21 Injury Prevention

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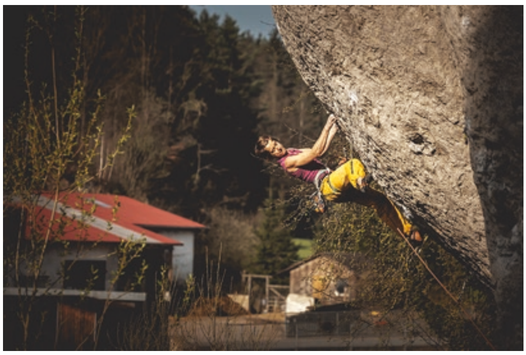

Isabelle Schöffl in „Feuerball", Loch, Frankenjura, Germany, Photo Enrico Haase

21.1 Introduction

The International Olympic Committee consensus statement recommends the accurate monitoring of training load to reduce injury risk in athletes. Although a high level of physical preparedness is likely protective against injury occurrence, failure to manage athletic workloads effectively have been found to be predictive of injury [1]. The calculation of workload is reliant on the accurate recording of exposure. In the published climbing literature to date, methods used by authorship teams to record exposure and operational measures of performance are inconsistent. At present, there is no published consensus statement on design characteristics for use in epidemiological cohort studies in climbing.

In terms of injury prevention, this raises several issues. Firstly, differences in epidemiological design characteristics used by researchers impede accurate comparisons between climbing-related studies to be made. Therefore, our understanding of injury burden and associated risk factors is limited. Secondly, what are the variables that may be utilised to estimate athletic workload in climbers? Finally, given that exercise prescription is a key tenant of injury prevention, what additional

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physical preparation strategies need to be considered for the climbing athlete? In addressing these issues, effective injury prevention strategies may be developed.

The Aims of This Chapter Are to:

- Critically evaluate epidemiological design characteristics used in climbing research.
- Report methods and considerations for calculating athletic workload in climbing.
- Provide an overview of contemporary strategies used to develop soft tissue robustness and fatigue management.
- Report the role of skill development in the management of injury risk.

21.1.1 Evaluating Injury Terminology

The definition of injury used in climbing-related studies varies considerably and are not always clearly stated. The criteria used to define injury commonly include bodily damage, pain, disability, medical consultation, medical intervention, hospital admission, and withdrawal. For example, Neuhof et al. [2] only reported those injuries that required professional medical treatment intervention, whilst Bowie et al. [3] only included participants who had sustained an injury that required hospital treatment. Both injury definitions require participants to have received medical treatment but may exclude a participant based on the location of that treatment. In contrast, Van Middelkoop et al. [4] stated injury to be 'any damage as a result of climbing that caused pain and or disability irrespective of whether a treatment or medical intervention was administered'. Importantly, this definition acknowledges the reporting of pain, defined by the International Association for the Study of Pain (IASP) as 'an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage' [5]. Pain is rarely stated in injury definitions used in climbing studies, yet it is not uncommon for climbers to continue in their given activity, or modify their activity, whilst perceiving some level of pain or discomfort.

Injury definitions need to account for both time-loss and non-time loss injuries. Chronic overuse injuries often have an insidious onset which is manifested subclinically before being raised in the consciousness of the individual. Even then, initial symptoms do not usually result in the termination of activity as they are generally mild in severity. Importantly, individuals may not consider themselves to be in an injurious state or in a sufficiently injurious state to withdraw from activity regardless of the mechanism. Failure to capture such data may result in the under-reporting of injury occurrence and confounds comparison of estimates between studies.

Recurrent injuries in sport are common, and it is widely accepted that subsequent injury is strongly associated with previous injury occurrence. Authorship teams need to correctly categorise first injury, re-injury and multiple re-injury of the same or different type and identify the underlying mechanism. A study by Jones et al. [6] was the first attempt to analyse previous injury as a risk factor for re-injury in climbers. Individuals were categorised as sustaining a re-injury, if they reported an injury at the same anatomical site, precipitated by the same cause, on at least two occasions within the 12-month reporting period. Individuals were categorised as sustaining a multiple re-injury if they reported an injury at the same anatomical site, precipitated by the same cause, on at least three occasions or greater within the 12-month reporting period.

Injuries in climbing may be broadly categorised as 'acute' or 'traumatic' and 'chronic' or 'overuse'. The classification systems used need to clearly differentiate between acute impact injuries, acute non-impact injuries and chronic overuse injuries. Critical reviews by Jones et al. [7, 8] categorised climbing-related injuries as: acute impact injury caused by the climber falling onto a climbing surface and/or ground, or an object such as a rock falling on to the climber, and acute non-impact injury resulting from acute trauma to the body and chronic overuse injury of the body from repetitive climbing. The Union Internationale des Associations d'Alpinisme (UIAA) recommend the use of the MedCom Score [8] to classify injury. However, the MedCom Score does not account clearly for chronic overuse injuries and therefore may fail to capture this type of data. Inconsistency and ambiguity of classification between studies limit our ability to correctly identify and attribute an injury mechanism. The percentage of climbers sustaining at least one injury due to acute impact is difficult to establish because many studies combine acute impact and acute non-impact injury data. For example, Backe et al. [9] reported a high percentage of lower limb injuries inclusive of contusions and lacerations and categorised these as traumatic. This does not accurately account for the aetiology of injury, which is likely a result of impact with the climbing surface and/or ground and/or climbing equipment, for example, the rope. Failure to inform the reader of the exact category of injury makes interpretation of the findings of limited use as individuals may sustain injury multiple times and at multiple body sites.

