful periodization in sprint training.

TABLE 5. An example of a seven-day microcycle of high training load during the competitive phase I.

DAY	MORNING	AFTERNOON
1	Rest	Rest
2	Body care	Block start + acceleration
3	Speed endurance	Rest
4	Power (short)	Rest
5	Light preparative exercise	Rest
6	Competition	Competition
7	Competition	Competition

4.4 Transition phase I

The first transition phase begins immediately after the indoor competition phase is finished. Due to the long preparative- and competition phases that have included intense training and performance outputs, a sprinter is put under a large amount of cumulative fatigue and physiological stress. If this stress is applied for too long overtraining may occur, consequently decreasing performance capacity. Therefore, the transition phase is used for recovery and regeneration from the competition phase and is featured with a period of unloading that lasts a week. This will allow the sprinter to prepare for training in the second preparatory phase. Some practitioners may not use transition phase after the competitive phase I at all.

4.5 Preparatory phase II

The preparatory phase II is commonly shorter than the previous preparatory phase I. The second preparatory phase lasts approximately 2 months. The duration of the preparatory phase II can be shorter, since often the physiological base that is gained during the first preparatory phase is adequate for training to be continued with higher volumes and intensities with less gradual familiarization. Therefore, preparatory phase II includes only a short general preparatory subphase, while most of the training is performed in the specific preparatory subphase.

TABLE 6. An example of a seven-day microcycle of high training load during the preparatory phase II.

DAY	MORNING	AFTERNOON
1	Rest	Rest
2	Mobility + core strength	Acceleration + circuit training
3	Tempo	Maximal strength
4	Rest	Body care
5	Submaximal speed	Maximal strength
6	Rest	Tempo
7	Rest	Rest

4.6 Competitive phase II

Competition phase II (i.e. outdoor season) is the second competitive phase of the annual season and often identified as the more important one. Outdoor season lasts approximately for $3^{1/2}$ months. Especially, development of maximal velocity and sprint specific endurance are attained during the outdoor season. Similarly, to the indoor season training volume is reduced distinctly during outdoor season and is replaced with elevation of training intensity and peaking. The objective of training during competition phase is to induce optimal physiological adaptations at optimal times to consequently maximize performance at sprint races. Competitions are often arranged progressively in order of their importance and challenge (i.e. high performing peers), while also utilizing different events (e.g. 200-meter sprint) for performance optimization that lead to success in the main competitions. Therefore, in some cases, the outdoor season may be subdivided into early and late peaks in order to prepare for national trials and international championships. Early and late peaking may be dissociated with a brief preparatory period to enable the ultimate peak in performance to be reached at the main competitions. Some sprinters compete less than others and seek speed development through intense training while others use competitions as practice, yet in general minimum of 2–3 sprint races are needed to elevate performance up to personal standards (Mero Jr 2020). Annually, the total number of races vary from 20 to 30 among elite sprinters (Mero 2020).

TABLE 7. An example of a seven-day microcycle of high training load during the outdoor season.

DAY	MORNING	AFTERNOON
1	Rest	Rest
2	Block start + acceleration	Power
3	Rest	Light exercise + body care/massage
4	Power (short)	Rest
5	Rest	Rest
6	Competition	Competition
7	Competition	Competition

4.7 Transition phase II

Transition phase II (i.e. compensation phase) completes the annual season/training plan and links to the next annual training plan. Main objective of the transition phase II is to remove physiological and psychological fatigue, allow the athlete to recover fully, induce regeneration and prepare for a new annual season. For injured athletes, transition phase is used for rehabilitation and restoration of movement capacity. These objectives can be attained via unloading and the use of active rest (chapter 4.8.3). Regardless of injury or rehabilitation status, all sprinters should apply periods of active rest. In addition, applying mild resistance training, exercises targeted to improve weaknesses (e.g. mobility), exercises addressing musculature stabilization and other less usual forms of exercise should be considered. Consequently, all loading factors should be reduced, training components are focused on general training, with minimal technical development. Usually an adequate level of general physical preparation to be maintained during the transition phase is approximately 40–50 % of the competitive phase. Consequently, through the active rest physiological and psychological rest, broader trainability base and decrease for potential risk of injury can be accomplished. However, total unloading (i.e. training pause) is not recommended, as it may cause excessive decrease in performance (Mero et al. 2016). Transition phase II can last up to one month before the next annual training plan is initiated.

4.8 Special concerns

Variation of load and other training variables within systematic training periods is found most effective for long-term adaptations. As the sprinter ages and advances, more systematic variation within periodization is required while also performing training with higher relative loading (ACSM 2014). Training culture, environment and individualization all influence to the choice of periodization model as amateurs, high school-/college-/ university level, semi-professional and professional sprinters require diverse planning.

A traditional periodization model involves an early emphasis on high training volume with low intensity that is conversely transitioned to low volume with high intensity as competition phase approaches. However, traditional periodization is not often applied in its standard form as initial high-volume/low-intensity is argued to lead to inappropriate adaptations when applied in early preparatory phase (Banta 2017). Conversely, high-intensity close to competition phase may cause insufficient volume and unnecessary increase of injury risk (Francis 2019; Banta 2017). In block periodization training is orientated through macrocycles with concentrated skill development and specialized loads. Banta (2017) questioned the usefulness of block periodization as the model prohibits the sprinter to maintain the developed skills throughout the alternating macrocycles.

Periodization model also depends on the sprint distance, as 100-meter sprinters often apply short-to-long model, whereas 400-meter sprinters may apply long-to-short model. The long-to-short periodization model focuses on long distances in the preparation phase from where it continues to shorten as the training year proceeds (Khmel & Lester 2019). In contrast, short-to-long model advances from short sprints to longer distances throughout the training year. More closely, the emphasis is set on each phase of a sprint: block start, acceleration, maximum running, and deceleration. The initial macrocycles focus on power training, acceleration and short sprints, that leads to indoor competitive phase where races culminate to the 60-meter sprint event (Francis 2019). After the indoor competitive phase, the emphasis turns to maximal velocity training and transitions towards the improvement of sprint-specific endurance (i.e. deceleration phase) when the outdoor competitive phase approaches. According to the model it is preferable to improve maximal velocity first and to extend the duration of maximal velocity maintenance later. Often a polarized intensity features are applied with the short-to-long model, where sprint training is only performed either ≥ 95 or <70 % of maximal velocity to enhance sprint speed or stimulate recovery, respectively (Francis 2019). It is claimed that mid-range intensities of approximately 70–95 % are not optimal either for performance nor recovery and therefore, should be avoided (Francis 2019; Banta 2017). However, mid-range intensities are broadly used for improving sprint technique and in lactic exercises (Mero Jr 2020).

Overall, there is no direct evidence of the superiority of any periodization model as the underlying mechanisms of the specific methodologies do not contribute to success solely and cannot predict outcome advances in sprint running. Therefore, periodization models and variation in training rarely follows the concepts presented in literature, rather elite sprint training is a unique mixture of periodization practices, that contain features from several models and is planned with significant detail.

Loading is another important aspect of variation within periodization. Training can be distributed into more high and low training loads in relation to the individuals' capacity to absorb loading. Commonly, a loading paradigm of 2:1 and 3:1 is used, that is, relatively high and increasing training load across two or three microcycles followed by a microcycle of unloading for recovery purposes and to avoid problems associated with overtraining (Haugen et al. 2019b; Bompa & Buzzichelli 2018). The same training load is usually repeated over several training sessions within a microcycle, since one session tend to be insufficient to establish noticeable adaptations. Therefore, the increase in training load rather occurs in the subsequent microcycles two and three. As the sprinter adapts to the stimulating load, that load becomes a retaining load and the previous retaining load becomes a detraining load, thus a wavelike increase in training load (i.e. performance) occurs.

4.8.1 Individualization

To optimize sprint performance at the desired times sprinters must undergo several months of preparative training. In an advanced annual plan, all periodization phases of training are tailored according to the individual needs of the sport and the sprinter, to achieve the best individual response to training. With elite sprinters the training plan should be created in collaboration with the athlete and the coach in order to establish objectives and structures that meet with the intrinsic desires of the athlete. Conversely, with inexperienced athletes, the coach can create the training plan with less input from the athlete. In either case, the coach is responsible for the optimal dose of training and recovery. A well individualized training plan considers predisposition such as age, gender, anthropometrics, genetic endowments, training status, injury status, psychological traits, recovery capacity and force-velocity profile (Haugen et al. 2019b). Training must include spatiotemporal mechanisms that comport with the physical features and the performance level of the sprinter. For example, it is not beneficial for a mediocre sprinter to attempt to reach steps of an elite sprinter, since with inadequate strength the ground reaction forces may become more vertically oriented.

