BIOSCIENCE JOURNAL

BLOOD GLUCOSE KINETICS DURING CONCENTRIC AND ECCENTRIC MUSCLE CONTRACTIONS

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How to cite: TALIARI, J.D.S., et al. Blood glucose kinetics during concentric and eccentric muscle contractions. *Bioscience Journal*. 2022, **38**, e38078. https://doi.org/10.14393/BJ-v38n0a2022-60463

Abstract
Studies comparing the two classes of stimuli (concentric and eccentric) have shown differences in the improvement of cardiovascular, metabolic, and muscle strength gain. This is an experimental, quantitative, and prospective study that aimed to verify the effect of eccentric exercise on glycolytic consumption and kinetics. The blood glucose kinetics of 17 male subjects was evaluated during a treadmill exercise with a 10% declined floor and velocity that required a 60% metabolic activity of VO_2max, for 30 minutes. Seventy-two hours later, the same subjects exercised on the treadmill with a 10% inclined floor and 60% VO_2max, for 30 minutes. To quantify glucose, blood samples were collected before the exercise, every three minutes along the 30 minutes of physical activity, and five and 10 minutes after finishing the exercise. For the downward slope, there was a homogeneous group behavior for blood glucose dynamics during the exercise, which was characterized by a monotonic decrease of glucose levels until reaching a minimum value at experimental times between 20 and 30 min, followed by a progressive recovery toward initial values. For the acclivity condition, blood glucose dynamics did not follow such a homogeneous behavior. A set of different types of dynamics could be identified. Experimental data showed that the type of dynamics could be predicted, to some extent, by the basal blood glucose level of subjects. The type of floor slope (upward or downward) directly affected glycolytic consumption and kinetics for the individuals analyzed.

Keywords: Blood glucose. Muscle contraction. Physical conditioning, Human.

1. Introduction

Eccentric exercises and their ability to ensure a maximum load are a form of muscle activity that constitutes an important part of athletic activities (Paschalis et al. 2007). Their benefits to physical performance have been clearly described to develop strength and increase the cross-sectional area of the muscle (Dudley et al. 1991). However, the intensity and duration of eccentric muscle contractions can acutely induce muscle damage, considering that high levels of force performed at higher levels of muscle stretching are one of the main causes of damage to the contractile and connective elements of muscles (Brughelli and Cronin 2007).

During an exercise of 30 minutes or more, insulin concentrations tend to fall and, although the plasma glucose concentration may remain fairly constant, hepatic glycogenolysis is stimulated and the glucose released into the blood can be taken to the muscles as an energetic source (Bird and Hawley 2017). This is probably due to the increased number of insulin receptors, increasing the sensitivity of the body to this hormone during exercise (McArdle et al. 2014). Intensity, exercise volume, and types of muscle contractions appear to be the key factors for a substantial effect on performance during training and directly affect blood glucose concentrations (Rodriguez et al. 2009). During aerobic activities such as running, cycling, and swimming, the anaerobic threshold (AT) is considered an excellent determinant of the rhythm of athletes (Kenney et al. 2019; Puccinelli et al. 2020).

Among sports modalities, there are different particularities regarding biomechanics, kinematics, and movement kinetics, in which muscle requirement is the main characteristic that differs from aerobic modalities such as running, swimming, and cycling. Lower glycemic variations provide greater safety during a physical exercise session for healthy individuals. Considering specific populations such as people with diabetes mellitus, lower energy expenditure is important for maintaining stable glucose levels. Modalities that require less muscle activity and individuals that present greater mechanical efficiency within a specific modality tend to have lower blood glucose variations during a physical exercise session. Observing blood glucose kinetics among the main aerobic modalities, verifying the smallest metabolic variations, and transferring the data obtained to specific populations are essential for safely prescribing the intensity and type of physical exercise.

Based on the assumption that blood glucose levels and AT are important to maintain the intensity and volume of a specific physical activity, this study aims to measure the variations of blood glucose in aerobic activities performed in acclivity and declivity. The study was conducted with healthy individuals to allow future projections for special populations, such as people with diabetes mellitus, due to the importance of glycemic control in these individuals. Therefore, the present study analyzed blood glucose kinetics during concentric and eccentric muscle contractions.

The present study tests the hypothesis that blood glucose kinetics during aerobic activity should depend on the predominant type of muscle contraction (concentric, or eccentric).

2. Material and Methods

Ethical approval

This study was conducted according to the principles of the Helsinki declaration and approved by the institutional Ethics Committee of the Education and Culture Foundation of Santa Fé do Sul, state of São Paulo, Brazil (Protocol 0000092 of August 03, 2011). All research volunteers signed their informed consent for participating in the study.

Study subjects

The present study is experimental, quantitative, and prospective. The sample was composed of 17 male volunteers, players of a non-professional soccer team, and, therefore, with a history of regular practice of physical activities. The group of 17 healthy young men had a body mass index (BMI) ranging from 20 to 27 kg/cm^2 and were 18 to 33 years old.

The inclusion criteria were healthy youngsters with a history of physical training, young adult male subjects, and those with BMI between 20 and 27 kg/cm^2. The exclusion criteria were subjects with cardiovascular, respiratory, or neuromuscular diseases; significant limitation of joint mobility; impossibility to remain active for a long period; use of any type of medication; smokers; and those who did not sign the informed consent form.

Experiments

The study was performed in five phases at the Department of Cardiology of the Rehabilitation Center of the Education and Culture Foundation of Santa Fé do Sul (SP, Brazil).