21.1.2 Evaluating Study Design and Data Collection Procedures

Studies determining incidence and prevalence of injury in climbing utilise prospective and retrospective cross-sectional survey methods. Although prospective cohort studies are considered the gold standard of observational research and should provide accurate and reliable data of injury and exposure, they are difficult to conduct in large sample climbing populations. Conversely, retrospective studies are particularly prone to measurement error. Jones et al. [7] reviewed four retrospective cohort studies that estimated incidence rate based on data captured by postal survey [10], memory recall [2], medical records and interview [3] and national park registrant data on accident occurrence [12]. Relying on the memory of participants to recall the number of injuries that they have experienced over a period of time is particularly error prone, especially when the recall period extends in excess of 12 months. However, retrospective studies that use survey methods do allow relative ease of access to large sample populations. Jones et al. [12] surveyed a large sample of climbers: Injury and performance behaviour questions were framed to remind participants of the recall period, i.e. 'how many times in the last 12 months'. In contrast, participants in a study by Neuhof et al. [2] were asked to recall injuries that occurred over a 5-year period. All study designs can introduce measurement error due to imprecise recording, interpretation, calculation and recollection of climbing exposure and injury occurrence.

The UIAA Medical Commission recommends that incidence rate of injury in climbing be expressed as injuries per 1000 h of exposure to control for variation in exposure, especially between different types of climbing activity [8]. However, reporting injuries per 1000 h of exposure is an imprecise measure because it may not account for non-climbing activities such as preparation, rest periods between attempts and belaying a fellow climber. The Medical Commission further recommends studies that do not measure the hours of exposure record 4 h for sport climbing outdoors and traditional climbing and 2 h for any indoor climbing activity per day. Outdoor bouldering is not accounted for in this recommendation; moreover, calculating climbing exposure using such methods is likely to introduce significant error into estimates. Performing secondary analysis of data to produce estimates of exposure per 1000 h is also likely to produce errors. Schöffl et al. [13] performed a secondary analysis of data reported by Limb [10], Bowie et al. [3] and Schussman et al. [11] to estimate the respective incidence rate of injury per 1000 h of climbing exposure. The survey methods used by each study were significantly different and raise a legitimate concern in regard of conducting analysis to generate such data on heterogeneous studies.

The incidence rate in climbing may additionally be expressed as the number of new injuries in a specified time period (e.g. per year), number of new injuries per number of visits to a climbing venue (e.g. injuries per one million visits) or number of new injuries per number of athletic exposures (injuries/100 participants). The calculation total is inclusive of first injury, multiple injuries and re-injuries. In their systematic review

Woolings et al. [14] reported incidence as a function of athlete exposures. For example, incidence of injury over the entire career was reported as 300 (95% CI 250, 357) injuries/100 participants [15] and incidence in regard of a type of climbing behaviour as 103 (95% CI 71,146) and 127 (95% CI 85,184) injuries/100 participants/year for outdoor and indoor bouldering respective [16]. Such measures are perceived as a useful method for estimating resource utilisation for healthcare providers and clinicians [17]. However, the problem with reporting incidence of injury in a specified time period, in relation to visits to a climbing venue or as a function of athlete exposures, is that the duration of individual exposures will vary and again introduce error into estimates. Therefore, such methods may not reliably indicate the extent of the injury problem.

In a study by Jones et al., individual climbing exposure was captured using estimates of the frequency of ascent [12]. Climbers were also asked to provide additional information regarding consistency of their performance standard. This better reflects actual participant exposure in climbing and importantly controls for performance standard as a potential confounder in the calculation of risk. To date this published work is the only study that has considered both frequency of ascent and the operational standard of ascent to calculate risk of injury across a wide range of climbing behaviours. As such, this method may be used to predict risk based on an individual climber's profile of climbing behaviours and athletic load.

Precise information about the environment, climbing behaviour and practice of climbing populations is needed. Correctly categorising exposure allows a direct link to be made between the specific situation and injury occurrence. Study reports are often not explicit in how other climbing behaviours of participants are accounted or controlled for. Moreover, even when precise information about the cause of the injury is captured, it is possible that other climbing activity may have contributed to the injury. For example, a traditional climber who was sampled in an outdoor climbing setting may be undertaking indoor bouldering far more frequently, and this may be the precipitating factor for injury occurrence. Inconsistency in categorising the type of climbing activity between studies can cause under- or over-reporting of a particular type of injury to a climbing behaviour. It is imperative that injury data is captured with the exact climbing behaviour and practice that caused the injury.

