Universidade de Trás-os-Montes e Alto Douro

Monitoring training load in U20 track and field junior athletes

Master's Thesis

International M.Sc. in Performance Analysis of Sport (IMPAS)

Candidate: Alberto Franceschi

Supervisor: Professor Dr. Jaime Sampaio

Co-supervisor: Dr. Daniele Conte

Vila Real, 2018

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Acknowledgements

"*A continuous and challenging learning process tailored for highly-motivated sport science students ready to support the performance development of the next sport generations*".

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Abstract

The aim of this study was to investigate changes in training load, neuromuscular readiness, perceptual fatigue and competition performance in junior track and field athletes during an outdoor season. To fulfil this purpose, data from six athletes (age 17.5 ± 1.7 years; height 172.6 ± 9.9cm; body mass 62.1 ± 6.4kg) were collected from both training sessions and athletics competitions during a 16-week period, divided into a preparation (week 1 to 8) and a competitive period (week 9 to 16). Training load was computed through training diaries, the countermovement jump and the repeated jump test were executed on a weekly-basis, and perceptual fatigue measures were collected using a wellness questionnaire. At the end, a hierarchical cluster analysis was conducted to identify similarities and differences between the two periods. The results showed a substantial reduction in training load during the competitive phase. The countermovement jump and sleep quantity were associated with the best competition performance of the competitive season and indicated a positive development during the outdoor season. The others variables showed different patterns between athletes. This outcomes can be used as framework for implementing athlete monitoring system with young athletes involved in track and field sprint-power events.

Keywords: training load, athletics, monitoring, neuromuscular readiness, wellness

Abbreviations, acronyms and symbols

ADP: adenosine diphosphate

ATP: adenosine triphosphate

BRUMS: Brunel Mood Scale

CGS: centimetres, grams, or seconds

CMJ: countermovement jump

CR: category ratio

DALDA: Daily Analysis of Life Demands

DJ: drop jump

DOMS: delayed-onset muscle soreness

GAS: General Adaptation Syndrome

GPS: global positioning systems

GPT: general physical training

HRR: Heart rate recovery

HRV: heart rate variability

IAAF: International Association of Athletics Federations

LTAD: Long-Term Athlete Development

MBI: magnitude-based inference

mRSI: modified reactive strength index

NMF: neuromuscular fatigue

POMS: Profile of Mood States

RESTQ-Sport: Recovery Stress Questionnaire for Athletes

RJT: repeated jump test

RPE: rating of perceived exertion

RSI: reactive strength index

SFRA: Stimulus-Fatigue-Recovery-Adaptation

SJ: squat jump

s-RPE: session-rating of perceived exertion

SSPT: sport-specific physical training

TDS: Training Distress Scales

TRIMP: training impulse

VAS: visual analog scales

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1. Introduction

The limits of human performance are continually being pushed in keeping with the Olympic motto ‘stronger, higher, faster’. World-class athletes are the finest result of action and interaction of genes and environmental stimuli. Sport performance requires an athlete to integrate many factors, some trainable (psychology, physiology and skill), some teachable (tactics) and others outside the control of the athlete and coach (genetics and age) (Smith, 2003). Due to the highly complex and the non-linear path of athlete development, sports academies and talent identification programs drive the initial stages of the new sport generations aiming to achieve with some of them the international stage.

Despite the increasingly higher number of scientific resources, the debate about the ideal pathways for young talented athletes is divided between the idea of early specialization against the long-term athlete development framework. If in the past century coaches often adopted early specialization approaches, nowadays scientific evidences are showing that performance at young age is often not a good predictor for senior success and, consequently the development strategies are changing (Boccia et al., 2017; Kearney, Hayes, Kearney, & Hayes, 2018). In athletics, or track and field, tracking performance and physical development seems to be an effective way to deepen the concept behind the success at senior level (T. A. Haugen et al., 2018). Previous investigations suggested that in CGS sports (i.e. in sports measured in centimetres, grams, or seconds), long-term strategies appear to be a practical solution considering both performance outcome (Moesch, Elbe, Hauge, & Wikman, 2011) and athlete’s integrity from injury and illness (Huxley, O’Connor, & Healey, 2014). Training plan and periodization strategies in young athletes need to be tailored on the physiological needs using a multidisciplinary approach. The training process must provide an appropriate stimulus for adaptation, an effective means for assessing progress (i.e. athlete monitoring) and include rest-recovery strategies, psychological reinforcement, daily nutrition, supplements, sleep, so that recovery–adaptation is optimized (DeWeese, Hornsby, Stone, & Stone, 2015b). In this view, longitudinal studies investigating monitoring approaches in young athletes are warranted to assist coaches in designing appropriate training program (Murray, 2017).

Nowadays sport science support staff are investigating evidence-based approaches to both designing and monitoring appropriate and effective training programs with the ultimate aim to improve athlete's performance and favour the success at international stage starting from the development of young athletes (Halson, 2014). In the light of the previous concepts, the ultimate objective of this master's thesis is to describe the application of a set of monitoring tools within youth national track and field athletes and to adopt an evidence-based model as example of long-term athlete development approach.

1.1 Performance development in track and field athletes

Understanding performance development in young athletes represents a key point for creating a favourable environment for the growth of the next sport generations. Increasingly new models and approaches have been developed by sports academies and scientific communities, but a generalized consensus on the topic seems to be dependent by the sport-specific context (Bourdon et al., 2017). In this first chapter a review of the athletic development models and pathways for young athletes is presented with a specific emphasis on athletics scenario and on the influence of biological maturation on athlete performance.

Sport career can be defined as a set of stages, moments and transitions that lead to a comprehensive growth which involves physical, psychological, social and performance development. A global and complete model that aimed to characterize the sport career has been purposed earlier (Wylleman & Reints, 2010) identifying four levels of analysis describing the athletic, psycho-logical, psycho-social, and academic and volitional level. Despite this schema describes globally the figure of young as individual involved in a society with a network of relationship and environments, the Canadian model known as Long-Term Athlete Development (LTAD) also appears to be useful for explaining performance and physical development in young athletes. LTAD model is built on theoretical physiological principles and aims to promote physical activity as component of long term development for sport career. The final outcome is to favour a sport career characterized by diversified sport experiences on the first stages purposed and then to adopt a process of gradual specialization according to the state of biological maturation (Ford et al., 2011).

Those before-mentioned models born as alternative pathway to the "early specialization" approach in which the young athlete is practicing in a specific sport-event from an early stage (i.e. childhood) with high and systematic training volumes. Early specialization is grounded on the theory of Ericsson and colleagues (Ericsson, Krampe, & Tesch-Römer, 1993) who suggested a positive relationship between the number of hours of activity-specific training and the level of performance. Early specialization presumes to achieve high-level results starting from young age even before the pubertal phase.

The associated risks to early specialization approaches touch all aspects of adolescent athlete life. Previous studies have shown links between high training load and injury in adolescent population. In athletics, the probability to sustain an overload injury is greater when a subject is training with higher volumes during the age of 13-16 years-old as showed in Australian elite track and field athletes (Huxley et al., 2014). Moreover, under 16 cricket players had three times the risk of an injury when they had less than 3.5 days rest between bowling episodes (Dennis, Finch, & Farhart, 2005) and, as well a similar relationship was shown in youth soccer players (Brink et al., 2010). Overall in different sports settings, early specialization models that do not consider the maturational status level can lead to a reduction in biomotor qualities, a greater risk of injuries and consequently a decrease in performance level (Malina, 2010). Furthermore, the negative outcome of an injury in an adolescent athlete can sometimes be identified not only in the interruption of competitive activities, but also as the end of access to physical activity and sport participation. For this reason, young athletes should undertake athlete development program in which the risk of injury is minimized by management of training load.

Talent identification or school sport programs routinely select promising youth athletes in their full-time activities expecting to support the athlete development of the currently best athletes in their location. In CGS sports the selection is based on the current performance level (e.g. personal best, national title at young age) without fully considering the maturational status and the relative age effect (Andronikos, Elumaro, Westbury, & Martindale, 2016). Fortunately, in the last years, research has investigated the career performance trajectories of elite and non-elite athletes identifying some valuable insights for track and field sport. A study of Boccia and colleagues (Boccia et al., 2017) studied performance development in Italian long and high jumpers showing that only from 23 to 42% of top young athletes became top senior athletes in jumping events. Similarly, a research from UK athletes confirmed that less of 40% of senior top athletes were ranked in the top 20 list when they were under 13 and under 15 in all athletics events (Kearney et al., 2018). Moreover considering that peak performance of world-class athletes is achieved at 25-27 years-old in most of track and field events (T. A. Haugen et al., 2018), this evidences support that excelling at youth level in competitive track and field is not a prerequisite for later success and consequently at least in athletics, practitioners need to consider long-term development strategies for their athletes.

From a practical standpoint, research identified that most of young and senior athletes careers are not linear and present peak and plateau phases. Performance result is improved substantially over the adolescence especially during the period of 13-17 years old as showed in young athletes (Tonnessen, Svendsen, Olsen, Guttormsen, & Haugen, 2015), but the rate of performance development during the entire length of adolescence (from 13 to 19 years old) period seems to be a good predictor to achieve national elite level in athletics (Boccia et al., 2017). At the end, Gulbin and colleagues noticed that during the transfer from junior (i.e. under 20) to senior level more than 50% Australian track and field athletes showed a diminished transition in competition level (e.g. from international competition at junior stage to national competition at senior level) (Gulbin, Weissensteiner, & Oldenziel, 2013).

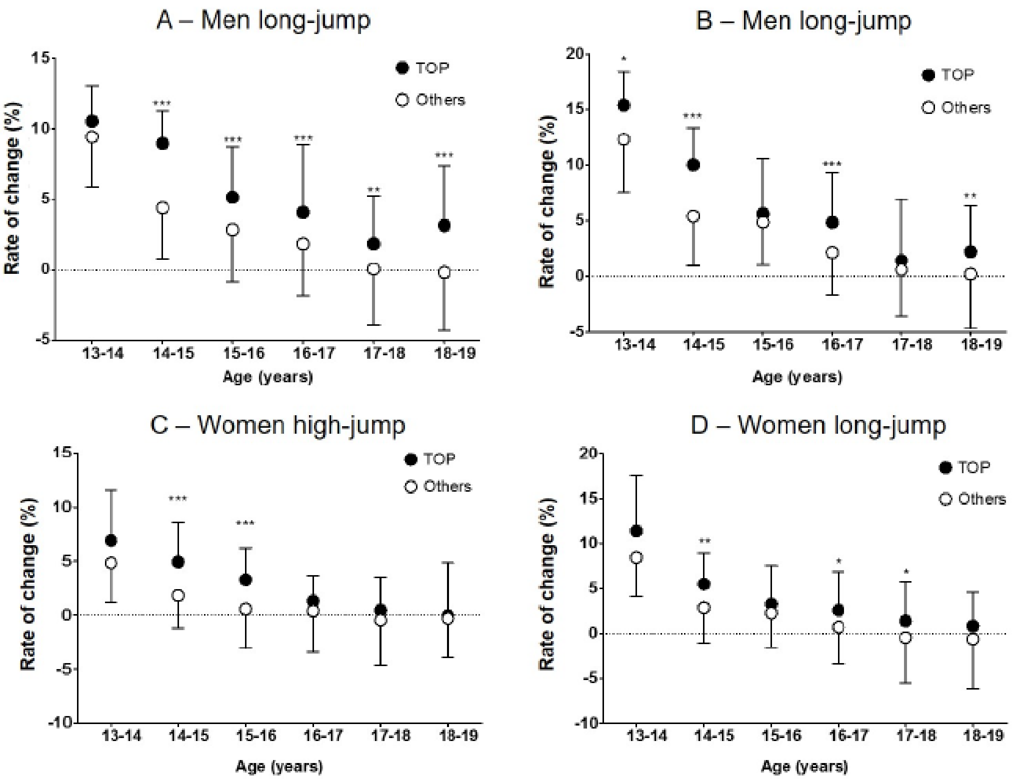

Figure 1.1. Differences in annual rate of change in performance between elite and non-elite in track and field. From *Tonnessen et al. (2015).*

What appears to influence the most performance development during adolescence is the impact of biological maturation during the puberty. Scientific research has outlined a couple of primary considerations for young sport participation and long term performance. Starting from the concept presented by Balyi and Way (Balyi & Way, 2005), each individual pass through a complex process of growth and maturation during the first two decades of life and only at the age of 20 the human body achieves the full maturation. The growth process is described by three different sub-processes: the general growth process which implies the body maturation considering weight and height measures; the neural growth process which describes the brain and nervous system growth indicating windows of opportunity for the development of balance, agility and coordination; and, the genital growth process which shows the formation of primary and secondary sexual characteristics indicating hormonal maturation and the consequences on physical and performance development.

The complexity of the growth suggests to carefully consider the biological maturational status of each individual. For instance, it is relevant for practitioners to understand if a certain performance result at 14 years-old has been achieved by an early-, mid- or late-maturation subject. As children reach the onset of puberty, they experience rapid growth along with observable non-linear gains in muscular strength and other biomotor qualities. Awareness of the potential variation in biological age among children of the same chronological age group is a central tenet of most long-term physical development programmes in order to ensure that youth are trained according to their biological status, as opposed to age-group classifications (Faigenbaum et al., 2009). In this view, peak height velocity (PHV) plays a primary role. It represents the period of time in which a child experiences their fastest upward growth in their stature (Lloyd & Oliver, 2012). Before, during and after PHV there appears to be certain periods in time in which young athletes are more sensitive to a particular types of training and those are referred as "windows of opportunity". It seems that biomotor qualities experiences periods of accelerated adaptation during PHV and constitute real opportunity of physical and performance development for young athletes. A longitudinal study in youth rugby players showed differences in early-, mid-, late-maturation subjects stressing the influence of PHV for athlete and performance development (Till, Cobley, O'Hara, Chapman, & Cooke, 2013). Moreover what seems to track the difference between performance and physical qualities pre and post PHV is represented by hormonal activity which differs between men and women. An interesting research by Tønnessen and colleagues (Tonnessen et al., 2015) investigated the performance development in youth track and field athletes considering the age, the sex and the sport disciplines. The difference between genders can be explained by the hormonal activity and the pattern of growth. Until 12 years-old girls and boys perform with similar results, but after 13 years-old the biological growth processes cause a significant variation in body composition and a consequence differentiation in favour of the male young athletes in performance outcome related to sprint and power events (e.g. 100m, long jump). Despite scientific resources have not presented yet solid practical application for each sport settings, several studies indicate the ideal pathway for long-term performance and especially primary elements needed to achieve elite level at the senior stage (Ford et al., 2011). Athletics scenario is variegated but generalized guidelines from youth sport participation and other similar sport context seems to be effective for supporting the next talented sport generations.

1.2 Periodization strategies and physiological adaptations to training

A solid understanding of the physiological effects of training stress is essential to optimize the training process. The dose-response relationship needs to be appreciated by practitioners in order to improve training sessions and consequently performance outcome. Several models explain the physiological effects of an acute training stimulus (e.g. fitness-fatigue model), but all of them recognize that excessive fatigue without adequate recovery can results in maladaptation, including decreased performance and overtraining syndrome (Sue L. Hooper & Mackinnon, 1995). In this chapter, periodization strategies and physiological principles are discussed together with the aim to underline the theoretical framework behind training prescription strategies and fatigue management.

Training periodization is intended to offer coaches basic guidelines for structuring and planning training. Periodization is also described by its progression from general to special tasks; as the program progresses and competition nears, the incorporation of sport-specific development is required. It is structured into cycles: macro-, meso- and micro-cycles defines the features of the training program and they generally refers to year, month and week periods, respectively (Plisk & Stone, 2003). However, cycles present variability in order to provide the optimal time frame for adaptation. As suggested by (Bompa & Haff, 2009), a preparatory and a competitive phase are identified and, in addition, the preparatory phase should be structured into general physical training (GPT) and sport-specific training (SSPT). Each phase has a specific goal: GPT aims to improve the athlete’s work capacity and maximize adaptations for further periods, while SSPT focuses on the development of a sport-specific physiological profile for the athlete. In order to avoid negative outcomes, training periodization represents an optimal strategy for the development of biomotor qualities (e.g. strength, speed) and the management of fatigue. This superior method has been studied in the last decades and has shown to contribute to achieve athlete’s peak performance. Despite the large amount of studies about periodization in sports, practitioners should be cognizant of the fact that the science and the practice of periodization is largely based on the hypothesis-generating studies, anecdotal evidence and related research (Turner, 2011). Considering all levels of sport participation, training periodization and the consequent physiological effects share some general commonalities, but the models and the prescriptions change according to the needs of the sport-specific context.

Preparation planning in individual performance-based sport differs drastically from the planning routines of team sports. In the recent decades, periodization paradigm has changed a lot in function of the sport setting. A review by Iussurin highlighted these mutations that has influenced the majority of sport realities (Issurin, 2010). The implementation of advanced sport technologies (e.g. athlete monitoring system) (Torres-Ronda & Schelling, 2017), the increased number of competitions and the financial motivations have made an huge impact on training methodologies for high-performance sports. For instance, team sports athletes need to sustain high-intensity matches for a period of at least 20 weeks, which in some cases can last until 35 weeks per year. In this light, periodization approach is built on playing season needs and the traditional main phases (i.e. preparation and competition phase) purposed by Bompa and colleagues (Bompa & Haff, 2009) are translated in “off-season”, “pre-season” and “in-season” period (Gamble, 2006). In professional teams, coaching and sport science support staff works generally using the competitive microcycles (e.g. 7 days). Microcycle is modified according to the frequency of weekly games when the schedules often require players to undertake two competitive fixtures within 7 days. During period of congestion fixtures advanced training methodologies and recovery strategies have been investigated in order to optimize the methodological approach. A recent paper confirmed the relationship between congested fixture and an increased muscle injury rate in football players playing the UEFA Champions League (Bengtsson, Ekstrand, & Hägglund, 2013) underlining the importance of training loads and modalities during the previous week.