In the first phase, the volunteers were submitted to anamnesis and anthropometric evaluation. The height and weight of each subject were measured using an anthropometric scale with a built-in ruler (Filizola, Brazil). The BMI was provided by a formula (Weight / Height^2) and calculated and expressed in kg/cm^2 to characterize the sample profile.

In the second phase, electrocardiography at rest was performed to verify any arrhythmias or chain injury with an EKG-ECG electrocardiograph, model ECG6. Both the first and second phases aimed to select research individuals. The candidates that fit the profiles were selected and instructed on the schedule of the stages (3rd, 4th, and 5th).

In the third phase, the volunteers selected were submitted to an ergospirometry treadmill test (model ATL 10200, Inbrasport) and the subjective sensation of effort was described according to the BORG scale, every three minutes. Gas analysis for determination of VO_2max was conducted using an AeroSport gas analyzer, model TEEM-100. The Anaerobic Threshold (AT) and the Respiratory Compensation Point (RCP) were determined with the respiratory equivalent method. Both AT and VO_2peak were determined with a visual analysis of the behavior of metabolic curves (Ve / VO_2 and Ve / VCO_2). The verification of an increase in Ve / VO_2 without the concomitant increase in Ve / VCO_2 was the criterion used for determining AT. When these curves did not allow a good visualization, the criterion used was the point of inflection in the relationship curve of VCO_2 with VO_2. The palpation method was used to measure blood pressure using a Becton Dickinson sphygmomanometer, a Littmann Cardiology III stethoscope, and a Polar FT1 heart rate monitor (Polar Electro OY, Finland). The ergospirometry data are not presented in this study. Such preliminary measurements were required to set the level of treadmill effort at the 60% metabolic activity of VO_2max for each individual.

On the fourth day, a blood sample was collected on the left-hand digital pulp to quantify blood glucose (G-tech™ Free Glycosimeter). Then, the physical exercise was started with a duration of 30 minutes, which was performed on a treadmill with the floor inclined upward (10% slope) and velocity that led the subject to a metabolic consumption equivalent to 60% of the VO_2max. During the 30-minute exercise, blood samples were collected every three minutes in the left-hand digital pulp for glycemic analysis. After the exercise, each subject walked for five minutes and rested for additional five minutes. Hence, blood was also collected at the 35th e 40th minutes of the experimental time. In the last phase of the research, the process of the fourth stage was repeated but with the treadmill floor inclined downward. Therefore, at this stage, blood was collected with the ergometer positioned and the treadmill simulating a downhill at a 10% slope. The ergometer used for data collection was the treadmill model Pro-Plus, Pace Master. The time interval between downward and upward data collections was 72 hours. Treadmill sessions were conducted at the university fitness center that serves the physiotherapy and physical education courses. Due to the short time interval between blood sample collections, treadmill exercises were performed individually with one-on-one supervision. Interventions were performed by an experienced physiotherapist with a postgraduate master's degree (J.D.S.T.) who teaches exercise physiology at the university, a nurse with a Ph.D. in the field of health sciences (R.R.R.), and an undergraduate medicine student (M.A.S.T.).

To prevent a potential source of bias, the initial glycemic conditions each time the research subjects showed up for the experiments were statistically tested for homogeneity.

There were no reported adverse events during treadmill exercises.

Statistical analyses

The sample size was computed using the G*Power software (Faul et al. 2007). In an *a priori* power analysis, the sample size (N) was calculated by specifying a power level of 85%, type I error probability of α=0.05, and effect size of 0.8. Considering these input values, the computed sample size for a two-tail and paired *t*-test was *n*=17. The effective power levels achieved in the experiments were calculated on a *post hoc* basis from values of α=0.05, *n*=17, and the effect size values extracted from the experimental data.

Cohen's *d* descriptor was used to calculate the effect size in the statistical analysis, with the scores in the following scale: 0.01 for a very small effect size, 0.2 for small, 0.5 for medium, 0.8 for large, 1.2 for very large, and 2.0 for huge effect size.

The Prism 8.0 software (GraphPad Software Inc., La Jolla, CA, USA) was used for overall statistical analyses, which included descriptive statistics, statistical frequency distribution shown in a column histogram, linear regression analysis, and paired *t*-test for comparing group means, at a significance level of $\alpha=0.05$. The Kolmogorov-Smirnov method was used for normality tests.

3. Results

Initial sample characterization

The anthropometric measurements allowed the statistical characterization of the sample studied. The subjects of this research were 18 to 33 years old, with an arithmetic mean of 23.4 years old, and a standard deviation of the mean (SD) of 2.9 years old. The BMI distribution ranged from 20.6 to 27 kg/m^2, with a mean value of 23.6 kg/m^2, and SD=1.5 kg/m^2. The height of the subjects ranged from 165 to 186 cm, with a mean value of 178.2 cm, and SD=6.1 cm.

Considering the research subjects showed up twice for experimentation, the homogeneity between the two initial glycemic values of the sample was tested. Descriptive statistical data for the two initial blood glucose distributions, disclosed in Table 1, show that the set of individuals had similar initial glycemic conditions each time they showed up for the experiments. When applying the paired *t*-test to compare the two initial conditions, $p=0.7487$ was obtained, indicating that the mean of differences between the two initial conditions does not differ significantly from zero. The set of differences passed the normality test with $p>0.05$.

Table 1. Statistical summary for initial glycemic values in each data collection.

