Recovery and Adaptation

by William A. Sands

Introduction

Is systematic recovery necessary for the modern athlete, and are prescribed recovery activities effective? As the developing field of modalities to promote athlete recovery in training moves beyond its first baby-steps, we see there are numerous paradoxes and uncertainties that make this a difficult question to answer. For example, prior to the 2008 Olympic Games, Australian sport scientists concluded that traditional and well-accepted methods such as sufficient nutrition, hydration, and rest appear to be the more effective for optimising recovery in Olympic athletes than newer, more exotic strategies. Another study found that athletes using the Recovery Center at the U.S. Olympic Committee’s Training Centre showed a negative relationship with medals won, in other words, those who used the available advanced recovery modalities the most fared less well in competition. Interestingly, three decades ago, VERKHOSHANSKY was already thinking along these lines when he identified the potential conflict of using artificial restorative means that may contaminate the natural recovery process.

Paradoxes usually indicate incomplete understanding and it must be said that conceptual and definitional problems continue to plague recovery studies. Most definitions infer a return to a homeostatic state following a training-induced disturbance. KELLMANN defined recovery as the compensation of deficit states of an organism (e.g., failure or decrease in performance) and, according to the homeostatic principle, a reestablishment of the initial state. However, I for one believe that recovery defined by a return to prior conditions is insufficient for use in training for high-performance sport. A unity of recovery and adaptation (RA), like that described by STONE et al., is more relevant.

The aim of this article is to help advance the work of scientists and practitioners by providing an overview of the field, including the latest thinking on various RA strategies, as the basis for further discussion and study.

Fatigue-Recovery-Adaptation

Establishing a unity of training and recovery and adaptation as expressed by HARRE is essential for the effectiveness of athletic training. Training causes fatigue and temporarily lowers performance but also sets off two processes that may temporarily run along parallel lines:

- the recovery process leading to the reestablishment of the full ability to function,
- the adjustment or adaptation processes leading to the functional improvement of performance and the morphological reorganisation of the functional systems under stress.
RA appear to share feedforward and feedback pathways both sequentially and simultaneously\(^7\text{-}^9\). There are also aspects of force production and regulation, important keys to athletic performance, that share these pathways. Fatigue expression may involve a threshold: below it, fatigue may be present but not influencing performance, above it, performance declines.

Figure 1 shows a schematic of the progress of a training stimulus and response resulting in early fatigue followed by RA.

Fatigue results in a reversible decline in biological systems. Importantly, it may be present \textit{before} a marker of physiological or psychological task failure is observed\(^7\). Fatigue and RA appear to share feedforward and feedback pathways both sequentially and simultaneously\(^7\text{-}^9\). There are also aspects of force production and regulation, important keys to athletic performance, that share these pathways. Fatigue expression may involve a threshold: below it, fatigue may be present but not influencing performance, above it, performance declines.

Figure 2: Example of body area fatigue, pain, and soreness of weightlifters from the U.S. Olympic Training Center. (Note the differences in percentages of reports for various body areas.)
If fatigue is present with no impaired performance, available methods of detection are lacking. However, if fatigue is cumulative, the background and undetectable aspects merit research.

Sources and regulation of fatigue may be central, peripheral, or both. Muscle performance studies regularly distinguish between peripheral (i.e. from the neuromuscular junction to the protein filaments) and central (i.e. proximal to the neuromuscular junction to the cerebrum). Peripheral fatigue is defined by two characteristics: 1) an exercise-induced force or power reduction, regardless of task completion\(^9\), and 2) inability to maintain a maximal or expected force or power level\(^10\). Central fatigue is a progressive, exercise-induced reduction in voluntary activation of a muscle\(^11\).

In spite of previous work demonstrating different types, locations and sources of fatigue, most work on recovery does not address the possibility of different types of RA targeting different locations or sources of the fatigue and its regulation. Figure 2 shows the body areas in most need of recovery based on fatigue, pain and soreness reported by Olympic-level weightlifters.