On the contrary individual Olympic sports (i.e. track and field, swimming) have the necessity to achieve peak performance results over a limited time period. Using traditional approaches to periodization practitioners plan the macrocycle with the aim to perform in the best shape over the most important event of the year (e.g. World Championships, Olympic Games). According to Deweese and colleagues (DeWeese, Hornsby, Stone, & Stone, 2015a; DeWeese et al., 2015b), training periodization in athletics is organized into 5 major phases over the macrocycle as defined in the table 1.2: a general preparation phase, a special preparation phase, a competition phase, a peaking phase and an active rest or transition phase. Each phase denotes variations in volume, intensity, density together with the characteristics of basic training principles: overload, variations, specificity and reversibility. During these periods the manipulation of volume and intensity alongside the optimal management of fatigue makes an impact into the most relevant phase of the training plan (i.e. competition and peaking phase). Specifically, volume and intensity share an inverse relationship and during the period of preparation such as GP and SSPT the training volume is high, while intensity increase progressively until the end of special preparation period. During the competition and the peaking phases the volume drop drastically and the intensity remain almost stable favouring the implementation of sport-specific or technical training sessions (Turner, 2011).

At the end, the peaking phase is characterized by advanced training strategies also known as tapering. The taper describes a reduction in training volume load in the final days before important competition with the aim of optimizing performance (Bosquet, Montpetit, Arvisais, & Mujika, 2007). As highlighted by a meta-analysis on the topic, taper strategies has the main goal to dissipate levels of fatigue rather than advance the athlete level of preparedness. Wilson and Wilson (Wilson & Wilson, 2008) summarized the possible performance gains after a taper period indicating improvements in training (e.g. neuromuscular function) and extra-training (e.g. sleep quality) components. The benefits include strength and power levels (up to 20%), specific-competition performance gains (about 5%), decreased sleep disturbances and reduced internal load (Turner, 2011). Especially the training variables that seem to affect taper-induced performance adaptations are: a) reduction of training volume by 40-60% while maintaining both intensity and the frequency of sessions; b) a duration of the taper between 8 and 14 days; and, c) a progressive pattern (e.g. gradually decreasing the volume in a linear fashion) of taper (Bosquet et al., 2007).

Term	Timeframe
GP	Typically denotes a higher volume, low intensity, relatively low mechanical specificity phase with the intention of raising sport specific fitness, which includes altering body composition and raising work capacity.
Special preparation	A relatively high volume, low to moderate intensity, higher mechanical specificity oriented phase. A portion of this phase typically emphasizes the athletes' ability to repeat exercise with a greater mechanical specificity. This phase can be used to transition from higher volume, less-specific GP training to a higher-intensity, very specific training phase that closely associates with competition.
Competition phase	Commonly refers to a moderate to low volume phase with moderate to high intensity that is mechanically specific. The purpose is to maintain fitness while enhancing technical consistency/efficiency. The competition phase can last several months and may contain periods of mini-preparation, if volume reduction should last more than 12–16 weeks. These mini-preparation periods may include periods of functional overreaching which appear to enhance competition performance if timed correctly.
Peaking phase	A segment of the competition phase lasting a short time (usually ≤4 weeks), that takes place just before major competitions. During the early portion of peaking, volume can be reduced and training intensity (or exercise intensity, depending on the sport or performance goals) is increased or maintained at relatively high levels. Typically, during the last few days before important competitions, intensity factors are also reduced to encourage adequate recovery. The later portion of a peaking phase (typically 8–14 days), when volume is markedly reduced, is referred to as a "taper".[8,46,47] A taper consists of a reduction of training volume in order to reduce fatigue and take advantage of the fitness–fatigue paradigm.[8,25,46,47] A taper can be coupled with planned overreaching in order to boost performance beyond that of a typical taper.
AR	A period of recovery after peaking and major competitions (usually 1–2 weeks) using a reduce volume and intensity of training). Recovery includes healing and rehabilitation of any injuries that may have occurred as well as recovery from the emotional rigors of competition. Complete rest allows sports-specific fitness to deteriorate to a degree from which it is difficult to recover without extensive training. Compared to complete rest, AR allows for less deterioration of fitness and a faster return to peak fitness during the next cycle. AR usually lasts about 1 week. At times the training may be re-directed into another activity to improve the psychological/emotional recovery aspects (make the training more recreational).

Table 1.2. Definition of periodization phases in track and field. From *DeWeese et al. (2015a).*

The common point throughout all periodization strategies is the need to manipulate volume loads, progress from general to specific training, and dissipate fatigue. Although individual sports have usually adopted traditional approach to periodization, nowadays athletes are requested to compete over a longer period comparing to the past due to the introduction of new rules and the financial needs of competing in world-class circuit, meeting and championships. The International Association of Athletics Federations (IAAF) has recently introduced a ranking system in which athletes are listed according to their 5 best performances of the year. The entries into the next editions of World Championships and Olympic Games will be based on this ranking. If until now an athlete needed to achieve a minimum performance called 'standard' once in a year for securing a place in the international events, now the scenario will face new challenges for coaching staff. As a consequence even training strategies in terms of periodization and planning need to be adopted.

Likely during the competitive season, practitioners need to tailor the daily sessions to the competition schedule of the athlete and monitor fatigue to optimize the adaptations over a period characterized by high-intensity (e.g. maximal) efforts required by the competition setting. As previous research has shown (G G Haff et al., 2004), training adaptations take place during the recovery weeks or periods and the association between recovery and adaptation plays a primary role in the training plan success. For instance, using a 3:1 loading paradigm (i.e. 3 weeks of progressive load and 1 unloaded week) the 4th week is planned to avoid excessive fatigue and favour the training effects. When the training stressors exceed in volume and intensity, period of accumulated fatigue can lead to negative outcomes including non-functional overreaching and overtraining. In this view, three principles theories or models has been developed to fully understand the physiological effects of training stress (Stone et al., 1999):

- General Adaptation Syndrome (GAS): The GAS model is part of the work of Hans Selye. The basic concept of the model indicates that the body's physiological response to a certain stress goes through the following type of stimulus. In other words, all training stressors result in a similar response (Selye, 1956). This model is useful for explaining the adaptive response to an acute training stimulus, but problems arise when a secondary training stimulus is applied to early. A first phase is characterized by the recognition and the initial response to the training session: the body enters the shock phase in which expected levels of fatigue occur. The response to the stress may be in form of fatigue, stiffness or delayed onset of muscle soreness (DOMS). If adequate recovery follows the initial stress, the human body system returns to baseline levels even known as homeostasis. In this second phase (resistance phase) the physiological adaptations occur. When recovery period is prolonged, an new adapted higher state (i.e. supercompensation) is initiated. Supercompensation phase refers to a return to a level that exceeds the baseline, resulting in an increased performance capacity. On the contrary, whether the training stressors are too high and the recovery period too brief, a state of decreased performance can lead to non-functional overreaching and overtraining. GAS model is a simple and good starting point about training adaptations, but its oversimplification nature can lead to miss some aspects of athlete training process considering the complex reality of training adaptations from a physiological standpoint.
- Stimulus-Fatigue-Recovery-Adaptation (SFRA): this model suggests that fatigue is accumulated in proportion to the magnitude and the duration of a training stimulus. The magnitude of the stimulus plays a primary role in determining the length of the recovery-adaptation period (Stone, Collins, Plisk, Haff, & Stone, 2000). This model has been applied by Verkhoshansky in programming strength and speed program for track and field athletes (Verkhoshansky, 1981). Using this model perception of high level of fatigue is generally not an issue with athletes as long as it is followed by a recovery period. In this view, coaches plan period of functional overreaching in order to ensure a performance supercompensation after the return of the human body function to the baseline level. A strategy to manage fatigue according to this model is to alternate heavy and light training days to offset extended period of high fatigue. In the case no new

training stimuli are applied during the period following the superior adaptation, the preparedness of the athlete will decline referring to a state of involution (Stone et al., 1999). The SFRA seems to be more functional comparing to GAS due to the consensus about the influence of different training mode on hormonal responses (Crewther, Keogh, Cronin, & Cook, 2006).

- Fitness-Fatigue: currently, the Fitness-Fatigue concept is the most prevailing theory of training and adaptation (Chiu & Barnes, 2003). Fitness-fatigue model differs from the before-mentioned theories for two main reasons: a) while GAS and SFRA assume a cause-effect relationship between fitness and fatigue, this new concept highlights an inverse relationship. In this light, training strategies that maximize fitness and minimize fatigue will have the greatest impact on athlete preparedness; secondly, b) fitness-fatigue model suggests that effects of training stressors on the two parts are exercise specific. As a consequence, if an athlete is too tired to performed high-quality exercise, he/she may still be able to perform another exercise focused on a different biomotor quality (Plisk & Stone, 2003). A relevant contribution to this theory is attributed to Banister and colleagues, who described the relationship between fitness and fatigue. The basic idea refers to a definition of athletic performance as the difference between fitness and fatigue (Banister, Calvert, Savage, & Al., 1975). Despite the simplification multiple aspects including cumulative effect of the training load, cumulative level of neuromuscular and mental fatigue, level of deficit in recovery and severity of the fatigue symptoms ultimately determine the level of athlete preparedness.

Fatigue is a holistic phenomenon affected by several factors. Previous research has demonstrated that competition and training stress result in temporary decrements in physical performance including muscle damage, impairment of immune system, imbalances in anabolic-catabolic homeostasis, alteration of mood and reduction in neuromuscular function (Jones, Griffiths, & Mellalieu, 2017). Several definitions exist, but measuring fatigue in sport competition and training can present challenges because its multifactorial nature (Edwards et al., 2018). All the definitions share the concept of reduction in physical, physiological and/or psychological performance. Athlete fatigue is a complex topic to define, making its measurement equally problematic. Fatigue represents a necessary part of the training puzzle. A recent review defined fatigue as “a disabling symptom in which physical and cognitive function is limited by interactions between performance fatigability and perceived fatigability” (Enoka

& Duchateau, 2016). Performance fatigability refers to the decline in objective performance measures derived from the capacity of the nervous system and contractile properties of muscles over time, while perceived fatigability describes the maintenance of homeostasis and subjective psychological state of athlete. However, until now a substantial decline in peak muscle force or power output in response to an acute exercise is widely accepted as practical definition of fatigue in applied sport science setting and moreover what is clear is that fatigue in sport is task dependent (Allen, Lamb, & Westerblad, 2008; S. Cairns, 2006; Ndlec et al., 2012).

Despite this simplification the physiological mechanisms behind a fatigued athlete refers to both central and peripheral fatigue. Central fatigue refers to diminished motor drive from the central nervous system (brain and spinal cord); while peripheral fatigue is due to changes that occur directly in the muscle and impair the contractile process. At peripheral level many factors alter performance. Those are called putative factors and they include adenosine triphosphate (ATP), phosphocreatine (PCr), adenosine diphosphate (ADP), inorganic phosphate (Pi), lactate, hyperthermia (i.e. high core body temperature), and hypoxia (decreased oxygen), hydrogen ions, ammonia muscle glycogen, blood glucose, potassium and sodium, calcium, magnesium and cytokines (S. Cairns, 2006; S. P. Cairns, 2013).

As previously stated, period of functional overreaching are part of most sport performance training program and the athlete's response can be thought of as existing on a continuum with several variables having the potential to make an impact. Period of high stress together with inadequate recovery can lead to maladaptation. Maladaptations are related to the hypothalamic-pituitary-adrenal axis and all other hypothalamic axes. This region of the body plays a key role in the brain for regulating the central responses to stress and training (Meeusen et al., 2013). Considering functional overreaching as part of the adaptation process, on the contrary unplanned fatigue and decreased performance following extended period of overload training with inadequate recovery can cause non-functional overreaching. This stage precedes the overtraining syndrome in which large decrements of performance occur and for consistent period (e.g. from weeks to months) a set of psychological disturbances are associated. However delineating normal from abnormal physiological adaptations to training is a big problem for practitioners (Sue L. Hooper & Mackinnon, 1995). For instance the length of time taken to recover to baseline level is a major factor that distinguishes functional overreaching and non-functional overreaching (Meeusen et al., 2013). Non-functional overreaching is characterized by psychological distress and hormonal disturbance and it is viewed as a precursor of overtraining. In order to avoid it, previous investigations suggested that a set of monitoring tools including reaction time task, psychological questionnaire (e.g. RESTQ-Sport) and exercises protocol appear to be promising tools for diagnosing non-functional overreaching (Nederhof, Zwerver, Brink, Meeusen, & Lemmink, 2008).

Nowadays the risk of injury is still high along elite and young athletes. Overtraining is certainly a condition that can lead to injury especially in international athletes (Matos, Winsley, & Williams, 2011). Previous research confirmed that athletes from different sports sustain regularly overreaching and overtraining (Koutedakis & Sharp, 1998). Moreover individual-based sport athletes are exposed at a higher risk of overtraining due to the periodization paradigm which involves periods of really heavy training comparing to team sports players. Performance decrements (i.e. up to 15%) together with high and chronic levels of fatigue are the most obvious indicators of overtraining syndrome. Overtraining can be defined as being excessively fatigued and underperforming for longer than 6 months where the time to restore normal performance is largely exceeded (Matos et al., 2011). Due to its multifactorial nature, identifying conditions of this syndrome is not easy especially in an applied field when sport scientist and coaches tend to consider the management of training variables only. As suggested by (Lewis, Collins, Pedlar, & Rogers, 2015), diagnosis of overtraining syndrome requires specific exclusion criteria focusing on clinical aspects, followed by non-clinical elements such as training volume, intensity, recovery strategies and nutrition. Despite the guidelines for identifying negative outcomes of the training process, sport training adaptations are not well described and further research is needed to support the decision making of practitioners.

There is a delicate balance between loading and unloading phases over the training plan and having markers that inform about fatigue levels and training stress can help in supporting practitioners. Specifically practitioners need to understand how athletes perceive the stress and how the training histories affect how they cope with it. In the next chapters, the topic of athlete monitoring is described in details with the aim to provide an evidence-based approach and a box of metrics that can be applied on the field.

1.3 Quantifying the training load in young athletes

Monitoring athletes' training load is essential for determining whether they are adapting to their training process, understanding individualized responses, assessing fatigue and the associated need for recovery, and minimizing the risk of non-functional overreaching, injury, and illness

(Bourdon et al., 2017). In the context of young athletes, practitioners need to take into account both training load and extra training load components (e.g. work, study, relationship) in order to assist coaches in designing appropriate training programs and support them in the challenging process of youth athletic development. Especially considering the catastrophic outcome of injury in adolescent athletes that sometimes can lead to burnout, but also as the end of access to physical activity and sport participation, creating a safe and successful environment for youth should be a priority in sports communities (Murray, 2017).
In this view, a set of common measurement tools have been adopted to systematically monitor the physical, physiological and psychological variables related to performance with the ultimate goal to support practitioners in measuring the effectiveness of their training program and inform the decision-making process (Halson, 2014). Despite several monitoring tools have been adopted in various sport settings showing moderate and high levels of validity and reliability, in athletics only few studies examined their usefulness with track and field athletes.

Starting from few simple questions, the training sessions can be easily measured in terms of frequency (*how often*), intensity (*how hard*), duration (*how long*), and mode (*type of exercise*). Athlete training program can be quantified in numerous ways (Bourdon et al., 2017), but a clear distinction is made between measures of external and internal load. Markers of external load have been the foundation of most monitoring systems traditionally and define the objective work completed by the athlete. External load looks at factors such as mean power output in road cycling, distance covered in runners and time-motion analysis in team sport players. While internal load refers to the physiological and psychological stress imposed on the subject, which is what largely determines the adaptation to the training program (Kellmann et al., 2018). This is characterized by the disturbance in homeostasis of the physiological and metabolic processes during the training session. Examples of measures of internal load are heart rate and rating of perceived exertion (RPE). Those metrics are used both with senior and young athletes in different sport setting, but the choice to adopt certain measures within a given team should be sport-specific according to the needs analysis of the sport context (Gabbett et al., 2017).

External load measures are commonly used for quantifying training in aerobic endurance sports and team sports. The increasing use of wearable technologies has allowed for more systematic and detailed information on the external measures (e.g. distance covered, speed), but in some sport environment (e.g. swimming, athletics) detailed training diaries can be a valid alternative to quantify the workload (Leif Inge Tjelta, 2013; Plews & Laursen, 2017; Solli, Tønnessen, & Sandbakk, 2017). Time-motion analysis, defined as the tracking of performance during training and competition, is becoming increasingly popular to monitor athletes. The information obtained can be used for the following purposes: a) to monitor fatigue and athlete's pacing strategies during the activity, b) to assess athletes across levels of performance (e.g. elite, sub-elite, youth), c) to gain information about position-specific demands, and, d) to control the injury risk associated with training load measures. Global positioning systems (GPS) and inertial sensors (accelerometers, gyroscopes and magnetometers) have the huge potential to provide real-time data and a wide application in a range of sports including swimming, soccer, rugby, American football, and running. GPS units are used mainly in team sports for tracking work rate (e.g. meters covered per minute), load (e.g. acceleration), time spent in high intensity work ranges and total distance covered (Taylor, Chapman, Cronin, Newton, & Gill, 2012), while inertial sensors provide additional data on mechanical characteristics such as collision and impact, metabolic power, and accelerometer load (Scott, Scott, & Kelly, 2016). Despite the sheer number of variables that can be obtained, in an applied sport science environment daily and weekly reports should focus on three to five measures that are most important to the coaching staff so as to not overwhelm them with unnecessary information. In the context of run-based sports, preliminary results have opened new perspective for monitoring of neuromuscular fatigue and performance using GPS-embedded tri-axial accelerometers to assess stride variables and vertical stiffness (Martin Buchheit, Gray, & Morin, 2015). Given the widespread use of technologies for athlete monitoring systems, it is critical that practitioners understand the benefits and limitations of this technologies. Many studies investigated the reliability and validity of GPS devices in different sport settings, but clearer insights are gained considering the limitations of these devices. In fact, the reliability of GPS appears to decrease as the speed of the activity increase underling the influence of factors such as the sampling rate and type of activity (Aughey, 2011).

Power meters are also used as part of athlete monitoring in cycling disciplines. Variables such as power output, speed, acceleration and cadence can provide valuable information about performance and training adaptation. In aerobic endurance sports, real-time power meters data is relevant for informing coaches and athletes about the effectiveness of pacing strategies (Jobson, Passfield, Atkinson, Barton, & Scarf, 2009; Nimmerichter, Eston, Bachl, & Williams, 2011; Pinot & Grappe, 2015).