Both the total training volume and the attention to biomechanical specifics of the sprint performance increase with age, individual ability to tolerate and adapt to a training, and sprint performance development. However, as sprinter approach their highest potential, training volume may decrease to accommodate propriate recovery between high-intensity sessions (United Kingdom Athletics 2019). The age-related changes also appear with metabolic changes as anabolic hormone (e.g. testosterone) concentrations begin to decline (Bosco et al. 1996). In addition, there are gender-related differences in endocrine response to training. For instance, adult males have significant elevations in the recovery of testosterone and free testosterone through 30 minutes into recovery, while adult females have limited or no acute elevations (Kraemer 2017). However, it is debatable whether females should perform less volume in training because of this or not, since conversely substantially lower peak forces and power loads allow females to a better neuromuscular recovery and therefore to higher training volumes (Haugen et al. 2019b). Scientific literature provides limited information regarding gender differentiation of sprint training prescription.

According to United Kingdom Athletics (2019) the duration, number of repetitions and recovery time in sprint-specific training should be adjusted according to the performance level and training status of the sprinter. It is suggested that maximal sprint performance is more demanding to the neuromuscular system of an elite sprinter than for lower performing counterparts, therefore more recovery time is needed for more advanced sprinters. To define optimal recovery times, information provided by performance testing can be useful.

Morin & Samozino (2017) suggested that individualized sprint training should be based on a force-velocity profile. Meaning that sprinters with force deficits should focus training to horizontal strength while sprinters with velocity deficits should perform more sprinting at maximal velocity. For this approach there are reference values available across sprint performance values, however the effectiveness of force-velocity profile approach is unclear (Haugen et al. 2019b). Helland et al. (2019) questioned force-velocity profiling due to its assumption of direct relationship between acceleration and peak velocity measurements and underlying contractile characteristics of muscles. Running velocity is not considered as appropriate correlative of muscle contraction velocity, since fascicle shortening velocity do not necessarily alter with respect to running velocity, as the increasing contribution of elastic components affect running as well.

4.8.2 Tapering

As mentioned, the greatest challenge within a sprint training is peaking the sprinter at the appropriate times. Therefore, a method of tapering/unloading is applied to peak sprinter's preparedness at the appropriate time, thus ensuring a peak sprint performance to occur. Tapering is simply defined as a reducing training load prior to a competition. In sprint training tapering is usually applied as a progressive non-linear reduction of the training load during a predetermined time prior to competition, as an attempt to systematically reduce physiological and psychological cumulative fatigue. Tapering (i.e. peaking) can be affected by the training volume, frequency, intensity and by the duration of the taper. The premise behind a taper is somewhat simple, yet executing a successful taper is a complex process. In case the tapering is implemented correctly, extreme peak performance will occur in response to the physiological and psychological adaptations (i.e. supercompensation of performance) induced by the whole annual training plan. In contrast, if tapering is applied imprecisely, for instance when the duration of the taper is too long the adaptations stimulated by the training program may disappear, resulting in detraining and reduced preparedness.

As the training load is high during the preparatory phase and still later during the pre-competitive phase (i.e. pretaper), athlete's preparedness is low as a result of a high level of accumulated fatigue. Primarily, tapering is initiated via manipulating both volume and intensity to reduce the accumulated fatigue from previous training and competition. Volume is decreased while only moderate alternations are made to training intensity. Optimal intensity for a taper depends on the level of training undertaken prior to the taper. Greater reduction and duration of a taper will be necessary if the training load prior to the taper has been high, in order to maximize the decrease in fatigue required to elevate preparedness.

Intensity and volume are the primary training components under regulation during a taper. Volume is reduced from all other training factors, whilst sprint and power training remain a priority. Reduction in training load can be considered both as reduction in the extent of the training and the duration of this reduction, which both combine to determine preparedness. Training intensity is maintained equal as prior to the taper or is slightly elevated. Moderate to high training intensities are maintained during the taper to avoid detraining.

Also training frequency must be reduced during a taper. Meaning, all extraneous factors and activities that may contribute to the sprinters fatigue should be eliminated. In addition, the sprinter should be advised and encouraged to use leisure time for rest and recovery. According to Bompa & Buzzichelli (2018) physiological adaptations can be maintained with training frequencies between 30 % to 50 % of the pre-taper frequencies, in moderately trained sprinters. However, elite sprinters may need training more frequently during the taper period to maintain technical proficiency. Therefore, among elite sprinters training frequency should not be decreased more than 20 % of pre-taper training values to attain optimal performance outcomes and maintain technical proficiency. Among some leading practitioners, the predetermined duration of the unloading/tapering usually lasts from 8 to 14 days, covering two microcycles. As mentioned earlier, the strategy used for tapering depends largely on the type of training undertaken prior to the taper and of the individual sprinter (e.g. level).

To produce the unloading effect in the first microcycle the training volume is commonly reduced by 40 % to 50 %, depending on the level of training undertaken prior to the taper. Some literature has reported reduction in training volume of 50 and 90 % at most, in running. Reduction of 60 to 90 % of pre-taper values is only advisable if extensive training has preceded the taper. Ergo, moderate volume degradation of 40 to 60 % are adequate to dissipate fatigue in most cases. Shorter duration of taper is warranted for larger reduction in training volume. To enhance the unloading effect during the first microcycle it is possible to reduce the number of daily training sessions on some days and to modulate training intensity to begin the recovery process. Further, reducing the duration of each training session is preferable to reducing the training frequency. For instance, because during competitions the sprinters preparedness must be elevated repeatedly during the day.

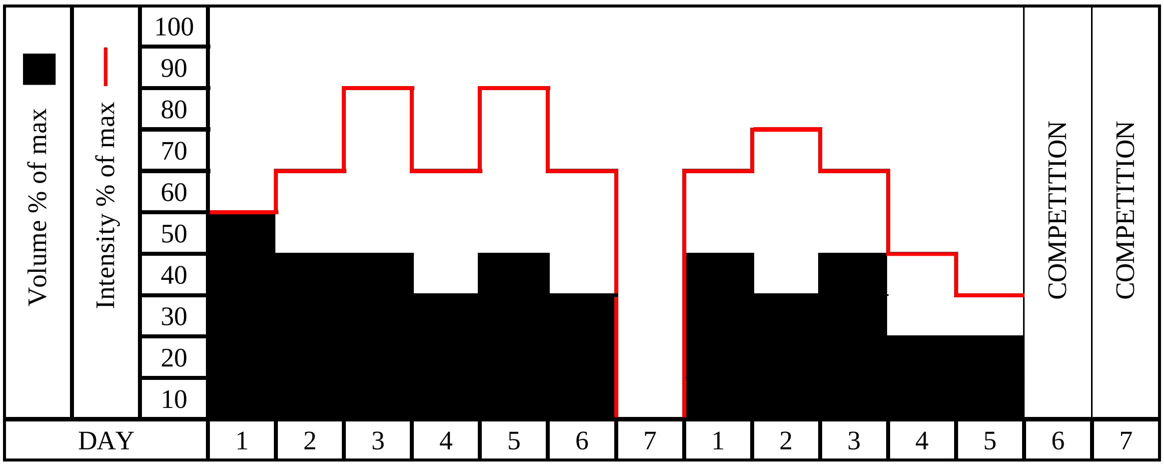
A two-peak microcycle structure may be adapted during the first microcycle of the taper. Adequate peaks may be accomplished by consistently reducing volume across the microcycle and to alter the intensity of the training while having two distinctly more intense sessions to maintain the adaptations induced by previous training phases. The less intense training sessions should alternate submaximal intensities between low and very low intensities. The more intense sessions should include only dynamic exercises and of short duration between medium- to high-intensity loading. Although intensity may be set high, long rest intervals need to be included between repetitions to ensure avoiding cumulative fatigue and stress.

The volume and frequency of strength training is reduced while maintaining moderate to high intensities during sessions. Strength training during the first week may be limited to one or two sessions. As power and speed are crucial functions of sprint performance a complete removal of strength training is not advised, in order to maintain strength levels. Further reductions in volume, intensity and frequency may be assessed during the second microcycle of the unloading period.

The main competition occurs during the second microcycle of the taper. Therefore, during the second microcycle the unloading process will involve further reductions of training volume and the intensity of training in contrast to the two peaks of the first microcycle of the taper. The volume should be reduced to even greater extent than intensity. The second microcycle may include two or three peaks, latest being at the competition. Objective remains to be reducing fatigue and stress maximally while elevating preparedness and maintaining the gained physiological adaptations.

During the second microcycle of the taper first of the peaks occurs during the early portion of the microcycle, while the latter, extreme peak is targeted to occur at competition. In case, the microcycle includes two peaks before the competition then the first peak should be performed at 15–20 % higher intensity than the second (Bompa & Buzzichelli 2018). Over two days prior to the competition the sprinter is advised to undergo only short training sessions of low- to very low intensities. As a result, to a taper performance gains of approximately 3 % can be expected.

TABLE 8. Two microcycle taper prior to two-day competition illustrated with adjustments in volume and intensity.