Parameter	Downward floor	Upward floor
Mean	92.3	92.9
n	17	17
Std deviation	8.1	8.4
Minimum	79	78
Maximum	110	114

Downhill and uphill blood glucose dynamics

Figure 1 shows blood glucose kinetic curves for three of the subjects studied, in the condition of a downhill floor at a 10% slope. The subjects were settled at a metabolic consumption of 60% of the VO_2max. The blood glucose dynamics disclosed in Figure 1 represent the behavior observed for the entire group. For this condition, overall dynamics could be described by a monotonic decrease in blood glucose levels that reached a minimum value at experimental times between 20 and 30 minutes, followed by a progressive recovery towards initial glucose levels. Figure 1 includes one subject with a higher initial blood glucose level, one with an intermediate level, and one with a lower initial glycemic level.

Figure 2 shows representative blood glucose dynamics with the treadmill floor prepared in acclivity, at a 10% slope. The subjects were settled at a metabolic consumption of 60% of the VO_2max. The curves were vertically shifted from each other for clarity. Numbers at the left side correspond to the initial blood glucose level (at $t=0$) for each subject represented. Numbers on the right side identify the experimental subject. The plot in Figure 2 includes three subjects with higher initial glycemic values (top-three curves), three subjects with intermediate initial glycemic values (three curves at the middle), and three subjects with lower initial glycemic values (three bottom curves).

Considering the treadmill floor was settled to simulate an uphill run, the blood glucose dynamics did not reproduce, for the entire group, the homogeneous behavior observed for the downhill condition. Four of the 17 subjects in the uphill run showed blood glucose dynamics similar to that obtained in Figure 1 for the downhill floor, with a monotonic decrease in glycemic levels, reaching a minimum value, and recovering progressively toward initial values. Figure 2 does not show the curves for these four subjects, as their behaviors are well represented in Figure 1. Although the four subjects repeated the dynamic behavior observed in the downhill run, presenting curves with similar features, they reached the minimum blood glucose values in the uphill floor in 15 minutes against the typical 20-30 minutes of the downhill condition.

On the uphill floor, most subjects presented periodic increments and decrements in blood glucose levels, resulting in curves with multiple peaks and valleys (Figure 2). Such behavior suggests a reduced but progressive intensity of hepatic glycogenolysis, which would aim to keep glycemic levels in the bloodstream as stable as possible in the period of high glycolytic metabolic consumption. Figure 2 shows that the blood glucose level at t=0 plays, to some extent, a predictive role for the type of dynamic a subject might follow during an uphill run. Some of the subjects, noticeably those with higher blood glucose levels at t=0, presented a glycemic reduction right after starting the effort, as expected. Subjects with low blood glucose levels at t=0 (the three bottom curves in Fig.2) presented an immediate increase in blood glucose at the beginning of the effort, which could be interpreted as a prophylactic response of the body to potential hypoglycemia from the physical effort.

Those four subjects, who, when in the uphill condition, reproduced the kinetic features shown in Figure 1 for the downhill floor, had initial blood glucose values of 93, 93, 94, and 99 mg/dL. Although it is interesting to disclose the initial blood glucose for these subjects for the sake of comparison with the entire study group, it is relevant to state that blood glucose values at t=0 should not be considered alone to predict the kinetic behavior of a given subject. Other variables and/or physiological conditions not considered in this investigation may be involved.

Figure 2 also shows that individuals following curves with multiple peaks and valleys can present, during the physical effort, blood glucose levels higher than the initial value (at t=0). This figure shows the extreme case of subject 11, who presented glucose levels above the initial value during most of the time submitted to the effort, reaching, in this case, levels classified as hyperglycemia. Glucose values above the basal level, measured at t=0, were not observed for the downhill physical activity.

