Energy sources and FuelWise

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Polar Research Center

CONTENTS

1 Introduction

The human body uses mainly carbohydrates and fats as sources of energy. Proteins are used to a limited extent. In physical exercise, the amounts of different energy sources used vary greatly depending on the intensity and duration of the exercise and the physiological characteristics of the individual. During rest and light exercise, mainly fats are consumed, but the more intensive the exercise is, the more carbohydrates and protein are consumed. In order to use energy, the human body must also maintain sufficient storages of different energy sources in the form of blood glucose, glycogen in muscle and liver, and fat. By eating and drinking during physical exercise it is possible to ensure the availability of energy during exercise.

By modeling the biochemical systems underlying the usage of different energy sources, it is possible to estimate how much different energy sources are used during physical exercise and what is the optimal amount of fueling during exercise. In this white paper, the scientific background for energy sources and fueling during exercise is reviewed. The Polar solutions for estimating energy sources and reminding about fueling and hydration during physical exercise are also described.

2 Physiological background

ATP (adenosine triphosphate) provides the energy needed for muscle contraction. The primary energy source for ATP synthesis in events lasting longer than a few seconds is muscle glycogen. Glycogen reserves are limited and are therefore depleted quickly. Glycogen reserves can be affected by carbohydrate intake. Insufficient intake of carbohydrates can lead to a depletion of the glycogen stores. Conversely, a diet rich in carbohydrates offers major benefits to performance. Endurance performance can be enhanced when carbohydrates are consumed an hour or more before beginning the exercise, within 5 min of starting the exercise, and during the exercise. Carbohydrate stores can rapidly be replenished by ingesting carbohydrates during the first 2h of recovery. This can be facilitated by the addition of protein to the carbohydrate supplement. It should also be noted that in post-session nutrition, the percentages of carbohydrates, fat and protein consumed during exercise shouldn't be used as a guideline. This is because carbs, fat and protein play different roles as energy sources than as a nutrients on your plate. For example, protein doesn't play a big role during exercise, but it is an important nutrient in your daily intake.

2.1 Carbohydrates

Carbohydrates are sugars and starches. Before the body can use them as fuel, carbohydrates are broken down into monosaccharides, mainly glucose. Diets rich in carbohydrates include grains, fruit, vegetables, milk, and concentrated sweets. Carbohydrates serve many functions in the body, including being the major energy source, particularly during high-intensity exercise. The body stores excess carbohydrate as glycogen primarily in the muscles and liver (Murray & Rosenbloom 2018). Muscle glycogen provides a major source of energy during exercise. Therefore, carbohydrate consumption directly influences muscle glycogen storage and the ability to train and compete in endurance events. It appears that athletes need from 3 to 12 grams of carbohydrates per one kilogram of body weight per day in order to maintain glycogen stores. The range is so wide because training intensity and total daily energy expenditure, the person's sex, and environmental conditions affect the glycogen stores. (Burke et al., 2011; Jeukendrup and Gleeson, 2010). The size of the glycogen store is also related to body weight, especially to fat-free mass. Therefore, women in general have smaller glycogen stores relative to body weight since they have a lower percentage of muscle in relation to body weight. Furthermore, endurance athletes can restore more glycogen than untrained individuals (Hickner et al., 1997). Insufficient intake of carbohydrates can lead to a depletion of glycogen stores. Muscle glycogen depletion has been shown to be a major cause of fatigue and ultimate exhaustion in high-intensity exercise of short duration or in moderate-intensity exercise lasting more than an hour. On the other hand, glycogen loading by consumption of a diet rich in carbohydrates improves performance. Although, from an energy point of view there is not much need for refueling during short exercises, consuming carbohydrates during shorter performance may be beneficial for alertness and focus. However, carbohydrate refueling during exercise becomes important with longer exercise duration. Numerous studies have shown that athletes' performance enhances when they are fed carbohydrates during exercises lasting longer than one hour (Kenney et al., 2019; Cenmark et al., 2013). Providing carbohydrate during exercise will provide an alternative fuel for the exercising muscle while maintaining high rates of carbohydrate oxidation. Furthermore, carbohydrate intake also assists in maintaining blood glucose levels within normal range. Finally, when carbohydrate stores have been reduced or depleted after for example a high-intensity and long-duration exercise, it is important to consume carbohydrates immediately after the exercise. Rates of glycogen resynthesis are very high during the first two hours of recovery and progressively decrease thereafter.