As part of physical preparation program in all sport disciplines, resistance training is a common component of various athlete monitoring system. Despite the measures of force and displacement calculated instantly by linear position transducers and accelerometers, a starting point to quantify resistance training workload is to record the number of exercises, repetitions and sets in a training diary and then calculate the volume and intensity load performed during the physical conditioning session (Campbell, Bove, Ward, Vargas, & Dolan, 2017; G Gregory Haff & Ph, 2010). A simple approach can be used to calculate the volume load multiplying the total number of repetitions by the load lifted.

Volume load (lb or kg) = number of sets x number of repetitions x weight lifted (lb or kg)

As alternative method, the volume can be expressed in terms of the athlete's maximal capacity using 1-repetition maximum as follow:

Volume load (lb or kg) = number of sets x number of repetitions x (% of 1RM x 1RM)

Previous studies suggested to use the second formula purposed as planning tool when writing a strength and conditioning plan because it allows one to work with percentages and to use the first formula previously listed as monitoring tool (Bompa & Haff, 2009). Then, training intensity can be calculated by dividing the volume load by the number of repetitions, which represent the average load lifted across the training session.

Training intensity = volume load (kg or lb) / total repetitions

The before-illustrated methods should be considered a reasonable estimate of the workload even if they do not include a measure of distance travelled (e.g. displacement) during the exercise and consequently the accuracy of the evaluation decreases. In athletics, a review outlined two aspects of intensity: training intensity and exercise intensity. Training intensity is concerned with the rate at which training session proceeds and relates to training density (i.e. see the formula related); while exercise intensity refers to power output of movements and can be calculated through velocity testing devices (DeWeese et al., 2015a). Thanks to the technological development linear position transducers and accelerometers can be used to determine both external load and athlete's response during resistance training in team and individual sports. Using the velocity-based approach practitioners can gain live data about force and displacement for each repetitions.

Quantifying the workload sustained by the athlete can be a valid technique to determine the dose of training stimuli, but it may not provide an accurate description of the physiological response. Monitoring internal load provides important information on how the athlete is adapting to the training. Internal measures has a primary role in individualizing the responses in different athletes and on the same athletes over different periods (e.g. pre and post injury). The same external load can result in very different internal responses for different athletes underlining the concept of individualization determined by a range of factors such as age, training history, physical capacity, genetics, and injury history.

The rating of perceived exertion (RPE) is one of the most common means of assessing internal load. Using a non-invasive and field-based technique, RPE can be used to identify inter-individual differences in perceived exertion (BORG, 1982). It provides an overall subjective measure of perception of effort by integrating the information from the muscles and joints (periphery) with the information from the cardiovascular and respiratory system. A variety of scales can be used to measure RPE: Borg 6-20 scale which is linked to exercise heart rate; category ratio (CR)-RPE scale (0-10), which may be better for high-intensity exercise in which fatigue involves nonlinear responses (e.g. team sports); Borg CR-100 scale that equates to a percentage, which may make it more intuitively appealing to coaches and athletes; OMNI RPE scale that provides pictorial representation. To date, no ideal scale exits that can be used in athlete monitoring, but using RPE measures in conjunction with other measures to monitor training load is common in high-performance sport. Nowadays, the best practice is the session RPE (s-RPE) method, developed by Foster. The aim is to obtain the athlete's global rating of the training bout, which incorporates all aspects. The session RPE asks the athlete, "How hard was your session?" using number range and verbal descriptors as follows: 0 = rest, 1 = very, very easy, 2 = easy, 3 = moderate, 4 = somewhat hard, 5-6 = hard, 7-9, very hard, 10 = maximal [69]. The session load is defined in arbitrary units (AU) as duration of the session multiplied by s-RPE. This technique has been validated across a wide range of exercise modes (e.g. resistance training) and sports (Day, McGuigan, Brice, & Foster, 2004), but an higher level of validity and reliability has been revealed when it is used for measuring exercise intensity in aerobic exercise when compared to heart rate-based methods. Considering the resistance training exercise mode, researches shows a positive relationship between the intensity of the training and the perceived exertion (i.e. s-RPE increases with increase in the intensity of training given the same volume) remarking the ability to reveal intensity during resistance training (Day et al., 2004; Sweet, Foster, McGuigan, & Brice, 2004). Modification of classic RPE scales have been developed with potential application for athlete monitoring. Perceived exertion in various region of the body (e.g. leg and breathlessness) (Borg, Borg, Larsson, Letzter, & Sundblad, 2010) and the demands of the activity (e.g. technical) (Weston, Siegler, Bahnert, McBrien, & Lovell, 2015)seems to have good sensitivity, but this benefits might not offset the impracticability of using multiple scales. The use of RPE with youth athletes may be of limited application due to the ability of young people to be able to reliably assess the perceived exertion and as well as potential on language and cultural issues with anchoring scales when translated from the original constructs (Murray, 2017).

Another implementation of the s-RPE is represented by the measures of training stress balance calculated as the ratio between the current weekly load (acute load) and the 4-week rolling average (chronic load), which represents the strain to the average monthly load. This technique has been showed to be useful in the contest of performance outcome and injury (Aughey, Elias, Esmaeili, Lazarus, & Stewart, 2016; Blanch & Gabbett, 2016; Hulin et al., 2014). Despite the strengths and limitations of this technique, RPE reveals how athletes are perceiving the training stimulus and in conjunction with other monitoring tool could be even use to prescribe the training session. Using the same metrics of s-RPE, other measures can provide insights about athletes such as training monotony and training strain (Foster C, 1998). Training monotony is defined as the variation of the session load over the week (i.e. the sum of the session loads for each training session for the entire week) and it is calculated by taking daily mean load and dividing it by the standard deviation of daily load. Taking into account the microcycle, the monotony can be calculated from 7 to 10 days. Training strain is the product of monotony and the weekly load. This metric represent the product of high training load and high training monotony which has shown to increase the risk of injury and illness (Blanch & Gabbett, 2016; Foster C, 1998). In conclusion, using session load is a robust method for determining training load in team sports athletes (Gaudino et al., 2015; Lovell, Sirotic, Impellizzeri, & Coutts, 2013), but presents limitations within youth. Moreover, a combination of internal and external load factors predicts session RPE in team sports better than individual measures alone. The importance of considering a mixture of measures is proof by researches which investigated the relationship between internal (e.g. s-RPE) and external measures to monitor training and athletes' response (Scanlan, Wen, Tucker, & Dalbo, 2014).

Another common way to quantify training stress is represented by questionnaires and training diaries. Coaches and athletes differ in their perception of what occurs in training and how hard the sessions are and because each athlete's response to the training stress is unique, a variety of wellness metrics have been developed. It has become a commonplace to monitor an athlete's stress-recovery balance using subjective daily wellbeing questionnaires due to their inexpensive and time efficiency features (Saw, Main, & Gastin, 2016). Especially, these self-reported measures are becoming increasingly prominent at youth level (Sawczuk, Jones, Scantlebury, Weakley, et al., 2018). In the context of youth sport, the stress-recovery balance may vary in response to training and non-training variables as athletes attempt to cope with educational (e.g. academic examinations), maturational (e.g. pubertal changes) and social (e.g. relationships and peer pressure) demands alongside their sporting endeavours (Mountjoy et al., 2008). Practitioners often use their own questionnaires in order to increase sport specificity but research into the effectiveness of these custom-designed questionnaires is limited. Wellness inventories can be used to monitor athletes because they gather different measures including ratings of perceived muscle soreness, general well-being, fatigue, stress and sleep. Custom-designed forms typically have 4 to 12 items that are measured using either 1-5 or 0-6 Likert scales (Taylor et al., 2012). Research has shown that these questionnaires are sensitive to detecting changes in measures of stress and fatigue in elite athletes (McLean, Coutts, Kelly, McGuigan, & Cormack, 2010; Montgomery & Hopkins, 2013; Saw et al., 2016). Within the scenario of young athletes, a study indicated that daily well-being measures were shown to be responsive to sleep duration and to training load considering the subscales of muscle soreness (Sawczuk, Jones, Scantlebury, & Till, 2018). Moreover, a variety of questionnaires have been developed investigating: mood states using tools such as Profile of Mood States (POMS) and Brunel Mood Scale (BRUMS); training stress, pain and delayed-onset muscle soreness (DOMS) using the visual analog scales (VAS), the McGill Pain Questionnaire and the Training Distress Scales (TDS), and, finally stress and recovery levels filling in the Recovery Stress Questionnaire for Athletes (RESTQ-Sport) and the Daily Analysis of Life Demands (DALDA) questionnaire. As previously stated, concerning the use of other monitoring tools, again practitioners should never rely on a single questionnaire as the basis of monitoring programs but they can constitute a component of the athlete monitoring system. Identifying threshold values for meaningful changes and empowering the process within educational meeting explaining to athletes the need for honest and accurate answer are important elements for gaining advantages of this tool.

Heart rate measures are one of the most common ways to monitor exercise intensity and enables practitioners to accurately control the relative intensity of each bout of exercise and any associated recovery periods (Akenhead & Nassis, 2016). Heart rate recovery (HRR) and heart rate variability (HRV) are two methods for athlete monitoring (e.g. exercise quantification and fitness measures) and provide objective markers of fatigue. As comprehensive athlete monitoring system, practitioners should use them in conjunction with other tools such as RPE. Those measures are collected often in conjunction with GPS devices during each training session. Moreover, a range of heart rate measures can be to quantify the training impulse (TRIMP) intended as the total training load imposed on the athlete during the exercise bout. As showed below, the formula multiplied the session duration (D), the constant e = 2.718, the weighting factor b (1.67 for women and 1.92 for men) and delta heart rate ratio = (average exercise heart rate – resting heart rate) / (maximal exercise heart rate – resting heart rate) (Banister et al., 1975; Morton, Fitz-Clarke, & Banister, 1990).

$$\text{TRIMP} = \text{D x } (\Delta \text{ heart rate ratio}) \text{ x } e^{(\text{b x } \Delta \text{ heart rate ratio})}$$

From a physiological standpoint, heart rate responds to periods of stress and rest in a non-linear way due to the interactions between sympathetic and parasympathetic nervous system. Sympathetic response is characterized by an increase in heart rate during high-intensity exercise, while the parasympathetic function describes decreases of heart activity over low-intensity work or recovery. HRV data are used to provide insights into an athlete's readiness to train (e.g. normal state, overreaching, overtraining) and it is a measure of the normal variation in beat-to-beat intervals. For monitoring purpose is relevant to underline a couple of concepts related to the use of HRV as athlete monitoring tool. The recommendation to collect data under consistent conditions (e.g. when the athlete wakes up) is a must and secondly due to high day-to day variation, previous investigation have suggested to measure HRV at least 3 times per week and to analyse data taking a weekly average or using rolling 7-day average (Plews, Laursen, Kilding, & Buchheit, 2013; Plews, Laursen, Stanley, Kilding, & Buchheit, 2013). An increase in chronic HRV is associated with a positive response to the training workload, while a decrease indicates that the athlete is not tolerating the training load (Martin Buchheit, 2014).

At the same time, heart rate recovery can be used as monitoring tool and describes the decrements after exercise. It has been used as indicator of fatigue or fitness, detraining, overreaching, however the finding are not consistent. On the field of applied sport science, daily HRR presents impracticality because it requires an exercise performance test, but evidences showed the advantage of using it as part of warm-up (Lamberts, Swart, Capostagno, Noakes, & Lambert, 2010). HRR can be calculated over varying periods of time such as 5-min submaximal cycle followed by 5-min recovery; heart rate is averaged during the final 30s of the exercise bout. It can be expressed as the absolute hear rate or the relative difference between average hear rate in the final 30s of the exercise and the heart rate 60s after the end of the exercise (Martin Buchheit, 2014).

1.4 Measures of fitness and fatigue

In this section, measures of fitness and fatigue (e.g. neuromuscular, hormonal and biochemical markers) are outlined for gaining information about the athlete's response to the training program and the management of levels of fatigue. As athletes strive to improve their performance, modifications in training load are required at various times during the training cycle to either increase or decrease fatigue levels depending on the phase of the season (Halson, 2014). Fatigue management strategies are needed to support the coaches' decision-making and to individualize further sessions according to the current athlete's functional status. To optimize an athlete's adaptation to a training program, practitioners must initially quantify the training and competition workload the athlete has completed and consequently track the physiological responses (e.g. fitness, fatigue) to that training stress to evaluate whether an athlete is prepared to train or compete at his/her best (Gabbett et al., 2017). Combining the athletes' workload and fatigue measurements will allow practitioners to optimally determine the dose-response relationship.

As previously defined, from a physiological standpoint, fatigue can be categorized as central or peripheral (Cairns, 2013). A multitude of methods are available to assist in informing coaching staff when an athlete is in a state of fatigue or recovery, but no single and reliable diagnostic marker has yet been identified (Taylor et al., 2012). In the other hand, however, many monitoring test used in research studies are not suitable for regular monitoring on the field (e.g. low portability, expense, unsuitability, fatiguing effects) as proved on the lab. Especially, the measures and tests adopted in an athlete monitoring system must have good levels of validity and reliability in order to identify threshold values for helping effective coaching decision making. Lately, a magnitude-based inference (MBI) approach is becoming increasingly popular to assess test outcomes and the comparison of results against the smallest worthwhile change and the typical error of measurement seems to be a valid research tool (Hopkins, Marshall, Batterham, & Hanin, 2009), even if is not widely accepted into the sport science community. A list of the main indicators of fitness and fatigue is presented with a special reference for the context of athletics and young athletes.

Neuromuscular fatigue (NMF) assessments are widely used in high-performance sports. NMF is defined as reduction in maximal voluntary contractile force. Vertical jump test have been suggested as common and effective way to assess levels of NMF and readiness in different sport settings (Watkins et al., 2017). Considering an applied sport physiology stand point, these tests involve the stretch-shortening cycle (SSC), a fundamental activity in multiple sports and so they allow the evaluation of both slow-SSC (>0.25s) and fast-SCC (<0.25s). Traditionally, the most common protocols are the countermovement jump (CMJ), the squat jump (SJ) and the drop jump (DJ), but according to the needs of the sport environment different protocols have been developed. Using technology such as force plates, optical bars, contact mats, linear position transducers, accelerometers and validated smartphone apps, allows practitioners to collect a sheer number of variables including force, velocity and displacement. Specific measures such as jump height, power (mean and average), velocity (peak and average) and force (peak and average) are popular, but other metrics including the ratio of flight time to contraction time or jump height to contact time have been used for monitoring purpose. Despite the great amount of data available, not all measures are sensitive to fatigue as underlined in a study by Gathercole who emphasized the role of time-related variables (e.g. eccentric phase of vertical jump) as monitoring tool (R. Gathercole, Sporer, & Stellingwerff, 2015; Rob Gathercole, Sporer, Stellingwerff, & Sleivert, 2015). In this view, previous research noticed that vertical jump measures declined following a match play, but the main performance measure (vertical jump height) remained stable (Cormack, Newton, McGulgan, & Doyle, 2008). On the other hand, other evidences reported variations in jump height following intensive sport activities (McLean et al., 2010). The disparity of this findings seems due to the wide range of equipment, testing protocols, sport and athletes level used in these studies. The reactive strength index (RSI) and the modified reactive strength index (mRSI) have been proposed as measures of explosiveness (Kipp, Kiely, & Geiser, 2016) and are common variables used to evaluate drop jumps test or plyometric movement in general. Moreover, muscle stiffness and force production assessments (e.g. isometric mid-thigh pull, isometric squat) have been proposed as strength and fatigue monitoring tool, but they have found less application due to the impracticability on the field.

In athletics previous research investigated the role of vertical jump as monitoring tool over the entire season or a part of it. A study of Spanish senior track and field athletes, participating in power-speed events (e.g. 100m, 200m, long jump, triple jump), described the variations in CMJ performance over a period of 72 weeks highlighting the significant and progressive increase in CMJ jump height in the last 4 weeks prior of the season best result, while noticing no variations in the 4 weeks before the season worst result (Jiménez-Reyes & González-Badillo, 2011). The correlation between performance result and vertical jump performance in athletics was also studied by (Balsalobre-Fernańdez, Tejero-Gonzaĺez, & Del Campo-Vecino, 2014) which identified significant difference in weekly CMJ score between the best and the worst results over a competitive season in elite middle and long distance runners. Considering the context of young athletes, recently a report investigated the individual changes in CMJ performance in national youth long jumpers showing no acute variations (i.e. weekly changes) over an indoor season, but a substantial greater average CMJ score during the competitive weeks only (Franceschi & Conte, 2018). In order to gain a comprehensive view on the topic of NMF, the identification of fatigue status can vary according to the environment: research-based works consider more complex statistic techniques for getting results, while in an applied sport science environment (e.g. athlete monitoring system in a rugby team) basic descriptive statistics (e.g. z-score, SD) can support the decision making process.

Hormonal, biochemical and immunological measures have been used in athlete monitoring as markers of training stress. All of them have the common characteristics to provide information about how an athletes are adapting to training load, but comparing to other monitoring measures are less used in high performance sports (Taylor et al., 2012). In fact, they mostly involve complicate and expensive assays, making the monitoring process impractical in most athletic environment. Despite these limitations, measurements of blood, saliva and urine are used as hormones and biochemical markers. Hormone monitoring includes cortisol, testosterone and catecholamines which provide insight into the functioning of the hypothalamic-pituitary-adrenal axis, which has implications for the early detections of overreaching and overtraining. Especially, the role of monitoring hormones is intended for both predicting and tracking the effects of training programs. In sports the hormones that have been investigated the most within

high-level athletes are testosterone and cortisol which have the ability to indicate anabolic or catabolic states (Izquierdo et al., 2004; Kraemer et al., 2004). Saliva is the most used technique for measuring hormones levels in athletes: a study by Cormack and colleagues analysed the evolution of free cortisol in saliva within Australian football players concluding that those athletes with higher levels of cortisol at the beginning of the season could see reduced further performance (Cormack, Newton, McGuigan, & Cormie, 2008). In athletics, the relationship between salivary free cortisol concentration and CMJ performance was studied in middle distance athletes showing a negative very strong correlation between the two variables (Balsalobre-Fernańdez et al., 2014). Despite the advantages of measuring hormonal markers, it is worth to mention that the analysis is costly and the variability is high.
Biochemical measures includes many metabolites (e.g. creatin kinase, alpha-amylase), but weekly variations in elite level athletes are still poorly understood. Immune system monitoring has suggested that periods of intensified training result in depressed immune cell function (Gleeson & Walsh, 2012). However, the implementation of these markers needs to be weighed against the financial cost and complex analysis required, making the process impractical in the majority of athlete development environment.