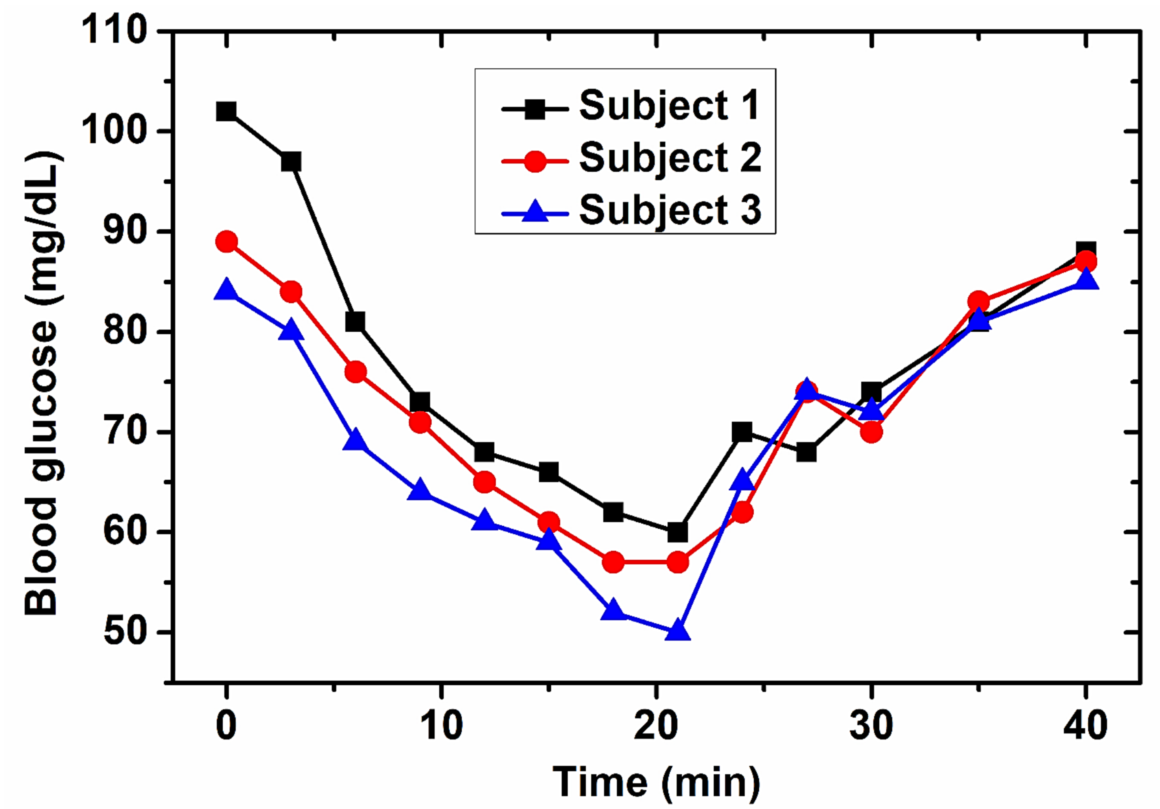

Figure 1. Typical blood glucose kinetics obtained with the treadmill floor settled for downhill running (10% inclination). A monotonic decrease of blood glucose values until reaching a minimum value, then a progressive recovery towards initial values was a homogeneous behavior for the downward floor.

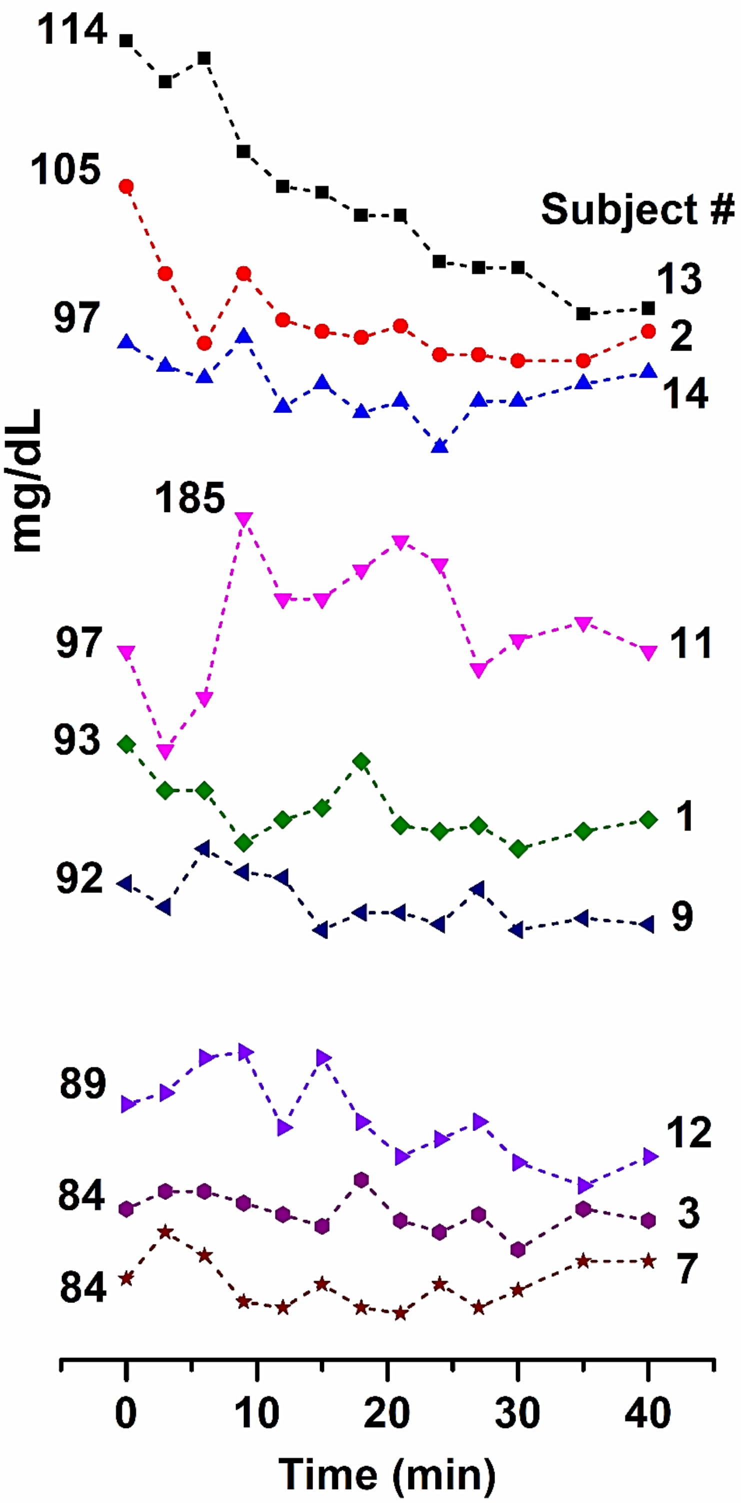

Figure 2. Blood glucose dynamics obtained with the treadmill floor settled for uphill running (10% inclination).

Comparative overview between downhill and uphill blood glucose dynamics

Figure 3 offers a comparative view of the general results obtained in both uphill and downhill conditions. The histogram (Figure 3a) shows the statistical distribution of the time the research subject took to reach the minimum blood glucose value during physical activity. The narrow distribution for the downhill floor reflects the homogeneity of responses obtained from the experimental sample when subjected to a downhill run. The broad distribution for the uphill floor reflects the diversity of responses obtained from the experimental sample when subjected to an uphill run. Besides the diversity of behavior in the uphill floor, most subjects follow kinetic curves with multiple peaks and valleys, resulting in several relative minimum values. Experimental data showed that the absolute minimum might occur in any of the valleys, not necessarily the first one, which contributes to broadening the histogram.

