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Abstract

Background: The integration of physical activity into everyday contexts, including cultural and natural environments, represents a promising strategy to counteract sedentary behavior and promote cardiovascular and metabolic health. Walking is a highly accessible form of physical activity that can be performed in both structured indoor settings and ecologically valid outdoor contexts, such as culturally relevant walking routes. The aim of this doctoral work was to investigate the physiological and perceptual responses to walking exercise performed in indoor and outdoor environments, and to provide a methodological framework for the classification of walking intensity and walkability based on objective and subjective measures. The project was structured into four main phases: (1) development of a standardized protocol for psychophysiological data collection during outdoor walking; (2) evaluation of walking-related metabolic and cardiovascular responses across different environments; (3) comparison of acute hemodynamic adaptations, including post-exercise hypotension, following indoor and outdoor walking sessions; and exploratory assessment of the feasibility and physiological impact of a multidimensional physical activity intervention in a clinical case of Type 1 Diabetes. Across the experimental studies, participants completed walking sessions while physiological variables such as heart rate, blood pressure, oxygen consumption, and energy expenditure were continuously monitored using portable and laboratory-based devices. Exercise intensity was expressed both in absolute terms and relative to individual maximum heart rate, and perceptual responses were assessed using validated scales of perceived exertion and enjoyment. Acute

cardiovascular responses were evaluated before and after exercise to assess post-exercise hypotension in indoor and outdoor conditions. Overall, the findings indicate that outdoor walking performed under naturalistic conditions elicits cardiovascular and metabolic responses comparable to those observed during structured indoor walking, supporting its effectiveness as a health-enhancing physical activity. The exploratory clinical case further suggests that multidimensional physical activity interventions may be feasible and well tolerated in individuals with Type 1 Diabetes, although generalization is limited. This work provides methodological and applied insights into the use of walking as a sustainable and inclusive physical activity, highlighting its potential role in health promotion when embedded within natural and cultural environments.

Methods: This doctoral work integrates three complementary studies involving a total of 38 participants (37 healthy recreationally active adults and 1 individual with Type 1 Diabetes) to investigate cardiovascular, metabolic, and perceptual responses to indoor and outdoor walking. The first study presents a standardized protocol for the psychophysiological characterization of hiking, combining laboratory-based treadmill testing and field-based hiking sessions. Measures included heart rate (HR), heart rate variability, blood pressure, oxygen consumption, energy expenditure, rating of perceived exertion, and physical activity enjoyment, collected using portable and laboratory-based instrumentation. The second study experimentally compared acute hemodynamic responses following an outdoor hiking session (~3800 m) and an indoor maximal walking test of comparable duration (~40 min) in 37 young adults. Systolic and diastolic blood pressure, HR, and rate pressure product were assessed at rest, immediately post-exercise,

and up to 30 minutes post-exercise. The third study explored the effects of a multidimensional indoor and outdoor exercise intervention in one individual with Type 1 Diabetes, integrating continuous glucose monitoring, insulin intake, dietary assessment, and perceptual measures.

Results: The first article describes the development of a standardized protocol aimed at the psychophysiological characterization of walking and hiking. The protocol integrates laboratory-based treadmill testing and field-based outdoor sessions and is designed to be applied to participants stratified by sex, age, and physical activity level. Across sessions, physiological and perceptual variables, including heart rate, heart rate variability, blood pressure, oxygen consumption, energy expenditure, rating of perceived exertion, and physical activity enjoyment, are assessed using portable and laboratory-based devices. This methodological framework provides a harmonized approach for evaluating the cardiovascular and metabolic demands of outdoor walking under ecologically valid conditions. The second article experimentally investigated acute cardiovascular responses to indoor and outdoor walking in 37 healthy young adults (18 females, 19 males). Participants completed an outdoor hiking session (~3800 m) and an indoor maximal walking test of comparable duration (~40 min). Systolic and diastolic blood pressure, heart rate, and rate pressure product were measured before exercise and up to 30 minutes post-exercise. Both walking conditions elicited significant post-exercise hypotension, with systolic blood pressure reductions of 10.4 ± 2.1 mmHg following outdoor walking and 12.3 ± 2.3 mmHg following indoor walking. No significant differences in post-exercise hypotension were observed between environments ($p > 0.05$), despite higher relative exercise intensity during

indoor walking. The third article presents an exploratory case study conducted in one individual with Type 1 Diabetes, evaluating the effects of a differentiated indoor and outdoor walking intervention. Continuous monitoring of blood glucose, insulin intake, dietary habits, sleep quality, chronotype, and physical activity levels was performed. Across the intervention, time spent in hyperglycemia (>250 mg/dL) decreased from 56.5% to 0%, while time within the target glycemic range (70–180 mg/dL) increased to 63.9%. A reduction of approximately 47% in daily insulin requirements was also observed. Outdoor walking sessions were perceived as more enjoyable than indoor sessions. Across all three articles, involving a total of 38 participants, walking performed in both indoor and outdoor environments induced meaningful cardiovascular and metabolic responses. Outdoor walking elicited physiological adaptations comparable to structured indoor exercise, including significant reductions in blood pressure and favorable metabolic responses, while offering higher perceived enjoyment.