4.8.3 Recovery strategies

There is a wide variety of different recovery interventions and modalities that can be used during the different phases of training and competing. Each of the modalities, either pre-, inter- or post exercise and long-term recovery strategies are used to maximize training outcomes. Inter-exercise recovery occurs in between the bouts of the exercise and is related to the bioenergetic variants discussed in chapter 3.2. Post-exercise recovery is commenced after the training session is finished and is related to the removal of metabolic by-products, the replenishment of energy stores and anabolic processes (e.g. tissue repair). Meaning that the body does not immediately return to a resting state after the cessation of training. In addition to a careful planning of a taper (chapter 4.8.2) long-term adaptations can be evoked with a well periodized annual training plan where long-term recovery is considered with detail, thus resulting in a supercompensation effect.

Recovery is a complex multifactorial process where it is beneficial to understand the psychological and physiological mechanism that affect to the recovery. Furthermore, it is essential to understand the inter-individual differences and preferences of, especially our own sprinters. Generally, recovery is affected by factors such as age, training status, gender, time zone shifts and nutrition. The propriate recovery strategies alter over the phases of annual training and therefore practitioners should be familiar with concepts that can be applied to enhance recovery. Although, much scientific research has been conducted around all the following recovery modalities this chapter’s objective is only to introduce the reader to the variety of recovery interventions.

The most natural form of recovery is passive recovery performed by sleeping. The sprinter must always be ensured with adequate nighttime sleep. Many of the literature suggests that sleep for 8 to 10 hours is referred to be adequate for an elite athlete, from which 80–90 % should occur at nighttime (i.e. both REM and NREM), while the remaining may be made up with naps (i.e. light sleep). Among elite sprinters, sleeping rhythms may be disturbed during competitive season if the traveling requires crossing multiple time zones. It needs to be noted that it usually takes between 2–3 days for sleep quality to return to normal, 3–5 days for jet lag symptoms to dissipate and 6–8 days for performance variables to return to normal (Bompa & Buzzichelli 2018). The sprinter must be prepared with an individual recovery plan for competitions at different time zones.

In contrast to the characteristics of passive recovery active functions can also be undertaken to enhance recovery. Post exercise active recovery is commonly initiated with a warm-down routine of light exercise. This seems to be more efficient in augmenting recovery compared to remaining passive immediately after the exercise. Active recovery is found to be beneficial since it increases the rate of lactate clearance significantly, allows a more gradual body temperature decline, dampening of the central nervous system activity and reduces the perceived degree of exercise-induced muscle soreness and/or delayed onset muscle soreness (DOMS). The most noted effects of an active recovery seem to be performed at intensities of <50 % of VO2 max (Bompa & Buzzichelli 2018). Active recovery may also include stretching and other muscle care exercises.

Another commonly used method of recovery enhancement is massage therapy. Massage therapy is exploited throughout the training year as well as during competitive phases, with slightly different approaches. Massage can be undertaken both prior to training or competition (i.e. preparatory massage) and after it (i.e. restorative massage). Optimal times for massages need to be implemented as part of the recovery plan. It seems that a combination of active recovery techniques, followed by massage and completed with passive rest is superior compared to only one recovery technique (Bompa & Buzzichelli 2018).

Other recovery strategies may include thermotherapy (e.g. sauna, hot water immersion), cryotherapy (e.g. cold-water immersion, ice massage) or a combination of these to (i.e. contrast therapy). Thermotherapy is performed as an intention to increase body temperature by techniques such as sauna, hot water immersion, steam bath, warm whirlpool, hydrocollator packs, paraffin baths and infrared lamps or rooms. Whereas cryotherapy includes techniques such as cold-water immersion, ice bath, ice massage or usage of ice packs for treating acute traumatic injury and facilitating recovery. Contrast therapy is a combination of the two mentioned techniques, where heat and coldness are alternated to induce a “muscle pumping” -like action as a result of the alternation between vasodilation and vasoconstriction. Most common form of contrast therapy is hot-cold water immersion. In some literature water immersions may be referred to as hydrotherapy. In addition to hot and cold-water immersion, hydrotherapy can be also performed with thermoneutral water temperatures of 16–35 °C. The beneficial effects of hydrotherapy are hypothesized to occur as a function of the hydrostatic pressure that it created towards the body when immersed in water. Hydrostatic pressure stimulates the displacement of fluids away from the extremities and towards the central cavity of the body. Therefore, water immersion could theoretically provide similar effects to those of active recovery, by increase cardiac output that increases blood flow (Bompa & Buzzichelli 2018). Some may also use compression garments for promoting blood flow.

Furthermore, recovery can be enhanced with nonsteroidal anti-inflammatory drugs and nutritional strategies that are discussed in chapter 4.8.4. Altogether a combination of different strategies is believed to be most beneficial for inducing recovery. As briefly mentioned, there are variety of recovery strategies available, ranging from passive rest to special modalities that are designed to enhance and speed up the recovery process. Appropriate combination of interventions appears to result in most rapid rates of recovery. Although further research is needed to elucidate the optimal combination and sequencing of these methods. As well as the inter-individual preferences always need to be considered by the sprinter and the practitioners, based on the sprinter’s tolerance and response to the different modalities. A wide scientific database is available for studying the optimal apply and usage of the before mentioned recovery strategies along with researched information about the underlying mechanisms and physiological adaptations (e.g. Kraemer et al. 2017).

4.8.4 Nutrition

In sprint training and especially while competing the optimization of power-to-weight ratio and enhancement of anaerobic energy production are crucial in order to achieve biomechanical efficiency and successful performance. For this reason, sprinters should have high muscularity and low relative adiposity. Although nutritional strategies are dependent on the training phase and specific training intervention applied, it appears that sprint training induces enzymatic adaptations to all three energy systems (see chapter 3.2). The adaptations result in faster rates of phosphocreatine break down and greater glycolytic and mitochondrial enzyme activity (Ross & Leveritt 2001). Ergo, intense sprint training increases both aerobic and anaerobic energy turnover. Therefore, contribution of each energy system stimulated in training should be considered for optimal nutritional prescription during both training and competitive phases. Furthermore, adjustments in macronutrient intake may be warranted if optimization of power-to-weight ratio is considered through reductions in body fat, for instance prior to the competitive season. Despite the short duration of 100-meter race and relatively long recovery periods between races, nutrition is still a key component in sprint performance.

Due to the high contribution of glycolysis in energy production during sprint training, carbohydrate availability needs to be ensured. It is suggested that daily carbohydrate intakes of 4–6 g/kg body mass are adequate for both male and female sprint athletes, while no conclusive evidence is presented of benefit from maintaining higher habitual carbohydrate intake (Slater et al. 2019). Carbohydrate should be ingested before, during (in long sessions) and after exercise.

Similarly, for protein intake there is likely no further benefit from exceeding the upper range of protein intake recommendations (Witard et al. 2014). It is suggested that daily protein intakes of 1.5–2.0 g/kg body mass are adequate for both male and female sprint athletes (Hulmi &

Ahtiainen 2016). Protein should be consumed by meals containing ~0.4 g/kg high biological value protein (i.e. includes essential amino acids) every 3–5 hours. Majority of the daily protein intake should be ingested toward the evening with less consideration for breakfast and between-meal intake. Sprinters undertaking heavy strength and power training often exceed the recommendations for protein intake. Thus, rather than focusing on total daily intake, sprinters are recommended to focus on having wide distribution of high biological value protein in their meal plan with the adequate (~0.4 g/kg) single-doses (Slater et al. 2019).

What comes to hydration sprinters are encouraged to train in a euhydrated state, as all athletes. However, the short duration of 100-meter sprint ensures that no dehydration occurs due to the event itself. Therefore, sprint performance does not appear to be impaired by a state of hypohydration within range of 2–3 % (Slater et al. 2019). Watson et al. (2005) agreed by stating that performance over distances of 50–400 meters remain constant despite an acute reduction in body mass equivalent to 2.0–2.5 % caused by diuretic-induced dehydration. Ergo, it is advised to begin training in a state of euhydration, ingest small ounces of fluid despite of thirst but with gastrointestinal tolerance (Hietavala 2020). In addition, body mass should not be reduced more than 2–3 % within one training session. Fluid balance must be repaired with post exercise recovery strategies that include adequate fluid and electrolytes.

All proposed dietary recommendations should be modified to meet with the necessities of the individual. An emphasis should be placed on the strategic timing of pre-, during and post exercise nutrient intake. Daily training may include both sprint- and resistance training, followed by other activities such as massage, traveling and personal commitments. The daily routines have an important impact on meal scheduling and access to food, these matters need to be considered when designing a nutrition plan. A well designed nutrition plan will include strategic timing of nutrient intake to achieve adequate fueling (i.e. capacity to train), recovery objectives and the regulation of power-to-weight ratio, achieved through maintaining/change in body fat levels and/or muscle hypertrophy (i.e. body composition). While pursuing to optimize power-to weight ratio prior to main competitions or trials, there may arise occasions where restricted energy intake is used for reducing total body mass or fat mass. If this is experimented the process must be undertaken strategically to ensure retention of lean body mass and hormonal status (Huovinen et al. 2015). Weight loss of 2–3 kg is often adequate to enhance velocity and power. All proposed dietary interventions must be trialed first in training to assess individual tolerance and responses, before implementing them at competitive phases.