Figure 3b was built by normalizing the data sequence of each subject so that the value at t=0 is equal to the unity. The set of 17 normalized curves was averaged to yield a graphic perception of the mean behavior in each floor type. The error bars correspond to the standard error of the mean (SEM). Table 2 presents the non-normalized blood glucose data obtained for each experimental time, expressed as mean ± SEM for uphill and downhill floor conditions along with intergroup statistical comparisons of group means for each experimental time. All sets of data passed the Kolmogorov-Smirnov normality criteria. The effect size, expressed by Cohen's *d* descriptor, ranges from medium to a huge effect size when excluding the first nine minutes of physical activity, as well as recovery and rest times. The power of the statistical test, which is also presented in Table 2, was computed on a *post hoc* basis from α=0.05, sample size n=17, and values obtained for Cohen's *d* descriptor at each experimental time.

The absolute amplitude of blood glucose variation for a given subject was defined as the difference between maximum and minimum values achieved during the experimental period. The amplitude of blood glucose variation was plotted for the BMI or age (plot not shown) of subjects to verify whether these variables could bias the data. Highly scattered data points and no correlations were found. Figure 3c shows the amplitude of blood glucose variation for each floor type for the basal value, measured at t=0. Straight lines are the linear regression model for each set of data points. Pearson's correlation coefficients are 0.768 and 0.698 for downhill and uphill data points, respectively. The plot shows that blood glucose levels change more expressively in downhill than uphill running, which agrees with the averaged data shown in Figure 3b. The data suggest that regulatory physiological responses triggered in the uphill run preclude larger variations in blood glucose levels. The data also confirm the initial hypothesis of the present study, meaning that blood glucose kinetics during aerobic activity depends on the concentric or eccentric nature of the evoked muscle contractions.

Table 2. Blood glucose levels for each experimental time expressed as mean ± SEM for uphill and downhill floor conditions. The p-values correspond to the intergroup statistical analyses of group means for each experimental time.

	Blood glucose level Mean (±SEM) (mg/dL)			Effect size	Achieved power
Time (min)	Uphill	Downhill	p	Cohen's d	(1−β)
0	92.9 (2.0)	92.3 (1.9)	0.7487	<0.1	small
3	87.4 (1.7)	87.8 (1.7)	0.8486	<0.1	small
6	86.8 (2.6)	81.2 (2.3)	0.0276	0.5	small
9	85.5 (3.4)	77.1 (2.3)	0.0161	0.7	0.773
12	82.1 (2.5)	74.1 (2.5)	0.0078	0.8	0.871
15	80.9 (2.9)	70.3 (2.3)	0.0009	1.0	0.972
18	81.9 (2.7)	66.6 (2.2)	< 0.0001	1.6	1.000
21	81.8 (2.6)	63.2 (1.9)	< 0.0001	2.0	1.000
24	79.9 (2.5)	66.1 (1.4)	0.0001	1.7	1.000
27	82.8 (1.6)	70.1 (1.9)	0.0001	1.8	1.000
30	82.8 (1.7)	73.6 (1.9)	0.0004	1.2	0.996
40	84.5 (2.3)	81.6 (1.1)	0.2143	0.4	small
45	84.8 (1.9)	85.7 (1.2)	0.5585	0.1	small

4. Discussion

The bipedal posture used in human locomotion promotes the translocation of the body through space, requiring a complex combination of alternating events from one limb to the contralateral. Therefore, gait is considered an event of great complexity, which evaluation requires well-defined criteria. This is associated with the high degree of freedom granted to the joints participating in this cluster of movements (Zelik et al. 2015).