It is important to note that RA strategies and techniques are not sufficiently powerful to overcome stupid coaching, bad planning or lack of talent. Moreover, it is essential for athletes to inform the coach of their fatigue status. With that said, modern training theory and psychophysiology present three broad categories of concepts for RA:
- Training planning,
- Physical RA,
- Psychological RA.

**Training Planning**

There are at least a dozen training planning models, most with subtypes, and a number of training and recovery guidelines are discussed...
in the extant literature. A common theme among these is that RA activities should be systematically planned\(^4, 12, 13\) with the following principles and considerations identified:

- RA activities can be withheld when appropriate in order to enhance the body’s ability to heal itself. It is necessary to consider that immediate use of artificial means that help restoration weaken the natural ability of the body to restore itself\(^14\).

- Variation of RA activities is important because athletes become adapted to a particular form with reduced efficacy from continued treatments. Therefore, long-term use of any given means of restoration has a decreasing recuperative effect, as the body adapts more rapidly to local-effect means than to general means\(^14\).

- RA effects tend to be short-lived, especially following high-intensity training, lasting from hours to the next day\(^15\).

- Rest does not mean bed rest, it simply means active rest for those fatigued from short-duration, high-intensity training. Athletes fatigued by long-duration, low-intensity training require calm rest\(^16\).

- Athletes incorporate RA strategies and modalities on their own.

- Relaxation may be a foreign idea to some athletes, and systematic instruction may be needed to help the athlete learn to relax\(^17\).

- Both sleep duration and quality are important for RA, provisions for adequate sleep should be included in training plans\(^16\).

- Local and systemic recovery strategies should be planned and implemented. Local RA occurs more quickly and easily than systemic RA\(^14\).

- A day or two of active rest following a competition is recommended (Figure 4)\(^5, 18, 19\).

- Every training programme should be combined with a monitoring programme of training dose-response relationships\(^5, 20\).

The goal of training planning is an optimal training load for each athlete, implying that training activities are sufficiently stressful to challenge and fatigue the athlete, and that these are punctuated by rest. Figure 4 is a schematic of the concept of optimisation with training loads that are too little, too much, and just right\(^2, 21\).

**Figure 4: A theorised optimal path of adaptation and recovery adaptation contrasted to two other paths exhibiting non-optimal adaptation (Note periods of hard training followed by periods of rest (recovery-adaptation)).**
Training plans may be developed in many ways. A common planning method uses an annual plan form. However, specific RA activities in such plans are rare. An example of an annual plan with RA activities is shown in Figure 5.

**Rest and Sleep**

Modern life tends to intrude frequently on an athlete’s time for rest and measuring rest is difficult. In fact, rather than measure rest, we measure a pertinent negative - the absence of known responses to stress. For example, the Rusko Test exploits the known response to orthostatic changes by comparing morning heart rates in a lying position with those observed after standing (i.e. orthostatic intolerance).

When heart rate variability is relatively low, we assume that the athlete is stressed. Figure 6 shows an example of Rusko Test results from a synchronised swimming national team athlete showing that the standing heart rate was too high, indicating that RA was incomplete.

In the RA paradigm, the detection of the presence of RA is based on the absence of fatigue markers. Demonstrating an absence of fatigue markers is, in turn, based on the presence of adaptation (i.e. recovered) performance.

**Sleep**

Sleep studies involving elite athletes are rare. Sleep loss is known to reduce cognitive effectiveness. However, the complex nature of sleep betrays the fact that many people, especially those in high-stress situations, cannot obtain the sleep that is refreshing and regenerating. Shortening the sleep period to 4-6 hours per night for four or more nights in a row resulted in disturbed mood states and reduced cognitive abilities. One of the simplest recommendations for sleep is that people should obtain at least eight hours of sleep per night. However, there appear to be wide variations in individual sleep duration needs.

Napping may hold benefits for those who must live and perform with less than optimal sleep. A 30-minute lunchtime nap was shown to decrease sprint times and increase alertness when compared to a no-nap control group. Naps can also enhance learning and other cognitive abilities.