Fatigue during sprint training is likely multifactorial, including cortical, neural, neuromuscular and peripheral factors. The peripheral factors include changes in metabolic substrate concentrations such as reductions in phosphagen energy system stores and accumulation of by-products from anaerobic energy production, that result as decline in intramuscular pH. Metabolic fatigue may also include mild acidosis and impaired energy production from glycogenolysis (Green 1997). There are variety of supplements available for sprinters from which only some have strong research evidence about enhancing performance in training (i.e. repeated performance) and/or competition (i.e. single performance). Multivitamin and mineral supplements are found beneficial for all human, while elite sprinters may use buffering agents, whey protein- and specific amino acid supplements, caffeine, creatine monohydrate alongside their diverse nutrition, to enhance both recovery and performance (Slater et al. 2019).

Similar to nutrition plans, supplement ingestion should be preceded with trialing in training to confirm tolerance and perceived ergogenic potential. Few supplements may be of benefit to sprinters in training and/or competition. Especially, the use of prerace ergogenic aids, such as buffering agents (i.e. sodium bicarbonate, β-Alanine) or caffeine requires optimal timing and dosage for enhanced performance to occur across single and repeated performances (e.g. semifinal and final). Note, sodium bicarbonate and β-Alanine are more suitable for sprint training with multiple sprint rather than competition. In turn, creatine monohydrate may enhance both single and repeated sprint performances by improving the re-phosphorylation of high-energy phosphates, muscle relaxation time and increases working capacity (Mero 2020). However, there is a contradiction to performance gains in using creatine monohydrate supplementation, as energetic costs associated with extra body mass and fluid retention may occur. Therefore, creatine is most often used during preparatory and pre-competition phases of higher volume and intensity.

4.8.5 Testing and monitoring

Testing has a vital role in goal-orientated long-term training plan. Both field- and laboratory tests can be used with sprinters. Field test are usually inexpensive, time saving and mimic the factors that are related to the actual sprint performance, whereas laboratory test can provide more specific information from all areas of fitness and physiology. Comprehensive testing and monitoring program may be used to:

1) determine training status and absolute performance level
2) determine strengths and inadequacies
3) determine responses to the training plan
4) determine appropriate standards for training and competition
5) evaluate and develop psychological attributes (e.g. maximal exertions and tolerance of fatigue)
6) identify potential overtraining
7) monitor dose-response relationship
8) monitor improvement in specific biomotor abilities and bioenergetic attributes
9) evaluate biomechanics and movement skill (e.g. technique)

Similarly to periodic training, testing should be conducted in a periodic-fashion. Testing should be conducted at the beginning of each new training phase and prior to competitive phases with different emphasis. Whereas factors that affect the daily training (e.g. resting heart rate, heart rate variability, arousal, vigilance, mood status, sleep patterns) should be monitored as a routine. For elite sprinters monitoring can be affiliated with a sport science facility, whereas less expensive solutions such as wearable technology may provide enough information for less trained athletes. Furthermore, on many occasions a simple strategy such as maintaining a training log with rates of subjective perception of fatigue, alertness etc., can be adequate. The numerical scales used in training logs must have definitions that are understood by both the coach and the athlete. Monitoring should also include injury updates to help recognize if the volume or intensity of training, quality of sleep, length of training session etc., are associated with the injuries. In addition, nutritional practices can be included to monitoring. The more comprehensive the training log/monitoring strategy is, the more specific information it provides about the sprinter’s tolerance for the training stimulus, thus prevents overtraining and allows supercompensation to occur.

Testing must be integrated into the training plan, occur at appropriate times (i.e. performed after adequate rest), contain tests that measure valid features (e.g. power, running velocity, force-velocity profiling) of sprint performance, mimic the direction of force production (i.e. horizontal > vertical) and that relate to the sprinters objectives (i.e. performance outcomes). Furthermore, the test must be reliable and repeatable, consequently the test protocol (i.e. test order, technique) and equipment in use must be standardized. Not too many tests should be performed during the same day, rather test batteries should be performed on multiple days and be formed according to specific categories to prevent contradictory effects from occurring. Test batteries usually include 4–8 tests (Keskinen et al. 2018; Bompa & Buzzichelli 2018).

Testing program that is targeted to measure areas of performance related to sprinting should consider the bioenergetics (i.e. metabolic specificity), biomechanics (i.e. sprint specificity, joint angles) and the sprinter’s training status. Sprinters must be familiarized with the tests but should not train for only mastering the test. The dates of performance tests that occur repeatedly during the annual training plan should be decided while constructing the annual training plan. It is recommended to perform start tests during the first microcycle of the preparatory phase since the test results may lead to modifications in the training plan. All macrocycles with specific objectives should consist specific testing/monitoring that determine whether the objectives have been accomplished.

It is beneficial to set standards for each test, at least the results from previous training year can be set as a minimal threshold. Standards should raise progressively year by year and be challenging (i.e. slightly superior to potential) but realistic to stimulate increases in performance and to achieve linear progression. For sprinters who are aiming to international success the standards must resemble those of world top sprinters, whilst some of the top sprinters may concentrate on maintaining the standards and aim to preserve an optimal level of preparation. Standards are also useful for evaluating the effectiveness of the training plan during the different phases. If the test results reveal consistent improvement, the original training plan should be maintained. Conversely, if the test results remain the same over the course of training phases or indicate decreases that cannot be explained otherwise, modifying the next training cycle must be considered. Note, when evaluating the testing data, the purpose of the training phase must be recognized since training may cause some decreases in specific areas of performance (while other improve) that are expected. For example, the high training volume, workload and fatigue during general preparation phase may cause deficits in markers of maximal power. Detailed and organized data must be collected about the test results in order to perform a consistent analysis of the sprinter's rate of improvement and adaptation to training.

Comprehensive and more diverse tests are often performed in the beginning of a new season, where the tests evaluate other than sprint-specific features. For example, medical control, muscle ultrasound and mobility may be reviewed to evaluate the sprinter for areas of physical inadequacies, hormonal content, overall health, range of motion and muscle imbalances that may increase injury risk or affect training on one way or another. Whereas direct or predicted maximal oxygen uptake measurement (VO2max) can provide useful information about the condition of the respiratory- and circulatory system as well as lactate- and heart rate thresholds, that can be used in training (Nummela 2016). Laboratory measures (e.g. muscle biopsy, muscle ultrasound) also provide information about the structural factors of muscles such as muscle fiber composition, fascicle length and pennation angles that may provide valuable information for elite sprinters.

Sprinter's force-production capacity (e.g. peak force, rate of force development, maximal strength) and power (e.g. peak power, power snatch-, power clean-, jerk 1RM) should be tested in the beginning and at the end of preparatory phases. The results can be used to determine specific workloads, to measure development and to assess the absolute performance level. Test that are used to measure progression in strength and power often contain activities that are suitable for training too. This is an exception to what was mentioned earlier about not wanting sprinters to train for only mastering a test. Therefore, in this instance if back squat is used to develop lower extremity strength it is beneficial to use the same movement in a 1RM -test to evaluate maximal strength. The evaluation of more specific areas of force (e.g. peak power, RFD) require laboratory facilities (i.e. force plate sensors) or device (e.g. accelerometer, potentiometer) that track bar speed. Furthermore, EMG-patterning and video analysis/imaging technology may provide useful information and help to assess detailed areas of force-production and sprinting technique that cannot be detected by eye. In addition to clean and snatch, power is often tested with different vertical jumps (e.g. static, squat, counter movement and drop jump) on contact mat or by flag-reach, and horizontal jumps (e.g. standing long jump, triple jump, 5-jump and 10-jump) as a field tests. Similarly, shot throws (e.g. an overhead throw to behind and a throw from below to forwards) can be used as field power tests. Most of the field tests can also be used as monitoring tool prior to exercises.

Sprint specific testing often includes measuring velocity at different phases of 100-meter sprint (e.g. acceleration, maximal velocity, sprint-specific endurance) and technique testing. Measuring velocity precisely requires photoelectric cells that are placed to exact distances from each other. Acceleration is often tested with a 30-meter sprint from block start. Maximal velocity is tracked usually over 20- or 30-meters from a flying start. Sprint-specific endurance is often tested with sprint distances of 80-, 100-, 150-, 200- and 300-meters. More information about sprint-specific endurance (i.e. anaerobic power and capacity) is acquired when blood lactate measures are included to the test protocol. In addition to video analysis and other imaging technology stride length and stride rate can be measured more easily by running on a paper surface.