21.1.3 Evaluating Data Processing

A variety of different grading systems exist worldwide to report the operational standard of climbing performance. Although the use of number-based scales is commonly reported by authorship teams, inconsistencies in the conversion of identical operational standards of performance exist. As a consequence, the International Rock Climbing Research Association (IRCRA) produced a positional statement in regard of comparative grading scales for future use in climbing research [3, 18]. The authors developed a reporting scale to standardise the conversion of climbing performance, regardless of behaviour, into a numerical value suitable for data analysis. The authors acknowledged a limitation of the proposed scale is the use of the British technical grade for traditional climbing only. Traditional climbing in Britain is graded using a combined system that assigns both an adjectival and technical grade, for example, Very Severe 4c. The adjectival grade provides information about the level of difficulty, overall seriousness and potential risks to the climber. The corresponding technical grade provides information about the hardest technical movement required to complete the climb. The comparative grading scale proposed by IRCRA [20] contains considerable overlap between the British technical grade and the recommended reporting value, for example, British technical grade 6a may be recorded as 13, 14, 15, 16 or 17. Therefore, the use of the IRCRA scale in its current format may introduce significant measurement error when applied to sample populations of British traditional climbers. An amendment to the IRCRA comparative grading scale was presented to the 4th International Rock

Table 21.1 Amendment to IRCRA comparative grading scale [19]

IRCRA Reporting scale	British adjectival and technical grade	French sport
1	M	1
2	D	2
3	VD	2+
4	S	3-
5	HS/VS 4a	3
6	VS 4b	3+
7	VS 4c	4
8	VS 5a/HVS 4c	4+
9	HVS 5a	5
10	HVS 5b/E1 5a	5+
11	E1 5b	6a
12	E1 5c/E2 5b	6a+
13	E2 5c	6b
14	E3 5c	6b+
15	E3 6a	6c
16	E4 6a	6c+
17	E4 6b	7a
18	E5 6b	7a+
19	E6 6b	7b
20	E6 6c	7b+
21	E7 6c	7c
22	E7 7a	7c+
23	E8 6c	8a
24	E8 7a	8a+
25	E9 6c	8b
26	E9 7a	8b+
27	E9 7b/E10 7a	8c
28	E11 7a	8c+
29	E11 7b	9a
30	E11 7c	9a+
31	E12 7b	9b
32	E12 7c	9b+
33	E13 8a	9c

Climbing Research Congress in 2018 [18] to address this issue (see Table 21.1).

21.1.4 Summary

Inconsistency in the use of injury terminology, data collection procedures, calculation of exposure and operational measures of performance by researchers exist. Such inconsistencies likely contribute to the large variance in the incidence and prevalence of injury reported. Continued reporting of heterogeneous results in population samples limits meaningful comparison of studies to be made and an understanding of injury burden and risk factors to be known. Standardising the criteria used to attribute injury and climbing activity, coupled with more accurate methods of calculating exposure, will overcome such limitations.

21.2 Monitoring Athletic Load

21.2.1 Introduction

An International Olympic Committee consensus statement defined load as, 'the sport and non-sport burden (single or multiple physiological, psychological or mechanical stressors) as a stimulus that is applied to a human biological system (including subcellular elements, a single cell, tissues, one or multiple organ systems, or the individual)' [21]. The key variables that are required to accurately calculate load include the type, duration, frequency and intensity of activity. Load can be further quantified as external load, i.e. the objective work undertaken (training and competition), and internal load, i.e. an individual's physiological and perceptual response [20] The differentiation of load type is important as an identical external load stimulus can elicit a range of stressors. Furthermore, an individual's response to the same external stimulus may differ, at different time points [20].

Challenges in accurately calculating load and interpreting the evidence of associations between load, injury and illness exist. Primarily, athletes undertake high training loads to prepare for the demands of competition. A high level of physical preparedness likely mitigates some injury risk, but failure to manage load effectively could be detrimental to the athlete's health.

21.2.2 Session Rating of Perceived Exertion (Session-RPE)

Session-RPE is a simple method of calculating athletic load by multiplying the session intensity (normally measured using a modified Category

Ratio 10 scale) by the duration of the individual session measure in minutes [22]. The subsequent calculation is considered a quantity of total load and measured in 'arbitrary' units. It is recommended that session intensity recording using a modified Category Ratio 10 scales (CR 10) be undertaken 30 min after cessation of activity and familiarisation of the athlete with the scale necessary prior to use [22]. A review of session-RPE by Haddad et al. [23] reported the validity, reliability and internal consistency of session-RPE across a wide range of sports and physical activities. RPE is appropriate to use as a measure of internal load [20] and valid to use with men and women of different ages, including children and adolescents [23]. Session-RPE may be used as a standalone method of calculating load but can be combined with other factors to create a sport-specific measure [24].

Derivative characteristics of session-RPE are 'monotony' and 'strain' and are suggested to relate the onset of overtraining [23]. Monotony is a measure of training load fluctuations, and strain is a measure of how hard an athlete is working for a fixed time period, usually a week. Monotony and strain are characteristics of training variability derived from session-RPE and are suggested to relate to the onset of overtraining [23]. The research underpinning these measures used illness as a proxy marker of overtraining syndrome: currently insufficient evidence and data to quantify the risk of illness in response load fluctuations exist, and further studies are required [22].

Measuring the intensity of a climbing session using time likely provides an imprecise statistic that fails to capture significant performance data. In order to create a sport-specific sessional measure of external load, we suggest the following factors to be considered and appropriate weightings applied: sum of ascents; grade of ascents; climbing behaviour; nature of ascent, e.g. redpoint; and completions to non-completion ratio. The IRCRA comparative grading scale could be used to provide a single value that accounts for both operational performance grade and climbing behaviour. Internal load could be captured using the CR10 scale and multiplied with external load to calculate total load.

