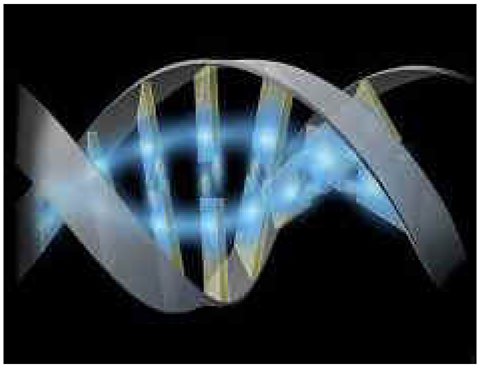
Direct Comparisons of Fuel use during Low, Moderate, and High Intensity Exercises



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Abstract

Several studies have examined and compared the effect of exercise intensity on substrate utilization. The purpose of this paper was to provide insight on these findings.

Exercise Intensities Compared in terms of Fat Oxidation during the Exercise Session

In one of the most well composed studies in modern times, Romijn et al. (1995) investigated the effect of intensity and duration on substrate utilization during exercise. Participants consisted of six trained endurance athletes, while the apparatus consisted of a cycle ergometer. Exercise was performed at 25, 65, and 85 % V02 maximal capacity. Whole body carbohydrate as well as lipid oxidation were measured. Carbohydrate oxidation was fractionated into fuel utilized from plasma glucose, as well as intramuscular glycogen stores. Fat oxidation was fractionated into exogenous fatty acids derived from adipose depots and intramuscular glycogen stores. Whole body lipolysis was also measured.

In review, oxidation is the process by which energy is extracted from fuels. Fat oxidation, in laymen’s terms is often referred to as fat burning. In this context whole body lipid oxidation, would refer to the amount of total fat ‘burned’ during a workout. In scientific terms it is more accurate to use the term oxidation as opposed to burned. Whole body carbohydrate as well as lipid oxidation were measured by indirect calorimetry. Indirect calorimetry can be defined as the process which measures oxygen consumed and correlates it to fuel metabolism. For example, if carbohydrates are used as fuel, then one liter of oxygen consumed is assumed to have metabolized 5.047 kilocalories of carbohydrate. However, more complex procedures allow the experimenter to extrapolate the percentage of fuel used from carbohydrates as well as fats from this method (for more on indirect calorimetry, see Wilson and Venom, 2004 - Energetic Transference Occurring in the Biosphere Part I). Endogenous or peripheral carbohydrate and lipid oxidation were found by measuring the rate of glucose and fatty acid disappearance rate to indicate the amount taken up by the musculature and oxidized. To find intramuscular glycogen and triglyceride utilization, peripheral glucose and lipid oxidation were subtracted from whole body carbohydrate and glucose oxidation.

Lipolysis is defined as the catabolism of a triglyceride into three fatty acids and one glycerol molecule. In order to be metabolized, glycerol must be first phosphorylated by glycerol kinase. However, only the liver has a significant amount of this enzyme, meaning it is not utilized by muscle tissue in significant amounts, and is therefore released into the blood stream. Therefore, glycerol released by lipolysis from muscle and adipose tissue provide an accurate reflection of whole body lipolysis.

Comparison of various exercise intensities on plasma glucose concentrations after 30 minutes of cycling found that as intensity increased, plasma glucose concentration increased. Specifically, the mean values were 77, 98, and 147 milligrams per deciliter of plasma glucose concentrations for 25, 65, and 85 % V02 max intensities. This facilitated a higher reliance on glucose, as carbohydrate utilization increased as intensity increased. In the 25 % V02 max condition, carbohydrate oxidation provided approximately 7.5 % of the fuel used. Further, muscle glycogen stores did not contribute significantly to this number, suggesting almost complete reliance on peripheral glucose. In the 65 % condition, carbohydrate utilization provided approximately 50 % of the fuel utilized, with 80 % of this coming from intramuscular glycogen stores. During the 85 % V02 max condition, 75 % of the energy was derived from carbohydrate utilization, with 80 % coming from muscle glycogen stores.

