Injury, tissue capacity and load management

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Injuries can be broadly categorised into two groups; direct and indirect. A direct injury is one that occurs from an external force imposed on the body, such as a kick in sport, or a fall in daily living. The cause is obvious and the injury could, for example, be a bruise (haematoma) or cut (laceration). An indirect injury is one which occurs as a result of internally imposed forces, such as shin pain or a pulled muscle. The cause is often less obvious, making management of this injury more challenging.

LEARNING OUTCOMES

1. To enhance knowledge of exercise therapy and its prescription for musculoskeletal injury.
2. To develop knowledge of tissue homeostasis and tissue loading during injury and rehabilitation.
3. To increase awareness of load monitoring during exercise and rehabilitation.

One of the ways of looking at the causes responsible for an indirect injury is to consider that the tissue involved was loaded to the extent that it exceeded its capacity. In this case, the capacity of a tissue is how much it can be loaded or stressed without breaking down. Tissue capacity will clearly differ between individuals, depending on the requirements of their work or sport, the condition of their tissues and their age. In any movement several tissues may be loaded, but it is the one with the lowest capacity that will represent the weakest link in the chain of movement, and is often the one which breaks down (Cook & Docking 2015).

Tissue homeostasis

Homeostasis is the method by which the body actively maintains a constant state in its internal environment. To maintain tissue capacity, there is a continuous process of physiological maintenance via adaptations in the body's metabolism (Dye 2005). Injury or overuse can disrupt homeostasis, leading to a cascade of biochemical changes. Excessive or supra-physiological loading on tissue will cause adaptation providing there is sufficient time for recovery. A sudden imposition of extreme force, however, may exceed the load capacity of tissue leading to maladaptation. Similarly, repetitive small forces which occur too frequently may not allow sufficient time for the tissue to adapt to the new loading level. At the other extreme, too little (sub-physiological) loading, that occurs with prolonged rest, also disrupts homeostasis leading to changes such as muscle atrophy and bone mineral loss, reflecting deconditioning. Clearly, with tissue function it's a case of "use it or lose it".

The region of loading between under- and over-usage represents the area of load acceptance, and has been described as the "envelope of function" (Dye 2005). Where loading exceeds capacity, the action can be envisaged as occurring outside the envelope of function, and may irritate the tissue, giving rise to symptoms such as pain and swelling. At this stage homeostasis may be restored by reducing or changing the loading, with a view to later increasing tissue capacity with progressive rehabilitation and elevating the upper limit of the functional envelope.

Poor load management can have effects on the body as a whole and at a local tissue level. Repetitive loading without sufficient recovery can cause cumulative tissue fatigue and increase susceptibility to injury. At whole body level, inappropriate loading can cause psychological impairment to the individual, for example, by impairing decision making ability, and physiologically with compromised co-ordination and neuromuscular control. Fatigue of this type reduces muscle force and muscle contraction velocity (Soligard *et al* 2016). Joint kinematics and neural feedback can be compromised with ongoing detriment to joint stability. Locally, excessive micro-damage may occur if the magnitude of loading is beyond the load-bearing capacity of individual tissues. Initially, when loaded, tissue changes are short-term and reflect reaction, and can show symptoms such as increased blood flow through muscle and increased metabolic activity that are reversed when the loading stops, homeostasis is restored, and the tissue resumes its resting state. Repeated loading, however, causes the tissue to change more permanently and adaptation occurs which may result in

"WITH TISSUE FUNCTION IT'S A CASE OF 'USE IT OR LOSE IT'"

increased muscle strength and bone mineral density. Training loads that are too low may not stimulate sufficient adaptation and can impair the tissue's ability to cope with higher loads in the future. Adequate training stimulates biological adaptation, increases the capacity to accept and withstand load, and builds resilience.

The aim of rehabilitation is to increase the capacity of the injured tissue and to offload it by enhancing the strength of surrounding muscle. Tissue capacity may be built with progressive overload, which may be either simple or complex (Cook & Docking 2015). Simple loading targets the specific tissue, for example the medial collateral ligament of the knee, while complex loading targets the tissue within the context of the whole limb or body region, for example a squat action. The load chosen for rehabilitation must accurately reflect the type of load the tissue may be placed under during any functional action in daily living or sport. Training specificity of this kind is vital to increase tissue capacity relevant to the patient's actions, rather than increasing the therapist's need to fulfil predetermined goals.