Performance test are sport-specific measures that can be useful for athlete monitoring. They can be part of the control system on a weekly or monthly period. The main issue for practitioners is again related to find a test that they can use on a regular basis (i.e., daily or weekly), but if the protocol is a maximal performance test it can be challenging to implement it due to its resulting fatigue. Valid and useful sub-maximal test have been developed and an excellent example of it is represent by the application of sub-maximal test in football players and road cyclists for evaluating the aerobic fitness (Impellizzeri, Rampinini, Sassi, Mognoni, & Marcora, 2005). Test battery includes submaximal cycling (Lamberts, Swart, Noakes, & Lambert, 2011) and running tests (M. Buchheit, Simpson, Al Haddad, Bourdon, & Mendez-Villanueva, 2012), maximal strength and jumps tests (Loturco et al., 2015), sprints (T. Haugen & Buchheit, 2016) and sport-specific test. Lately, research in team sports is introducing the concept of “invisible monitoring” using measures of estimation from global position systems which may provide useful markers for mechanical and neuromuscular work (Carling et al., 2018). At the end, the ultimate goal of performance testing session is to determine the potential for overreaching and overtraining in athletes. Moreover, movement screening, flexibility and balance testing are part of monitoring systems in sports. They can be used to assess general movement capacity and to monitor the risk of injury. In athletics, vertical jumps test are widely used for testing strength and power profile. In a study by Loturco and colleagues, a group of Brazilian Paralympic sprinters with visual impairment were tested using SJ prior to the main competitions over the 2014-2015 athletics seasons indicating that vertical jump test could be used as a good indicator of athlete's sprinting performance (Loturco et al., 2015). Furthermore, Gonzalez-Badillo and colleagues investigated the relationship between kinematic factors and CMJ height in track and field athletes suggesting that peak power represents the best predictor of jump height and confirming the use of this simple protocol in track and field scenario (Jiménez-Reyes P., Cuadrado-Peñafiel V., & Gonzalez- Badillo JJ., 2011; Jiménez-Reyes & González-Badillo, 2011).

As can be noticed, the current evidences focus solely on young athletes and track and field scenario are poor. The need of having evidence-based guidelines has been outlined in different consensus statements (Bourdon et al., 2017; Kellmann et al., 2018; Murray, 2017), but the process of implementing scientific support in those afore-mentioned scenario is not accepted in all athletics environments. One of the aim of this research project is to present an athlete monitoring system for junior track and field athletes with the objective to support coaches in the long-term development process.

2. Aim

The aim of this dissertation was: a) to investigate changes in training load, neuromuscular readiness, perceptual fatigue and competition performance; b) to identify associations between the aforementioned variables and the best competition performances, and c) to provide a set of training load variables that describe the variations during the outdoor season in U20 track and field athletes.

3. Methods

3.1 Subjects

Six under-20 track and field athletes (age 17.5 ± 1.7 years; height 172.6 ± 9.9cm; body mass 62.1 ± 6.4kg) representative of a part-time athletics academy participated in the study. Three boys and three girls took part in the observational study for a 16-week period. Despite all athletes selected have a training experience of at least 2 years, all of them experienced the academy context for the first season. Participants competed at regional, national and international level in athletics speed-power events (i.e. sprint, hurdles and jumps competitions). Written informed consent was obtained from participants along with parental consent. The study is conformed to the recommendation of the Declaration of Helsinki.

3.2 Design

Observational study and study cases. Participants were monitored during an athletics outdoor season for a period of 16 weeks. Athletics outdoor season was divided in 2 phases: the preparation period (from week 1 to week 8) and the competitive period (from week 9 to week 16). Athletes were involved in regular training sessions, training camps and competitions as prescribed by the coaching staff. Training load was quantified as external workload through detailed training diaries indicating weekly frequency, duration, modes (*technical, conditioning, combined, recovery, rehab*) and training components (*sprint, running, jumping and weights*). On a weekly basis, the countermovement jump (CMJ) and the ten to five repeated jump test (RJT) were executed to assess the neuromuscular readiness of each subject during the first training session of the week. Perceptual fatigue measures were collected on a daily basis through a wellness questionnaire filled by the athletes each morning. Moreover competition performance was observed throughout the season, registering the 3 best competition results for each athlete.

3.3 Methodology

3.3.1 Training load

To quantify training load, coaching staff noted the workload performed by each athlete on training diaries. For the entire period, descriptive weekly workloads were quantified as training frequency (i.e. number of sessions per week), training duration (i.e. total length of sessions per week) and training mode (i.e. main emphasis of the training per week).

Moreover, external training volumes were collected and estimated for sprint (m), running (m), jumping volume (counts) and weights (kg) training. Sprint training implies all forms of acceleration and sprint run with maximal effort, while running training includes all the other forms of running performed at submaximal intensity. Jumping training refers to all forms of jumping movements such as in place jumps, short bounds, extended bounds, depth jumps and discipline-specific jumps. At the end, weights training estimates the quantification of workload lifted during conditioning workouts using the formula suggested by Haff for monitoring purposes as follows (Haff & Ph, 2010):

Volume load (kg) = number of sets x number of repetitions x weight lifted (kg)

In the table 3.3.1 are reported all training load variables and the associated definitions.

Training load variables	**Unit of measure**	**Definition**
Training frequency	Session counts (AU)	Indicates the number of training sessions performed per week
Training duration	Hour (h)	Indicates the total length of training sessions performed per week
Training mode	---	Refers to the main training modality of the week. It is defined as: technical, conditioning, combined, recovery or rehab.
Sprint training	Meters (m)	Estimation of sprint training performed each week. It includes all forms of acceleration and sprint run with maximal effort (>85% max speed)
Running training	Meters (m)	Estimation of running training performed each week. It includes all forms of running performed with submaximal effort.
Jumping training	Activity counts (AU)	Estimation of jumping training performed each week. It includes all

		forms of jumping movements such as in place jumps, short bounds, extended bounds, depth jumps and athletics jumps.
Weights training	Kilograms lifted (kg)	Estimation of weights training performed each week. It includes the quantification of workload lifted during conditioning workouts using the formula studied by (G Gregory Haff & Ph, 2010).

Table 3.3.1. Definition of training load measures used to quantify external training workload.

3.3.2 Neuromuscular readiness

The countermovement jump (CMJ) and the ten to five repeated jump test (RJT) were used to assess neuromuscular readiness during the 16-week outdoor season. Weekly testing measurements were performed on the first training session of the week ensuring 48h of recovery from the last training session and/or competition. After a 20-min standardized warm up (i.e. jogging, hurdles mobility, sprinting and jumping drills) vertical jump tests were administered using the OptoJump Next (Microgate, Bolzano, Italy). Both tests have been previously validated for the purpose to monitor neuromuscular readiness in athletes (Harper & Hobbs, 2011; Jiménez-Reyes & González-Badillo, 2011).

The CMJ was performed by each athlete executing two trials separated by 2-min passive rest. The athletes began the test with fully extended legs and their feet at a self-selected width. They were then instructed to squat down and jump as high as they could in a fluid countermovement motion. The depth of the countermovement was self-selected and they were finally instructed to keep their legs extended in flight and to land with their legs straight. Jump height was reported in centimetres (cm) and used for the subsequent analyses as average value.

The RJT involved participants performing optimal vertical rebounds (i.e. maximal elevation at each jump) with minimal ground contact (i.e. <0.250ms) performed for a series of 11 jumps. The instructions given to the athletes were to “maximize jump height” and “minimize ground contact time”. From the eleven jumps that were recorded the first jump was discarded from the analysis since this did not involve a fast stretch-shortening cycle (Harper & Hobbs, 2011). From the remaining ten jumps, the five jumps with the greatest reactive strength index (RSI) (i.e. the ratio of jump height to contact time) were averaged and used for further analysis.

3.3.3 Perceptual fatigue

Subjective data from a wellness questionnaire were collected each morning by the athletes through a smartphone app (Athlete Monitoring, FITSTATS Technologies, Moncton, Canada). Using a 7-point Likert scale (e.g. 0 = *no soreness* to 6 = *extremely sore*) the questionnaire describes the perceptual level of wellbeing of each athlete. It is inspired by the works of Hooper and Impellizzeri (S L Hooper, Mackinnon, Howard, Gordon, & Bachmann, 1995; Impellizzeri & Maffiuletti, 2007) and was translated in Italian with the scientific support and coaching staff with the additional objective to better understand the extra-training load variables in young (i.e. high school) athletes.

Lower scores indicate a better perception of wellbeing, and higher scores indicate a worse sense of wellbeing. The questionnaire gathers ratings of perceived fatigue, DOMS, health, sleep quantity, sleep quality, mood and then calculates the total score as shown in the figure 3.3.3. Weekly average values for the aforementioned perceptual fatigue variables were used for the analyses.

	FATIGUE	DOMS	HEALTH
Point	Do you feel tired today?	Do you feel some muscle soreness?	How is your general health?
0	No fatigue	No soreness	Excellent
1	Minimal Fatigue	Very little soreness	Very good
2	Better than normal	Better than normal	Normal
3	Normal	Normal	Slightly unwell
4	Worse than normal	Worse than normal	Moderately unwell
5	Very fatigued	Very sore / tight	Severely unwell
6	Exhausted, major fatigue	Extremely sore / tight	Terribly unwell

	SLEEP QUANTITY	SLEEP QUALITY	MOOD
Point	How many hours did you sleep last night?	How was your sleep last night?	How is your mood?
0	More than 10	Outstanding	Feeling great – very relaxed
1	9 - 10	Very good	Feeling good - relaxed
2	8 - 9	Better than normal	Better than normal
3	8	Normal	Normal
4	7 - 8	Worse than normal	Worse than normal
5	5 - 7	Disrupted	Very stressed
6	5 or less	Horrible, virtually no sleep	Extremely stressed

Figure 3.3.3. Wellness questionnaire filled by the young athletes each morning during the 16-week outdoor season.

3.3.4 Competition performance

Competition performance was recorded for each athlete indicating the 3 best performance results obtained in their main athletics event during the season. Since the athletes involved competed in different athletics events (e.g. 100m, 400hs and long jump), the results were converted in in score points (AU) following the IAAF Scoring Tables of Athletics available online on the webpage of the International Association of Athletics Federation (IAAF). Moreover, all competition performance were achieved in regional, national and international competitions approved by the Italian Athletics Federation (FIDAL) for regional and national events or by European Athletics for international events. The correspondent database of the two aforementioned sport federations contains all competition performance results.

3.4 Statistical Analysis

Data are expressed as mean ± standard deviation (SD). Differences between preparatory and competitive period in training load variables were computed on a customized spreadsheet (Hopkins, 2007) using a magnitude-based inferences (MBI) approach. The smallest worthwhile change (SWC) was calculated as 0.20 times the between-subjects SD. Quantitative chances of real differences in variables were assessed qualitatively as <1%, almost certainly not; <5%, very unlikely; <25% unlikely, probably not; 25% to 75%, possibly, possibly not; >75%, likely, probably; >95% very likely; >99.5%, almost certainly (Hopkins, 2006). If the chances of a variable having higher and lower differences were >5%, the true effect was deemed to be unclear. Otherwise, we interpreted that change as the observed chance. Thresholds for effect size (ES) statistics were interpreted as <0.2, trivial; 0.2 to 0.6, small; 0.6 to 1.2, moderate; 1.2 to 2.0, large; >2.0, very large (Hopkins et al., 2009). Changes in neuromuscular readiness test and perceptual fatigue measures were also calculated using MBI. Linear trend and changes were assessed against the coefficient of variation (CV) and the typical error (TE) on a second customized spreadsheet (Hopkins, 2017). SWC, TE and CV were calculated for each athlete. To assess the changes from linear trend, data from the 4 weeks preceding the data collection were averaged and included to fit a straight-line trend (baseline) in order to calculate changes during the 16-week outdoor season. Average changes from the baseline were calculated including the measurements performed during the weeks in which each athlete achieved the 3 best competition performance to better understand the association between the aforementioned measures and competition result. Chances of real differences in variables were assessed qualitatively as <10% very unlikely; 10-90% possibly, and >90% very likely. Clear effects greater than 90% were considered substantial. If the chances of a variable having higher and lower differences were both >10%, the true effect was deemed to be unclear. Additionally, two hierarchical clustering analysis were performed with the aim of identifying most likely groupings variables and cases in all data. The model was carried using all variables (training load, neuromuscular readiness test and perceptual fatigue measures) and cases (athletes per each week) for the preparatory and competitive period. This analysis was carried with the statistical software JMP (SAS Institute, Cary, North Carolina, US).

4. Results

4.1 Training load differences between preparatory and competitive period

In the figures 4.1a and 4.1b are reported the differences in external training load data between the preparatory and the competitive period for the athlete A, B, C, D, E and F. Training frequency (AU) was substantial different between the preparatory and competitive period for athlete E [mean difference (90% CI) = -1.0 (-1.7;-0.3), ES (90% CI) = -1.72 (-2.86;-0.57) - large, MBI = *very likely negative* (1/1/98)] and athlete F [mean difference (90% CI) = -1.1 (-1.8;-0.4), ES (90% CI) = -1.41 (-2.33;-0.50) - large, MBI = *very likely negative* (0/3/97)]. Athlete C and D displayed *likely negative* differences, while for athlete A and B the differences were *unclear*. Training duration (hour) data indicated the same differences as showed for training frequency. In fact, athlete A and B displayed *unclear* differences, athlete C and D *likely* negative differences, and athlete E and F *very likely negative* differences between the preparatory and competitive period.

In external training load data were registered substantial differences in sprint volume (m) for athlete E [mean difference (90% CI) = -402.5 (-559.6;-245.4), ES (90% CI) = -1.96 (-2.72;-1.19) - large, MBI = *most likely negative* (0/0/100)], athlete D [mean difference (90% CI) = -260.0 (-434.6; -85.4), ES (90% CI) = -1.02 (-1.70;-0.33) - moderate, MBI = *very likely negative* (0/3/97)] and athlete F [mean difference (90% CI) = -315.0 (-497.2;-132.8), ES (90% CI) = -1.15 (-1.81;-0.48) - moderate, MBI = *very likely negative* (0/1/99)]. While for athlete C the difference was *likely negative*, and for the athlete A and B was *unclear*. Running volume (m) for all athletes was deemed as *unclear,* except for athlete A who recorded a *very likely negative* difference [mean difference (90% CI) = -1993.8 (-2037.8;-349.7), ES (90% CI) = -0.89 (-152; 0.63) - moderate, MBI = *very likely negative* (1/3/96)]. A similar trend was displayed in weights volume (kg) where all athletes recorded an *unclear* difference, except for athlete B who showed the only *very likely* positive difference from the training load data [mean difference (90% CI) = 747.5 (268.3; 1226.7), ES (90% CI) = 1.34 (0.48; 2.20) - large, MBI = *very likely positive* (98/2/0)]. Jumps volume (AU) was deemed as *likely negative* for athlete A, C, D and F. The difference between the two period was *very likely negative* for athlete E [mean difference (90% CI) = -96.9 (-146.2;-47.6), ES (90% CI) = -1.25 (-1.88;-0.61) - large, MBI = *very likely negative* (0/1/99)]. On the contrary athlete B showed an *unclear* difference.

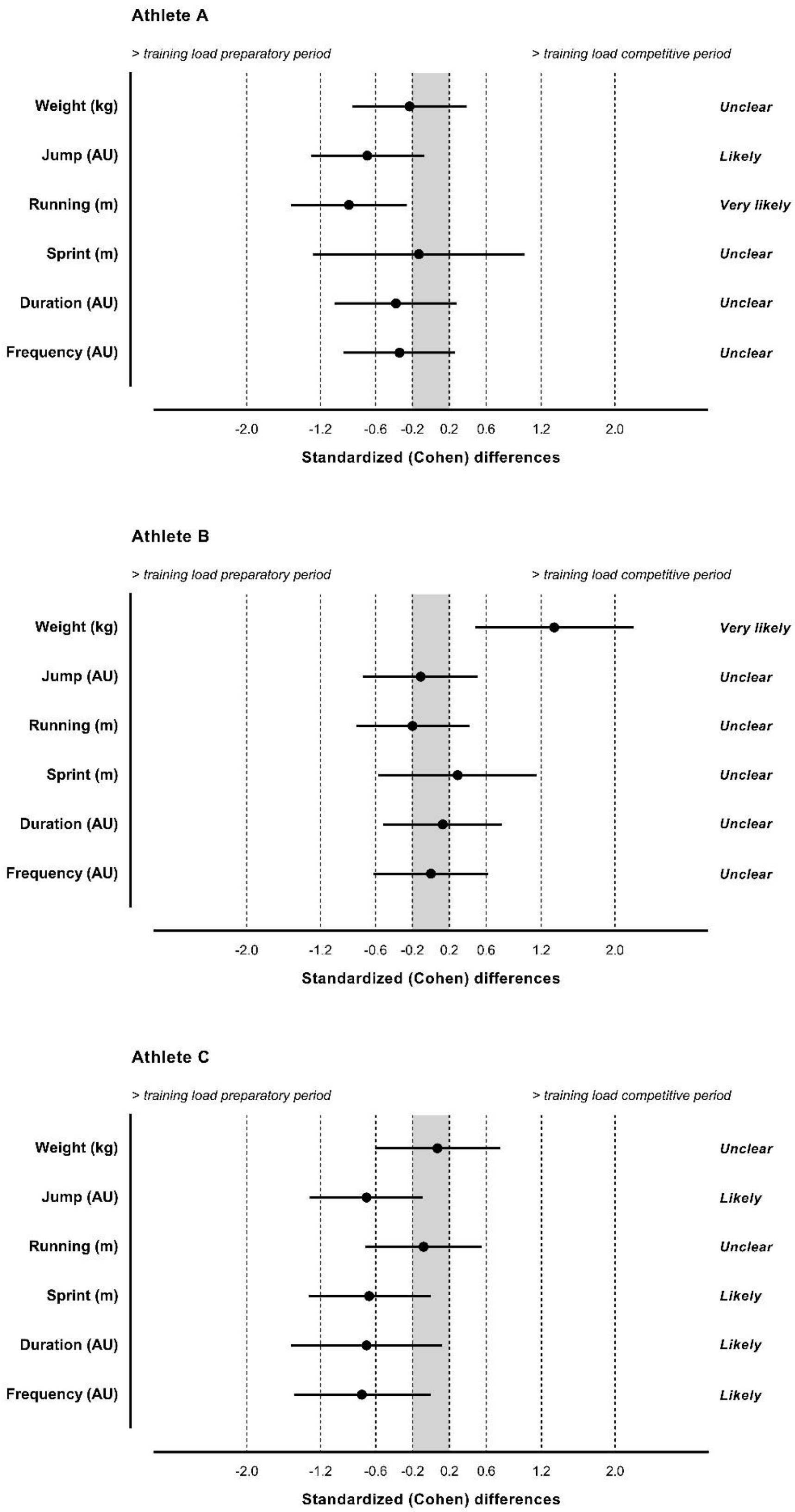

Figure 4.1a Differences in external training load between the preparatory and competitive period as standardized Cohen differences in athlete A, B and C.