Comparison of glycerol utilization among conditions found that there was no significant difference between intensities on lipolysis from adipose tissue. However, intramuscular lipolysis at 65 and 85 % V02 max conditions had higher glycerol levels than the 25 % V02 max condition. This may be a consequence of catecholamine concentration. Catecholeamine plasma concentration increased with exercise intensity. This suggests that adipose tissue can have a high rate of lipolysis at low catecholamine stimulatory levels. It further suggests that the threshold for intramuscular triglyceride lipolysis is higher than the adipose tissue threshold. However, even though whole body lipolysis was greater during higher intensities, fatty acid appearance in the blood plasma was highest in the 25 % and 65 % V02 max conditions and lowest in the 85 % V02 max condition. This is a consequence of the chemical properties of triglycerides. As stated, they are comprised of a glycerol molecule and three fatty acids. The glycerol is water soluble, however, the fatty acids are water insoluble and must be transported by albumen (a transport protein) in the blood. High catecholamine levels appear to cause vasoconstriction to adipose and inhibit blood flow to the region, and therefore do not supply an adequate amount of albumen for transport. This does not impede the water soluble glycerol from increasing in its rate of appearance, as it is not dependent on any transport protein. This postulation was further supported upon cessation of exercise. Romijn et al. (1995) found that as high intensity exercise ended, a transient rise in free fatty acids was found, with a concomitant decrease in plasma glycerol. This suggests that triglycerides were not being catabolized, but rather the fatty acids previously cleaved from the glycerol molecule during high intensity exercise were now able to be transported out of the adipose, after sympathetic activity lowered, and blood flow increased to the region.

The proportion of fat oxidation, showed an inverse relationship with exercise intensity. Over 85 % of the fuel during 25 % V02 max was provided by fatty acids from adipose, while 7.5 % was provided by intramuscular TGs. In the 65 % condition, 50 % of the fuel was derived from lipid oxidation, in equal measure from adipose and intramuscular stores. The lowest percentage was found in the 85 % condition, with only 25 % of the fuel coming from lipid oxidation from equal measure of adipose and intramuscular TGs. However, total calories utilized increased as exercise intensity increased. Of those calories, total fat oxidation was highest in the 65 % V02 max condition, while there was no significant difference between the 25 and 85 % V02 max conditions. Of those fats utilized, the greatest amount of lipid oxidation derived from adipose tissue came from the 25 % V02 max condition, followed by the 65 % V02 max condition. Adipose derived fat oxidation was lowest in the 85 % V02 max condition.

Romijn et al. (1995) was not able to quantify the effect of duration on the 85 % V02 max condition, due to the inability to maintain that intensity for longer than 30 minutes. The effect of duration from 30 minutes to two hours found no change in fuel availability in the plasma or percentage of fuels utilized. However, the effect of duration on the 65 % V02 max condition found that plasma glucose and FFA availability increased from 30 – 120 minutes, suggesting that the musculature began to rely to a greater extent on peripheral fuels. There are several possible mechanisms for this. For example, it could be postulated that a decrease in intramuscular TGs stimulated the increase in plasma ffas. Romijn et al. (1995) postulates the opposite. This is because currently there is no known mechanism by which intramuscular TGs can regulate lipolysis from adipose tissue. Therefore, they suggest that an increase in plasma FFA concentration, and subsequent increase in muscular FFA uptake and concentration, decreased the utilization of intramuscular TGs. This is supported by the rate of fatty acid appearance when comparing the 25 to 65 % V02 max conditions. In the 25 % condition, fatty acid appearance in blood plasma increased immediately. However, it slightly decreased at first in the 65 % V02 max condition, followed by a progressive increase.

From the above findings it should be noted that total fat oxidation is greatest at moderate intensity, while total glycogen depletion is greatest at high intensity exercise. Fat utilized from adipose tissue was greatest in the low intensity condition, while glycogen depletion was lowest at this intensity. This suggests, that based on lipid oxidation, that 65 % V02 max is optimal, followed by low intensity exercise. Further, the lower the intensity, the greater the sparing effect on glycogen stores will be.