Monitoring tissue load

Load imposed on a tissue is often monitored using a variety of laboratory devices, such as dynamometry or EMG which measure the external load and may quantify training using, for example, sets, repetitions, poundage lifted, distance run, or watts produced. Internal load measurement assesses the physiological and psychological responses to an activity, for example heart rate, the rating of perceived exertion, or psychological inventories. While external load gives an understanding of the work completed, internal load can be viewed as more patient-centred in that it determines whether training is creating an appropriate stimulus for optimal biological adaptation. Internal load monitoring is generally more sensitive than external measures in determining both acute and chronic changes to the wellbeing of the patient (Soligard *et al* 2016).

There is a high correlation between the results of external measurement and the use of a rating of perceived exertion (RPE) scale focusing on each individual training bout. The RPE scale was originally developed in the 1970s by physiologist Gunnar Borg (Borg 1970) and has been modified several times since then. Currently, RPE is on a 10-point scale of body sensations to create a perception of how hard the patient is working. It is a measure of exercise intensity at a specific time point, and is extended to **sessional RPE** (sRPE) by multiplying the total time in minutes of an exercise session by the exercise intensity based on the score of the RPE 10-point scale. For example, a 30-minute workout at an RPE intensity of 5/10 would give a sRPE value of 150 units, whereas a longer, more intense workout of 40 minutes at 7/10 would give a sRPE of 280 units, clearly illustrating the difference between the two exercise sessions in terms of load.

Adding the sRPE values up over a continuous seven day period gives a value called the **acute workload**, and taking the average of these over a four week period gives a value for **chronic workload**. The ratio of these two values is known as the **acute to chronic workload ratio** (ACWR). If, for example, a subject's sRPE values for a week came to 2100, and their average to 2500, the ACWR would be 1.19 and this value can be used as part of an overview to predict risk of injury.

The ACWR and injury

The ACWR is a useful model of the relationship between changes in training loads. Absolute load represents less injury risk than rapid increases in load over and above that which the subject is prepared for. Large week to week changes in intensity, duration, or frequency may increase the risk of injury. Where chronic load increases slowly but progressively to high levels, and acute load is low, subjects are able to adapt to the changing workload and the risk of injury is lower. However, if acute load exceeds chronic load, injury risk is increased as tissue adaptation may not be sufficient.

In general, the body adapts more effectively to relatively small increases or decreases in training volume rather than large fluctuations. High training loads which have been brought about by controlled progression offer a protective effect against injuries by increasing tissue capacity. Where the ACWR exceeds 1.5, i.e. the load is one-and-a-half times greater than the average during the last four weeks, the likelihood of injury more than doubles. Monitoring over the training or rehabilitation is important as it has been noted that higher loads may have little immediate obvious effect, with latency periods shown to possibly delay injury risk for up to one month (Soligard *et al* 2016). Research has also shown that a "sweet spot" exists, at between 0.8 – 1.3, within the centre of the ACWR values (Gabbett 2016). Values below 0.8 represent undertraining, and those above 1.3 overtraining, and both make indirect injury more likely.

Consideration of both physical (sports / work) and mental (psychological wellbeing) loads is important when

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> "THE EFFECT OF TRAINING WILL DEPEND ON BOTH THE INTENSITY AND THE RECOVERY PERIOD FOLLOWING EXERCISE"

using exercise therapy and sports training. Stress imposed on the body can cause either adaptation (positive) or maladaptation (negative). The effect of training on the body will depend on both the intensity and the recovery period following exercise, with positive and negative effects represented on the overtraining continuum (figure 1). With light training and adequate recovery, acute fatigue occurs, followed by functional and non-functional overreaching as training intensity increases and recovery reduces.