21.2.3 Acute Chronic Workload Ratios

High levels of physical preparedness and musculoskeletal adaptation likely protect against injury, but it is vital athletes achieve this in a controlled and systematic manner. The acute/chronic workload ratio (ACWR) is proposed as an effective method of monitoring training and competition load by means of modelling the relationship between changes in load and injury risk in athletes [23]. The ACWR is calculated by dividing an athlete's current training load (acute), usually gathered over the last 7 days by the typical training load the athlete has completed (chronic), usually gathered over the last 4 weeks. The typical training load may be calculated using a rolling average method or an exponentially weighted moving average. A ratio of greater than 1.5 is suggested to indicate an increased risk of injury; a ratio of 0.8–1.3 is suggested optimal and indicates a reduced risk of injury [23].

The IOC consensus group reviewed data in relation to relative load, rapid changes in load and injury risk in athletes and reported that team-sport athletes reacted significantly better when imposed load variations were controlled and relatively small in magnitude [24]. Furthermore, the consensus group reported ACWR to be applicable for use with individual sports participants [24]. A review of 22 studies supported the use of ACWR as part of a range of measures to monitor training load in athletes but concluded that further research across a range of sports is needed [25]. Legitimate conceptual and methodological concerns in regard of ACWR to predict injury risk have been raised. Impellizzeri et al. [26] and the Australian Institute of Sport now advise it should not be used as an indicator of injury risk.

21.2.4 Summary

Athletes need to be physically prepared to fully meet the demands imposed upon them.

Despite a paucity of empirical research evidence in climbing populations and methodological concerns of the efficacy of ACWR to predict injury risk, we recommend coaches and medical teams use monitoring protocols to better plan for the training and competitive requirements of their climbing athletes.

21.3 Contemporary Strategies Used to Develop Soft Tissue Robustness and Fatigue Management

21.3.1 Physical Preparation and Athletic Development

Injury is an inherent consequence of professional and amateur sport. The cause of injury is often multifactorial and rarely the preserve of one independent factor [23]. Therefore, the prevention of injury in sport per se is governed by logical principles that provide the athlete, healthcare professional and coaching team with direction. In the sport of climbing, these concepts are no different. Climbing, due to its heavy burden on the musculoskeletal system, clearly lends itself to an injury profile which is bias towards injury of the upper quadrant, e.g. the shoulder elbow, wrist and hand [27], but must also consider the lower limb as the spectrum of injury changes with better injury surveillance [25] The principles of acute and chronic load management, protective equipment, skill development and physical conditioning act as the cornerstone of injury prevention strategies similar to other sports [26].

Injury to musculoskeletal tissues causes a cascade of events which ultimately lead to tissue trauma. The insult to musculoskeletal tissues is often the cause of acute or chronic manifestations of mechanical load to biological tissues [27]. The biological load imposed upon musculoskeletal tissues may lead to adaptation, maintenance or maladaptation [28]. Adaptation occurs when tissue is subjected to load and modifies to the imposed demands through positive changes in its material, morphological and/or physiological properties [29]. In maintenance the load applied to tissues is within its biological capacity such that no appreciable changes occur. In the maladaptive state, the tissues are subjected to mechanical and/or physiological loads that exceed the capacity of the tissue to tolerate the imposed demand [32]. This may cause a chronic injury state from excessive cumulative microtrauma, leading to insidious tissue disruption before being raised into the consciousness of the athlete. Contrastingly, injury can be the result of acute traumatic insult in which the force profile causes rapid catastrophic failure of tissues. The underpinning theories which encapsulate these ideas of biological adaptability to mechanical and physiological stress are numerous [31, 34, 35]. However, all purport to optimally elevate tissue capacity to higher levels of performance and ultimately protection of the athlete.

Pragmatically, healthcare professionals and members of the multidisciplinary team from an injury prevention perspective should familiarise themselves with the following strategies:

- Strategies to increase the ultimate load profile of tissues to mechanical stress
- Strategies to increase the metabolic capacity of the athlete to encourage fatigue resistance
- Strategies to decrease the acute and chronic stress imposed upon tissues
- Strategies to manage fatigue without affecting performance

21.3.2 Strategies to Increase the Ultimate Load Profile of Tissues to Mechanical Stress

Although, it may be self - evident that reducing the mechanical stress imposed upon musculoskeletal tissues in the sport of climbing can be injury protective. It is important to realise that mechanical load is a potent stimulus for positive adaptations of biological tissues [35]. In order for the athlete to develop physical expertise in bio-motor capacities (such as strength, rate of force development, endurance, work capacity and power) which provide a performance advantage, there must be physiological stress [36]. The adaptive capabilities of the athlete's musculoskeletal tissues are influenced by the process of mechanotransduction.

Mechanotransduction is the biological processes in which tissues respond to mechanical load at cellular level [37]. The cells of mechanically responsive tissues sense mechanical stimuli at the extracellular tissue level. This causes a cascade of events in most but not all musculoskeletal tissues. In responsive tissues, this leads to the deposition of collagen in architectural arrangements aligned to stress adaptation [38]. The stress adaptation is governed by the application of appropriate mechanical stress which does not exceed the capabilities of the target tissues. This leads to positive adaptations in the tissues tolerance to manage stress and impose loads associated with physical activity [39]. Therefore, with appropriate physical training and athletic preparation, it is possible to alter the material and morphological properties of biological tissues. In the literature, this has been shown to be beneficial in both muscular [38], bone [39], tendon [42] and connective tissue models [41] both in vivo and in vitro and in cross-sectional studies in upper limb-based sports [42] and [45] climbing.