Romijn’s et al. (1993) findings on maximal fat oxidation occurring when training within 60% of VO2 max has been supported by numerous studies. Achten et al. (2002) had eighteen moderately trained cyclists perform a graded exercise test to exhaustion, with 5-minute stages and 35-weight increments. To elaborate, a graded exercise test is when an athlete progressively increases intensity after each time steady state is reached, usually until complete exhaustion. It was found that maximum fat oxidation occurred at 64% VO2 max, +/- 4%. Conversely, the contribution of fat oxidation to energy expenditure became negligible above 89%. In another study fifty-five male subjects performed another graded exercise test on a cycle ergometer (Achten and Jeukendrup, 2003). Results demonstrated that maximum fat oxidation was reached at 63% VO2 max. Thus, evidence clearly suggests that training within 60% of your VO2 max is optimal for fat oxidation.

The Effect of Exercise Intensity on EPOC

It is well established that exercise increases oxygen consumption for several hours after its completion (Gaesser and Brooks, 1984). As discussed, oxygen consumption is used to assess caloric expenditure. Therefore elevated levels of 02 consumption reflect a higher resting metabolic rate. Explanations for such a phenomenon are connected to a number of historical events. It all began with Berzelius, who in 1808 found that lactate concentration was increased in ‘ the muscles of hunted stags(Gladden, 2004)’ who relied on anaerobic pathways to attempt to escape their predators. This was followed by Myeroff’s (1920) discovery that glycogen served as a precursor for lactate (Gladden, 2004). Building on this work, Hill proposed the 02 debt theory, which suggested that 1/5 of the increase in 02 consumption was used in the oxidation of lactate. This in turn provided the energy to convert lactate build up during exercise back to glycogen, thus repaying the ‘debt’ incurred through anaerobic processes. Scientists further noted that the 02 debt produced a curve that was characterized by a rapid phase of 02 dissipation, followed by a slow phase of decline. Margaria et al. (1933) called the fast phase alactacid, followed by the slower lactacid phase. The alactacid phase was postulated to account for replenishment of non lactic acid components of anaerobic energy utilization, such as the phosphorylation of free creatine to form creatine phosphate. The lactacid phase was said to replenish glycogen stores from lactate. However, Gaesser and Brooks (1984) suggested that these explanations were to simplistic and that evidence pointed to the majority of lactate being oxidized following exercise, with the remainder serving as a carbon skeleton for a number of processes of which glycogen replenishment is just one. Further, it was stated that the oxygen utilization could be linked to a number of phenomenon, including the residual effects of hormones, and increased temperature. In this historical review, Gaesser and Brooks (1984) introduced the new terms - excess post exercise oxygen consumption (EPOC) and recovery 02 to eliminate the ‘ implication of causality in describing the elevation in metabolic rate above resting levels after exercise.’

Today another historical battle exists. Across countries exercise participants purport the superiority of high intensity interval training (HIIT) which is short over low to moderate intensity long duration training. One of the purposes of this article is to analyze the evidence for this claim and allow the reader to conclude from there. Shawn Phillips, one of the leading spokesman for HIIT stated that

‘You knew deep down, anyhow, that busting your butt burned off more fat than an exercise that allowed you to read at the same time, didn't you? Well, research shows our instincts were right…

HIIT speeds up your metabolism and keeps it revved up for some time after your workout. The bottom line is HIIT training burns a greater number of total calories than low-intensity training, and more calories burned equals more fat lost. What I'm suggesting is you forget about the "calories burned" readout on the stairstepper or Lifecycle; if you practice HIIT training, the majority of calories burned will come after your workout!’

The above statement paints an appealing picture. In reality however, the scientific evidence suggests that it is unequivocally false (Laforgia et al., 1997, Gore and Withers, 1990, Freedman-Akabas, 1985). First, HIIT training is normally purported to take less time than lower intensity sessions. However, to control variables Laforgia et al. (1997) examined the effect of intensity on EPOC, while matching total work performed in each session. Participants consisted of eight male middle distance runners, who performed 30 minutes of 70 % V02 max treadmill running in condition one, and interval training in condition two. Interval training consisted of 20, one minute sprints at 105 % of V02 max. The session lasted 60 minutes, as sprints were interspersed with 2 minute intervals in which participants performed active recovery. It was found that the 70 % V02 max condition metabolized 31 extra calories over the entire nine hours following exercise, while the high intensity condition metabolized 64 extra calories as extrapolated by EPOC. This equates to a negligible 33 extra calories for the high intensity condition. Laforgia et al. (1997) suggests that a comparison of the excess calories above moderate intensity exercise 'for the interval treatment is of little physiological significance to the energy balance of athletes because this amount of energy is equivalent to the kilojoules in only 75 ml of orange juice (1/3rd cup).' They further conclude that 'the major contribution of both treatments to weight loss was via the energy expended during the actual exercise. The excess post exercise energy expenditure is therefore of negligible physiological significance as far as weight loss is concerned.'