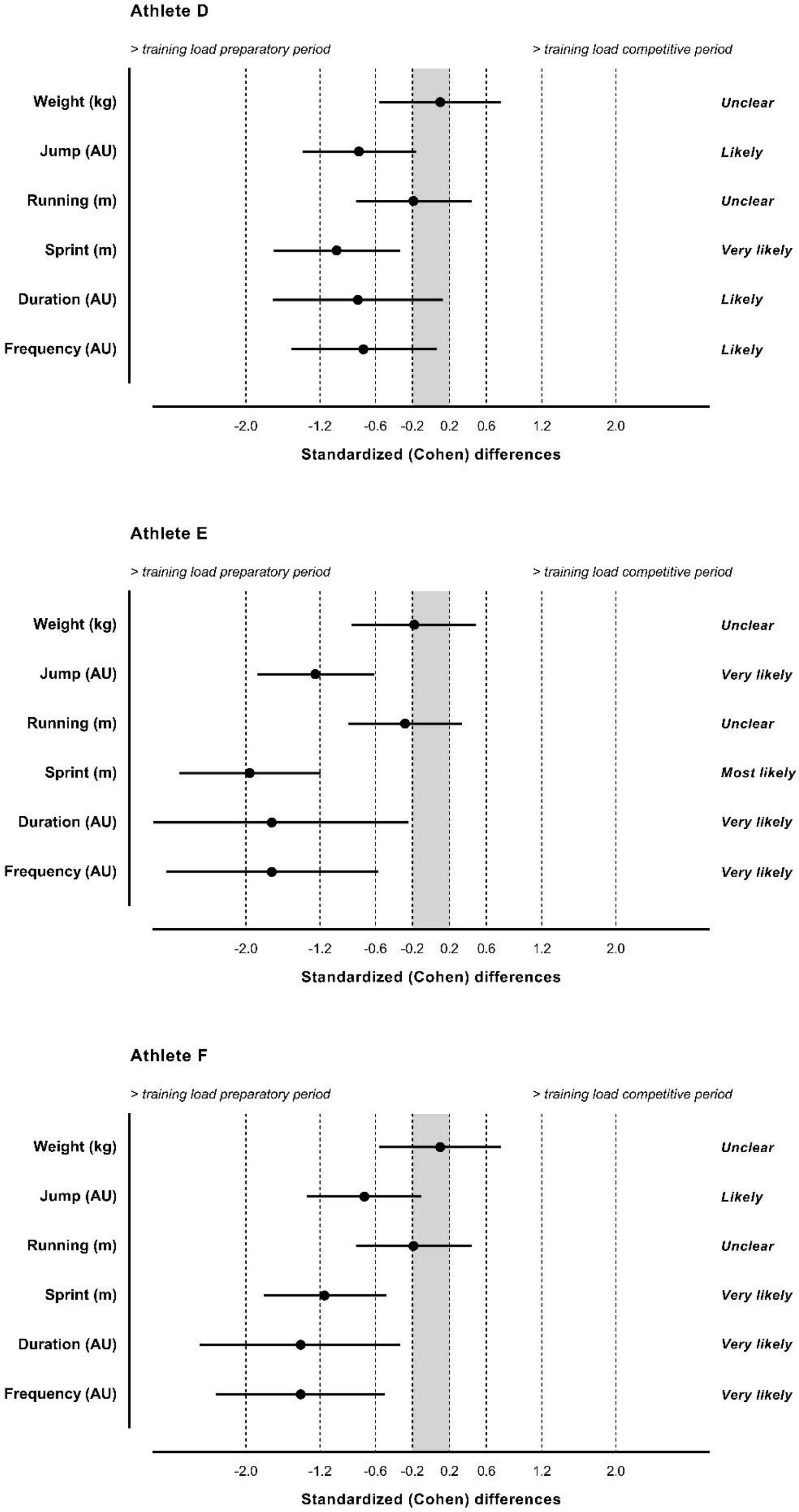

Figure 4.1b Differences in external training load between the preparatory and competitive period as standardized Cohen differences in athlete D, E and F

4.2 Individual trend and changes in neuromuscular readiness tests during the outdoor season

4.2.1 CMJ

Individual trend and changes in countermovement jump (CMJ) performance during the outdoor season are depicted in the figure 4.2.1 for each athlete. Athlete A displayed *very likely* higher CMJ performance in week 8 (95/5/0), week 10 (95/5/0) and week 11 (96/4/0). Athlete B recorded a *very likely* higher CMJ performance in week 11 (97/3/0) and week 15 (92/8/0). Athlete C performed a *very likely* higher vertical jump height in week 16 (99/1/0), while athlete D reported a *very likely* lower performance in week 5 (0/8/92) without reporting substantially higher CMJ performance during season. Athlete E recorded a *very likely* lower vertical jump height in week 1 (0/5/95) and a *very likely* higher performance in week 15 (90/10/0). At the end, athlete F displayed a *very likely* higher CMJ performance in week 11 (90/10/0), week 13 (93/7/0) and week 14 (97/3/0). All the other variations in CMJ for each athlete were deemed as no substantially different (*possibly or trivial*).

Moreover, CMJ performance average change from the baseline period are reported in the table 4.2.1 for athlete A, B, C, D, E and F. The average CMJ during the weeks of the 3 best competition performance (i.e. the weeks in which each athlete performed his/her 3 best results) was *very likely* higher for athlete C (98/2/0), while for athlete A, B, E and F was deemed as *possibly* higher. On the contrary, athlete D recorded a *possibly* lower change.

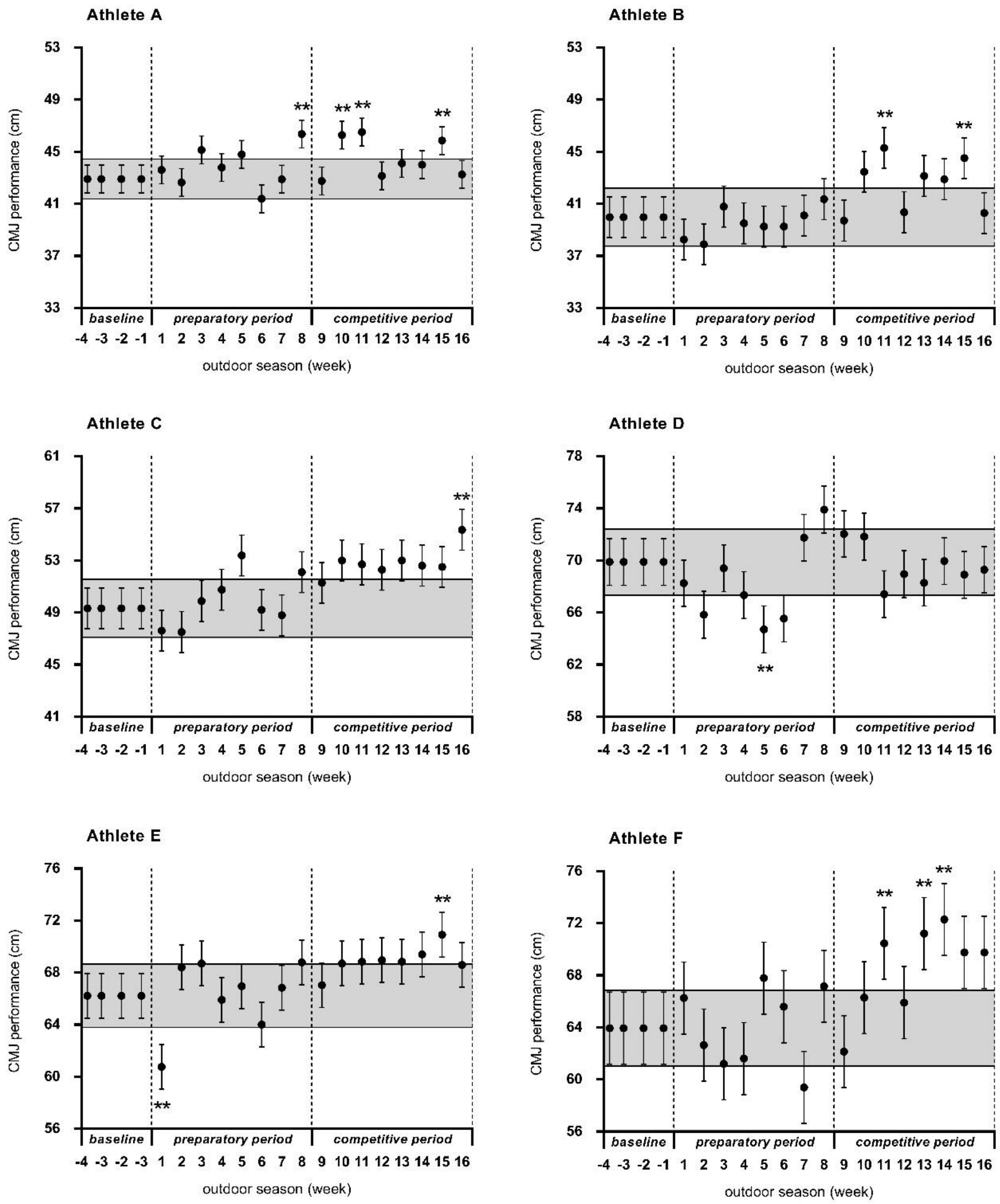

Figure 4.2.1 Individual trend in CMJ performance (cm) for each athlete. Grey area represent the coefficient of variation (CV) to assess meaningful change during the outdoor season from the baseline. Black dots depict vertical jump height (± typical error of measurement) during the preparatory and competitive period (**: very likely).

Athlete	Athletics event	CMJ during baseline (cm)	CMJ during the weeks of the 3 best competition performance (cm)			Average change from baseline	
						Quantitative chances (%)	Magnitude based inference
A	400hs	42.9	46.4	43.2	43.3	38/62/0	*Possibly +*
			week 8	*week 12*	*week 16*		
B	400hs	39.9	41.4	43.5	45.3	89/11/0	*Possibly +*
			week 8	*week 10*	*week 11*		
C	Long jump	49.3	52.3	53.0	55.4	98/2/0	*Very likely +*
			week 12	*week 13*	*week 16*		
D	High jump	69.9	67.4	68.9	69.3	0/86/14	*Possibly -*
			week 11	*week 15*	*week 16*		
E	Long jump	66.2	68.9	71.0	68.6	80/20/0	*Possibly +*
			week 12	*week 15*	*week 16*		
F	Triple jump	63.9	65.9	71.2	69.8	89/11/0	*Possibly +*
			week 12	*week 13*	*week 16*		

(+: higher; =: trivial; -: lower)

Table 4.2.1 Average change from linear trend (baseline) in countermovement jump (CMJ) performance.

4.2.2 RJT

Individual trend and changes in repeated jump test (RJT) performance during the outdoor season are depicted in the figure 4.2.2 for each athlete. Athlete A displayed a *very likely* lower RJT performance in week 12 (0/5/95), while athlete C a *very likely* higher performance in week 16 (93/7/0). Athlete D showed a *very likely* higher performance in week 4 (96/4/0), week 8 (97/30) and week 10 (98/2/0). Athlete E recorded a *very likely* higher RJT performance in week 14 (92/8/0) and week 16 (91/9/0). Athlete F displayed a *very likely* higher RJT performance in week 8 (93/7/0), week 10 (93/7/0) and week 11 (96/4/0). At the end, athlete B did not display any substantial changes over the season. All the other changes in RJT for each athlete were deemed as no substantially different (*possibly or trivial*).

Moreover, RJT performance average change from the baseline period are reported in the table 4.2.2 for athlete A, B, C, D, E and F. The average RJT during the weeks of the 3 best competition performance (i.e. the weeks in which each athlete displayed his/her 3 best results) was *very likely* trivial for athlete A (6/94/0), athlete C (9/91/0) and athlete D (8/92/0). The average changes for athlete B, E and F was deemed as *possibly* higher.

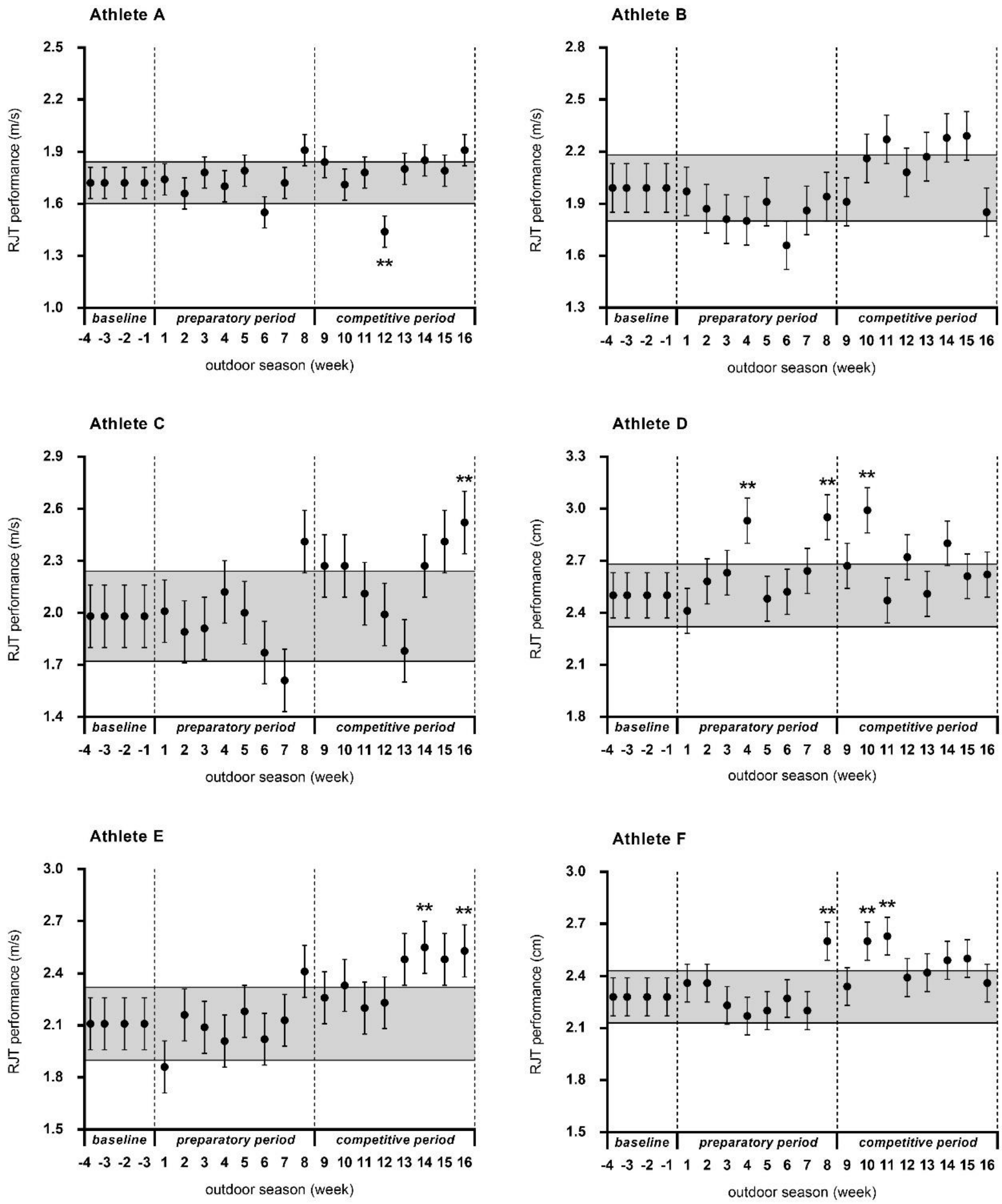

Figure 4.2.2 Individual trend in RJT performance (m/s) for each athlete. Grey area represent the coefficient of variation (CV) to assess meaningful change during the outdoor season from the baseline. Black dots depict the reactive strength index (± typical error of measurement) during the preparatory and competitive period (**: very likely).

Athlete	Athletics event	RJT during baseline (m/s)	RJT during the weeks of the 3 best competition performance (m/s)			Average change from baseline	
						Quantitative chances (%)	Magnitude based inference
A	400hs	1.72	1.91	1.44	1.99	6/94/0	*Very likely =*
			week 8	*week 12*	*week 16*		
B	400hs	1.99	1.94	2.16	2.27	26/74/1	*Possibly +*
			week 8	*week 10*	*week 11*		
C	Long jump	1.98	1.99	1.78	2.52	9/91/0	*Very likely =*
			week 12	*week 13*	*week 16*		
D	High jump	2.50	2.47	2.61	2.62	8/92/0	*Very likely =*
			week 11	*week 15*	*week 16*		
E	Long jump	2.11	2.23	2.52	2.53	88/12/0	*Possibly +*
			week 12	*week 15*	*week 16*		
F	Triple jump	2.28	2.39	2.42	2.36	27/73/0	*Possibly +*
			week 12	*week 13*	*week 16*		

(+: higher; =: trivial; -: lower)

Table 4.2.2 Average change from linear trend (baseline) in repeated jump test (RJT) performance.

4.3 Individual trend and changes in perceptual fatigue measures during the outdoor season

Perceptual fatigue measures indicate the wellbeing score for each athlete and are presented in the following section. According to the 7-point Likert scale described in the section 3.3.3, lower scores correspond to a better perception of wellbeing (i.e. less perceptual fatigue or DOMS, good quality of sleep, higher sleep time), while higher scores to a worse wellbeing (i.e. high level of soreness, few hours of sleep time). All athletes responded to the daily questionnaire for the 16-week period for a total of 649 questionnaires collected and analysed (average per athlete: 108.2±4.4 on 112 days).

