Post-Exercise Recovery Tracking Based on Electrocardiography-Derived Features

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Abstract : The method of Electrocardiography (ECG) interpretation for post-exercise recovery tracking was developed. Metabolic indices (aerobic and anaerobic) were designed using ECG-derived features. This study reports the associations between aerobic and anaerobic indices and classical parameters of the person's physiological state, including blood biochemistry, glycogen concentration and VO2max changes. During the study 9 participants, healthy, physically active medium trained men and women, which trained 2-4 times per week for at least 9 weeks, fulfilled (i) ECG monitoring using Apple Watch Series 4 (AWS4); (ii) blood biochemical analysis; (iii) maximal oxygen consumption (VO2max) test, (iv) bioimpedance analysis (BIA). ECG signals from a single-lead wrist-wearable device were processed with detection of QRS-complex. Aerobic index (AI) was derived as the normalized slope of QR segment. Anaerobic index (ANI) was derived as the normalized slope of SJ segment. Biochemical parameters, glycogen content and VO2max were evaluated eight times within 3-60 hours after training. ECGs were recorded 5 times per day, plus before and after training, cycloergometry and BIA. The negative correlation between AI and blood markers of the muscles functional status including creatine phosphokinase ($r=-0.238$, $p < 0.008$), aspartate aminotransferase ($r=-0.249$, $p < 0.004$) and uric acid ($r = -0.293$, $p<0.004$) were observed. ANI was also correlated with creatine phosphokinase ($r= -0.265$, $p < 0.003$), aspartate aminotransferase ($r = -0.292$, $p < 0.001$), lactate dehydrogenase (LDH) ($r = -0.190$, $p < 0.050$). So, when the level of muscular enzymes increases during post-exercise fatigue, AI and ANI decrease. During recovery, the level of metabolites is restored, and metabolic indices rising is registered. It can be concluded that AI and ANI adequately reflect the physiology of the muscles during recovery. One of the markers of an athlete's physiological state is the ratio between testosterone and cortisol (TCR). TCR provides a relative indication of anabolic-catabolic balance and is considered to be more sensitive to training stress than measuring testosterone and cortisol separately. AI shows a strong negative correlation with TCR ($r=-0.437$, $p < 0.001$) and correctly represents post-exercise physiology. In order to reveal the relation between the ECG-derived metabolic indices and the state of the cardiorespiratory system, direct measurements of VO2max were carried out at various time points after training sessions. The negative correlation between AI and VO2max ($r = -0.342$, $p < 0.001$) was obtained. These data testifying VO2max rising during fatigue are controversial. However, some studies have revealed increased stroke volume after training, that agrees with findings. It is important to note that post-exercise increase in VO2max does not mean an athlete's readiness for the next training session, because the recovery of the cardiovascular system occurs over a substantially longer period. Negative correlations registered for ANI with glycogen ($r = -0.303$, $p < 0.001$), albumin ($r = -0.205$, $p < 0.021$) and creatinine ($r = -0.268$, $p < 0.002$) reflect the dehydration status of participants after training. Correlations between designed metabolic indices and physiological parameters revealed in this study can be considered as the sufficient evidence to use these indices for assessing the state of person's aerobic and anaerobic metabolic systems after training during fatigue, recovery and supercompensation.

Keywords : aerobic index, anaerobic index, electrocardiography, supercompensation
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