In another study, Gore et al. (1990) examined the effect of both intensity and duration on EPOC. Participants consisted of nine males with an average of 21 years of age. Participants exercised at 30 %, 50 %, and 70 % V02 max, each at 20, 50, and 80 minute durations. The effect of duration on exercise found no significant difference in the 30 % V02 max condition, whose 8 hour EPOC was a little over 1 liter of 02, amounting to approximately 5-6 extra calories metabolized. The effect of duration on the 50 % V02 max condition found that EPOC went from approximately 3 liters at 20 minutes, to 5 liters at 50 minutes, and finally to 6 liters at 80 minutes of duration. The effect of duration on the 70% V02 max condition found that EPOC went from 6, to 10, and finally 14.6 liters of 02 consumed for 20, 50, and 80 minute durations. As a reference the 14.6 liters of 02 consumed in excess in the 70 % V02 max, 80 minute duration condition was approximately 70 extra calories of energy expended or approximately 40 extra calories than the 50 minute condition at 50 minutes duration. While the data from this study clearly shows a positive relationship between intensity and duration on EPOC, the amount of calories metabolized in excess is concluded by the authors to be ' of little physiological significance for weight loss…' Further, the average amount of calories metabolized during EPOC was approximately 4 % of the total energy cost of exercise, which addresses the statement that , 'the majority of calories burned will come after your workout(Phillips)!

Further, the 70 % V02 max condition is comparable to the 65 % condition discussed in the Romijn et al. (1995) study which metabolized the highest amount of fat during training. This is significant because the EPOC in the supramaximal high intensity condition in the Laforgia et al. (1997) study, was nearly equivalent to the 70 % V02 max, long duration session. This suggests two outcomes. First, if exercise is performed at 65 % V02 max for a longer duration such as 60 minutes, then the EPOC generated may possibly approximate HIIT training intensities, secondly during the training session overall calories expended will be greater, with a higher proportion of those calories coming from lipids, as opposed to the overwhelming majority of glycogen utilization found in the supramaximal protocol.

The next inherent flaw made in the hi intensity vs. low to moderate intensity argument is that it fails to take into account the fact that bodybuilders are primarily high intensity athletes. As such they may already receive the benefit of optimized EPOC.

Melby et al. (1993) tested the effect of resistance exercise on metabolic rate during the 2 hours following exercise and on resting metabolic rate (RMR) the following day, measured 15 hours after exercise. Seven males with previous experience in resistance training performed 60 sets of both upper and lower body exercises, over a 90-minute time span. 2 hours after exercise, the average total EPOC was 7 Liters of O2, which adds up to about 35 extra calories oxidized in comparison to the control group. The total EPOC after 15 hours of exercise accounted for approximately 180 extra calories metabolized. In another experiment (Jamurtas et al., 2004) ten male athletes lifted weights for 60 min at 70-75% of 1-RM. It was found that the weight lifting group utilized had a 150 calorie increase in resting energy expenditure as extrapolated from EPOC.

Optimizing Hi and Low Intensity Exercise

Again, the inherent flaw in HIIT arguments when appealing to bodybuilders is to negate the fact that they are exposed almost daily to high intensity exercise. The key is to understand the purpose of various exercise regimens and incorporate them properly. Bodybuilders enter the weight room with the goal of maximizing hypertrophy. In order to maximize hypertrophy, they attempt to continually perform at extremely intense protocols within an optimal hypertrophy repetition range (Fry, 2004). However, the ability to maintain intensity during a cutting phase is highly dependent on intramuscular glycogen stores. Wilson (2003) in his article on ' Pre Contest An In Depth Analysis' explains:

> Glycogen's importance in athletic performance is well documented. For example, in the Canadian Journal of Physiology, biopsies (in the biceps) were examined in 8 bodybuilders across a typical arm-curl training session. After only one set researchers found that muscle glycogen stores in the Biceps had decreased by a whopping 12 percent (MacDougall et al. 1999)! Haff et al. (2000) noted that after three sets of leg extensions, that the vastus lateralis (outer quad sweep) was depleted of 17 percent of its glycogen stores. Tesch et al. (1998) found a 40 percent decrease in glycogen stores after 5 sets of 10 repetitions on concentric knee extensions (extensions minus the lowering phase) at 60 percent of the participants 1 repetition maximum.
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> In another study Robergs et al. (1991) investigated skeletal muscle glycogen metabolism in eight male participants during and after six sets of 70 % one repetition maximum. It was found that leg extensions performed at 70 percent 1RM, decreased muscle glycogen stores by 39 percent. The question now is, what happens to performance when fuel is low. Jacobs, Kaiser, and Tesch (1981) investigated the effect of depleting varying muscle fibers on strength levels. One group depleted both fast and slow twitch muscle fibers through long duration cycling and sprint cycling on the bicycle ergometer. In a second condition, Slow twitch fibers were depleted through extremely long duration marathon style training. It was found that glycogen exhaustion from the group that depleted both fiber types in the vastus lateralis was associated with impaired maximal muscular strength produced during a single dynamic

> contraction, as well as with reduced muscle fatigue patterns. When glycogen depletion was induced in slow twitch muscle fibers mainly, maximum strength was not hindered. Suggesting that the loss in strength in the two fiber group was primarily a function of glycogen depletion in fast twitch muscle fibers.

In another study Balsom et al. (1999) examined the effect of glycogen depletion during a low carbohydrate diet compared to a high carbohydrate diet on hi intensity all out 6 second sprints on a cycle ergometer, with 30 second intervals between sprints. Conditions were further divided into a 10 minute or 30 minute total session of sprints. Glycogen levels were significantly lower in the low CHO diet than the hi CHO diet. In both the short and long hi intensity training sessions, significantly less work was performed following LOW-CHO compared with HIGH-CHO protocol. The ability to maintain pre determined intensities was 265 % higher in the high cho condition than the low cho condition. Further, at the point of fatigue the low CHO group had significantly lower glycogen stores than the hi CHO condition. For more information on glycogen and its effect on exercise see Wilson and Venom (2004) Energetic Transference Occurring in the Biosphere Part II.

Results consistently show that the key to maintaining performance is intensity. The word intensity, however, is ambiguous. In this case, it refers to percent of a one repetition maximum performance. What this means is that the participant must maintain their original intensity, in order to preserve their gains. Therefore if an individual usually lifts at 6 repetitions for squats, they should maintain that lift during their cut. As an illustration, if on most weeks the individual squats 400 pounds for a rep scheme of 10, 8, 6, and they decide to drop this down to 300 during their cut, they would lose a significant amount of adaptations, and very rapidly.

For example, to test changes in V02 max—which is the maximal amount of oxygen an individual can take in, transport, and utilize to produce energy at the cellular level—athletes were put on a 10 week intense interval training program, followed by a 15 week reduction in training frequency (Hicksonm et al., 1981). Training was reduced from 6 days per week, to 2-4, while intensity and duration were maintained; training induced improvements in VO2 max were maintained. Further, when duration was decreased from 40 minutes, to 26, and finally13, VO2 max was also maintained. Now here is the interesting part; when intensity was reduced by 1/3 to 2/3rds, improvements were not maintained. Additionally, once flexibility has been attained, it can be maintained by just one session per week of training at the same intensity (Walin et al., 1985).

Trappe, Costill, and Thomas (2000) performed an excellent experiment to examine the changes in whole muscle function and single cell contractile properties of Type I and II muscle fibers from the deltoid muscle of highly trained swimmers before and after a 21-day reduction in training volume, while maintaining there intensity. Results demonstrated whole muscle power increased 17% and 13% on the swim bench and swim power tests; Type IIa fibers were 11% larger; Peak force increased significantly in fast twitch fibers; and shortening velocity was 32% and 67% faster in the Type I and IIa fibers, respectively.

This phenomenon of restitution gains is know as ”tapering”, and will be covered in-depth in future issues of JHR. Suffice if to say, results suggest that intensity is the number one variable for maintaining performance gains, and excessive depletion of glycogen stores will inevitably hinder this aspect of training.