A common complaint arising from naps is the phenomenon of sleep inertia, the feeling of drowsiness or sluggishness that may follow a nap. A study of 20-minute naps to simulate jetlag showed no benefits to performance. The regulation of sleep and sleep inertia may rely on limb temperature during sleep, particularly of the hands and feet. Increased distal skin temperatures are related to short sleep onset while sleep inertia may represent a thermal reversal of sleep-onset (i.e. warmer hands and feet).

Extending the idea of adequate sleep, MAH et al. showed that increased sleep duration resulted in better performance in basketball. The subjects in this study underwent a five- to seven-week period of extended sleep. Their minimum goal was to achieve 10-hours of sleep per day. Basketball skills and several laboratory measures showed improvement. When early morning practices and training are imposed, there is an increased perception of fatigue and a decrease in normal sleep duration.

**Blood and Lymphatic Flow**

The majority of RA approaches involve increasing blood and lymphatic flow. Fluid flow is encouraged by light exercise, thermal therapies (hot and cold), mechanical devices (compression), nutrition (protein and carbohydrate timed feedings), touching (massage), and increased comfort. Exercise-induced oedema is an important aspect of all exercise. The inflammatory cascade regulates and assists healing in muscle and other tissues during and following training. Pain is a common complaint following hard training. Thus, control of the magnitude of oedema and the body’s ability to reduce pain is a fruitful area for study and RA strategies.
Figure 5: Example annual plan including recovery-adaptation scheduling
Light Exercise and Active Rest

One of the simplest means of increasing blood flow is light exercise. Lowering of lactate, heart rate, and better Profile of Mood States results were obtained by low-intensity cycling in trained cyclists\(^3\). Increased blood flow is more likely to be encouraged by active rather than passive rest. Lactate elimination and better subsequent performance following judo combat exercise were promoted more by active rest\(^3\). Perhaps the best fate of post-exercise lactate is consumption by active muscle, but the muscle activity for RA should not be great enough to produce new lactate. Cycling at 40% of VO\(_2\) max was better at eliminating post-exercise (15-20 min) lactate than massage or passive recovery\(^4\). GILL et al. showed an increased effectiveness of RA in rugby players following a match by using active recovery (light exercise), hydrotherapy, and a compression garment\(^5\). Massage and passive recovery were ineffective in lactate removal when compared to active recovery\(^6\). A recovery swim with runners led to enhanced next day running performance, possibly due to the hydrostatic properties of water\(^7\).

Thermal Therapies

Heat packs and heating pads have been a mainstay of sport therapy and self-administered treatments for decades\(^8\). Moist heat packs were shown to be effective in hamstring muscle range of motion when compared to stretching alone\(^9\). Hot baths, steam baths, and saunas are also common RA practices. SOBOLEVSKY describes the methods for sound sauna use along with precautions for young athletes\(^10\). SANDS (In Press) studied hydration in Olympic level athletes using a sauna and steam bath, insisting on fluid ingestion during use. Urine specific gravity values did not show dehydration, and body weight

Figure 6: An example of the application of the Rusko Test of orthostatic tolerance (The athlete applies a heart rate monitor with storage capabilities upon awakening but before rising from bed. After a few minutes of lying heart rate measurements, the athlete suddenly stands up and the heart rate is recorded continuously. Large differences between lying and standing heart rates may indicate a lack of recovery and adaptation from the previous day’s training. The handwritten annotations demonstrate how rapidly this information can be returned to coaches.)
increased following sauna and steam bath use. Anecdotal support for sauna use among Finnish athletes was provided by REHUNEN\textsuperscript{47}. A study of delayed onset muscle soreness (DOMS) showed that only superficial heat was effective in reducing DOMS as compared to cold and control\textsuperscript{48}.