4.3.1 Total perceptual fatigue

Individual trend and changes in total perceptual fatigue score during the outdoor season are depicted in the figure 4.3.1 for each athlete. Athlete A did not display any substantial changes over the season, while athlete B during the week 1 (99/1/0) and 2 (91/9/0) reported a *very likely* higher score for total perceptual fatigue. Athlete C displayed a *very likely* lower score in week 7 (0/7/93) and in week 10 (0/9/91), athlete D in week 5 (0/6/94) and week 16 (0/2/98), athlete E in week 14 (0/1/99) and week 16 (0/0/100) and, athlete F in week 16 (0/0/100). All the other changes in total perceptual fatigue score were deemed as no substantially different (*possibly or trivial*).

Moreover, total perceptual fatigue average change from the baseline period are reported in the table 4.3.1 for athlete A, B, C, D, E and F. The average total perceptual fatigue score during the weeks of the 3 best competition performance (i.e. the weeks in which each athlete displayed his/her 3 best results) was *very likely* lower for athlete E (0/0/100) and athlete F (0/4/96). A *very likely* trivial change was recorded for athlete A (0/93/7). The average change for athlete C and D was deemed as *possibly* lower, while for the athlete B as *possibly* higher.

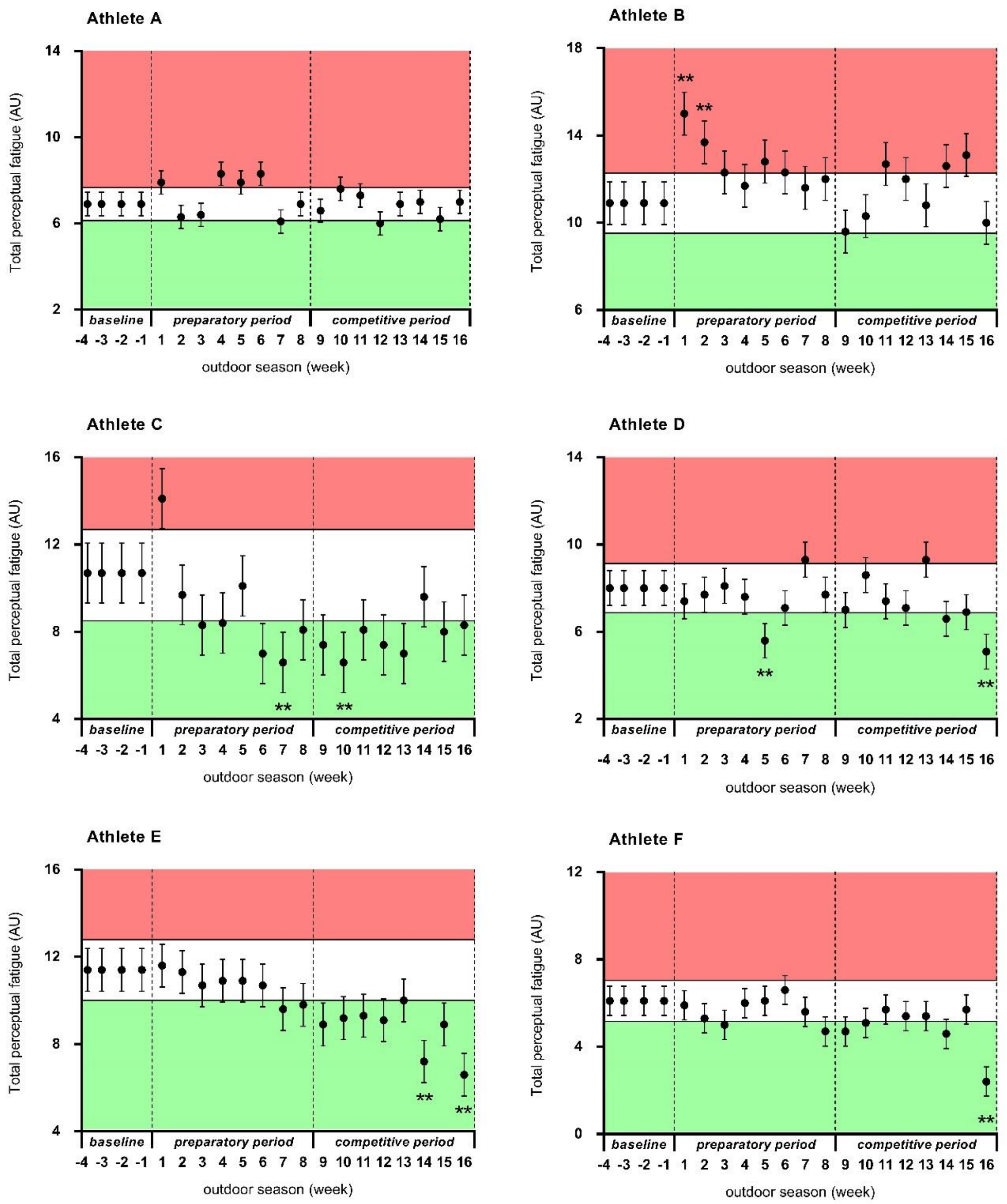

Figure 4.3.1 Individual trend in total perceptual fatigue (AU) for each athlete. The 2 black horizontal lines represent the limits of the coefficient of variation (CV) to assess meaningful change during the outdoor season from the baseline. Lower scores indicate a better perception of total perceptual fatigue (green area), and higher scores indicate a worse sense of total perceptual fatigue (red area). Black dots depict the total perceptual fatigue (± typical error of measurement) during the preparatory and competitive period (**: very likely).

Athlete	**Athletics event**	**TPF during baseline (AU)**	**TPF during the weeks of the 3 best competition performance (AU)**			**Average change from baseline**	
						Quantitative chances (%)	**Magnitude based inference**
A	400hs	6.9	6.9	6.0	7.0	0/93/7	*Very likely =*
			week 8	*week 12*	*week 16*		
B	400hs	10.9	12.0	10.3	12.7	14/86/0	*Possibly +*
			week 8	*week 10*	*week 11*		
C	Long jump	10.7	8.0	8.3	8.3	0/25/75	*Possibly* -
			week 12	*week 13*	*week 16*		
D	High jump	8.0	7.4	6.9	5.1	0/20/80	*Possibly* -
			week 11	*week 15*	*week 16*		
E	Long jump	11.4	9.1	8.7	6.6	0/0/100	*Very likely* -
			week 12	*week 15*	*week 16*		
F	Triple jump	6.1	5.4	5.4	2.4	0/4/96	*Very likely* -
			week 12	*week 13*	*week 16*		

(+: higher; =: trivial; -: lower)

Table 4.3.1 Average change from linear trend (baseline) in total perceptual fatigue (TPF).

4.3.2 Fatigue

Individual trend and changes in fatigue score during the outdoor season are depicted in the figure 4.3.2 for each athlete. Athlete A and C displayed a *very likely* higher fatigue score in week 16 (95/5/0) and week 2 (97/3/0), respectively. Athlete D outlined a *very likely* higher fatigue score during the week 7 (98/2/0) and week 9 (96/4/0), while athlete F in week 13 (93/7/0). On the contrary, athlete B recorded *very likely* lower fatigue scores in week 3 (0/10/90), week 10 (0/10/90) and week 11 (0/6/94), while athlete E in week 11 (0/4/96) and week 14 (0/1/99) showed the same statistical outcome. All the other changes were deemed as no substantially different (*possibly or trivial*).

Moreover, fatigue average change from the baseline period are reported in the table 4.3.2 for athlete A, B, C, D, E and F. The average fatigue score during the weeks of the 3 best competition performance (i.e. the weeks in which each athlete displayed his/her 3 best results) was *very likely* lower for athlete B (0/2/98) and athlete E (0/6/94). A *very likely* trivial change was recorded for athlete A (4/96/0) and for athlete F (7/93/0). The average change for athlete C and D was deemed as *possibly* lower and *possibly* higher, respectively.

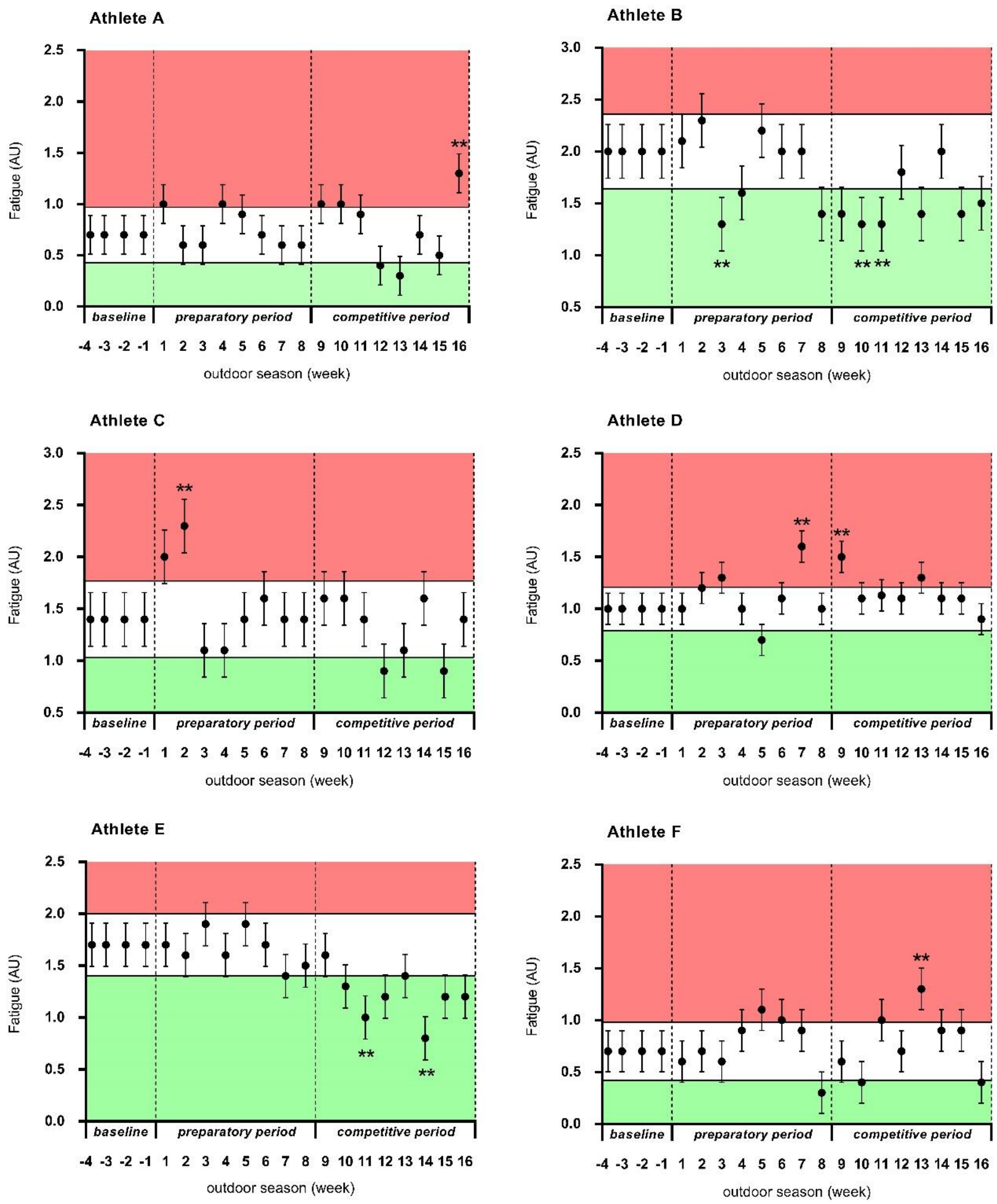

Figure 4.3.2 Individual trend in fatigue (AU) score for each athlete. The 2 black horizontal lines represent the limits of the coefficient of variation (CV) to assess meaningful change during the outdoor season from the baseline. Lower scores indicate a better perception of fatigue (green area), and higher scores indicate a worse sense of fatigue (red area). Black dots depict the total perceptual fatigue (± typical error of measurement) during the preparatory and competitive period (**: very likely).

Athlete	Athletics event	FAT during baseline (AU)	FAT during the weeks of the 3 best competition performance (AU)			Average change from baseline	
						Quantitative chances (%)	Magnitude based inference
A	400hs	0.7	0.6 *week 8*	0.4 *week 12*	1.3 *week 16*	4/96/0	*Very likely =*
B	400hs	2.0	1.4 *week 8*	1.3 *week 10*	1.3 *week 11*	0/2/98	*Very likely* -
C	Long jump	1.4	0.9 *week 12*	1.1 *week 13*	1.4 *week 16*	0/75/25	*Possibly* -
D	High jump	1.0	1.3 *week 11*	1.1 *week 15*	0.9 *week 16*	13/87/0	*Possibly +*
E	Long jump	1.7	1.1 *week 12*	1.2 *week 15*	1.2 *week 16*	0/6/94	*Very likely* -
F	Triple jump	0.7	0.7 *week 12*	1.3 *week 13*	0.4 *week 16*	7/93/0	*Very likely =*

(+: higher; =: trivial; -: lower)

Table 4.3.2 Average change from linear trend (baseline) in fatigue score.

4.3.3 DOMS

Individual trend and changes in DOMS score during the outdoor season are depicted in the figure 4.3.3 for each athlete. Athlete D did not display any substantial changes over the season, while athlete B during the week 6 (96/4/0) reported a *very likely* higher score for DOMS score. All the other athletes showed at least one *very likely* lower score in DOMS as follows: athlete A in week 12 (0/8/92) and week 13 (0/1/99); athlete C in week 1 (0/2/98), week 3 (0/2/98), week 7 (0/2/98) and week 10 (0/2/98); athlete E in week 11 (0/6/94), week 12 (0/2/98), week 15 (0/2/98) and week 16 (0/1/99); and athlete F in week 4 (0/7/93) and week 5 (0/7/93)

displayed a *very likely* lower score in week 7 (0/7/93) and in week 10 (0/9/91), athlete D in week 5 (0/6/94) and week 16 (0/2/98), athlete E in week 14 (0/1/99) and week 16 (0/0/100) and, athlete F in week 16 (0/0/100). All the other changes in DOMS score for each athlete were deemed as no substantially different (*possibly or trivial*).

Moreover, DOMS average change from the baseline period are reported in the table 4.3.3 for athlete A, B, C, D, E and F. The average DOMS score during the weeks of the 3 best competition performance (i.e. the weeks in which each athlete displayed his/her 3 best results) was *very likely* lower for athlete A (0/8/92) and athlete E (0/0/100). A *very likely* trivial change was recorded for athlete D (1/97/2). The average change for athlete C and F was deemed as *possibly* lower, while for the athlete B as *possibly* higher.

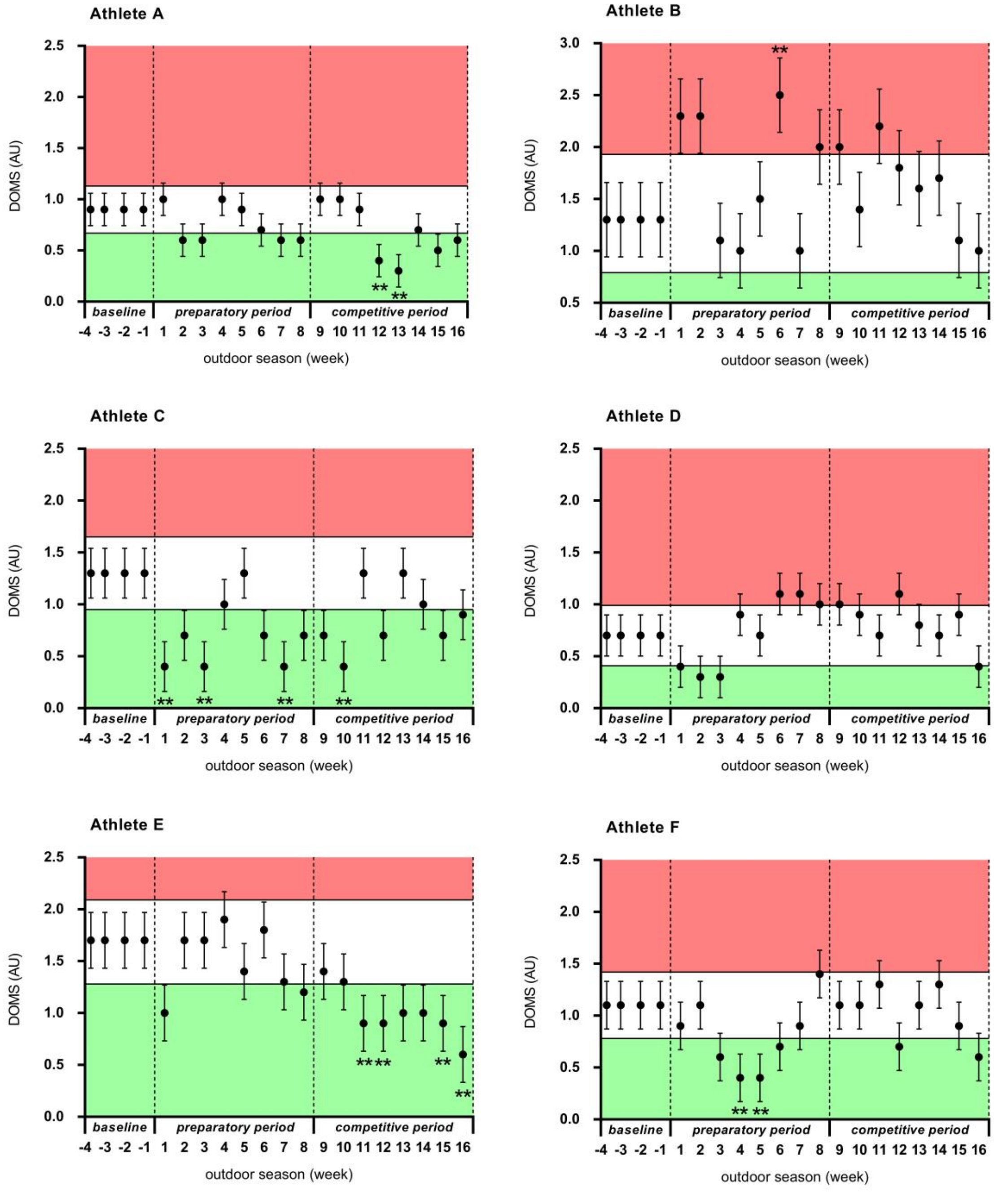

Figure 4.3.3 Individual trend in DOMS (AU) score for each athlete. The 2 black horizontal lines represent the limits of the coefficient of variation (CV) to assess meaningful change during the outdoor season from the baseline. Lower scores indicate a better perception of DOMS (green area), and higher scores indicate a worse sense of DOMS (red area). Black dots depict the DOMS score (± typical error of measurement) during the preparatory and competitive period (**: very likely).