From a pragmatic perspective, the ability of a tissue to generate force provides an obvious performance advantage in a sport such as climbing [46]. Morphological changes in muscle, tendon, bone and connective tissue are also associated with improved muscular force capacity [39]. The nature of adaptations sought should be determined by the specific needs of the athlete and the injury profile of the sport [47]. For example, increasing the stress tolerance of the wrist and forearm flexor muscles with resistance training may reduce injury risk in boulderers that are required to generate high levels of force at high velocities (Fig. 21.1). However, compare, for example, the alpine climber in which their sports-specific conditioning needs lend itself to lower force-velocity requirements.

Furthermore, it is important to realise that the technical demands of climbing are such that a significant reduction in chronic training load may not be advantageous for the climber's yearly performance progression. A chronic reduction in training load would cause insufficient adaptive stress and also reduce the opportunity for technical improvement. This technical improvement or skill development is important in body weight-dominated sports [48]. The opportunity to refine movement skills and tactical awareness can be lost if too great a reduction in training load is used as a strategy for injury prevention.

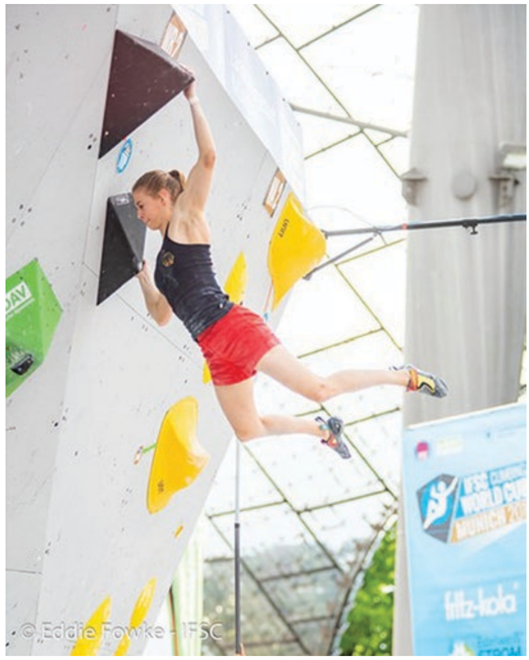

Fig. 21.1 Bouldering athlete displaying high force output during a bouldering problem

21.3.3 Strategies to Decrease the Acute and Chronic Stress Imposed upon Tissues

Climbing is a sport based upon the skilful application of force to optimise athletic performance [48]. Climbing requires the awareness and application of temporal and spatial relationships between the centre of gravity and the base of support. The centre of gravity is a point of equilibrium in all directions and a focal point for the earths gravitational pull on the body [49]. The climber must be cognisant of their line of gravity and the orientation of the body to this line. This understanding of the centre of mass in relation to the base of support allows the climber to minimise the effect of gravity and make progress during climbing [50]. These basic biomechanical concepts affect balance and movement efficiency of the climber. Balance and efficiency are governed by skill development [51]. A skill is an action or task directed towards achieving a specific goal [52]. In climbing, a motor skill requires voluntary movement of the athlete's body segments to achieve a specific task. Motor skills in climbing require both gross motor skills involving large muscle groups and fine motor skills involving small muscle groups. Climbing is a continuous motor skill which is distinguished by its arbitrary beginning and end points [53].

Skill development utilises the application of physics to ensure effective force generation, force transfer and force absorption [54]. Skilful movement is a strategy that aims to reduce the stress placed upon the musculoskeletal system. This is achieved by optimising energy-efficient movement patterns [55]. In essence the objective is to ensure that the climber does not place excessive force through structures that are either not suited to the role or lack the capacity to adapt to load because of their biology. This requires an in-depth understanding of both functional anatomy and clinical biomechanics to make a reasoned hypothesis about the potential effects of movement inefficiency as a basis for pathomechanics [56]. In this regard, it is important to understand that strategies to decrease acute and chronic stress on musculoskeletal tissues are often interrelated. For example, the climber's body position during movement is important because it influences the centre of gravity in relation to the base of support and hence the climber's degree of balance on the wall (Fig. 21.2). These issues ultimately affect the metabolic cost of climbing and likely the performance outcome.

The mechanical output of an activity is supported by the body's metabolism and the energetics of exercise [57]. Therefore, the energy cost of a given mechanical output to ascend a climbing route is dependent upon the climber's efficiency of movement. Inefficiency has the potential to increase the metabolic cost of mechanical work leading to premature fatigue

Fig. 21.2 Lead climber displaying technical skill whilst ascending a competition route

[58]. Fundamentally, poor body positioning and technique regardless of its cause can affect the interplay between biomechanics, injury and performance [59]. Biomechanical moment arms both at a whole body, body segment and local joint muscle region are important in human movement. Moment arms influence the magnitudes of force which must be overcome and generated by the climber during all activities. The musculoskeletal system generally works at a mechanical disadvantage when compared to the external environment. This often means the muscular system is required to generate significant forces to overcome external resistances because of this disadvantageous arrangement [60]. This is why movement efficiency is theoretically of critical importance in delaying the onset of fatigue. Fatigue has been shown consistently to cause a reduction in muscle force [61], joint stability [60], impaired decision making [63] and reduced proprioception [64]. Fatigue of the muscular system may place greater demands on noncontractile neuromuscular components such as bone, connective tissues and articular cartilage. This may manifest as a challenge to soft tissue integrity and the maintenance of optimal anatomical relationships within and between joints. This may potentially contribute to increased injury risk.