2.2 Fat

Fats, or lipids, exist in the body as triglycerides, free fatty acids (FFAs), phospholipids, and sterols. Only the FFAs are used by the body for energy production. Despite the negative effects of too much fat intake on cardiovascular health, fat is necessary in the diet. It serves many vital functions and is the primary energy source, providing up to 70% of our total energy in the resting state. Muscle and liver glycogen stores in the body are limited. However, the use of fat (or FFA) for energy production can delay exhaustion. Therefore, fat is especially important as an energy source for athletes. For endurance performance, any change that allows the body to use more fat would be advantageous. In fact, an adaptation that occurs in response to endurance training is an increased ability to use fat as an energy source (Kenney et al., 2019).

2.3 Protein

Protein is not a primary energy source for energy production during endurance exercise. Its role in endurance exercises is to increase mitochondrial content and to serve as an auxiliary fuel. The consumption of proteins during exercise is 0–10%. In low intensity and short exercises, protein consumption is 0–5%, but in an intensive or prolonged exercise, protein consumption can be 5–10%. If there is glycogen depletion, protein consumption can be even higher.

2.4 Hydration

During exercise, the body sweats to cool itself, and this results in the loss of body fluid. If this fluid loss is not replaced, it can lead to dehydration. Generally, the body can tolerate low to moderate levels of dehydration (<2% of body weight loss); however, as levels of dehydration rise, physical and mental performance may become impaired. Thus, athletes are encouraged to have sufficient volumes of fluid before, during and after exercise to minimize the risk of dehydration. Thirst is not an accurate indicator of fluid loss. Athletes who wait to replenish body fluids until feeling thirsty are already dehydrated. Drinking during exercise also provides an opportunity to take back the lost electrolytes.

3 Polar's solution, Energy Sources & FuelWise

3.1 Energy Sources feature

Polar products have provided consumed calories and fat percentage values after each exercise session for quite a long time. The Energy sources feature takes this further by showing a summary of what kind of energy sources (fats, carbohydrates, proteins) the body mainly used during the exercise (Figure 1). It provides also a detailed analysis of the usage rate of these sources that the body used at each point of the exercise. The Energy sources summary and detailed analysis are available after each exercise with heart rate data.

The Energy Sources feature helps Polar users to understand how exercise intensity and exercise duration affect energy consumption. The user can easily see that lower intensities consume more fats and higher intensities more carbohydrates. The user can also compare the breakdown from similar sessions over time and see how the body's ability to use fat as a primary energy source develops.

3.2 FuelWise feature

FuelWise is a fueling assistant that helps the user stay energized throughout the exercise (Figure 2). FuelWise includes three features that remind to refuel and help maintain adequate energy levels during longer exercises. These features are Smart Carbs Reminder, Manual Carbs Reminder and Drink Reminder. FuelWise reminder needs to be set from the sports watch before starting the exercise. FuelWise reminder can also be set for planned exercises. Once set, the sports watch reminds about refueling and drinking during the exercise.

To help the user to pack the right amount of portions, Smart carbs reminder shows the estimated refueling need before the exercise. This is based on intensity and duration estimation, personal details and also portion size. The portion size (carbs in grams) can be edited according to the used fuel. During the exercise, the sports watch will track actual energy expenditure based on intensity measured by heart rate, and adjust the frequency of the reminders accordingly, but the portion size of fuel will always be the same during a session.