Overtraining syndrome sees a reduction in sports performance and body function, with subclinical tissue damage and, eventually, clinical symptoms. The early part of this process can be reversed when adequate recovery time is given and tissue remodelling is allowed. Homeostasis is restored with an increased fitness level and improved sports performance. Maladaption can be triggered by poor load management interacting with psychological stressors and, if severe, complete recovery may not occur.

In sports, competition may represent a rapid increase in load and calendar congestion – an increased frequency of matches or events – has been shown in the majority of studies to lead to higher instances of injury rates. In addition, psychological variables such as negative life events, daily hassles and sports related stress may increase vulnerability to injuries. The mechanism is thought to include attentional and somatic changes leading to increased distraction and peripheral narrowing. Muscle tension, fatigue and reduced co-ordination may also be important factors (Soligard *et al* 2016).

Progressive tissue loading in rehabilitation

The challenge imposed upon the body through exercise can cause a series of tissue changes known as **super compensation**. To achieve a training effect, two principles are important; overload and progression. To **overload** the body, the load imposed by an exercise must be greater than that encountered normally through the activities of daily living. The body firstly reacts to this overload, but if loading is repeated frequently, tissue adaptation will occur. In the case of muscle, this includes neurogenic (neural control) changes such as motor unit synchronisation, recruitment of additional motor units and increased motor unit discharge frequency. With time, myogenic (structural) changes occur, such as additional actin and myosin protein production, more sarcoplasm and a greater amount of connective tissue. If the same overload is used repeatedly, however, the body will stop adapting as its tissues are now adequately prepared for the new imposed load. To continue to gain adaptation the overload must therefore **progress** to challenge the body further.

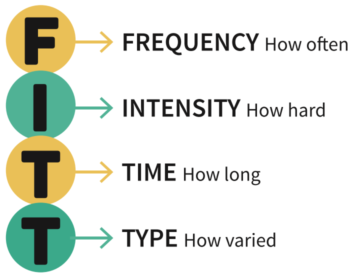

FIGURE 2: The FITT mnemonic

A simple method for remembering the basic training principles for overload is the FITT mnemonic, standing for Frequency, Intensity, Time and Type (figure 2). Originally designed to guide cardiopulmonary training, this mnemonic is also useful in strength and conditioning (S&C) training.

Frequency is how often an exercise is practised, for example, twice a day, or three times each week.

Intensity is how hard an exercise is. In strength training this is normally measured in comparison to the maximum weight the individual can lift once, or the maximum voluntary contraction (MVC) of a muscle. With stretching, intensity is measured in

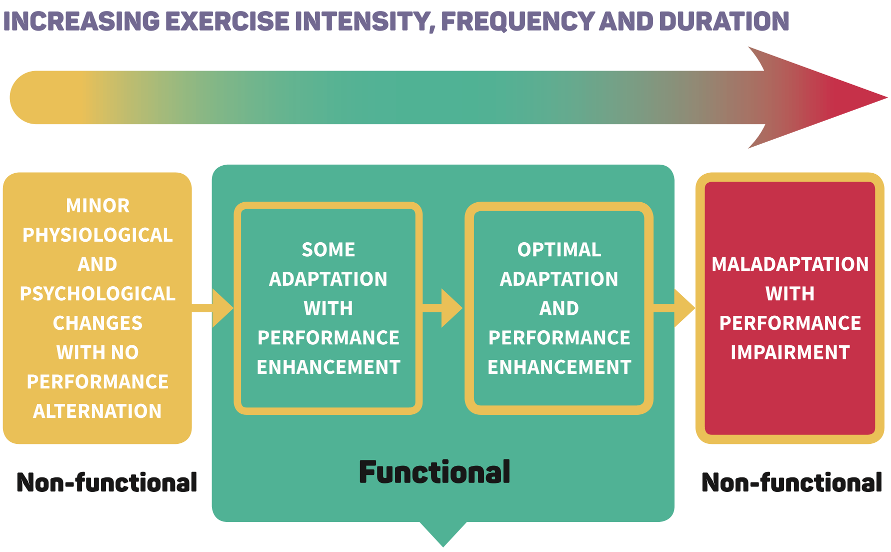

FIGURE 1: How much is too much? Levels of training and their effect on the body

how far the individual can stretch as a percentage of the maximum potential range of movement (ROM).