21.3.4 Strategies to Increase the Metabolic Capacity of the Athlete to Encourage Fatigue Resistance

Epidemiological evidence consistently reports a high occurrence of injuries to the upper limbs [27, 65]. Mechanical load imposes significant stressors on key structures such as muscle, tendon, peri-articular connective tissues and bone [64]. Contemporary models of training in climbing reinforce modalities which stimulate tissue adaptations using mechanical load [48]. There is an abundance of research and contemporary thought recommending the use of physical preparation modalities which condition the finger and forearm musculature [67]. Activities such as finger board training, use of campus boards, system boards and climbing-based activities are common [48]. However, while this has significant sports specificity, such modalities impose high mechanical loads on musculoskeletal tissues [69–71]. Repetitive high mechanical load will likely result in injury unless planned appropriately and utilised judiciously.

Broadly speaking climbing with the exception of speed climbing is by definition near maximal intermittent exercise interspersed with periods of submaximal exercise [71]. This suggests participants need to have a well-developed capacity to support both aerobic and anaerobic metabolism. Therefore, alternative modalities that stimulate positive training adaptations should be considered as an injury prevention strategy for the climber. The ability to endure mechanical work through effective training of the metabolic system is arguably an important parameter differentiating optimal and suboptimal performance [72]. The climber, whose body is conditioned to offset fatigue yet maintain optimal force output over the duration of a climbing route, will often determine sucess [46]. The ability to resist fatigue, regardless of the event duration, is associated with an effective metabolic system [71].

The physiological attributes associated with climbing has been extensively reported elsewhere [68, 75]. It is fundamentally important that the basic energetic requirements of climbing are adequately understood by healthcare professionals and support teams when developing training programmes. An appropriate training programme is one which prepares the climber for the demands of their specific discipline [75]. The metabolic demands of climbing are varied by the rate and duration of energy utilisation undertaken by the respective disciplines. For example, lead climbing and speed climbing imposed very different physiological demands upon the climber's metabolism to sustain mechanical work. The liberation of chemical energy for mechanical work occurs by the resynthesise of adenosine triphosphate (ATP) within the muscle cell [50]. The biochemical process by which this energy source is liberated is dependent upon the rate and duration of mechanical work.

The energetics of exercise broadly falls into three different categories which ensure optimal energy production for sports performance. Alactic, anaerobic glycolytic and oxidative phosphorylation energetics are the primary systems [77]. These systems while discrete in their configuration are interrelated and active to varying degrees during all activities. However, during specific activities, there is often a strong predominance of one system over another. For example, speed climbing because of its short duration (<10 s) and mechanical force output at high velocities utilises predominantly alactic energy systems of ATP and stored phosphagens [78]. Contrastingly, sport climbing routes utilise predominantly slow glycolytic and oxidative energy systems [79]. This contrast in energetics is attributed to the longer durations of physical activity associated with this type of climbing. There is an inverse relationship between the duration of a physical activity and the rate of energy production permissible and hence the system utilised for the resynthesise of ATP [80].

Traditionally, training to improve the metabolic capacity of the climber has focused upon modalities which target the sports-specific qualities of climbing. This has traditionally included climbing-based activities and off the wall training, for example, finger boards and campus boards [51, 80] (Figs. 21.3, 21.4, and 21.5). This type of training arguably provides sports specific-

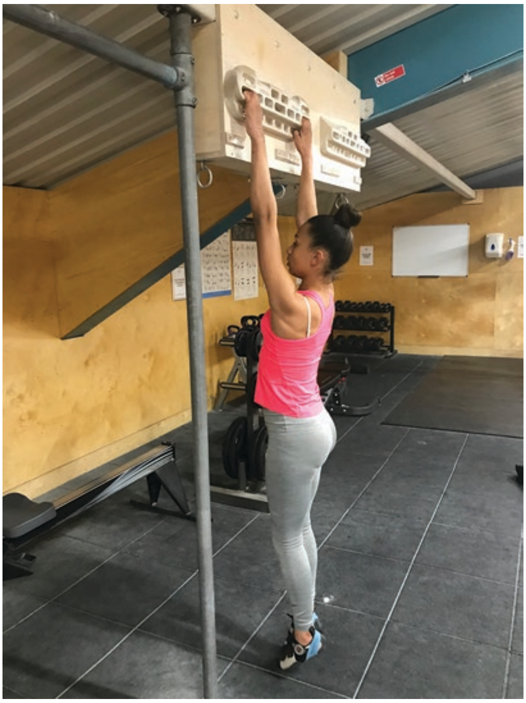

Fig. 21.3 Climber using a fingerboard to develop finger and forearm muscle capacity