**Applications of Cold**

Cryotherapy (i.e. application of cold) has been a method of choice for injury rehabilitation, reduction of oedema, and blood circulation enhancement for centuries. Cryotherapy has been applied for immediate wound care, sprains and strains, chronic injuries, before and after surgery, and as a modality for RA\textsuperscript{49}. Inter-set weight pulling performance has been enhanced by the application of cold\textsuperscript{50}. Cold-water immersion has been found to aid recovery in cyclists\textsuperscript{51}. Whole-body cryotherapy using a chamber cooled by liquid nitrogen to minus 135°C for several minutes is being used for RA. Reports on this type of therapy have included RA and other types of rehabilitation and have been largely Favorable\textsuperscript{52-54}. Figure 5 shows the author and colleagues about to enter a Cryotherapy chamber. Recovery centre surveys of athletes’ preferences for various therapies indicate that cold-water immersion ranks second only to massage (SANDS, in press).

Cryotherapy has recently been questioned based on investigations of the use of cold on oedema and the inflammatory cascade following injury\textsuperscript{55}. MIRKIN, who coined the acronym RICE – Rest, Ice, Compression, and Elevation – in 1978\textsuperscript{56} now finds that complete rest and ice prolong the disability and delay healing. Inflammation is necessary for healing, and the role of inflammation appears to have been misjudged\textsuperscript{56}. Ice therapy has also been shown to delay healing after intense eccentric exercise\textsuperscript{57}.

Moreover, the inflammatory process and immune response to injury, whether exercise-induced or from trauma, requires complex interactions of many physiological pathways and specialised cells of the immune system\textsuperscript{58}. Whole-body cold immersion resulted in decreased strength values, although the declines were small\textsuperscript{59}. A DOMS experiment using cold-water showed a minimal effect\textsuperscript{60}. The most current information indicates that anything that interrupts or delays circulation, or alters the inflammatory cascade is probably not ideal for enhancing RA.

**Static Compression**

Reduction of exercise-induced oedema is an important aspect of RA and often a key to healing\textsuperscript{37, 61}. Static compression garments in the form of stockings and leggings or tights are available in both graduated- and non-graduated pressure-types. Graduated garments are designed to exert greater pressure in some regions, usually circumferentially, with higher pressures distally. The elastic nature of the garments combined with motion of the limb can be used to assist the sequential nature of compression and fluid flow. Non-graduated stockings enhanced running in moderately trained runners with lower leg problems, however these runners also improved their aerobic capacity during the study making determination of the source of the change difficult\textsuperscript{62}.

A meta-analysis of compression garments concluded that the garments are effective methods to enhance RA\textsuperscript{68}. In contrast,
no physiological benefits were observed in a study of compression garments used by males and females following a marathon but the perceived soreness was lower in the garment group. Questions around the value of compression garment use remain open, but this modality appears promising.

**Intermittent Peristaltic Compression (IPC)**

IPC involves dynamic compression via a computer-controlled air pressure pump connected to a legging or sleeve. The basic premise is that pressures in a sequential, peristaltic fashion more closely mimics natural fluid flow and is thereby more effective. IPC requires a device that provides circumferential pressures to a limb, moving from distal to proximal (Figure 7).

The use of IPC has been shown to be effective for prevention of oedema formation, increasing blood flow, and stimulation of tissue healing. Although static compression is an effective therapy for oedema reduction, the intermittent compression optimises lymphatic drainage. IPC can accelerate recovery from either intense exertion or injury, especially when the athlete is incapable of generating rhythmic muscle contractions. Improved lymphatic function accelerates healing through the removal of oedema from injured soft tissues. An advantage of IPC is the intermittent nature of the applied pressure allowing the pressure to be greater than that achieved using static pressure or applied manually by a therapist.

The primary RA mechanism of IPC is enhanced lymphatic drainage and fluid return that accelerates circulatory responses and the removal of edema-containing waste products and damaged tissues. Dynamic compression can improve healing through oedema reduction, stimulation of platelet aggregation, and neutrophil adherence. Dynamic compression has been shown to enhance both fractures and soft-tissue healing, and pressure to pain threshold among Olympic level athletes.