Time is the duration of the exercise, for example running for 20 minutes or one hour. It also refers to the duration of a repetition, for example using a very slow action (super-slow technique) in weight training to emphasise muscle contraction.

Type is the category of exercise, such as strength training, aerobics, stretching or plyometrics.

These four factors are called training variables and altering any of them will change the overall work intensity. The total amount of work is often expressed in sets and reps and together the description of an exercise, using these variables, is commonly referred to as training volume (Norris 2013).

As mentioned earlier, tissue may be loaded in isolation (simple loading) or within a whole limb action (complex loading). For example, when managing a recovering hamstring muscle injury a Nordic curl will place intense eccentric loading on the hamstrings. However, this type of simple loading selectively strengthens the target tissue, in this case the hamstring muscles, but may not work other tissues involved in limb movements, leaving them with a proportionally reduced capacity and perhaps open to secondary injury (Cook & Docking 2015).

The training must match the requirements of the individual and a needs analysis should be performed to determine which aspects of training are important to them. The tissue changes which occur as a result of training will closely match the training type selected. In exercise prescription terms this process is often referred to as the SAID mnemonic; **Specific Adaptation to Imposed Demand**. This is where the tissue adaptation closely matches, or is specific to the training load, also known as the imposed demand. Typically, a needs analysis in S&C includes

SUBJECT / ATHLETE	TASK / SPORT
Exercise history	Movement analysis
Current fitness level	Physiological requirements
Neuromuscular skill level	Injury risk

TABLE 1: Needs analysis and strength conditioning (Baechle & Earle 2008)

assessment of the individual and assessment of the task, i.e. the work or sport they wish to undertake, as outlined in table 1. When structuring, adapting and progressing a training programme, it can be useful to address the components of fitness with a simplified plan to guide exercise prescription dependent on the outcome of the needs analysis (table 2).

Example loading programme

How do we use these principles in a day-to-day private practice scenario? Let's take a grade 2 medial collateral ligament (MCL) injury to the knee as our example. Our patient is a 28-year-old young mum with two children aged five and seven. She works part-time in an office and is a keen gym user.

Needs analysis: Fitness level prior to injury was quite high and although her job is fairly sedentary, caring for her young children will make high activity demands on our patient's knee. She will need to be rehabilitated beyond her previous fitness level to increase the tissue capacity of the injured ligament and ensure that her knee is resilient. Initially, exercise therapy is designed to ease pain and stiffness and reduce the likelihood of movement impairment.

FACTOR	INTERPRETATION
Stamina	Cardiovascular and local muscle endurance
Suppleness	Static and dynamic flexibility. Agility
Strength	Concentric / eccentric / isometric
Speed	Acceleration and deceleration / power
Skill	Movement quality / sensorimotor training
Structure	Body composition / anthropometry
Spirit	Psychological fitness / psychosocial aspects of injury
Specificity	Task and sport related requirements

TABLE 2: Fitness component checklist

This latter feature has both physical and psychosocial aspects. We know that, following injury, the knee musculature will waste so muscle strength and hypertrophy will be required. In addition, we must ensure full range of motion to both physiological and in accessory movements as combined bending and twisting of the knee is inevitable when playing with young children. Following any painful injury, it is likely that aspects of illness behaviour will occur such as hypervigilance, fragility and sensitisation. It is imperative, therefore, that we include a large variety of movements, known as a wide movement vocabulary, in order to avoid the patient from tending to overprotect her knee in the future.

For convenience we can divide the healing process into two overlapping components; the reactive phase during which the joint is painful, perhaps swollen, and irritable and, as this stage progresses and these symptoms lessen, we move towards the recovery phase where changes to the injured tissue have settled and the subject is left deconditioned with respect to the knee, requiring more intense S&C training. In the reactive phase we can begin with simple flexion and extension movements initially within painful range, and finally, as irritability settles, move to a time contingent action. Actions which are symptom contingent will be stopped when pain occurs, those which are time contingent will be stopped when a given number of repetitions have been completed. Symptom contingent exercises tend to facilitate the interpretation of a nociceptive signal as pain, while time contingent exercise is likely to deactivate this type of descending (top down) facilitation (Nijs *et al* 2014).