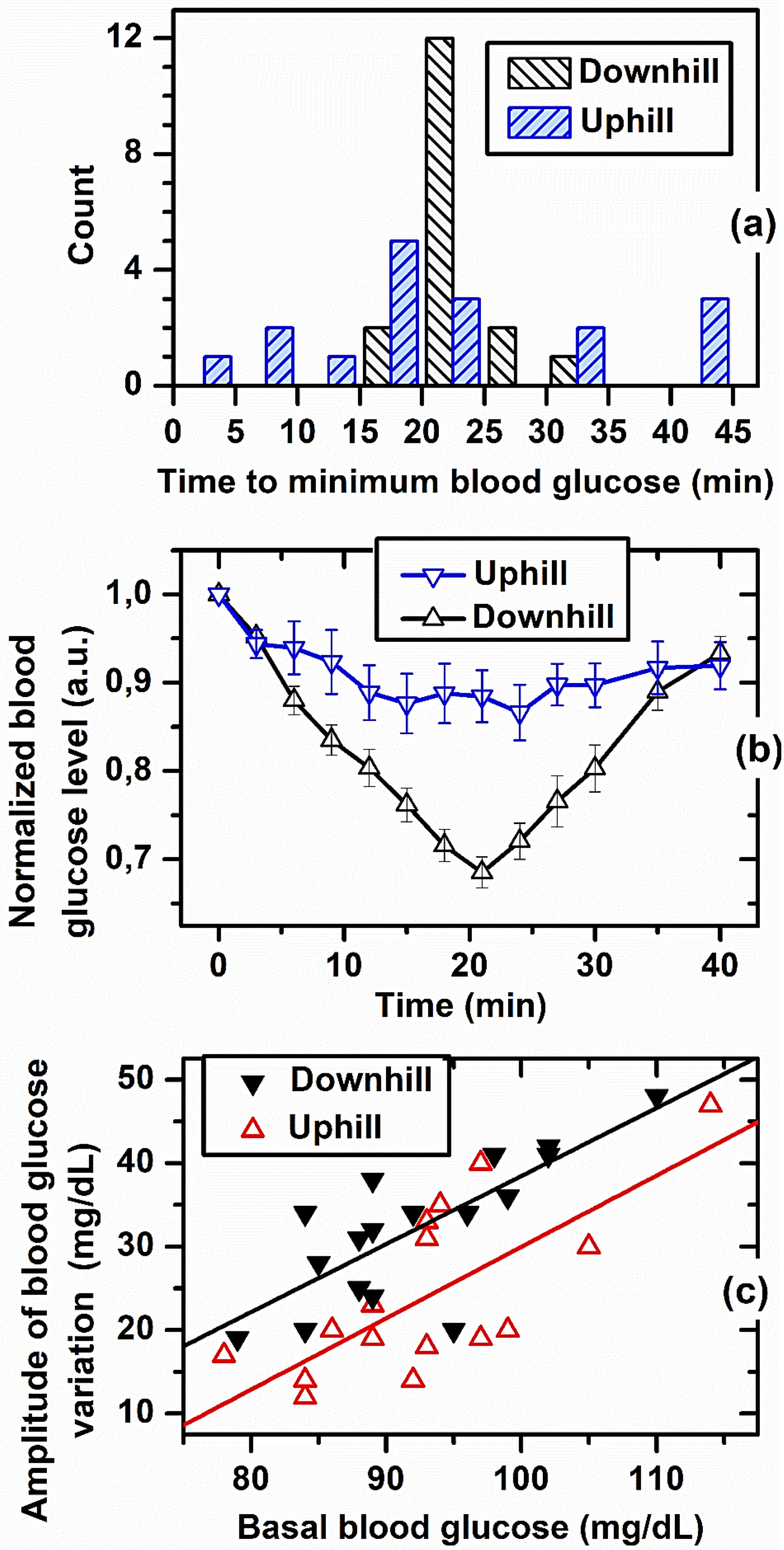

Figure 3. Statistical distribution of the time taken by the research subject to reach the minimum blood glucose value (a). Averaged blood glucose dynamics, with each subject's curve normalized regarding the value at *t*=0 (b). The amplitude of blood glucose variation for the basal value, measured at *t*=0 (c). Error bars correspond to the standard error of the mean.

Electromyography has been used to study an event called muscle co-contraction (Norkin and Levangie 1992; Balbino et al. 2019). This phenomenon is characterized by the simultaneous contraction of two or more muscles around a joint, in which muscle activity is directly related to the biomechanical needs of gait. The performance of a single human movement is linked to several muscular events, among which co-contraction stands out. This means that whenever a body segment develops a movement due to the contraction of a particular muscle or muscle group, another muscle or muscle group may act, stabilizing the participant joint or the proximal joint. The gait pattern is highly adaptable to the daily needs of human beings (Leroux et al. 2002). The angulation of lower limb joints adjusts to a greater degree to perform acclivity. However, a decrease in hip flexion or a certain degree of hyperextension may occur during the slope to facilitate the final positioning of the foot close to the ground (Leroux et al. 2002; Lay et al. 2005; McIntosh et al. 2006). Therefore, the human locomotor system has a highly modifiable and adaptive ability against different environmental conditions, such as stairs, alternating velocities, and slope changes in acclivity and declivity (Leroux et al. 2002).

Inclined surfaces require gait adaptations that are possible due to changes in the patterns of movements of the lower segments and the activation level of both flexor and extensor muscles. Data such as gait velocity and gait size change when the subject is submitted to steep slopes, above 9° (McIntosh et al. 2006). The greater the acclivity, the more inclined the trunk and pelvis, accentuating a hip flexion, and the opposite will occur in decline (Leroux et al. 2002). Such positioning constitutes a necessary adaptation process for displacing the body mass center forward and backward, as it develops an upward or downward gait, respectively, to maintain body equilibrium. Knee and ankle joints also play a prominent role because. During the support and balance phases on the upward slope, they present a significant angular increase directly related to the degree of trunk inclination (Leroux et al. 2002; Prentice et al. 2004; Lay et al. 2005; McIntosh et al. 2006; Lay et al. 2007). According to Lay et al. (2007), the three lower limb joints show a greater flexion degree during the initial contact phase of the calcaneus with the sloping ground. Therefore, there is a predominant extensor pattern during medial support when compared to the same calcaneus contact with the flat ground, suggesting that joint angulation is directly proportional to the degree of inclination. When running on a flat or inclined ground, the propulsive force of the anteroposterior component increases, elevating the peak corresponding to the end of the support phase, and the resulting force is usually similar with a greater effort of hip extensor muscles. The knee flexion helps to displace the body in front of the support foot, further assisting in the damping or braking of movement (Leroux et al. 2002; Lay et al. 2005; McIntosh et al. 2006). Hence, knee extensor muscles will exert an eccentric force to sustain this posture, which is unnecessary on the acclivity. The downhill gait presents a peculiar behavior regarding ground reaction force (GRF), with a greater response in the first point of contact when compared to the on-plane march. This suggests a greater shock absorption of the calcaneus at the beginning of the support phase (Lay et al. 2007).