Actual maximal sprint performance is often tested during the pre-competition phase via simulated races, thus acceleration, maximal velocity, technical proficiency, and other variables that contribute to the overall performance can be examined as a continuum. Simulated races also offer a better understanding of abilities for the sprinter as well as mental preparation for official competition. Furthermore, during the pre-competition phase exhibition- and other less important competitions can be used as a testing ground. During the competitive phase testing sessions are not needed since competitions themselves provide opportunities to evaluate the sprinters performance. In addition, anthropometric measures (e.g. body mass, body fat, lean body mass, weight to height -ratio) are beneficial to be assessed early before official competition phase, to have time to make transformations if needed.

At the end of each annual training season the training logs, test and competition results, and other monitoring strategies should be evaluated to determine what was effective in the previous training plan. The primary indicators of the effectiveness of the training plan are the competitive results. If the sprinter has achieved success in competition and development with respect to personal performance standards the training plan can be validated. Once the evaluation of the previous training plan and the sprinter's performance with regards to the set goals is completed (usually during the transition phase) modifications can be made to the following annual training plan. Re-evaluation must recur every year and all the data that is collected must be interpreted, in order to enhance the likelihood of development and high level of performance.

5 SPRINT TRAINING METHODS

The sprint training method recommendations presented (TABLE 9) below is retelling what Haugen et al. (2019b) recommended in their article. The running intensities of each method are expressed in percent of maximal velocity/personal best of the distance. Note, in resisted sprinting the velocity decline is caused by the resistance loading whilst the perceived effort is maximal. Recovery refers to the interval between sets (i.e. repetitions) and time to next high-intensive session (HIS) refers to interval between two sessions. The sections marked with * exclude flying start distance. All methods presented in table 9 are discussed with more detail in the following chapters. In addition, technical training of sprint running will be discussed.

TABLE 9. Sprint training method recommendations according to Haugen et al. (2019b).

Training method	**Distance (m)**	**Intensity (%)**	**Recovery (min)**	**Total session volume (m)**	**Initiation**	**Time to next HIS (hours)**	**Preferred footwear and surface**
Acceleration	10–50	>98	2–7	100–300	Block/3-point/crouched	48	Spikes on track
Maximal velocity	10–30*	>98	4–15	50–150*	20–40 m flying start	48–72	Spikes on track
Sprint-specific endurance	80–150	>95	8–30	300–900	Standing start	48–72	Spikes on track
Speed endurance	60–80	90–95	2–4 (8–15)	600–2000	Standing start	48–72	Spikes on track
Resisted sprints	10–30	80–95	3–6	50–200	3-point/crouched	48	Optional
Assisted sprints	10–30*	>100	5–15	≤100*	20–40 m flying start	48	Spikes on track
Tempo	100–300	60–70	1–3	1000–2000	Standing start	24	Sneakers on soft surface

The adaptations of training are specific to the stimulus applied. Stimulus can be altered through different movement patterns, speed of movement, range of motion, training load, targeted energy systems and force-velocity characteristics such as muscle action and targeted muscle groups (Haugen et al 2019b). For the 100-meter sprint, sprint running and other high-velocity movements are most vital for performance development (Kraemer et al. 2002). Furthermore, the main stimulus is the combined distance of sprint running at high intensities (Francis 2019).

Methods in sprint training are often classified either according to primary energy system in use or phase of interest. Sprint duration over 6–7 seconds is considered lactic, whereas shorter sprint performance is considered alactic. The sprint specific phases are acceleration (including block-start), maximal velocity and deceleration phase (i.e. sprint-specific endurance). All sprint phases can be varied via intensity as they can be performed either as maximal, submaximal, and supramaximal (e.g. resisted and assisted). In addition, training load in sprint running can be altered by duration, intensity, resting periods, session rate, running surface and footwear. Furthermore, underlying strength and conditioning components such as speed endurance, plyometrics, and strength and power training are essential for development in sprint running. In the following paragraphs training practice guidelines are presented mainly according to the phase of interest. Total volume within the training sessions can be regulated by both the intensity (e.g. performance drop-off) and visual inspection of the running technique (e.g. technical disorientation).

5.1 Acceleration

Acceleration is the primary focus between distances of 10 to 50 meters. The accelerative sprint can be initiated either from a light movement, crouched (i.e. standing up), a three-point start position or from blocks, in which case also block technique is trained. The block start is considered most energetically costly of the starts. The optimal distance in acceleration training varies between the performance levels of sprinters. Shorter distances are used among less trained (i.e. younger) and lower performing sprinters, since they reach their maximum velocity sooner, compared to better performing counterparts. In acceleration training full recoveries are required between each sprint in order to repeat powerful accelerations and sustain technical proficiency. Better performing sprinters usually require longer recoveries as they reach higher absolute intensities (United Kingdom Athletics 2019). Consequently, elite sprinters rather execute acceleration training within the upper region of the distance and recovery scale, whereas low performing and young athletes work at the lower region of the scale (TABLE 9).

5.2 Maximal velocity

The aim of maximal velocity training is to increase the absolute peak velocity of the running performance. Maximal velocity is often measured and developed by flying sprints, where the aim is solely to reach maximal velocity and maintain it for a brief period. Therefore, the aim of maximal velocity training is not to reach it in minimum time nor to maintain the velocity under fatigue. The maximal velocity can usually be maintained for 10 to 30 meters, depending on the performance level and training status of the sprinter (Mero 2016). The run-up distance to reach the maximal velocity normally ranges from 20 to 60 meters, again depending on the performance level as for better performing sprinters the acceleration usually takes longer (Jouste & Mero 2016). Therefore, in training the flying sprints are often performed from a rolling start to achieve higher maximum velocity or to reach same velocity, as after maximal acceleration, but with more efficient energy expenditure. Elite sprinters may use 40-meter build-up for 20 to 30-meter flying sprints with approximately 15-minute recovery intervals, whereas lower performing counterparts may use 20-meter build-up for 10–20 meters flying sprints with 4-minute recoveries (Haugen et al. 2019b).

5.3 Sprint-specific endurance

The aim of sprint-specific endurance training is to increase the distance over which maximal and near maximal running velocities can be maintained. For 100-meter sprinters this can be pursued by sprints lasting 7–15 seconds at 95–100 % intensity, followed by full recoveries. Elite sprinters may perform 4–6 times a 150-meter sprint with 20 to 30-minute recoveries, whereas 2–3 times 100-meter sprint may be enough to obtain sprint specific endurance stimuli for lower performing sprinter. Recovery periods increase along with the increase in running performance standard. United Kingdom Athletics (2019) presented a model of 1 to 2-minute recovery for each second spent running at maximal velocity.

5.4 Speed Endurance

There is an apparent deficit in the use of immediate phosphocreatine stores after 6 seconds of maximal effort sprinting, therefore the performance after 6 seconds sprinting is considered to be speed endurance (Mero et al. 1987). Speed endurance is usually performed at sub-maximal intensities. The lowest effective intensity for stimulating adaptations is not established in the current research literature. High but sub-maximal intensity is required, since interaction of high intensity and large accumulated work stimulates speed endurance adaptations more efficiently compared to maximal efforts that include the onset of fatigue (Kraemer et al. 2002). Therefore, intensities of either 90–95 % or 96–100 % of maximal velocity are recommended. According to these intensities speed endurance in 100-meter sprint training can be divided into maximal alactic speed endurance and short-term maximal lactic speed endurance (Mero et al. 1987). While both the alactic and lactic speed endurance produce lactate, at intensities over 96 % they are considerably higher. Speed endurance is often trained alongside with sprint-specific endurance (i.e. deceleration phase of the sprint).

Maximal alactic speed endurance is like maximal velocity sprinting but is differentiated by shorter recovery intervals, thereby stimulating endurance. Maximal alactic speed endurance can be trained by series of 60 to 80-meter sprints at 90–95 % intensity, followed by short recoveries of 2–4 minutes. Short-term maximal lactic speed endurance can be trained by sprints lasting from 16 to 25 seconds at 96–100 % intensity, followed by recoveries of 10–20 minutes. Blood lactate varies approximately between 11–19 mmol/l during short-term lactic speed endurance exercise, whereas in alactic speed endurance exercise blood lactate often remains under 10 mmol/l, respectively (note: individual variance).

5.5 Resisted- and assisted sprinting

Resisted- and assisted sprinting are used to modify sprint training to be more suitable for different portions of sprint performance. Resisted sprinting is used to stimulate acceleration performance by an overload. Overload can be attained by uphill sprinting, sled sprints, or by using motorized devices. Cross et al. (2018) suggested that resisted sprinting could be more effective for horizontal force and power production during sprinting compared to traditional (i.e. more vertical) strength and power training that is performed in weight rooms. A better transition to sprinting from resisted sprinting might be because of more similar motor pattern and contraction type to sprint performance movement. Loading in resisted sprinting is usually measured in relation to the decrement in running velocity: light (<10 % velocity decrement), moderate (10–15 %), heavy (15–30 %) and very heavy (>30 %) load (Petrakos et al. 2016). Further, Cross et al. (2018) claimed that the optimal loading for maximized power output in resisted sprinting is a load that induces a velocity decrement of approximately 50 %. However, possible constrains such as alternation in running technique need to be considered when choosing the optimal load. Therefore, United Kingdom Athletics (2019) states that only light loading in resisted training should be used to maintain correct running mechanics.