IPC may also be better than static compression based on the fragility of lymphatic vessels and valves. The intermittent nature of IPC may allow the fragile valves of lymphatic and capillary vessels to open. MARTIN et al. found that IPC did not reduce lactate values immediately but did so later. These investigators postulate that IPC could be useful for those athletes needing a form of inactive recovery.

---

Figure 7: About to enter the Kriotherapy Chamber at -135° in London, UK (The masks are needed to prevent sudden freezing of water in the mouth, nose, and on the lips.)
In contrast with many RA modalities, there appears to be less contradictory evidence regarding the effects of IPC on RA. However, the individual device pressures and the durations and sequences of the pressures remain to be investigated.

**Compassionate Touch Therapy-Massage**

Studying massage is difficult both because of the myriad techniques and because the rapport factor that appears to dictate the efficacy of much of the massage process. Massage appears to be a promising method for RA, but nearly all reviews and studies indicate that more high-quality research is needed, and that the mechanisms are poorly understood.

Massage therapy elicits a great deal of faith in its effectiveness from practitioners and recipients but most studies of DOMS and massage have shown serious methodological flaws and extant studies are equivocal on the effectiveness of massage. For example, an excellent review article on massage and DOMS concluded that massage is promising in reducing soreness but shows limited results in transfer to performance enhancement. In spite of these problems, most investigators suggest that post-exercise massage may alleviate the symptoms of DOMS.

HEMMINGS et al. raised questions about the efficacy of massage in a study of physiological and psychological recovery stating that massage may be beneficial psychologically but not physiologically. NELSON also noted that observations of massage effects were more easily shown in the psychological than the physiological domain.

The physiology of touch has recently received important support from the discovery of touch neurons called C-tactile neurons. These afferent neurons are found in the hairy regions of the body and provide light touch feedback. Results indicate that C-tactile afferents constitute a privileged peripheral pathway for pleasant tactile stimulation that is likely to signal affiliative social body contact. MC-GLONE et al. described the neurons as, a class of low-threshold mechanosensitive C fibres that innervate the hairy skin represent the neurobiological substrate for the affective and rewarding properties of touch. Thus, the physiological mechanism for the pleasant nature of massage may have been identified.

**Nutritional Therapies**

Nutritional interventions are perhaps the least controversial of all RA modalities. Those interventions known to enhance performance are creatine, hydration, carbohydrate loading, and supplemental protein. For example, when exercise is followed by carbohydrate feeding subsequent performance is augmented and when carbohydrate feeding is withheld subsequent performance declines. A likely influence on central fatigue and recovery was shown from simply rinsing the mouth with a carbohydrate solution that further resulted in decreased fatigue. However, carbohydrate and caffeine mouth rinsing did not enhance strength or muscular endurance.

Carbohydrate alone and in combination with other nutrients is important in brain tissue recovery and carbohydrate ingestion may alter neurotransmitter actions. The neurotransmitter serotonin is influenced by its precursor tryptophan. Tryptophan crosses the blood-brain barrier by binding to albumin. Albumin is reduced by carbohydrate interactions with fat metabolism along with tryptophan. Decreasing the precursors of serotonin or the relations of serotonin to dopamine and other neurotransmitters, is potentially important for recovery because of the relationship of serotonin to moods, depression, and sleepiness.

**Nutrient Timing**

Although nutrient timing and content has recently been shown to be somewhat less powerful than originally thought, work in this area has been one of the most important additions to modern training science. There appears to be a window of optimal nutrient intake...
Psychological Therapies

Application of recovery modalities usually occurs when the athlete is most vulnerable. The athlete is often physically exhausted, in pain, and cognitively deficient. Experience has shown that compassionate discourse, a strong social support network, and athlete confidence are good indicators of the success of RA. The human-to-human activities in sports recovery often involve caring conversation (e.g. counseling), compassionate touching (e.g. massage), and other close personal contact. SIFF wrote about athlete recovery, suggesting that often one cannot separate the therapy from the therapist, since the therapy works because of the rapport between therapist and client.