Inclined surfaces directly affect muscle work, with significant changes from 6° of inclination (Leroux et al 2002), which may be related to movement, speed, and posture demands (Prentice et al. 2004). Such changes involve modifications in the level of activation of flexors and extensors; for instance, muscles such as gastrocnemius and soleus working on the ankle joint, both in acclivity, and tibialis anterior in the slope. In the support phase, the initial contact of the calcaneus with the ground requires an eccentric contraction of the tibialis anterior muscle, which allows plantar flexion and consequently contact of the forefoot with the ground, always seeking a flat positioning of the foot with the ground. Such details confer a co-contraction activity between plantar flexors and the aforementioned muscles, also serving as ankle stabilizers, as observed when descending a ladder (Lay et al. 2007). This condition is more expressive on the slope, as plantar flexor muscles are active for much longer than in the flat ground. The exacerbated use of lower limb muscles to balance the biomechanical component of downhill gait implies a greater energy expenditure for these muscles, which would explain a greater glycolytic demand for a longer period when compared to the acclivity. For Lay et al. (2007), downhill physical exercise promotes an increased muscle power absorption, suggesting that eccentric muscle activity is greater, which is directly associated with the length of muscle spindles. This may also explain a co-contraction mechanism between lower limb muscles such as the quadriceps and gastrocnemius, which could justify an increase in energetic activity of the muscles involved, corroborating the results hereby obtained. It is worth noting that downhill exercise promotes greater joint instability than the same exercise in acclivity or flat ground. This is associated with a higher degree of joint shear and consequently a greater probability of postural imbalance with an increased potential for falls. To maintain optimal motor coordination, which is essential for physical activity, a high synergism of the musculature involved is required, which is again associated with the co-contraction mechanism.

A published study indicates that the GRF directly accompanies the surface slope gradient, that is, the greater the slope the greater the reaction force (McIntosh et al. 2006). The same study also reports high peaks of GRF associated with slopes of 8° to 10°, which could explain the results hereby presented. Other studies have also shown that the gait performed on inclined surfaces presents GRF with important asymmetry patterns, requiring various adjustments of the locomotor system regarding increased muscle activity and postural adaptations to compensate for the adaptations of GRF during gait or run on slopes (Damavandi et al. 2012). Such adaptations are required to improve dynamic stability, thus preventing sliding.

Muscle activity is directly involved with blood glucose concentration (McConell et al. 2020). During an exercise with time durations similar to those used in the present study (30 minutes), insulin concentrations tend to fall, hepatic glycogenolysis is stimulated, and glucose released into the blood can be taken to the muscles as an energy source. According to Guyton and Hall (2016), the energy expenditure can be up to 40% higher for sustaining muscles than the act of pushing. The results of the present study, supported by data from the literature, indicate that the muscles involved in gait performance, coordination, and stabilization work harder in activities performed in declivity than in acclivity. The eccentric muscle contractions evoked by downhill running are accompanied by a higher risk of muscle damage such as the Z-line rupture, as well as the destruction of the sarcoplasmic reticulum (Clarkson and Hubal 2002; McHugh 2003; Brentano and Kruel 2011). According to Paulsen et al. (2012), muscle damage can be classified, according to the modifications in isometric peak torque (IPT), as low (change of < 20% of IPT), moderate (change from 20% to 50% of IPT), and high (change of > 50% of IPT), which directly affects the responses expected for the protective effect promoted by downhill running. Chen et al. (2007) used experimental parameters similar to those used in the present study. Their experiment was designed for 30 minutes of downhill running, with 15% of inclination, at 70% VO_2max. They observed values of muscle damage at 15% of the IPT. According to the authors, muscle damage may interfere with the landing process during downhill running. Molina and Denadai (2012) observed acute fall behavior in the peak rate of force development after exercises that induced muscle damage followed by recovery after 48 hours.

The data hereby presented suggest different glycolytic consumption for the specificity of muscle contraction to the detriment of potential muscle damage, which according to existing publications, do not present physiological significance.

Limitations of the present study include the validity of the experimental data restricted for the age range and physical conditioning of the sampled subjects. Therefore, further experiments are required for expanding the validity of the data for populations of broader age spam and different levels of physical conditioning.

5. Conclusions

The results of the present study allow concluding that long-duration activities in declined floors, which evokes eccentric muscle contractions for a long period, contribute directly to increasing muscle work and, therefore, increasing muscular metabolic rate, which favors a high glycolytic consumption. Conversely, the upward slope requires a predominance of concentric muscle contractions with lower glycolytic consumption during exercise. The dependence of blood glucose kinetics on the concentric or eccentric nature of the muscle contractions performed is important for safely prescribing the modality and intensity of physical exercise.

Authors' Contributions: TALIARI, J.D.S.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article and critical review of important intellectual content; RAMOS, R.R.: conception and design, acquisition of data, analysis and interpretation of data and drafting the article; BALLARIS, A.L.: conception and design and acquisition of data; TALIARI, M.A.S.: conception and design and acquisition of data; MUNIN, E.: conception and design, analysis and interpretation of data and critical review of important intellectual content. All authors have read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethics Approval: Approved by the institutional Ethics Committee of the Education and Culture Foundation of Santa Fé do Sul, state of São Paulo, Brazil, having as a chair the person of Marilda Duran Lima (Protocol 0000092 of August 03, 2011). All research volunteers signed their informed consent for participating in the research study.

Acknowledgments: Not applicable.

References

BALBINO, L.F., et al. Analysis of co-contraction of the trunk muscles in the side bridge stabilization exercise with different unstable surfaces. *Bioscience Journal*. 2019, **35**(2), 640-649. https://doi.org/10.14393/BJ-v35n2a20198-41833

BIRD, S.R. and HAWLEY, J.A. Update on the effects of physical activity on insulin sensitivity in humans. *BMJ Open Sport Exercise Medicine*. 2017, **2**, e000143. https://doi.org/10.1136/bmjsem-2016-000143

BRENTANO, M.A. and KRUEL, L.F.M. A review on strength exercise-induced muscle damage: applications, adaptation mechanisms and limitations. *Journal of Sports Medicine and Physical Fitness*. 2011, **51**(1), 1-10.

