

# Physiological adaptations to exercise



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The aim of physical training is to systematically stress the body so it can improve its capacity to exercise. Physical training is beneficial only if it forces the body to adapt to the stress of the physical effort. If the stress is not sufficient to overload the body then no physical adaptation occurs, Brookfield J, (2004).

In order to achieve maximum effectiveness, it is necessary to consider factors including the body's energy pathways, muscular adaptations, and the cardiovascular system. Along side these considerations fatigue and the recovery process play an equally important role in achieving fitness. This report will initially consider the nature and necessity of the body's energy pathways as a means of providing energy for training, followed by an overview of physiological training, focusing particularly on muscular and cardiovascular adaptations. This is then followed by an experimental report in which an individual is initially subjected to a fitness test, a training regime, and finally retested in order to assess any physiological adaptations. Finally these results will be discussed with conclusions given. The operation of the body's energy systems While sports as diverse as for example, running, tennis, cycling or weight training may appear varied and diverse in nature, they do in fact share one aspect in common: the need for appropriate energy delivery.

Rather like fuel for a car engine, the human body requires carbohydrates, lipids and proteins. Unlike a car however which simply has one energy transfer system – the engine, the human body utilizes 3 distinct methods of energy transfer, or energy pathways. In order to get the most out of the human body and to succeed in sport, it is necessary to use appropriate

training principles to train these specific energy pathways, thus making them more resilient to fatigue. The Anaerobic (ATP-CP) Energy System The ATP-CP energy pathway supplies between 8 – 10 seconds worth of energy and is used for short bursts of exercise such as the 100 meter sprint. It first uses up any adenosine triphosphate (ATP) stored in the muscle, approximately 2-3 seconds worth, and then uses creatine phosphate (CP) to resynthesize ATP until the CP runs out, approximately another 6-8 seconds.

After the ATP and CP are used the body will move on to either aerobic or anaerobic metabolism (glycolysis) to continue to create ATP to fuel exercise. The Anaerobic Lactate (Glycolytic) System The anaerobic energy pathway, or anaerobic glycolysis, creates ATP from ingested carbohydrates with lactic acid being a by-product. Anaerobic glycolysis provides energy via the breakdown of glucose without the need for oxygen. It produces energy for short, high-intensity bursts of activity lasting no more than several minutes until ‘onset blood lactate accumulation’ or OBLA. OBLA refers to the point at which lactate begins to accumulate in the blood, usually measured at 4 mmol/litre of blood.

Lactic acid build-up increases until the lactate threshold is reached, at this stage muscle pain, burning and fatigue make it difficult to maintain intensity. The Aerobic System Aerobic metabolism fuels most of the energy needed for long duration activity such as distance running. It uses oxygen to convert nutrients (carbohydrates, fats, and protein) to ATP. This system is slower than the anaerobic systems because it relies on the circulatory system to transport oxygen to the working muscles before it creates ATP.

Aerobic metabolism is used primarily during endurance exercise, which is generally less intense and can continue for long periods of time. Energy System Recruitment During exercise an athlete will progress through these metabolic pathways. As exercise begins, ATP is produced via anaerobic (ATP-CP) metabolism. With an increase in breathing and heart rate, there is more oxygen available and aerobic metabolism begins and continues until the lactate threshold is reached.

If this level is passed, the body will not be able to deliver oxygen quickly enough to generate ATP and thus anaerobic metabolism starts once more. Since this system is short-lived and lactic acid levels rise, the intensity can not be sustained and the athlete will need to decrease intensity to remove lactic acid build-up Dick F. (2002). As the above table illustrates, different energy systems are employed at differing times and rates dependant upon the duration and intensity of the exercise.

For example it can be seen that ‘Sprints’ (specifically 100m) almost exclusively (90%) utilize the ATP-CP energy pathway whilst ‘Distance running’ primarily used aerobic metabolism. Sprinting requires a short, but extremely intense bout of activity which requires immediate energy delivery, thus utilizing the only system capable of immediate energy delivery: ATP-CP. Distance running, although employing the ATP-CP and the slightly ‘longer lived’ aerobic glycolysis system relies primarily on the aerobic metabolism in order to fulfill energy demand. With very little need for ‘explosive power’ the body can employ the usage of intramuscular glycogen stores. The graph below illustrates how the three energy systems interact during exercise.

Correct training will extend the time to exhaustion thus improving fitness. With appropriate training, these energy systems adapt and become more efficient, allowing greater exercise duration at higher intensity, thus resulting in musculoskeletal and cardiovascular adaptations. Adaptations to Exercise

When undertaking any physical task, the human body responds through a series of changes in function that involve most of its physiological systems. Movement requires activation and control of the musculoskeletal system with the cardiorespiratory system providing the ability to sustain this movement over extended periods, Astrand P, Rodahl K (1986). When the body engages in exercise training over extended periods each of the physiological systems undergo specific adaptations that increase the body's efficiency and capacity.