Assisted sprinting is used to obtain maximal velocity improvements. Supramaximal (e.g. assisted) sprinting is expected to result in higher stride rate, shorter ground contact times and higher hip angle velocities (Haugen et al. 2019b). Assisted sprinting can be attained by downhill running, tailwind running, being pulled by an elastic cord or motorized devices. However, possible disadvantages of assisted sprinting might be excessive increase of stride length, an increased foot touchdown distance relative to TBCG and increased injury risk (particularly when performed with devices). These matters need to be considered when choosing optimal supramaximal velocity (e.g. towing force) to avoid undesired changes in sprint mechanics. The study by Mero & Komi (1985) indicated that the primary objective, that is the increase of stride rate, can be achieved via assisted sprinting. The measures indicated increases in both stride rate (1.7 %) and stride length (6.8 %) when the increase in velocity was 8.5 %. Elite male sprinters were able to increase their stride rate with no alternations in stride length. Therefore, the data suggest that assisted sprinting can provide additional stimulus for the neuromuscular system that can engender beneficial adaptations when preparing for competition. However, Haugen et al. (2019b) stated that, whether resisted and assisted sprinting provides beneficial effect to overall sprint performance remains uncertain, since what is beneficial for some portion of the sprint might not be beneficial for overall performance. Nevertheless, assisted sprinting has been used by many leading elite sprinters. It is normally used only during competitive seasons after a gradual approach to maximal velocity is gained during the preparatory and per-competition phase. Total session volume is recommended to be no more than about 100 meters performed with 2 to 3 sprints (Mero 2020; Haugen et al. 2019b).

5.6 Technical training

Technical training in sprinting is needed throughout the athletes' career, yet the fundamental technique and movement skills need to be acquired in the childhood as learned running movements become more challenging to modify in adult age (Haugen et al. 2019b). Few sprint-related studies have focused on how optimal mechanics of sprint technique can be achieved. These matters are emphasized more in literature considering motor learning. Improving sprinter's technique can be considered a career-long pursuit during which the sprinter should not progress to more specific aspects before the underlying principles have been mastered (Schmidt & Wrisberg 2008). Running always involves some aspects of sprint technique training, however, to optimally practice technique the training must be executed separate from other sprint training. This can be attained by different sprint drills emphasizing technical work, proprioception, and specific isolated parts of the sprint movement. The drills may include hurdles, coordination, walking, running high knees, skips, straight leg bounding with variable focus on posture, high hips, landing on the ball of the feet and other configuration at touchdown and lift-off etc. (Haugen et al. 2019b). The drills must resemble the desired biomechanics of an actual competition performance, consequently the drills try to mimic key technical elements to ensure crossover to the original sprinting technique (Banta 2017). In addition, the drills must be selected according to specific qualities, limiting factors and objectives of the individual.

It is considered more advantageous to perform the drills at low-speed exercises and in a recovered state (e.g. as part of warm-up routines) for a better movement control. Therefore, running velocities of 70–95 % are considered suitable for improving technique as the sprinter is permitted with time to control and adjust movement during motion (Mero Jr 2020). Consequently, better technique will allow the sprinter to enhanced performance through biomechanically more economical running. Furthermore, Porter et al. (2010) explained how advanced guidance by the coach is essential in technique training, as accurate visual perception of technique followed by good verbal (e.g. allegorical / metaphorical) instructions and feedback by the coach, allow the sprinter to interpreted correct motor pattern changes. Verbal guidance should rather focus to external (i.e. on the desired movement effect) than to internal focus of attention (i.e. on body movements), for example, allegory “trim the grass with your toes” can be used to reduce the flight time during the first post block steps of the acceleration phase.

6 RESISTANCE TRAINING

The maximal strength, power, and endurance strength training method recommendations presented (TABLE 10) below are according to Häkkinen (1990) values of load to repetition relationship. The load of each method is expressed as percentage of one repetition maximum of the exercise in use. More specific load to repetition relationship values are presented in table 11. Note, the load to repetition relationship vary inter-individually. Recovery interval between sets usually vary between 2–5 minutes in high intensity exercises, between 3–5 minutes in power training and from 30 to 60 seconds in hypertrophic training (Häkkinen & Ahtiainen 2016). In circuit training the work rest interval ratios can be chosen according to the energy system that is desired to be stimulated: 1:3 (work : recovery) -ratio (e.g. 10 s:30 s) is directed to immediate energy stores, 1:2 ratio (e.g. 30 s:60 s) to glycolytic energy production and 1:1 (e.g. 90 s:90 s) to aerobic energy production.

TABLE 10. Recommendations for maximal strength, power, and endurance strength training.

Method	**Load (%/1RM)**	**Repetitions/set**	**Preferred implementation**
Maximal strength			
Neural	90–100	1–3	Weight room
Hypertrophic & neural	70–90	3–6	Weight room
Hypertrophic	60–80	6–12	Weight room
Power			
Neural	30–60	1–10	Weight room, plyometrics with added weight
Hypertrophic & neural	30–80	1–10	Weight room, plyometrics with added weight
Endurance strength			
Anaerobic	20–60	10–30	Weight room, circuit training
Aerobic	0–30	>30	Circuit training

The time to next high-intensive session after the methods presented above vary distinctly depending on the intensity and total volume. Zatsiorsky (1995) stated that extremely heavy resistance session may require more than 72 hours of recovery before next HIS, while recovery of 24–72 hours is adequate after mediocre to heavy resistance training. Light resistance training can be performed on consecutive days. Strength and power training, and plyometric training methods are discussed with more detail in the following chapters.

6.1 Strength and Power Training

Strength and power training are a well-recognized part of sprint training that has a distinct consequence to sprint performance. The up-to-date research literature provides training recommendations broadly for hypertrophy, maximal strength and power that are outlined for novice, intermediate and advanced sprinters. Some of the basic principles of strength and power training for sprint running is discussed in this subheading. Despite the essential role of strength training for sprinting it must be acknowledged that excessive strength training may also induce adverse effects to a sport with high relative strength requirements, due to disproportionate mass increasement. Higher mass causes a higher aerodynamic drag while sprinting, that together with a wider frontal area will result in increased energy cost. This explains the low body mass of elite sprinters (males 77 ± 7 and females 58 ± 5 kg) with high muscle mass and low fat mass (Uth 2005).

The fundamental relationship between strength and power is recognized, however the knowledge of interrelationship between power, strength, and the rate of force development (RFD) are incomplete (Bompa & Buzzichelli 2018). Therefore, periods of strength training do not necessarily occur as immediate improvements in sprint performance, rather the gained force development need to be transitioned to powerful movements and into horizontal orientation. The probability of a successful transition from vertically orientated strength training to higher horizontal force production is increased when strength and sprint training are combined (Jouste 2020; Haugen et al. 2019b). Strength and power training is commonly performed in weight rooms by using free weights, different machines, elastic bands, medicine balls and variety of other equipment. Popular exercises in weight rooms usually include vertically orientated multijoint-movements performed with free weights (e.g. squat, snatch, clean and jerk). More horizontally orientated and sprint specific exercises may include split squats, single-leg deadlifts, lunges, resisted sprints, step-ups, and one-legged squats.

Strength and power training are often structured into periods of 4–6 consecutive microcycles that follow a progression from hypertrophy to maximal strength and finally to sprint specific strength, plyometrics, power, and explosive strength (Francis 2019). Strength and power training are typically performed 2–3 times within a microcycle of preparatory periods. For a consistent interrelationship of strength training and sprint specific movement to evolve, heavy strength training periods in the preparatory phase are often combined with high volume of submaximal sprint training, while later as the competition phase approaches the emphasis proceeds to maximal velocity sprinting, explosive strength and ballistic exercises (Francis 2019). The exercise sequencing differs among practitioners, but commonly sprint specific exercises (i.e. running) are performed prior to weight room exercises to avoid sore muscles and to lower the risk of injury while sprinting (Haugen et al. 2019b). However, a vice versa sequencing would allow more logical transition of strength (vertical) from the weight room into horizontal power on the track. Therefore, some (usually 3–5) sub-maximal sprints may be performed immediately after a weight room exercise to improve the transition effect (Jouste 2020). A single strength and power exercise can be modified through training variables such as volume, intensity, adaptation target (e.g. neural, muscle fiber, elastic components, regulation systems) muscle contraction type, RFD, joint angles, sets, repetitions, load, duration, and rest intervals. The fundamental training variables include the number of sets, repetitions, and the duration of rest intervals.