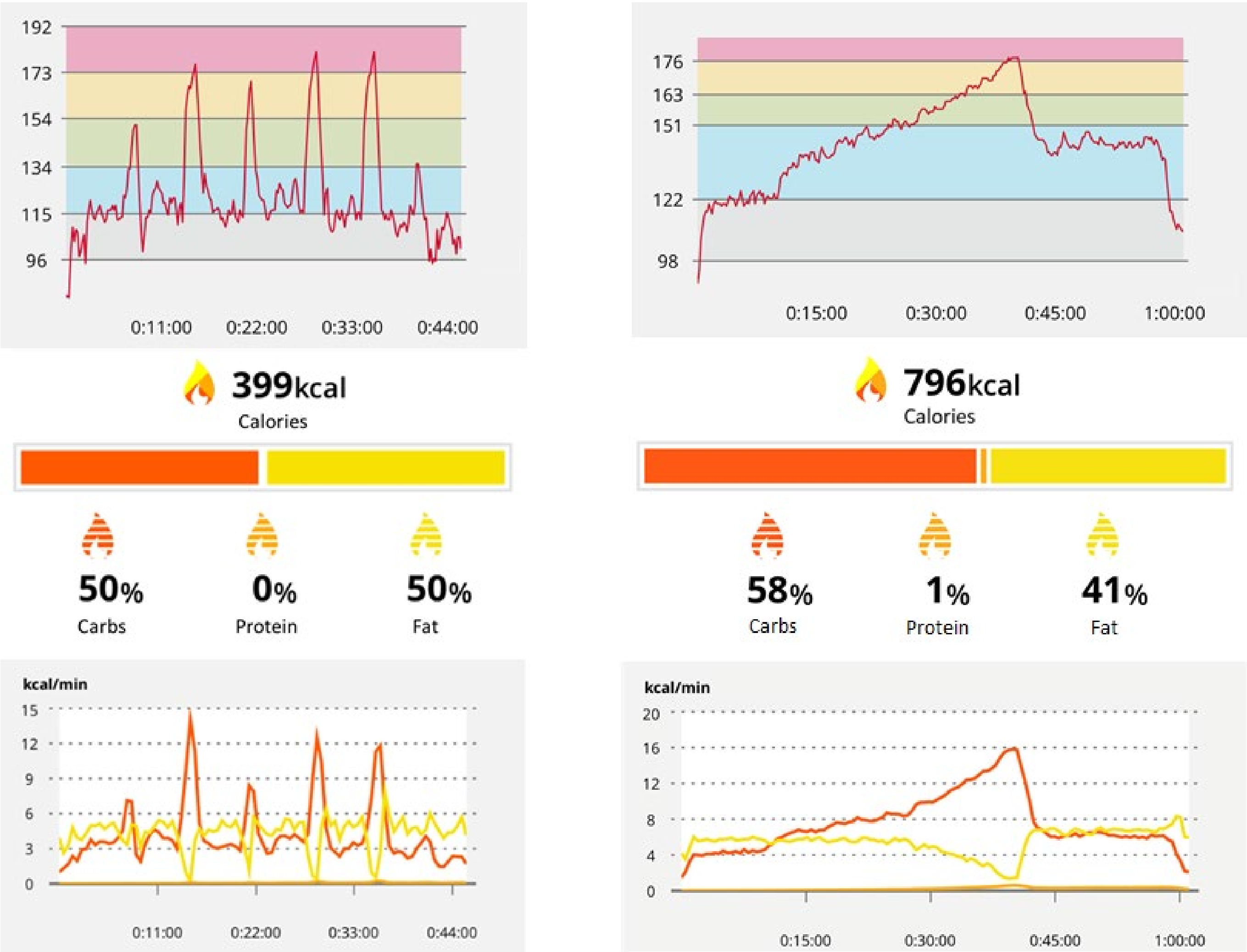

Figure 1. Example of energy sources analysis from two different type of exercises. Left: Interval exercise, Right: Exercise with constantly increasing intensity and cool-down. Top figure shows measured heart rate from exercise and bottom figure shows corresponding consumption rate for carbohydrates (red), protein (orange) and fat (yellow).

Manual carbs reminder and Drink reminder are simply time-based reminders. Both of these intervals (5-60 minutes) can be set separately and based on personal preferences and daily enviromental conditions. Sport watch reminds during session when to take energy or when to drink.

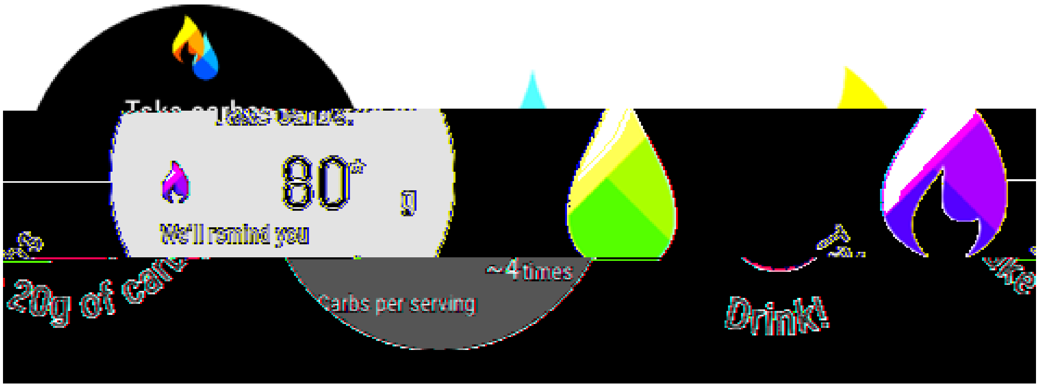

Figure 2. Examples of FuelWise feature user interface in wrist unit display. Left: Estimated refueling need before exercise in Smart Carbs Reminder. Center: Reminder for hydration during exercise in Drink Reminder. Right: Reminder for carbohydrate refueling during exercise in Smart Carbs Reminder and Manual Carbs Reminder.