Structuring rehabilitation: It is important that we begin muscle activation exercise as soon as possible in order to limit maladaptation through pain inhibition. Actions such as knee bracing and straight leg raise using maximum tolerable resistance ensure full locking (no extensor lag) and begin

FIGURE 3: Leg bracing

FIGURE 4: Leg extension

> "THE ABILITY TO ADAPT TO CHANGING AND UNPREDICTABLE SITUATIONS IMPLIES GREATER FLEXIBILITY WITHIN THE BODY SYSTEMS"

FIGURE 5: Leg press with resistance band

FIGURE 6: Leg press with gym ball

the redevelopment of muscle strength (figures 3 and 4). As we move into the recovery phase of the injury, exercises can progress to closed chain actions such as leg press using bands (figure 5), power loops, and gym balls as resistance (figure 6). Where a leg press machine is available this can be used to limited / controlled range, progressing resistance, speed, and motion range. Limited range squat actions together with supported lunge movements are further examples of closed chain progressions. Classic weight training actions such as squats, deadlifts and lunges can all be used with dumbbells and barbells where available, and adapted to the patient's needs.

So far, in the main we have addressed joint mobility and strength, together with initial confidence in the limb. We must now progress the programme further by increasing the variety of movements. Movement variability has been highlighted as an essential component of injury prevention (Glasgow *et al* 2013). The ability of an individual to adapt to changing and unpredictable situations implies greater flexibility within their body systems, while to reduce variability by training with constant repetition of the same actions is likely to prepare an individual to manage a limited number and types of load, i.e, the SAID mnemonic mentioned previously. Where loads are imposed outside the individual's experience, tissue capacity may be exceeded and injury can result. Varying load types will, therefore, better prepare an individual to manage a greater breadth of potential loading situations, making it less likely that their tissue capacity with any one load type will be exceeded.

Training for variability may begin with single leg balance and quarter squat actions, and while single leg standing, turning the shoulders and throwing a ball to a partner. Proprioception will be enhanced on an uneven surface such as a balance cushion, and by the individual performing the exercise with their eyes closed. In parallel we must enhance strength still further by getting our patient to take her full body weight on one leg while moving forward and twisting, an action that may be replicated when she plays soccer in the back garden with her children. To build a sufficiently robust limb the resistance on actions such as squats (figures 7 and 8) and the leg-press should increase to ¼ or ½ bodyweight. In addition, jumping, hopping and twisting actions should be progressed to full plyometric training. Acceleration, i.e. lunge, hop, sprint from a mark, and deceleration, i.e. hop-and-hold, run and stop movements, must both be incorporated within any training programme. Typically, plyometric actions include in-place, or jumping or hopping while staying on one spot, short response drills including moving forwards, backwards, sideways, twisting for a limited number of steps, and long response drills of repeated multidirectional actions over distance. By progressing the variety of movements we are incorporating additional fitness components such as speed, power and reaction time, and training specificity is providing the actions that closely mimic those to be used in the subject's future daily actions.

In the final exercise progressions we must ensure full movement range using actions such as kneeling and sitting back from heels and moving into a fall squatting position. In addition, while optimising lower limb alignment is required in the early phases of rehabilitation to reduce loading on the medial aspect of the knee, during later rehabilitation we must introduce valgus loading on to the knee to give our patient confidence that it will be resilient enough to withstand the very movement which caused the injury. Squat, lunge and leg press actions should therefore be performed pressing the knee into valgus and varus positions with gradually increasing degrees of movement and overload.

FIGURE 7: Goblet squat

FIGURE 8: Barbell squat

About the author

Dr Chris Norris is a physiotherapist with more than 35 years' experience. He is the author of 14 books on sports injury, exercise and acupuncture. He holds an MSc in Exercise Science and a Doctorate in Spinal Rehabilitation. Chris is the director of a private practice in Cheshire and visiting lecturer to several universities. He lectures widely, running a variety of CPD courses, further information for which can be found on his website is **www.norrishealth.co.uk**.

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