The practice in the use of the number of sets varies according to the training phase, targeted adaptation, and the practitioner, yet commonly minimum of three sets are required to induce notable strength development among sprinters of all level. The higher the ability to tolerate well performed sets, the greater the stimulus and the greater the strength gain (i.e. adaptation). Usually highly trained sprinters can tolerate, recover, and adapt from a higher number of sets. Therefore, coaches must consider the optimal amount of sets according to the training status of the individual. Bompa & Buzzichelli (2018) claimed that relatively less trained sprinters receive the most benefit from sets between 3 and 4, whereas more trained sprinters will gain the most adaptations from 4 up to 8 sets. Often during traditional set configurations there is a decrease in RFD, power, and quality of technique with each repetition and subsequently between sets. Therefore, the coach must observe how well the sets are performed and accommodate the tolerance of the sprinter through components such as load and rest intervals. Consequently, the traditional format of a set should be modified to change the training stimulus according to needs.

Similarly, the number of repetitions must be set according to the targeted adaptation, type of exercise and the training period. The load works as the determinant function on the maximum number of repetitions that can be performed, thus with high loading less repetitions can be performed. Loading is usually presented as a percentage of one repetition maximum (%/1RM). Table 11 presents averages of the load to repetition relationship that can be used as directional tool for loading in strength and power training. Definitive connections of the load to repetition relationship are complicated to assess, since variable such as training status, muscle mass engaged, gender and type of exercise may all affect the number of repetitions that can be performed at a given load (Bompa & Buzzichelli 2018). In common practice directional repetition schemes are set to reach specific physiological adaptations. For the development of maximal strength low-repetition schemes (1–6 repetitions) are used, whereas higher number of repetitions (>10 repetitions) are used for stimulating muscular endurance (Bompa & Buzzichelli 2018). Power training is also performed at low-repetition schemes (1–3 repetitions), however with lower loading and maximal RFD (Ahtiainen 2020). To choose an optimal repetition scheme and loading, the coach needs to acknowledge the phase of training and to consider the sprinters training status, gender, the muscle mass involved and the type of exercise when determining how many repetitions should be performed at certain percentage of 1RM. To facilitate specific adaptations and for optimal results a progressive overload appears together with manipulation of the repetition scheme.

Adequate rest intervals in strength and power training set between 2–5 minutes as by then force production capacity returns nearly to its starting level. Muscle ATP stores recover fully within 3–5 minutes (70 % recovered after 30 seconds) and phosphocreatine stores recover fully within 8 minutes (84 % recovered after 2 minutes; Bompa & Buzzichelli 2018). Similarly, Nummela (2016) reported that at rest 50 % of phosphocreatine stores is recover after 30 seconds and 85 % after two minutes, from the starting level.

TABLE 11. Maximum number of repetitions, intensity as percentage of 1RM and its standard deviation (Poliquin 1990).

Number of repetitions	**Percentage of 1RM**	**Standard deviation**
1	100	0
2	94.3	±1 %
3	90.6	±2 %
4	88.1	±3 %
5	85.6	±4 %
6	83.1	±5 %
7	80.7	±6 %
8	78.6	±7 %
9	76.5	±8 %
10	74.4	±10 %
11	72.3	-
12	70.3	-
13	68.8	-
14	67.5	-
15	66.2	-
16	65.0	-
17	63.8	-
18	62.7	-
19	61.6	-
20	60.6	-

6.2 Plyometric Training

Plyometrics are a form of exercises that include rapid stretch-shortening cycles (SSC). A stretch-shortening cycle is a combination of eccentric and concentric muscle actions where eccentric phase occurs prior to the concentric muscle action. Plyometric training develops performance on the final phase of the cycle (i.e. concentric muscle action) due to enhancement resulting in the storage of elastic energy (during the eccentric phase) and activation of the stretch reflex (Komi 1984). The underlying mechanisms for this are hypothesized to include adaptations in neural drive, rate of neural activation and intermuscular control that will result as improved rate of force development (RFD). However, Haugen et al. (2019b) questioned the reutilization of stored energy as a strategy to enhance sprint performance since storage and release of elastic energy requires time. As tendons and other elastic components of the muscle-joint complex can stretch relatively well under load, the sprinters should avoid an excessive elasticity of the muscle-joint complex, to minimize the downsides of elastic connectors (e.g. longer SSC time). In line with this argument is the discovery of elite sprinters having considerably higher leg stiffness than their lower performing counterparts (Haugen et al. 2019b).

Plyometric training can be performed with little or no external resistance by both unilateral and bilateral bounding, hopping, skipping, jumping, and medicine ball throw variations. Plyometric exercises may also include dropping/jumping from different levels and use of hurdles or other obstacles. Furthermore, in sprint training the more specific the plyometric exercise is to stretch rate and load characteristics of the sprint movement, the greater the transition effect from training to performance. Therefore, sprinters are encouraged to apply variety of high-intensity plyometric exercises that occur in the horizontal plane. In addition, the ground contact time of plyometric exercises should be like those obtained at maximal velocity running (i.e. <100 ms). Consequently, the crucial characteristics of adequate plyometric exercise for a sprinter include focus on leg stiffness (i.e. short ground contact time) and performing them in horizontal plane. Some practitioners may only use pure or modified running as plyometric training. For example, Vittori (2019) presented that assisted sprinting while equipped with a weight vests were used to stimulate higher impacts forces (i.e. plyometrics). Although this method offers a strong leg stiffness stimulation, it is also very demanding and may increase injury risk, particularly for the Achilles tendon (Haugen et al. 2019b). Therefore, the more traditional plyometric drills are recommended.

Plyometric training usually appears in high volumes during the preparatory phase and with high intensity as the competitive phase approaches. Plyometric training can be considered as part of strength and power training, in which case the emphasis of strength and power training is first put on hypertrophy, then maximal strength and finally to explosive strength and power (i.e. plyometric training). The goal of this sequencing is to transition maximum strength from the weight room exercises into functional power on the track, and to ensure that the power is exerted in horizontal plane. As mentioned before, often the heavy phases of strength training are combined with sprint training at submaximal intensity, that also acts as a plyometric stimulus. Mutually, it is suggested that strength improves as a result of improved ability to activate stretch-shortening cycles (Rumpf et al. 2016).

7 WORLD ELITE

The absolute performance level (i.e. record times) and other markers of world and European elite sprinters are presented in the following tables. A weight to height -ratio of each sprinter is presented to compare the relative mass that must be moved during the 100-meter sprint. Since body mass index (BMI) emphasize height (kg/m^2) the weight to height -ratio is used. Furthermore, as sprinters body fat percentage is known to be low during main competitions, to enhance relative force production, consequences of weight to height -ratio can be evaluated, presupposing that strength levels remain the same. Note, weight may have been measured at different year than the personal best result has been recorded, therefore the weight to height -ratio is only directional.

TABLE 12. All-time top ten 100-meter male sprinters in the world and their height, weight, weight to height -ratio, age at the time of record and nationality.

Time (s)	**Wind (m/s)**	**Sprinter**	**Height (m)**	**Weight (kg)**	**Weight to height -ratio (kg/m)**	**Age at the time**	**Nationality**
9.58	+0.9	Usain Bolt	1.96	86	43.9	22	🇯🇲JAM
9.69	+2.0	Tyson Gay	1.80	75	41.7	27	🇺🇸USA
9.69	-0.1	Yohan Blake	1.80	80	44.4	22	🇯🇲JAM
9.72	+0.2	Asafa Powell	1.90	88	46.3	25	🇯🇲JAM
9.74	+0.9	Justin Gatlin	1.85	79	42.7	33	🇺🇸USA
9.76	+0.6	Christian Coleman	1.75	72	41.1	23	🇺🇸USA
9.78	+0.9	Nesta Carter	1.73	78	45.1	24	🇯🇲JAM
9.79	+0.1	Maurice Greene	1.76	82	46.6	24	🇺🇸USA
9.80	+1.3	Steve Mullings	1.76	67	38.1	28	🇯🇲JAM
9.82	+1.7	Richard Thompson	1.88	79	42.0	29	🇹🇹TTO

TABLE 13. All-time top five 100-meter female sprinters in the world and their height, weight, weight to height -ratio, age at the time of record and nationality.

Time (s)	**Wind (m/s)**	**Sprinter**	**Height (m)**	**Weight (kg)**	**Weight to height -ratio (kg/m)**	**Age at the time**	**Nationality**
10.49	0.0	Florence Griffith-Joyner	1.70	58	34.1	31	USA
10.64	+1.2	Carmelita Jeter	1.63	59	36.2	29	USA
10.65	+1.1	Marion Jones	1.78	68	38.2	22	USA
10.70	+0.6	Shelly-Ann Fracer-Pryce	1.52	52	34.2	25	JAM
10.70	+0.3	Elaine Thompson	1.67	57	34.1	24	JAM

World all-time leaderboards in both the male and female 100-meter records are dominated by sprinters from Jamaica and the United States of America. There is no distinct characteristic to the height of the sprinter neither in male nor female sprinters as sprinters of different height seem to succeed evenly. There is a 23 cm range in height among male sprinters, 173 cm being the shortest and 196 cm being the tallest. In the weight to height -ratio there is a difference of 8.5 kg/m between athletes of highest and lowest mass relative to height. The average weight to height -ratio is 43.2 kg/m among top ten male sprinters in the world. The average age to record personal best is 25.7 years among males. There is a similar range of 25 cm in height of female sprinters 152 cm being the shortest and 177 cm being the tallest. Among females there is a range of 4.1 kg/m in the weight to height -ratio, the average weight to height -ratio being 35.4 kg/m. The average age to record personal best is 26.2 years among females

TABLE 14. All-time top ten 100-meter male sprinters in Europe and their height, weight, weight to height -ratio, age at the time of record and nationality.