4 Polar's solution, algorithm description

4.1 Energy Sources algorithm

The Polar Smart Calories algorithm is used to estimate energy consumption as calories based on accelerometer data and heart rate signals (Polar Smart Calories 2018). The Energy Sources algorithm divides the calorie estimate from Smart Calories to three components, which are calories consumed by using fat, carbohydrates and protein as a fuel.

In the Energy Sources algorithm, fat is seen as an infinite deposit; but carbohydrate stores (CHO) (glycogen in liver and muscles) and protein used via gluconeogenesis are seen as energy stores that can deplete. Using the athlete's anthropometry (height, weight, gender and age), heart rate dynamics (intensity) and cumulative strain (energy expenditure), both CHO store size and the state of its depletion can be determined. By using aerobic and anaerobic thresholds (AeTh and AnTh) normal CHO depletion, wasting of glucose in anaerobic glycolysis, and protein utilisation via gluconeogenesis can be individually deduced. When loading is performed on glycolytic intensity and CHO stores are diminished, the model assumes remarkable gluconeogenesis. The model assumes availability and adequate consumption of energy containing drinks (or food) during long lasting exercise sessions.

4.2 FuelWise algorithm

Polar has developed an algorithm to estimate optimal carbohydrate fueling during physical exercise. Optimal amount of fueling depends on the carbohydrate consumption during exercise and on the person's capability to absorb carbohydrates while exercising. The capability to absorb more carbohydrates while exercising can be improved by accustomizing the body to eating while exercising (Cox G et al. 1985). Usually persons who train more are somewhat more accustomed to eating and absorbing carbohydrates while exercising. Therefore, we assume that the absorption capacity is dependent on the users' training background setting.

The FuelWise algorithm uses the Energy Sources algorithm to estimate the dependence of carbohydrate consumption rate on heart rate. By knowing this relationship between heart rate and carbohydrate consumption, the heart rate signal can be used to estimate the requirement for carbohydrate fueling. The estimated absorption capacity is used to scale the requirement for carbohydrate fueling to such level that the person can also absorb. Finally, the size of one portion is used to calculate the required time interval for fueling.

5 Validity and limitations

The Energy sources and FuelWise algorithms use physiological parameters of the individual users to adjust the algorithms for each individual. One of the challenges is the estimation of amount of stored glycogen. The capacity of glycogen storage is estimated based on physiological parameters, such as body weight. It is also assumed that glycogen storages are full at the beginning of the exercise. However, this assumption is relatively valid since athletes rarely head at long, energy-consuming exercise sessions glycogen-depleted.

The algorithm for Energy sources was tested by simulating multiple possible exercise types with multiple artificial physical background parameters representing both males and females of various ages (20-60 years), heights (160-190 cm), weights (45-125 kg) and with training backgrounds ranging from occasional trainers to pro athletes. Parameter combinations with exceptionally low or high body mass indexes, i.e. below 17 or above 35, were excluded. The target values for the relative energy consumption were defined based on a review of various scientific papers and textbooks and practical knowledge. The results of this comparison (Table 1) showed a good agreement between the model and the expected portions for fat, carbohydrates and proteins.

Table 1. Comparison of simulated energy sources fractions to typical values from literature

	Simulated training			
	1-2 h at anaerobic threshold	1-2 h at aerobic threshold	30 min at 100 bpm	30 min at 95 % of hr max
Fat % simulated range *(typical values in literature)*	10-22 *(10-20)*	41-49 *(40-50)*	60-73 *(60-70)*	6-7 *(5-15)*
Carb % simulated range *(typical values in literature)*	68-86 *(70-80)*	48-58 *(50-60)*	27-40 *(30-40)*	89-91 *(80-90)*
Prot % simulated range *(typical values in literature)*	4-9 *(5-10)*	1-3 *(0-5)*	0 *(0)*	3 *(0-2)*

6 Patents

PSP150 OwnCal US6537227B2
PSP147 Energy metabolism from HR and personal data US6540686

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