Athlete	Athletics event	DOMS during baseline (AU)	DOMS during the weeks of the 3 best competition performance (AU)			Average change from baseline	
						Quantitative chances (%)	Magnitude based inference
A	400hs	0.9	0.6	0.4	0.6	0/8/92	*Very likely -*
			week 8	*week 12*	*week 16*		
B	400hs	1.3	2.0	1.4	2.2	60/40/0	*Possibly +*
			week 8	*week 10*	*week 11*		
C	Long jump	1.3	0.7	1.3	0.9	0/55/45	*Possibly -*
			week 12	*week 13*	*week 16*		
D	High jump	0.7	0.7	0.9	0.4	1/97/2	*Very likely =*
			week 11	*week 15*	*week 16*		
E	Long jump	1.7	0.9	0.9	0.6	0/0/100	*Very likely -*
			week 12	*week 15*	*week 16*		
F	Triple jump	1.1	0.7	1.1	0.6	0/61/39	*Possibly -*
			week 12	*week 13*	*week 16*		

(+: higher; =: trivial; -: lower)

Table 4.3.3 Average change from linear trend (baseline) in DOMS.

4.3.4 Sleep quantity

Individual trend and changes in sleep quantity score during the outdoor season are depicted in the figure 4.3.4 for each athlete. All the athletes showed at least one *very likely* lower score in sleep quantity score as follows: athlete A in week 7 (0/3/97) and week 10 (0/8/92); athlete B in week 10 (0/2/98) and week 16 (0/9/91); athlete C in week 9 (0/0/100), week 15 (0/5/95) and week 16 (0/2/98); athlete D in week 9 (0/9/91), week 10 (0/0/100) and week 16 (0/5/95). Athlete E (0/5/95) and F (0/1/99) displayed a *very likely* lower score in week 16. All the other changes were deemed as no substantially different (*possibly or trivial*).

Moreover, sleep quantity average change from the baseline period are reported in the table 4.3.4 for athlete A, B, C, D, E and F. The average sleep quantity score during the weeks of the 3 best competition performance (i.e. the weeks in which each athlete displayed his/her 3 best results) was *very likely* lower for athlete C (0/8/92). For the remaining athletes a *possibly* lower inference was recorded.

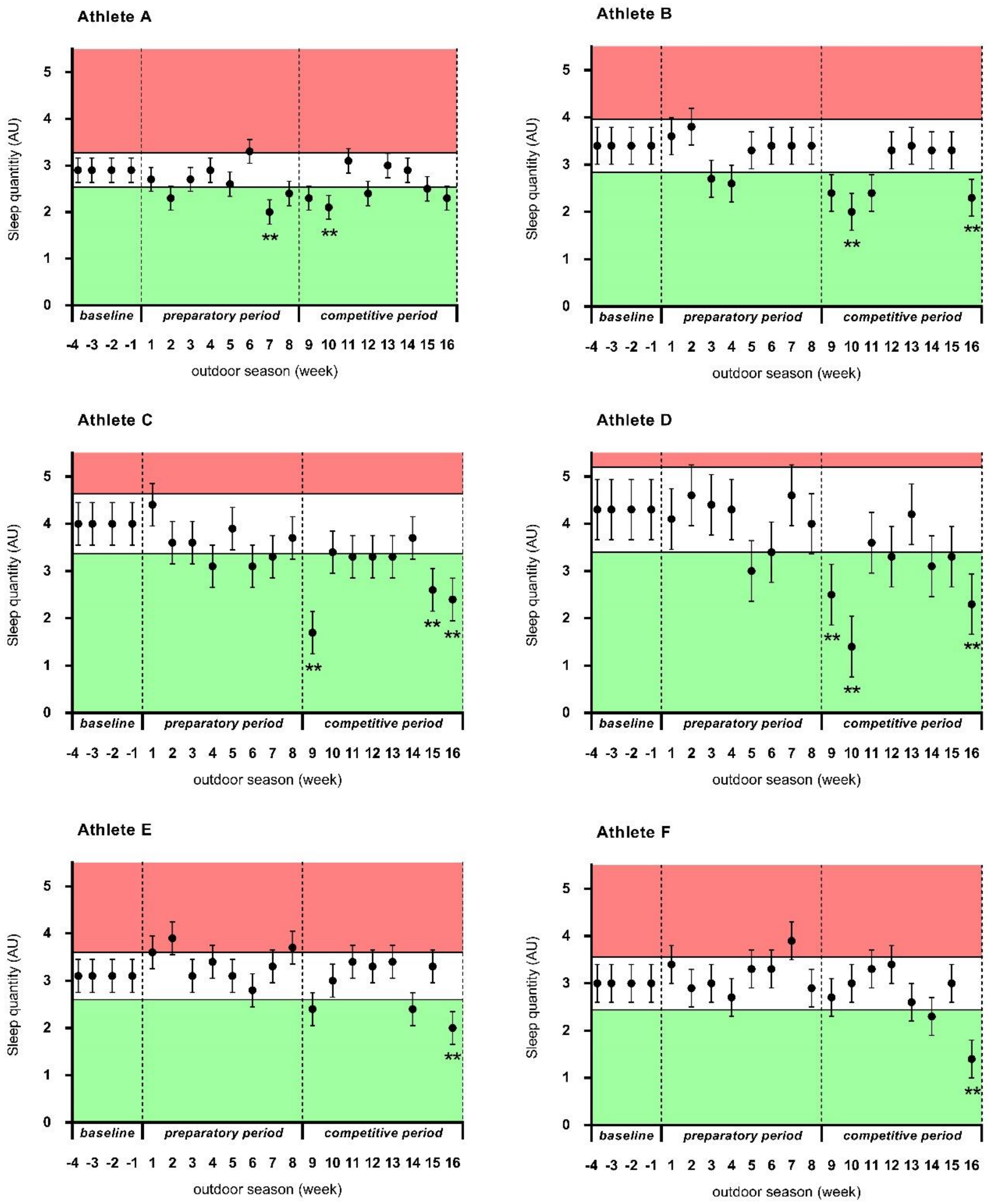

Figure 4.3.4 Individual trend in sleep quantity (AU) score for each athlete. The 2 black horizontal lines represent the limits of the coefficient of variation (CV) to assess meaningful change during the outdoor season from the baseline. Lower scores indicate a higher sleep time (green area), and higher scores indicate lower sleep time(red area). Black dots depict the sleep quantity score (± typical error of measurement) during the preparatory and competitive period (**: very likely).

Athlete	Athletics event	SLQUAN during baseline (AU)	SLQUAN during the weeks of the 3 best competition performance (AU)			Average change from baseline	
						Quantitative chances (%)	Magnitude based inference
A	400hs	2.9	2.4	2.4	2.3	0/18/82	*Possibly* -
			week 8	*week 12*	*week 16*		
B	400hs	3.4	3.4	2.0	2.4	0/15/85	*Possibly* -
			week 8	*week 10*	*week 11*		
C	Long jump	4	3.3	3.3	2.4	0/8/92	*Very likely* -
			week 12	*week 13*	*week 16*		
D	High jump	4.3	3.6	3.3	2.3	0/18/82	*Possibly* -
			week 11	*week 15*	*week 16*		
E	Long jump	3.1	3.3	3.3	2.0	0/89/11	*Possibly* -
			week 12	*week 15*	*week 16*		
F	Triple jump	3	3.4	2.6	1.4	0/55/45	*Possibly* -
			week 12	*week 13*	*week 16*		

(+: higher; =: trivial; -: lower)

Table 4.3.4 Average change from linear trend (baseline) in sleep quantity.

4.3.5 Sleep quality

Athlete B and D did not report any substantially different score during the 16-week period, while athlete A displayed a *very likely* higher sleep quality in week 8 (99/1/0). On the contrary athlete C, E and F showed a *very likely* lower sleep quality score [athlete C: week 4 (0/8/92); athlete E: week 2 (0/5/95), week 3 (0/5/95), week 4 (0/5/95)¸ week 7 (0/5/95), week 8 (0/9/91)¸ week 10 (0/9/91), week 11 (0/5/95), week 14 (0/1/99), week 16 (0/1/99); and athlete F: week 7 (0/5/95), week 8 (0/5/95)¸ week 11 (0/6/94), week 14 (0/6/96), week 14 (0/5/95)]. All the other changes were deemed as no substantially different (*possibly or trivial*).

Moreover, sleep quality average change from the baseline period are reported in the table 4.3.5 for athlete A, B, C, D, E and F. The average sleep quality score during the weeks of the 3 best competition performance (i.e. the weeks in which each athlete displayed his/her 3 best results) was *very likely* lower for athlete E (0/7/93) and athlete F (0/8/92). For athletes C and D a *possibly* lower inference was recorded, while athlete A and B showed the opposite statistical outcome as *possibly* higher score.

Athlete	**Athletics event**	**SLQUAL baseline (AU)**	**SLQUAL during the weeks of the 3 best competition performance (AU)**			**Average change from baseline**	
						Quantitative chances (%)	**Magnitude based inference**
A	400hs	0.4	1.3	0.6	0.4	59/41/0	*Possibly* +
			week 8	*week 12*	*week 16*		
B	400hs	1.7	1.8	1.7	2.3	14/86/0	*Possibly* +
			week 8	*week 10*	*week 11*		
C	Long jump	1.6	1.1	0.9	1.7	0/88/12	*Possibly* -
			week 12	*week 13*	*week 16*		
D	High jump	0.6	0.4	0.4	0.4	0/89/11	*Possibly* -
			week 11	*week 15*	*week 16*		
E	Long jump	1.7	1.4	1.6	1.2	0/7/93	*Very likely* -
			week 12	*week 15*	*week 16*		
F	Triple jump	1	0.6	0.4	0.1	0/8/92	*Very likely* -
			week 12	*week 13*	*week 16*		

(+: higher; =: trivial; -: lower)

Table 4.3.5 Average change from linear trend (baseline) in sleep quality.

4.3.6 Health

All the athletes showed at least one *very likely* lower score in sleep quantity score as follows: athlete A in week 7 (0/3/97) and week 10 (0/8/92); athlete B in week 10 (0/2/98) and week 16 (0/9/91); athlete C in week 9 (0/0/100), week 15 (0/5/95) and week 16 (0/2/98); athlete D in week 9 (0/9/91), week 10 (0/0/100) and week 16 (0/5/95). Athlete E (0/5/95) and F (0/1/99) displayed a *very likely* lower score in week 16. All the other changes were deemed as no substantially different (*possibly or trivial*).

Moreover, health average change from the baseline period are reported in the table 4.3.6 for athlete A, B, C, D, E and F. The average health score during the weeks of the 3 best competition performance (i.e. the weeks in which each athlete displayed his/her 3 best results) was *very likely* lower for athlete E (0/4/96). Athlete B (2/97/1) and D (0/92/8) recorded a *very likely* trivial change from the baseline. Finally, the change of the athlete A, C and F was deemed as *possibly* lower comparing to the baseline.

Athlete	**Athletics event**	**Health during baseline (AU)**	**Health during the weeks of the 3 best competition performance (AU)**			**Average change from baseline**	
						Quantitative chances (%)	**Magnitude based inference**
A	400hs	1.0	1.1	0.3	0.6	0/60/40	*Possibly -*
			week 8	*week 12*	*week 16*		
B	400hs	1.3	1.2	1.4	1.3	2/97/1	*Very likely =*
			week 8	*week 10*	*week 11*		
C	Long jump	1.1	0.9	0.3	0.0	0/49/51	*Possibly -*
			week 12	*week 13*	*week 16*		
D	High jump	0.4	0.4	0.1	0.0	0/92/8	*Very likely =*
			week 11	*week 15*	*week 16*		
E	Long jump	1.7	1.1	1.0	1.2	0/4/96	*Very likely -*
			week 12	*week 15*	*week 16*		
F	Triple jump	0.3	0.0	0.0	0.0	0/20/80	*Possibly -*
			week 12	*week 13*	*week 16*		

(+: higher; =: trivial; -: lower)

Table 4.3.6 Average change from linear trend (baseline) in health.

4.3.7 Mood

Athlete A, athlete B, athlete C and athlete F showed a *very likely* higher score in mood as follows: athlete A in week 6 (94/6/0) and week 16 (99/1/0); athlete B in week 4 (93/7/0), week 10 (93/7/0), week 11 (100/0/0), week 12 (97/3/0) and week 15 (99/1/0); athlete C in week 1 (93/7/0) and athlete F in week 6 (100/0/0). On the contrary, athlete D and athlete E displayed a *very likely* lower score in mood [athlete D: week 2 (0/6/94), week 12 (0/8/92), week 14 (0/2/98), week 16 (0/0/100); athlete E: week 15 (0/8/92), week 16 (0/0/100)]. All the other changes were deemed as no substantially different (*possibly or trivial*).

Moreover, mood average change from the baseline period are reported in the table 4.3.7 for athlete A, B, C, D, E and F. The average mood score during the weeks of the 3 best competition performance (i.e. the weeks in which each athlete displayed his/her 3 best results) was *very likely* lower for athlete D (0/0/100) and athlete E (0/4/96). Athlete C (0/96/4) and F (2/96/2) recorded a *very likely* trivial change from the baseline. Finally, the change of the athlete B was *very likely* higher, while athlete A did not displayed a substantially different change.

Athlete	**Athletics event**	**Mood during baseline (AU)**	**Mood during the weeks of the 3 best competition performance (AU)**			**Average change from baseline**	
						Quantitative chances (%)	**Magnitude based inference**
A	400hs	1.0	0.9	1.4	1.9	68/32/0	*Possibly +*
			week 8	*week 12*	*week 16*		
B	400hs	1.1	2.2	2.4	3.2	100/0/0	*Very likely +*
			week 8	*week 10*	*week 11*		
C	Long jump	1.3	1.1	1.3	1.1	0/96/4	*Very likely =*
			week 12	*week 13*	*week 16*		
D	High jump	1.4	1.0	1.0	0.4	0/0/100	*Very likely -*
			week 11	*week 15*	*week 16*		
E	Long jump	1.4	1.3	0.9	0.4	0/1/99	*Very likely -*
			week 12	*week 15*	*week 16*		
F	Triple jump	0.0	0.0	0.0	0.0	2/96/2	*Very likely =*
			week 12	*week 13*	*week 16*		

(+: higher; =: trivial; -: lower)

Table 4.3.7 Average change from linear trend (baseline) in mood.

4.4 Hierarchical clustering analysis

The figure 4.4.1 and 4.4.2 depict the hierarchical clustering analysis performed for the preparatory and competitive period, respectively. The analysis allows to describe the training profiles of the two aforementioned periods in terms of training load, neuromuscular readiness and perceptual fatigue measures related to the six athletes involved into the study. A total of 96 cases (48 preparatory + 48 competitive) were collected and analysed.

4.4.1 Clustering analysis during the preparatory period

From the dendrogram reported in the figure 4.4.1, five clusters were identified. These cases were classified according to the obtained data in three major groups of variables, as described: group 1 (DOMS, FATIGUE, SLEEP_QUAL, HEALTH, MOOD, TOT_FATIGUE), group 2 (SLEEP_QUAN, RJT, CMJ), group 3 (WEIGHT, JUMP, TR_MODE, RUN, SPRINT, TR_DUR, TR_FRE). Cluster 1 (*n*=4) included cases belonging to athlete A only. Cluster 2 (*n*=16) was the most copious with cases from athlete C, D, E and F, showing the lowest score in HEALTH. Cluster 3 (*n*=10) presented cases mainly from week 3 and 8 belonging to the athletes A, C, D and F, depicting technical training as TR_MOD. Cluster 4 (*n*=12) reported cases mainly from athlete E, B and C, showing higher score for DOMS and FATIGUE. Finally, cluster 5 (*n*=5) gathered cases mainly from athlete B, reporting higher score in HEALTH, SLEEP_QUAL and MOOD.

4.4.2 Clustering analysis during the competitive period

From the dendrogram reported in the figure 4.4.2, five clusters were identified. These cases were classified according to the obtained data in three major groups of variables, as described: group 1 (DOMS, FATIGUE, SLEEP_QUAL, HEALTH, MOOD, TOT_FATIGUE), group 2 (SLEEP_QUAN, RJT, CMJ) and group 3 (WEIGHT, JUMP, TR_MODE, RUN, SPRINT, TR_DUR, TR_FRE). Cluster 1 (*n*=6) included cases from the week 9 only, showing the highest scores during the period in terms of TR_FRE, TR_DUR, JUMP and WEIGHT. Cluster 2 (*n*=9) and cluster 3 (*n*=6) presented cases mainly from athlete A and athlete B, respectively. Cluster 3 included cases with high score in TOT_FATIGUE and MOOD. Cluster 4 (*n*=14) was the most numerous and reported cases from athlete C, athlete D and athlete E. Finally, cluster 5 (*n*=13) gathered cases mainly from athlete D and athlete F, showing lower scores in MOOD and HEALTH, but higher score in CMJ.