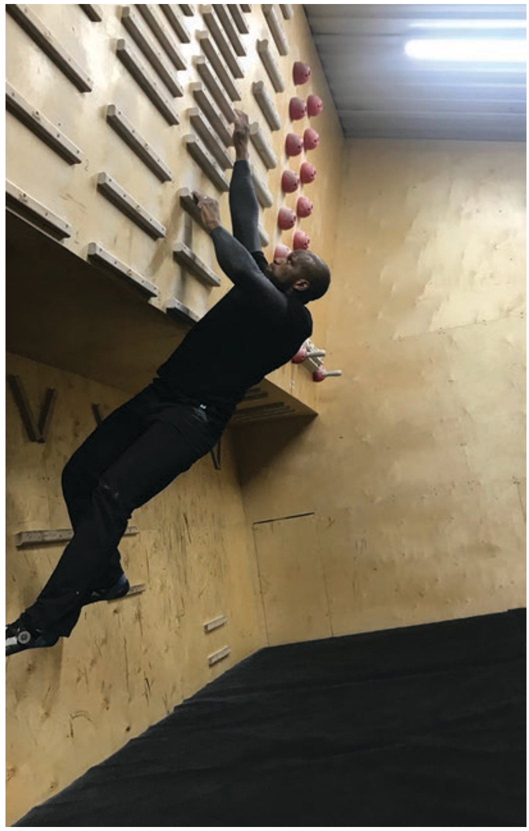

Fig. 21.4 Climber using a campus board to develop high velocity climbing-specific mechanical loading

ity because of the similarity in energetics, movement patterns, neuromuscular force profiles and specific muscle groups used. However, while this is sports specific, it imposes a high mechanical load on musculoskeletal tissues. Contrastingly, other modalities whilst not climbing specific may be relevant in regard to the underpinning physical qualities that are important for climbing performance [73, 80]. These modalities stimulate central and peripheral adaptations in the metabolic pathways that support climbing performance without the mechanical load [70]. The aerobic oxidative system is the primary system responsible for exercise at submaximal work rates. The efficiency of this system is of particular importance for achieving peak exercise performance in most sports [81]. The oxidative system has been suggested to contribute up to 50% of the energy requirement for force production after 75 seconds of maximal exhaustive exercise [81]. Oxygen uptake ($V0_{2max}$) ranging from 54 to 55 mL kg^{-1} min has been shown in climbers during treadmill running [82] which is consistent with that seen in team sports and gymnastics [73]. However, peak VO_2 of 43.8 mL kg^{-1} min has been reported during treadmill climbing [83]. This lower oxygen uptake is possibly attributed to the smaller muscle mass associated with climbing when compared to running and cycling. Therefore, this data, may suggest central factors such as cardiac output and oxidative capacity are not limiting factors affecting climbing performance. However, cardiac output is the delivery mechanism for oxygen and nutrition to exercising muscles [82]. This system facilitates the resynthesis of ATP between bouts of high-intensity exercise and sustains high submaximal work rates [79]. At the site of muscular tissue, the skeletal muscle cell needs energy to perform mechanical work [78].

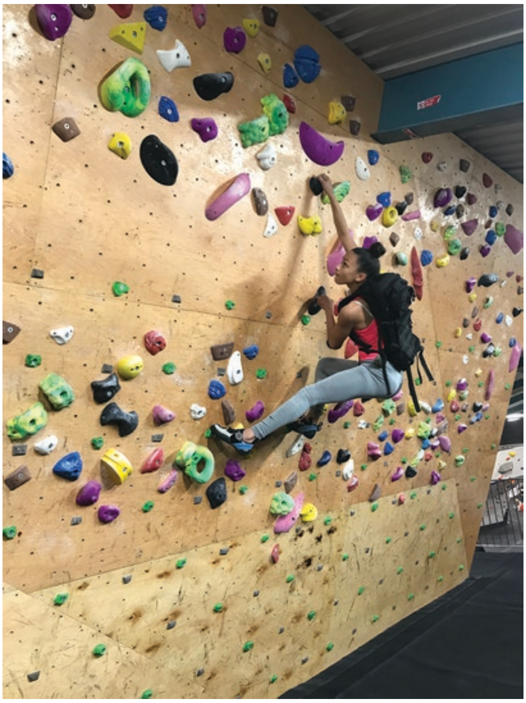

Fig. 21.5 Climber using a circuit board with additional system mass (weighted backpack) to mechanically overload the skill of climbing

High-intensity exercise close to VO_2 peak using various modalities has been shown to improve left ventricular contractile force and increased cardiac filling pressures [83]. Metabolic efficiency in skeletal muscle has also been shown to cause up regulation of oxidative and glycolytic enzymes [86]. Increase capillarisation within the muscle has been reported in addition to increased mitochondria protein transcription [85]. These central and peripheral adaptations collectively lead to a greater reliance on oxidative metabolism at any given workload [82]. This for the climber is suggestive of a reduced reliance on anaerobic pathways because the point of transition to glycolytic metabolism is delayed. This adaptation is performance enhancing due to the delay in fatigue. However, of greater relevance is that these adaptations may be achieved using training modalities which minimise mechanical stress through musculoskeletal structures. High intensity interval training (HIIT) has been shown to be a viable method for developing both aerobic and anaerobic performance in various upper and lower limb-dominant sports [88, 89]. HIIT can be used for climbing-related training [77]. However, from an injury reduction perspective, we would recommend a boarder remit in which it is used as an adjunct to stimulate both central and peripheral adaptations to enhance energetics in non-climbing activities. This can involve programming long and short HIIT interval training to target cardiopulmonary and oxidative muscle fibres, the glycolytic and alactic phosphate systems [73, 85]. This might include intervals sessions based upon predetermined work to rest ratios using, for example, medicines ball throws, battle rope conditioning and power bag drags for upper body conditioning or cycling and/or running bases activities to upregulate central adaptations [90] (Fig. 21.6).