BRUGHELLI, M. and CRONIN, J. Altering the length-tension relationship with eccentric exercise implications for performance and injury. *Sports Medicine*. 2007, **37**(9), 807-826. https://doi.org/10.2165/00007256-200737090-00004

CHEN, T.C., NOSAKA, K. and TU, J. Changes in running economy following downhill running. *Journal of Sports Science*. 2007, **25**(1), 55-63. https://doi.org/10.1080/02640410600718228

CLARKSON, P.M. and HUBAL, M.J. Exercise-induced muscle damage in humans. *American Journal of Physical Medicine and Rehabilitation*. 2002, **81**(11), S52-S69. https://doi.org/10.1097/01.PHM.0000029772.45258.43

DAMAVANDI, M., DIXON, P.C. and PEARSALL, D.J. Ground reaction force adaptations during cross-slope walking and running. *Human Movement Science*. 2012, **31**(1), 182-189. https://doi.org/10.1016/j.humov.2011.06.004

DUDLEY, G.A., et al. Importance of eccentric actions in performance adaptations to resistance training. *Aviation, Space, and Environmental Medicine*. 1991, **62**(6), 543-550.

FAUL, F., et al. Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*. 2007, **39**, 175-191. https://doi.org/10.3758/bf03193146

GUYTON, A.C. and HALL, J.E. *Textbook of Medical Physiology.* 13th ed. Philadelphia: Elsevier, 2016.

KENNEY, W.L., WILMORE, J.H. and COSTILL, D.L. *Physiology of sport and exercise*. 7th ed. Champaign, IL: Human Kinetics, 2019.

LAY, A.N., HASS, C.J. and GREGOR, R.J. The effects of sloped surfaces on locomotion: a kinematic and kinetic analysis. *Journal of Biomechanics*. 2005, **39**(9), 1621-1628. https://doi.org/10.1016/j.jbiomech.2005.05.005

LAY, A.N., et al. The effects of sloped surfaces on locomotion: an electromyographic analysis. *Journal of Biomechanics*. 2007, **40**(6), 1276-1285. https://doi.org/10.1016/j.jbiomech.2006.05.023

LEROUX, A., FUNG, J. and BARBEAU, H. Postural adaptation to walking on inclined surfaces: I. Normal strategies. *Gait and Posture*. 2002, **15**(1), 64-74. https://doi.org/10.1016/S0966-6362(01)00181-3

MCCONELL, G.K., et al. Insulin-induced membrane permeability to glucose in human muscles at rest and following exercise. *The Journal of physiology*. 2020, **598**(2), 303-315. https://doi.org/10.1113/JP278600

MCARDLE, W.D., KATCH, F.I. and KATCH, V.L. *Exercise physiology: nutrition, energy, and human performance*. 8th ed. Baltimore: Wolters Kluwer, 2014.

MCHUGH, M.P. Recent advances in the understanding of the repeated bout effect: the protective effect against muscle damage from a single bout of eccentric exercise. *Scandinavian Journal of Medicine and Science in Sports*. 2003, **13**(2), 88-97. https://doi.org/10.1034/j.1600-0838.2003.02477.x

MCINTOSH, A.S., et al. Gait dynamics on an inclined walkway. *Journal of Biomechanics*. 2006, **39**(13), 2491-2502. https://doi.org/10.1016/j.jbiomech.2005.07.025

MOLINA, R. and DENADAI, B.S. Dissociated time course recovery between rate of force development and peak torque after eccentric exercise. *Clinical Physiology and Functional Imaging*. 2012, **32**(3), 179-184. https://doi.org/10.1111/j.1475-097X.2011.01074.x

NORKIN, C.C. and LEVANGIE, P.K. *Muscle structure and function*. In: NORKIN, C.C. and LEVANGIE, P.K. *Joint structure and function: a comprehensive analysis*. Philadelphia: Davis Company, 1992, 92-104.

PASCHALIS, V., et al. The effects of muscle damage following eccentric exercise on gait biomechanics. *Gait and Posture*. 2007, **25**(2), 236-242. https://doi.org/10.1016/j.gaitpost.2006.04.002

PAULSEN, G., et al. Leucocytes, cytokines and satellite cells: what role do they play in muscle damage and regeneration following eccentric exercise? *Exercise Immunology Review*. 2012, **18**, 42-97.

PRENTICE, S.D., et al. Locomotor adaptations for changes in the slope of the walking surface. *Gait and Posture*. 2004, **20**(3), 255-265. https://doi.org/10.1016/j.gaitpost.2003.09.006

PUCCINELLI, P. J., et al. Predictors of performance in Amateur Olympic distance triathlon: Predictors in amateur triathlon. *Physiology and Behavior*. 2020, **225**: 113110 https://doi.org/10.1016/j.physbeh.2020.113110

RODRIGUEZ, N.R., DI MARCO, N.M. and LANGLEY, S. American College of Sports Medicine position stand. Nutrition and athletic performance. *Medicine and Science in Sports and Exercise*. 2009, **41**(3), 709-731. https://doi.org/10.1249/MSS.0b013e31890eb86

ZELIK, K.E., TAKAHASHI, K.Z. and SAWICKI, G.S. Six degree-of-freedom analysis of hip, knee, ankle and foot provides updated understanding of biomechanical work during human walking. *Journal of Experimental Biology*. 2015, **218**(6), 876-886. https://doi.org/10.1242/jeb.115451

Received: 14 April 2021 | **Accepted:** 21 October 2021 | **Published:** 23 September 2022