Time (s)	**Wind (m/s)**	**Sprinter**	**Height (m)**	**Weight (kg)**	**Weight to height -ratio (kg/m)**	**Age at the time**	**Nationality**
9.86	+0.6	Francis Obikwelu	1.95	80	41.0	25	POR
9.86	+1.3	Jimmy Vicaut	1.84	88	47.8	23	FRA
9.87	+0.3	Linford Christie	1.88	84	44.7	33	GBR
9.91	+0.7	Churandy Martina	1.78	74	41.6	28	NED
9.91	+1.1	James Dasaolu	1.86	87	46.8	25	GBR
9.91	+0.4	Zharnel Hughes	1.92	83	43.2	22	GBR
9.92	+2.0	Christophe Lemaitre	1.90	74	38.9	21	FRA
9.92	+0.9	Jak Ali Harvey	1.83	74	40.4	27	TUR
9.94	-0.5	Reece Prescod	1.93	68	35.2	22	GBR
9.96	+1.4	Chijindu Ujah	1.82	81	44.5	20	GBR

TABLE 15. All-time top five 100-meter female sprinters in Europe and their height, weight, weight to height -ratio, age at the time of record and nationality.

Time (s)	Wind (m/s)	Sprinter	Height (m)	Weight (kg)	Weight to height -ratio (kg/m)	Age at the time	Nationality
10.73	+2.0	Christine Arron	1.77	64	36.2	24	FRA
10.77	+0.9	Irina Privalova	1.74	54	31.0	25	RUS
10.77	+0.7	Ivet Lalova-Collio	1.68	55	32.7	20	BUL
10.81	+1.7	Marlies Göhr	1.65	55	33.3	25	GDR
10.81	-0.3	Dafne Schippers	1.79	68	38.0	23	NED

The European all-time leaderboards have more variety in the nationalities of both the male and female 100-meter record holders. Similarly to the world elite sprinters there is no distinct characteristic to the height of European male and female sprinters. There is a smaller (13 cm) range in height of European male sprinters, 182 cm being the shortest and 195 cm being the tallest. The average weight to height -ratio is slightly lighter (42.4 kg/m) among top ten male sprinters in Europe compared to the world elite. The average age to record personal best is approximately a year sooner (24.6 years) among males. Among females the height range (12 cm) of sprinters is smaller compered to world elite, similarly to men. The average weight to height -ratio among European female sprinters is being 34.2 kg/m and the average age to record personal best is 23.4 years. The European record holder earns the sixth place on the World record listing.

TABLE 16. The Finnish male and female 100-meter national record holders and their height, weight, weight to height -ratio and age at the time of record.

Time (s)	Wind (m/s)	Sprinter (gender)	Height (m)	Weight (kg)	Weight to height -ratio (kg/m)	Age at the time	Nationality
10.21	+0.5	Tommi Hartonen (male)	1.89	85	45.0	24	FIN
11.13	+1.0	Helinä Marjamaa (female)	1.68	58	34.5	27	FIN

Currently (30.7.2020) the Finnish national record holder in men’s 100-meter sprint earns shared position of 881st on the all-time 100-meter male sprinters in the world. Finnish women’s national record is ranked 271st (shared) on the all-time list. The Finnish national men’s record was recorded 2001 and women’s record as long as 1983.

8 DISCUSSION AND CONCLUSION

It is beneficial for coaches and other practitioners to familiarize themselves with the fundamental features of the 100-meter sprint presented in this paper. The biomechanical characteristics of all four phases of the event, functions of the neuromuscular system, and the underlying physiological mechanisms should be understood. After this, in order to implement adequate training, the practitioner should comprehend and exploit different programming fashions that are proven efficient, while also identifying the inter-individual differences and needs of each individual sprinter. A conclusion of these matters is presented below while also discussing some challenges in the Finnish coaching system.

Technique and biomechanics. A well-formed and individualized block start position from which sprinter can output highest force with best reaction time that commence the acceleration should be established and may be measured by block start tests. Block spacing and block obliquity may be assessed first, followed by knee- and hip angle and body alignment assessments. It is beneficial for a coach to be able to offer guiding for variety of different block start customs, for example as presented in chapter 2.1.1 (e.g. bunched-, medium- and elongated start positions). Block obliquity issue must be determined with the start block in use, but a coach should be able to reason why to select a particular obliquity. Optimal start position has been presented in picture 1. After all, block start is performed according as the sprinter's preference. In the beginning of acceleration a coach needs to be able to asses several things: is the angle of force production directed horizontally enough, does the first stride (i.e. stride length) occur at the optimal range, in which way do the post-block steps occur in relation to the total body center of gravity, and if all the variables contribute to a best possible block start and acceleration. A slow-motion video may benefit with the feedback from the coach to the athlete. Furthermore, **in the maximum running phase, a coach needs to assess, if the following biomechanical characteristics appear:**

1) an upright vertical alignment of upper body
2) active press down (i.e. striking/whipping movement) of the foot prior to ground contact
3) optimal initial ground contact point (i.e. short braking phase)

4) adequately big knee and hip joint angle in the beginning of the ground contact
5) short ground contact time, especially short braking time
6) stiff ankle throughout the ground contact
7) vertically directed force in the braking phase and horizontally directed force in the propulsion phase
8) after propulsion, the circular motion of the foot occurs more in front of body (i.e. heel is brought under the pelvis after toe-off)
9) fast maximum flexion of thigh (i.e. knee lift) in the flight phase
10) optimal stride length and stride rate

Physiology. The coach cannot influence how much fast type motor units and muscle fibers the sprinter has inherited. However, neuromuscular system and energy production can be trained. Emphasis in sprint specific training should be to stimulate ATP production via phosphocreatine and anaerobic glycolysis especially in fast type motor units and muscle fibers.

Programming of coaching. Both the biomechanics and physiology of 100-meter sprint performance should be understood when beginning to plan training for a sprinter. An individualized annual plan where training is periodized into smaller phases with specific objectives should be made. The training should include variety of sprint and resistance training methods. The training must be programmed with the volume and intensity as well as variation. Advanced long-term performance development is achieved, when the systematic training is executed with proper nutrition and exploit of different recovery strategies. In addition, prior to competitions a taper/unloading phase should be prepared.

Sprint coaching system. In Finland sprint running has retained its popularity, while the number of competing track and field athletes has decreased. While genetic features are often perceived as the definitive premise that differentiate Finnish sprinters from the world elite, the claim fails to take into account the considerable gap between top Finnish and top European sprinters. It cannot be explained only with genetics. Therefore, part of the difference may be partly explained with the challenges in Finnish sprint coaching system. As the population of Finland (approx. 5.5 million) is small the number of genetically gifted sprinters remain proportionally smaller compared to countries of high population. Discovering these sprinter prospects requires better organized scouting. Yet, over the past decade young Finnish sprinters have succeeded well throughout their junior years with respect to other Europeans. However, these prospects seem to disappear as they approach adult age, for an unknown reason. One explanation may be the issue of associating experienced and well-educated coaches with genetically gifted and talented sprinters early on in their career. Consequently, this may affect the level of competing within training groups and within national competitions, while on the other hand, sprinters may partly benefit from small training groups, as they can receive more individualized coaching. Furthermore, small and far apart distributed training groups bring forth the question of insufficient number of educated and experienced coaches. Since there are only some sprint coaches in Finland who coach full-time, while the other competent coaches may struggle with their time management that is due to the minor financial compensation that they receive from coaching. The financial issues are likely part of the reason for both sprinters and coaches to adopt other career choices.

Challenges in the future. Approaching adulthood bring out additional challenges when amateur, high school, college and university level sprinters aim to be semi-professional or professional sprinters and to succeed internationally. As athletic clubs and individual coaching organize majority of the training, top youth sprinters may not have enough opportunities to train among peers and the national elite. Hence, regional training camps that include multiple Finnish national team sprinters has been experimented in Finland. In addition to the regional training camps, sprint training and coaching is now concentrated to selected cities, to allow top sprinters to train and compete jointly, to provide them with a support network (e.g. medical staff, physiotherapy, nutritionist) and to ensure sufficient training facilities. This is somewhat similar to what for example the Polish Athletics Association has demonstrated to be successful. Furthermore, many of the challenges that the Finnish coaching system encounters are avoided in the United States with sports scholarships and the university-based programs. In addition, other foreign countries (e.g. Spain) offer alternative opportunities for development in sprint running with a variety of coaching systems in warm and hot climate.

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