Mental Fatigue

The concept of mental fatigue is certainly not new and occupies a common sense position in everyday discourse. Mental fatigue is a psychophysiological state that is the result of prolonged cognitive activity and can impair physical performance. Here, again, is an example of the potential role of central fatigue in athletic performance and emphasises a need for further investigations of methods designed from approximately 45 minutes to one hour post-exercise. The combination of protein and carbohydrate in chocolate milk has been identified as an ideal source of post-exercise nutrition. Other research supports the idea that carbohydrates are the most important macronutrient along with water and protein following exercise. A carbohydrate and protein supplement, while not improving performance, appeared to reduce muscle damage based on assessments of myoglobin and creatine kinase.

The International Society of Sports Nutrition developed a consensus position statement, which indicates that specific amino acid supplements, particularly branched chain amino acids, improve RA. However, there are still some enigmatic aspects of nutrition in RA. For example, a study of the benefits of fast food versus sports supplements showed no difference in glycogen resynthesis following exercise. If fast food can compete with designed sport supplements, then nutrition education may need recalibration.

Figure 8: Lower extremity IPC therapy
to understand central fatigue and enhance central recovery.

Mental fatigue tends to be cumulative and gradually acquired when compared to physical fatigue. In the ergonomics world, mental fatigue and recovery have been described with the following:

A distinction is made between ‘physical fatigue’ and ‘mental fatigue’ and its consequences for recovery. The discrepancy between ‘actual state’ and ‘required state’ has been suggested as the basis for ‘recovery’. This emphasis, that recovery is a dynamic and ongoing process, which also included motivational aspects, in particular as far as mental work is concerned. The capacity to maintain self-regulation of one’s psychophysiological state is important in this respect. Thus, we propose that ‘recovery’ is the continuous process of harmonising the ‘actual state’ with the state that is ‘required’ at that moment109.

Mental fatigue has been shown to reduce time to exhaustion in high-intensity cycling110. Mental fatigue resulted in worse intermittent sprint performance variables such as lower oxygen consumption and greater ratings of perceived exertion111. The preceding authors and others have subsequently found that mental fatigue does not have deleterious effects on whole body endurance exercise, sustained isometric tension, peak sprint velocities, and some mood variables111-113. The paradox described by these authors has been postulated to result from the activity of higher brain centers in self-regulation of effort113.

In spite of some paradoxical issues regarding the role of psychophysiological states on fatigue, and RA, and that of psychological investigations in general114, 115, there is little doubt that psychological factors play an important role in RA116-118. Athlete attitudes and volition may increase the variability of performance and psychological responses, and thus the experimental difficulties of cause and effect. Mental toughness and the ability to relax are considered essential RA characteristics119, 120.

Mental Resilience

Mental resilience is one of the newer concepts involved in one’s ability to handle stress and “bounce back” from stress and fatigue121-123. However, hardness and optimism failed to predict past staleness in high school age male and female endurance athletes124. Again, SIFF embraced the paradoxes, contradictions, and difficulties in RA research, particularly psychological factors suggesting that certainly many of these techniques work because they are placebos, because the user believes in them. Yet, this is a very good reason not to dismiss them. If the mind can be focused by an apparently illogical or foolish concept to perform unusual feats of performance or healing, then it is vital that we uncover the underlying physiological principles that make the placebo effect (or ‘faith factor’) so powerful. Placebos can produce positive and negative effects; it is up to science to sift the useful from the harmful125. Like massage, we tend to have faith that psychological factors are involved in RA, in spite of limited and contradictory evidence.

Conclusion

Recovery-adaptation is both new and old, with modern approaches facing new scrutiny. Research in RA is very young and full of uncertainty. There are many obstacles to the study of RA. One of the most serious obstacles is the lack of a theoretical or mechanistic framework from which to design studies and guide RA modality implementation. Perhaps, with apologies to Tolstoy, we can say that all recovered athletes are the same, but each unrecovered athlete is unrecovered in his or her own way.

Please send all correspondence to:
Dr William A. Sands
wmasands@hotmail.com
REFERENCES