Fig. 21.6 An athlete using battle ropes to develop high intensity metabolic fitness

21.3.5 Strategies to Management Fatigue Without Affecting Performance

A critical component underpinning injury prevention in a physical preparation model for the recreational climber or climbing athlete is the systematic management of training-related fatigue. Stress reduction in the musculoskeletal system can be achieved by the management of fatigue [91]. The practical application of fatigue management over a training and competition year is the planned variation in training load on a daily, weekly and monthly basis to reduce the monotony of training [92]. Over a training and competition year, monotony can influence the climber's risk of injury and illness. However, fatigue is an important part of the training and adaptation process and therefore must be managed appropriately.

Periodization is a system and philosophy of training management whose aim is to apply the manipulation of intensity and volume during the course of a training or competition cycle [34]. The cycle may be one month, one year or a quadrennial cycle such as used for Olympic sports planning. Planning the training loads and sequencing periodic recovery to allow biological adaptation is a critical step in the process [91]. Performance in any sport is often dependent upon on the interplay between the mechanical and metabolic work capacity the athlete can tolerate during physical activity. Periodization from a performance perspective has been shown to produce superior results for developing athletic performance [92]. This approach is driven by long-term planning to maximise the probability of physical preparedness of the climber. This minimises the risk of suboptimal underload or overload of bio-motor capacities deleterious to optimal performance and tissue robustness [93].

Periodization of mechanical and metabolic load is defined by training phases. In general, there are two major phases in the training system: the preparatory phase and the competitive phase. The preparatory phase can be further subdivided based upon the needs of the climber into the general physical training phase and the sports-specific training phase. The subphases allow the detailed manipulation of training loads and volumes based upon the intended physiological adaptations sought for optimal performance at a time point in the future [37, 90, 94]. There are various periodization approaches within the literature based on the needs of the athlete and philosophies of athletic development. However, we would recommend a linear approach to programming because this appears to offer a straightforward system for managing fatigue and load in a climbing athletes programme.

The methodology is operationalised by the structured variation in bio-motor capacities over the training year [94]. The principle of phase potentiation is an important construct of this method. Phased potentiation is the sequencing and ordering of physical qualities into training blocks. This ordering of bio-motor capacities is designed to ensure that physical qualities trained prior support the next phase of metabolic and mechanical loading of the climber. The manipulation of volume, load, work to rest ratios and progression of bio-motor capacities (e.g. muscle strength/endurance >strength >power) potentates the adaptive process [95]. The strategy is foundational in nature setting the framework for subsequent phases of training. This is designed to minimise inappropriate fatigue while optimising athletic performance [96]. From this position, the material and morphological (mechanical) drivers for developing tissues robustness are achieved to support higher work demands for subsequent phases of the climber's physical preparation plan. This type of systematic planning can also be applied to the metabolic development of the climber. In a similar manner to mechanical loading, the phases of development also are structured in a way that lay the foundations for subsequent sports-specific metabolic conditioning [99]. Central cardio respiratory adaptations may be used early in a training year to develop a foundation for sports-specific conditioning and recovery in later months [90]. The need to develop intra-muscular adaptations in sports-specific muscles for high levels of performance may be less relevant at this stage of the training year [84]. However, as the training year progresses, the emphasis will change to target the energetics of sport-specific musculature [100].

In the competitive phase, training modalities should mimic the kinetics and kinematic profile of climbing and the climber's end performance goals [101]. The training modalities will be highly sports specific and involve the refinement of climbing under realistic loads. The power and force output profiles should closely relate to either speed, sport, boulder, multi-pitch or other climbing speciality with identical work to recovery ratios. At this juncture of the training cycle, actual climbing will be the primary method of metabolic and mechanical development. This, for example, may involve competition simulation at or slightly higher intensities than normal for competitive athletes. Correspondingly, it may involve long indoor routes laden with gear to simulate the demands of alpine climbing for the alpine climber. The specifics of this phase will be determined by the needs of the climber, type of climbing and performance level sought [95, 103, 104]. The underpinning theoretical rational which supports a periodisation-based approach to training is the fitness fatigue model [34] and the general adaptation syndrome [31]. These theories elucidate how organisms adapt to training stress with positive or negative physiological adaptations.

21.3.6 Summary

Athletic development and physical preparation strategies are a cornerstone of climbing performance and injury prevention. The ability of musculoskeletal tissues to adapt its material, morphological and physiological properties to the imposed demands provides a performance advantage. However, this load must not exceed the physical capacity of the tissues. The principles of skill development, fatigue management, metabolic development and effective tissue loading underpin injury prevention management.

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