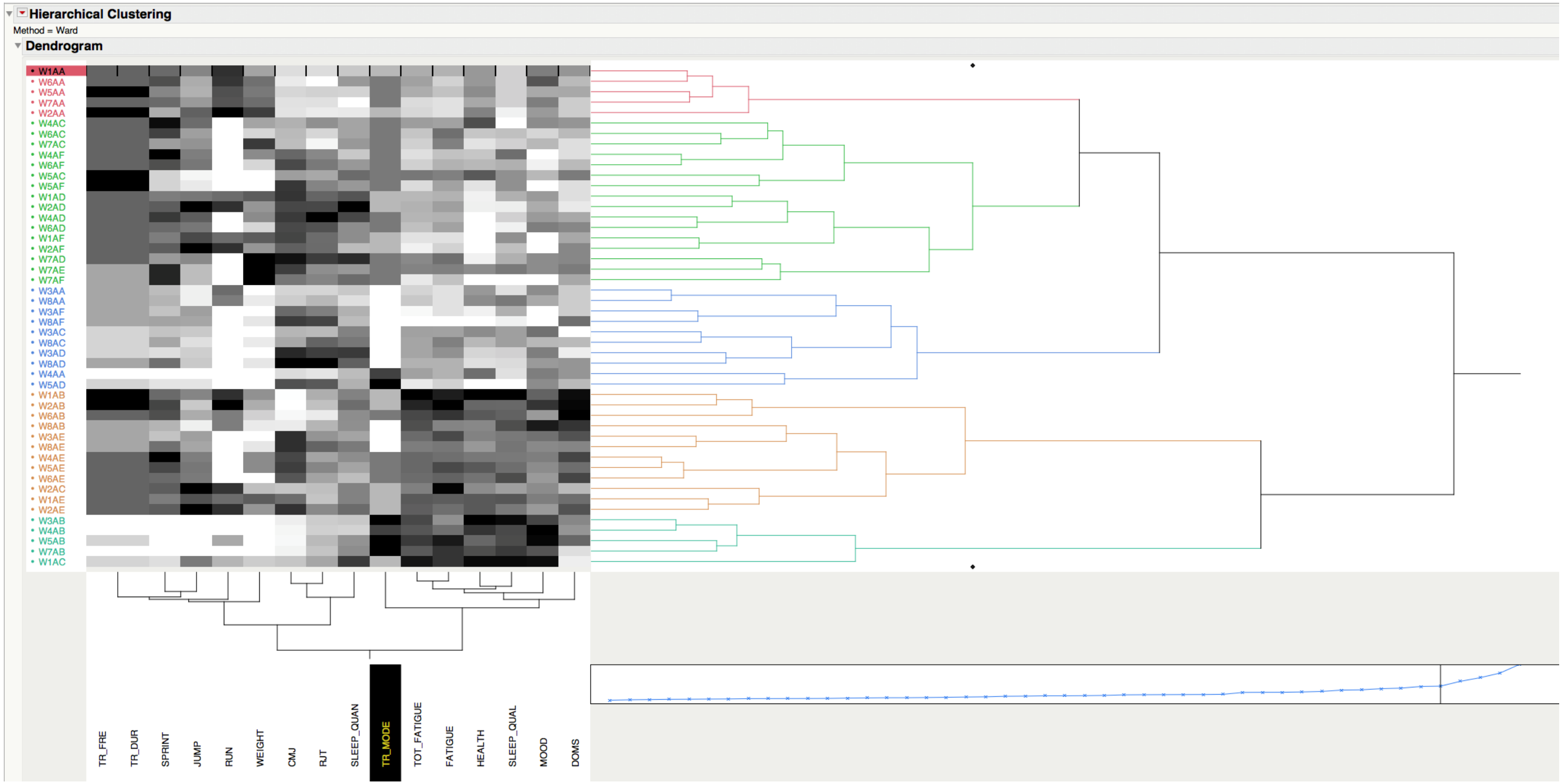

Figure 4.4.1 Hierarchical clustering analysis of training load, neuromuscular readiness and perceptual fatigue variables during the preparatory period. Weeks and athletes are shown in the rows (W: week, A: athlete). Heat map indicates the predominance of the values (i.e. black colour indicate higher values, while white colour lower values). (TR_FRE: training frequency; TR_DUR: training duration; SPRINT: sprint volume; RUN: running volume; JUMP: jumps volume; WEIGHT: weight volume; CMJ: countermovement jump performance; RJT: repeated jump test performance; TOT_FATIGUE: total perceptual fatigue score; FATIGUE: fatigue score; DOMS: DOMS score; HEALTH: health score; SLEEP_QUAN: sleep quantity score; SLEEP_QUAL: sleep quality score; MOOD: mood score).

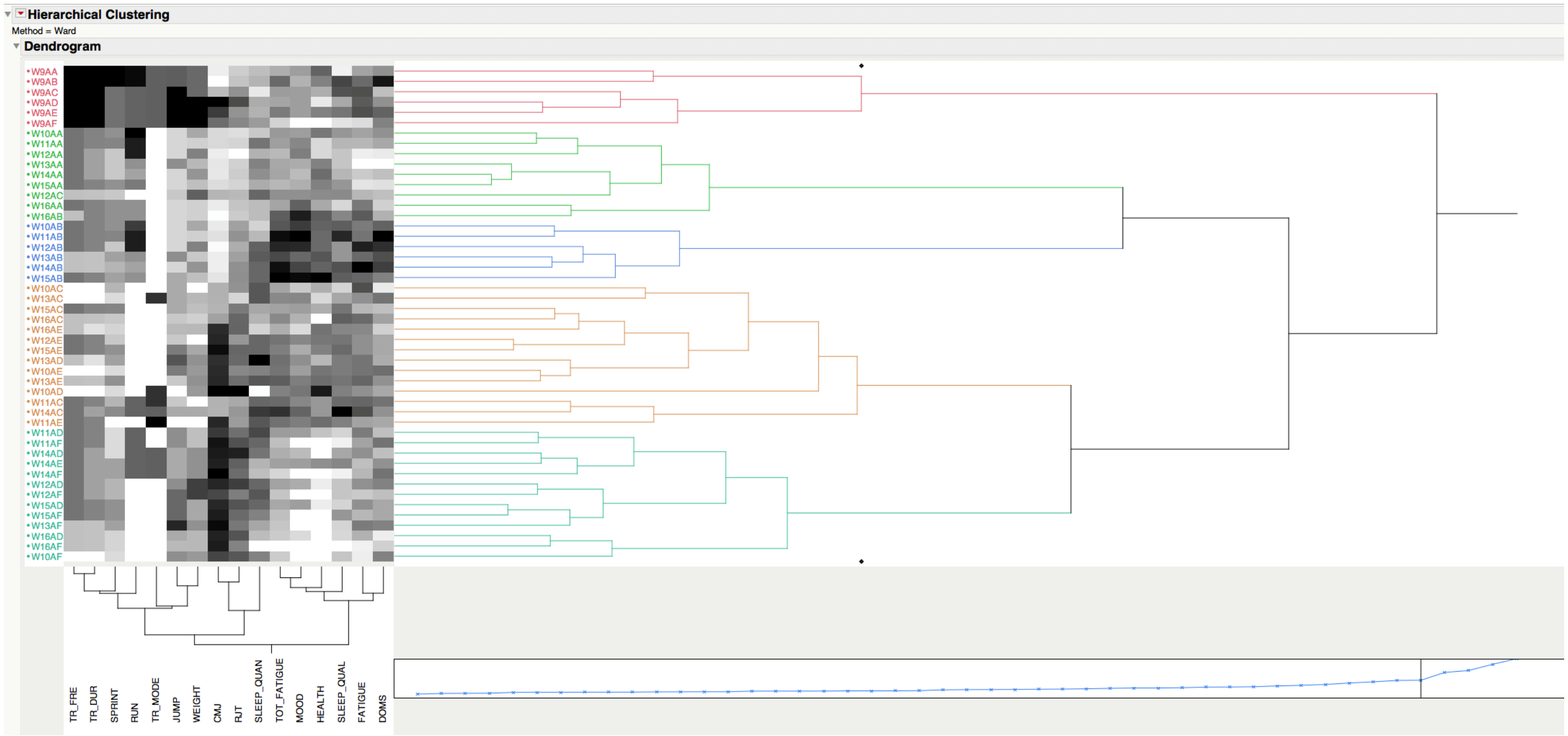

Figure 4.4.1 Hierarchical clustering analysis of training load, neuromuscular readiness and perceptual fatigue variables during the competitive period. Weeks and athletes are shown in the rows (W: week, A: athlete). Heat map indicates the predominance of the values (i.e. black colour indicate higher values, while white colour lower values). (TR_FRE: training frequency; TR_DUR: training duration; SPRINT: sprint volume; RUN: running volume; JUMP: jumps volume; WEIGHT: weight volume; CMJ: countermovement jump performance; RJT: repeated jump test performance; TOT_FATIGUE: total perceptual fatigue score; FATIGUE: fatigue score; DOMS: DOMS score; HEALTH: health score; SLEEP_QUAN: sleep quantity score; SLEEP_QUAL: sleep quality score; MOOD: mood score).

5. Discussion

The present study aimed to: a) investigate changes in training load, neuromuscular readiness, perceptual fatigue and competition performance; b) identify associations between the aforementioned variables and the best competition performances, and c) provide a set of training load variables that describe the variations during the outdoor season in U20 track and field athletes. The main findings demonstrated substantial decreases in training load during the competitive period comparing to the preparatory phase, especially in training frequency and duration, sprint and jumps volume. Secondly, CMJ and perceptual fatigue measures (mainly sleep quantity) were associated with the 3 best competition performances during the outdoor season but differences were found between athletes indicating the necessity of individualized monitoring strategies. Finally, the cluster analyses allowed the identification of the cases in which athletes performed at their best during the season underlining the practical connections between variables (i.e. neuromuscular readiness measures and sleep quantity).

The present results revealed an overall decrease in training load during the competitive period especially in terms of training frequency, training duration, sprint volume and jumps volume in all athletes analysed. These results are in line with the evidences presented in a recent work by Mujika and colleagues (Inigo Mujika, Halson, Burke, Balagué, & Farrow, 2018) in which clear differences between the preparation phases (general and specific) and the competition or taper phases were shown in individual sports athletes. The integrated periodization plan proposed for athletics is characterized by moderate-to-high training volume, high training intensity during the preparation phase and a diminished training load during the competitive period due to taper strategies. Indeed, a substantial reduction in volume is required in individual sports to achieve peak performance (Bosquet et al., 2007; Iñigo Mujika, Padilla, Pyne, & Busso, 2004; Turner, 2011). This may explain the decrease of the prescribed training load for sprint and jumps volume, and for training frequency and duration shown in the competitive phase. However, our results are referred to a small sample size (i.e. six athletes) under the supervision of the same coach. Therefore, the total training load reflects the periodization and training principles adopted by the coach. Despite this, our results are in line with the scientific-evidences from study report and cases published about training periodization for individual sports (Leif Inge Tjelta, 2013; Inigo Mujika et al., 2018) in which seasonal variations in training load were reported for a limited number of athletes. At the end, it is worth to mention that one athlete showed a different pattern. The athlete performed similar amount of training volume due to an injury sustained during the preparatory period that alters the training plan. This fact underlines the importance of having training load indicators as proof of the training periodization adopted with individual sports athletes (Murray, 2017).

Monitoring neuromuscular readiness through vertical jump tests on a weekly-basis provided a practical and useful tool for practitioners. In fact, the results indicated an increase of CMJ performance corresponding to a decrease of the prescribed training load during the competitive period. In particular, some athletes displayed an ideal trend with higher vertical jump scores in the weeks in which they performed their 3 best performances during official competitions underlining a possible association between the CMJ and athletics performance. Only one athlete did not show the same trend displaying average results during the competitive weeks. Previous research in athletics reported a correlation between CMJ and athletics performance in senior power-events (i.e. sprint and jumps) and middle distance athletes (Balsalobre-Fernańdez et al., 2014; Jiménez-Reyes & González-Badillo, 2011; Loturco et al., 2015). An increased vertical jump performance during the competitive weeks might be explained by a reduced total training load performed during the competitive period as outlined in a study with middle-distance runners (Balsalobre-Fernańdez et al., 2014). However, CMJ performance did not always increase during the competitive season possibly due to the accumulation of competition workloads and the training strategies adopted by the coaching staff may have limited the increase of neuromuscular fatigue. Also in team sports, assessing the level of neuromuscular fatigue using the CMJ is an effective and well-established tool implemented in several monitoring systems (Carling et al., 2018; Taylor et al., 2012). Indeed, previous research revealed that vertical jump measures declines following a rugby match and this diminished trend can last until 72 hours from the game (Cormack, Newton, McGuigan, et al., 2008). In athletics, no data exists on the management of neuromuscular fatigue after a track competition, but the outcomes obtained from this research confirmed the usefulness as indicator of neuromuscular readiness in young athletes competing in power events. Further studies have to investigates weekly variations in neuromuscular readiness during the microcycle to deepen the time needed to fully recover from an official competition.

A second vertical jump assessment, the repeated jump test (RJT), was performed on a weekly basis but the results obtained differ from the CMJ both as longitudinal trend and association with competition performance. Athletes displayed different patterns with some athletes showing increasing, stable or decreasing trend during the 16-week period. Moreover, only three athletes showed a possibly higher RJT score in the weeks of the best competition performance. From an athletics performance perspective, this protocol demonstrated not to be efficient in determining neuromuscular readiness, but it may be used for other purposes including return to sport and rehab process. In this view, previous evidences suggested repeated jumps protocols (unilateral and bilateral) as functional test to assess the neuromuscular function and asymmetries between limbs (Ardern et al., 2016). Furthermore, this outcome may be due to the repeated nature of the rebounding test (Harper & Hobbs, 2011); in fact, previous evidences demonstrated that repeated jumps protocols have a lower level of reliability and time efficient application comparing to single jumps test (Rob Gathercole et al., 2015). Despite this limitations, athletes competing in jumping events showed higher RJT scores comparing to the athletes comparing in sprint and hurdles events; further studies have to proof the real efficacy of this repeated jump protocols.

One of the aims of this study was to investigate the variations in perceptual fatigue measures in under 20 track and field athletes. Nowadays the use of wellness questionnaires to monitor the stress-recovery balance in athletes is s well-established method to monitor athlete readiness (Halson, 2014; Kellmann et al., 2018; Saw et al., 2016). To the best of our knowledge this is the first study analysing variations in perceptual fatigue during an outdoor season in junior track and field athletes. The results indicated that a low level of perceptual fatigue is associated with the season best results. In this view, one of the most significant outcome come from the measures of sleep quantity. Our results suggested the association between sleep quantity and competition performance in under 20 track and field athletes. In fact, all the six athletes showed higher sleep time in the competitive weeks in which they obtained the season best results. This outcome is in line with previous evidences that investigated the influence of sleep on sport performance (Bird, 2013). Sleep time is a hot-topic especially when it is about young athletes currently involved in school and sport activities. In fact, the training load sustained by the athletes should also consider the extra-training variables (e.g. lifestyle, relationship, daily routine) which can affect the sport performance. In this light, monitoring in a non-invasive and inexpensive way the wellness and fatigue levels of young athletes can provide relevant information to optimize competition performance and consequently to avoid illness, injury and overtraining (Meeusen et al., 2013). Measures of sleep could serve as an indicator to understand the delicate balance between stress and recovery (Lastella et al., 2018). A recent study proved the efficacy of a sleep extension program among professional athletes on sleep quality, stress hormone expression and reaction time performance (Swinbourne, Miller, Smart, Dulson, & Gill, n.d.).

Furthermore, also the other analysed variables (fatigue, DOMS, health, sleep quality and mood) reported association with competition performance but individual differences are highlighted. For example perceptual fatigue, health, sleep quality and mood showed different patterns and association between athletes. The individual differences seem to be affected by the training load sustained and the management of daily routine (i.e. lifestyle). In fact, mood scores presented differences between male and female athletes and, for DOMS, fatigue and sleep quality the variations during the season differed according to individual characteristics in terms of training and extra-training load. Previous investigations showed relationship between training load and daily wellbeing questionnaires with all its subscales (i.e. fatigue, muscle soreness, sleep, stress and mood) in Australian rules football players (Gallo, Cormack, Gabbett, & Lorenzen, 2016)and youth athletes (Sawczuk, Jones, Scantlebury, & Till, 2018). Possibly perceptual fatigue measures may be connected with change in training load but further studies have to deepen the topic studying the relationship between external (training load) and internal (wellness questionnaire) measures in young track and field athletes.

Finally, the cluster analysis allowed grouping all the collected variables in order to understand the scenario created during the two phases of the season. Despite few differences between the preparatory and competitive period, overall the variables selected were grouped in the same cluster for both periods, while athletes and weeks differed according to periodization program as previously demonstrated in individual sports (Plews & Laursen, 2017) . The ability to group variables confirmed differences in heavy weeks (i.e. training camp weeks) versus light weeks (i.e. competition phase weeks) and especially the cases (athletes and weeks) described the differences in training load. An interesting fact is the similarity of variables in both periods grouping together the neuromuscular readiness test (CMJ and RJT) and sleep quantity. The same outcome from the individual analysis were highlighted as well in the clustering analysis reinforcing the evidences of this study. Despite this, the outcomes from this study are limited by a restricted number of athletes involved and cannot be generalized for the entire young athletics population due to the differences between disciplines. Anyway, this study may be used as a starting point for implementing athlete monitoring system with young athletes involved in track and field with the practical goal to support the athlete development pathway of the next sport generations as outlined by a recent commentary about young athletes and high performance (Murray, 2017). The results can be used as well as reference values to compare training load and neuromuscular readiness variables for further research in track and field.

6. Conclusion

This research analysed the changes in training load, neuromuscular readiness, perceptual fatigue measures and competition performance in a restricted group of under 20 track and field athletes during a 16-week outdoor season. In conclusion, our results show a reduction in training frequency, duration and external load volume (sprint and jumps) during the competitive phase. Moreover, the CMJ and sleep quantity seems to be associated with the best competition performance of the competitive season, while the other neuromuscular readiness (RJT) and perceptual fatigue (fatigue, DOMS, health, sleep quality and mood) measures showed different responses between the athletes. Despite this fact, collecting wellness data on a daily-basis may provide insights about the stress-recovery balance and underline the importance of individualize recovery strategies among junior track and field athletes. Finally, the cluster analyses highlighted differences between the preparatory and competitive period. As proof of the previously identified association, the CMJ, RJT and sleep quantity were grouped together emphasizing the influence of those variables. This outcomes can be used as framework for implementing athlete monitoring system with young athletes involved in track and field sprint-power events with the practical goal to support the athlete development pathway of the next sport generations.

7. Practical Application

Considering the applied nature of our sport science research, here are listed the main practical applications:

- A reduction in training frequency and external training volume (sprint and jumps) is desirable to achieve peak performance during the competitive phase of the season working with young athletes;
- The countermovement jump performed on a weekly-basis can be used as practical monitoring tool for young track and field athletes to evaluate the level of neuromuscular readiness;
- Collecting data from extra-training variables (i.e. sleep quantity) through a daily subjective questionnaire can be an inexpensive and useful way to better understand the stress-recovery balance and underline the importance of recovery status among junior track and field athletes;
- Including a comprehensive athlete monitoring system in a track and field team may reveal useful insights about the training stress and recovery time needed to achieve higher individual competition performance.

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