As stated, the weight room provides a tool to hypertrophy as well as change body composition. However, cardiovascular training, in terms of bodybuilding can supplement this tool by providing a caloric deficit, conducive to maintaining current musculature. Evidence suggests that a caloric deficit induced through exercise is optimal for fat loss, then compared to the same deficit induced through diet. Tsai et al. investigated the effect of creating a 25 % caloric deficit through either diet or exercise in 13 participants. Participants were randomized into exercise or diet induced deficit conditions. This was a two phase study. Participants in condition 1, during phase 1 would switch to condition 2 in phase 2. Phases were separated by 5 days of energy repletion. Comparison of exercise and diet induced energy deficit conditions found that the dieting condition lost more weight, than the exercise condition. However, the exercise condition lost more body fat. For the bodybuilder, this provides the benefit of maintaining size while losing more body fat.
This combined with lower glycogen depletion of fast twitch fibers suggests that low to moderate intensity cardiovascular training can provide a tremendous tool to the bodybuilder.

Split Training

The question has arisen on whether splitting cardio into two sessions, rather than one in a given day, would increase gains. Almuzaini et al. (1998) investigated how splitting a 30-minute exercise bout on a cycle ergometer into two equal sessions effected excess post exercise oxygen consumption. Ten male volunteers participated in two trials. One trial consisted of 30 minutes of exercise at 70% VO2 max. The second trial was divided into two 15-min sessions, separated by 6 hours. A 20 minute measurement of EPOC was performed following each workout. Results showed that there was a significant overall increase from the two split training sessions (7.4 L of 02 consumed) compared to the single 30 minute session (5 L of O2 consumed). In a related study, by Kaminsky et al. (1990), EPOC was analyzed in six women following either a continuous 50 minute run, or 2-25 minute runs, separated by breaks in-between sessions, at 70% VO2 max during each trial. Results again demonstrated that EPOC following the split training session was significantly greater than one long duration session. Although, EPOC plays a small role in energy expenditure, split training will increase EPOC more than one continuous cardio session. Additionally, this could have psychological benefits, as doing a long cardio session, for instance, can be extremely tedious. Thus, separating cardio into two sessions may be of interest to the reader for this reason alone.

This further lends credence to Wilson's (2003) dissertation on split training (read Hippocrates - Was He Hardcore?). Within, he clearly demonstrated that split training improves focus, and performance during each training session. Further, splitting workouts into two sessions would raise anabolic hormones two fold, instead of only once per day.

However, there is another vital issue to consider here. During long duration cardio, your ability to mobilize peripheral fats for fuels progressively increases. Thus, an hour of moderate intensity cardio, for fat burning effects, may be more beneficial, than separating it into two thirty-minute sessions. However, if an individual is to perform a short, 20 minute HIIT workout, in which carbohydrates are the dominant fuel used throughout, there should only be benefits from separating this into two 10-minute sessions.

Practical Applications

Evidence suggests that as exercise intensity decreases, there is an increased reliance on the peripheral adipose depot, with a concomitant sparing of carbohydrates, particularly intramuscular glucose polymers. It appears that fat oxidation becomes optimal within the range of 60% VO2 max. However, training below this range (≥50% VO2 max) may be beneficial during states of overtraining, and or severe caloric restriction.

An analysis of scientific literature demonstrates that the maintenance of adaptations are intensity specific. The reader is, therefore, cautioned to avoid over reliance of high intensity, glycogen depleting protocols.

High intensity training may prove beneficial if used properly. For example, its potent stimulation of whole body lipolysis during exercise leads to a rapid influx of plasma free fatty acids after intensity is lowered. In this context, it is postulated that performing a notably short, high intensity session, followed by a long duration, low to moderate intensity workout, may optimize lipid oxidation.

Amidst hypertrophic growth cycles, in which there is a caloric surplus, short, high intensity workouts may elicit a supplementary anabolic stimulus. This is attributed to preferential recruitment of type II fibers, which have the greatest capacity for growth, as well as an increase in anabolic hormones.

Conclusion

> **John 8:32**
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> *And ye shall know the truth, and the truth shall make you free.*

Seek the truth, spurn unscientific dogma, and your gains will grow exponentially.

Happy New Year!

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