The magnitude of these changes depends largely on the intensity and duration of the training sessions, the force or load used in training, and the individuals' initial level of fitness. One of the reasons for undertaking fitness activities for most individuals is the enhancement of cardiovascular function and aerobic capacity. During the transition from rest to exercise cardiac output increases rapidly. ' Thereafter cardiac output rises gradually until it reaches a plateau when blood flow meets the exercise requirements' (McArdle W, Katch F ; Katch V 2001). In its most basic form this initial increase in demand triggers changes in the cardiovascular system including an increase in heart rate and stroke volume in order to supply oxygen demand. As training continues and becomes long term, cardiovascular adaptations become more permanent with the heart becoming stronger and more efficient, this increases the efficiency of both the pulmonary and

systemic circulation systems delivering more oxygen and removing more waste products.

With increased and sustained training it can be seen that pulmonary adaptations also occur. During exercise the body requires more oxygen and therefore the breathing cycle adapts by employing complimentary muscles. These muscles allow for more efficient respiration. The following muscles and their functions all play a part in this cycle:

- \* Internal and External Intercostals – Expansion and contraction of the rib cage
- \* Sterno Clado Mastoid – Elevates rib cage
- \* Scalenes – Elevates rib cage
- \* Pectoralis minor – Elevates rib cage.

- \* Quadratus lumborum – Pull lower ribs inward during expiration
- \* Abdominals – Compress the abdomen
- \* Obliques – Compress the abdomen

The result of these extra muscle functions is:

- \* An overall increase in Minute Ventilation (VE) ( $VE = TV \times F$ )
- \* An increased Tidal Volume (TV)
- \* An increased Inspiratory Reserve Volume (IRV)
- \* An increased Expiratory Reserve Volume (ERV)
- \* An increase of Forced Vital Capacity (FVC),  $TV + IRV + ERV$
- \* A decrease in Residual Lung Volume (RLV).

The combination of increased cardiac output and pulmonary function result in the muscles receiving more oxygen, thus increasing aerobic capacity. Similar adaptations can also be seen during anaerobic training although to a much lesser degree. Anaerobic training, although of marginal benefit to the cardiopulmonary system, is primarily concerned with short explosive burst of power, and training concentrates primarily on relevant muscle groups. Although aerobic and anaerobic training produces muscular adaptations, those adaptations differ. A distance runner or triathlete for example will

develop mainly sarcoplasmic protein, while a weight lifter will develop mainly contractile protein, Edgerton, V.

R (1978). When muscles are forced to contract they will increase in size and strength, in terms of anaerobic training therefore, muscles must be overloaded to a state of hypertrophy. This increase in size and strength as a result puts little demand on the cardiopulmonary system and therefore has limited benefits to aerobic capacity. Clearly, both aerobic and anaerobic training allows for health improvements as a result of physiological adaptations, but when training exceeds the body's recovery capacity an emotional, behavioral and physical condition called overtraining can occur Mac B, (2008). The individual will often cease making progress.

The most common symptoms are often disturbed sleep patterns and a loss of progressive improvement in training. In the most undesirable instance an individual can even begin to lose strength and fitness. Neuromuscular fatigue affects the central nervous system and makes the individual more prone to injury and illness; this is a direct result of overtraining and can be avoided by initiating the correct training program which is tailored to the individual athletes needs. The importance of fatigue and the knowledge to maximize the efficiency of energy systems is essential.

As previously stated, when there is insufficient ATP availability muscular contraction will weaken and performance will deteriorate, this combined with hydrogen ion (lactic acid) accumulation, where excess hydrogen increases the acidity of muscle tissue, are some of the main components of fatigue. Glycogen depletion and the decreased availability of calcium ions also

contribute to a decrease in performance, as does a decrease in availability of the neuro-transmitter acetylcholine. In all therefore there are several important aspects to consider when discussing fatigue, moreover it is important to understand the importance of the recovery process. Recovery immediately after exercise initially involves the recovery of oxygen debt known as 'excess post-exercise oxygen consumption' (EPOC).

This can be defined as 'the amount of oxygen consumed during recovery above that which normally would have been consumed at rest in the same period of time', Wesson K et al, (2000). This recovery process has 2 distinct components: Alactacid Debt: The first and fastest component of the oxygen debt that is replenished, it allows the restoration phosphocreatine used during the employment of the ATP-PC energy system. This faster recovery rate normally takes between 2 - 3 minutes, in which time 2 - 3 litres of oxygen is consumed providing the catalyst for resynthesis. Lactacid Debt: This slower replenishment is utilized to remove excess lactic acid from the muscles, where lactic acid is oxidized to produce carbon dioxide and water. This process takes approximately one hour but can be accelerated by using 'cooling down' as an exercise recovery.

Along with EPOC the body also needs to replenish its stores of glycogen. This process can take over 24 hours and often as long as 48 hours depending on the type and intensity of exercise. It is generally accepted that a high carbohydrate meal within 1 hour of exercise cessation will greatly enhance recovery times. Long term recovery brings repair and, as a result, physiological adaptation to training, this is especially important when undertaking anaerobic training where microtrauma is the catalyst for



muscular adaptations Edgerton VR, (1978). Tearing of muscle fibers, muscle sheaths and connective tissue along with stress to the tendons and bones creates an environment in which the body can be left in a weakened state.

This can, at times, result in cessation of training thus removing the training stimulus; this is a direct result of the emotional and behavioral damage caused by overtraining. The removal of the training stimulus will result in the loss of the efficiency, strength and capacity that has been gained through training-induced adaptations. Detraining, as it is known, creates an environment where the body, after months or possibly weeks, will revert back to its prior state and all benefits are subsequently lost.