Conclusions: The integrated findings of this doctoral work demonstrate that outdoor walking performed under naturalistic conditions is a feasible and effective form of physical activity capable of eliciting cardiovascular benefits comparable to indoor exercise. The proposed standardized protocol provides a robust framework for the assessment of walking-related fitness, while the exploratory clinical evidence suggests potential applicability in specific health contexts. Together, these results support the inclusion of outdoor walking within health promotion strategies and environmentally meaningful physical activity interventions, while highlighting the need for further research in larger and more diverse populations.

Literature Review

In the 21st century, sedentary behavior has emerged as a critical public health issue, with recent data indicating that approximately 40% of the Italian population remains physically inactive. Despite clear recommendations from the World Health Organization (WHO) and the American College of Sports Medicine (ACSM), which advise at least 150 minutes of moderate-intensity physical activity per week, adherence to these guidelines remains low across many demographic groups. This highlights the need for accessible and sustainable strategies to promote physical activity in daily life.

Concurrently, an increasing body of evidence suggests that engaging in physical activity within natural and outdoor environments may confer additional benefits compared to indoor exercise. Activities performed outdoors, particularly in green or culturally meaningful settings, have been associated with improvements in mood, reductions in perceived exertion, enhanced motivation, and greater enjoyment, all of which may contribute to improved adherence to physical activity over time. From a physiological perspective, environmental factors such as terrain variability, sensory stimulation, and thermal conditions may influence cardiovascular and perceptual responses to exercise. However, despite the growing popularity of outdoor physical activity, evidence directly comparing indoor and outdoor walking under controlled conditions remains limited.

Accessible public spaces, including natural parks, urban green areas, and heritage sites, offer valuable opportunities to integrate walking-based physical activity into everyday routines. These environments allow physical activity to be embedded within recreational

and leisure experiences, potentially reducing barriers to participation. Walking, in particular, represents a low-cost and inclusive form of exercise that can be adapted to different fitness levels and performed across a wide range of settings.

In parallel, recent years have seen increased interest in eco-sustainable and experiential forms of tourism that emphasize cultural, historical, and environmental engagement. Long-distance walking routes inspired by religious, historical, or natural themes are increasingly popular as experiential activities rather than purely sport-oriented endeavors. While these routes are often promoted for their cultural and touristic value, their physiological demands and potential health benefits are highly variable and remain insufficiently characterized. In particular, the lack of standardized methodologies to assess the psychophysiological demands of walking and hiking limits the ability to compare findings across studies and contexts.

Within this framework, walking-based physical activity may also have relevance for specific clinical populations. Aerobic exercise is known to support cardiometabolic health and glycemic regulation; however, responses to exercise can be influenced by modality, intensity, environmental context, and individual factors such as enjoyment and adherence. Evidence regarding outdoor physical activity in individuals with chronic conditions, including Type 1 Diabetes, remains scarce. Exploratory approaches, such as case studies, may therefore provide preliminary insights into feasibility and potential mechanisms, while acknowledging limitations in generalizability.

The present doctoral work integrates three complementary studies that address these gaps from a methodological, experimental, and applied perspective. The first study

proposes a harmonized framework for the psychophysiological assessment of walking and hiking in outdoor environments, aiming to improve methodological consistency and ecological validity. The second study experimentally compares acute cardiovascular and blood pressure responses following indoor and outdoor walking, with a specific focus on post-exercise hypotension. The third study explores the feasibility and potential metabolic impact of a multidimensional indoor and outdoor physical activity intervention in a clinical case of Type 1 Diabetes. Collectively, these studies contribute to a more nuanced understanding of how walking-based physical activity performed across different environments can support health promotion, while providing methodological tools to guide future research and applied initiatives.

sustainability

MDPI

Protocol

Psychophysiological Data Harmonization for the Sustainability of Outdoor Activities

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Psychophysiological Data Harmonization for the Sustainability of Outdoor Activities

1. Introduction

In recent years, the issue of sustainability has gained attention from the public. A well-known pathway to a sustainable future includes the 17 sustainable development goals, in reference to the United Nations 2030 sustainability agenda [1]. The 17 sustainable development goals are not limited to environmental conservation and economic development, but they also extend to improving the quality of human life. In particular, Sustainable Development Goal (SDG) 3 focuses on ensuring healthy lives and promoting well-being for everyone at all ages [1], emphasizing the critical importance of addressing health-related issues, including the alarming rise in sedentary behavior (SB). SB is defined as any waking behavior characterized by an energy expenditure of 1.5 metabolic equivalent of task (METS) or lower while sitting, reclining, or lying down, such as desk-based office work, driving a car, and watching television [2]. In the 21st century, the rate of a sedentary lifestyle in Italy has reached 35.2% of population, with a tendency to increase [3]. Sedentary lifestyles are considered the fourth leading risk factor for global mortality and are associated with poor health outcomes and deteriorating mental and physical health [2]. The key role of physical activity (PA) in reducing SB is well documented [4], and the beneficial effects of PA in enhancing overall health regardless of age confirm that it may contribute to the maintenance of general well-being, improving postural control and quality of life in general, as well as having an impact on health maintenance and disease prevention [5]. Moreover, PA is not solely an individual health behavior, but it can positively impact planetary health

and sustainable development. The literature shows how engagement in PA relates to the different SDGs and outlines how PA can contribute "to improving malnutrition (SDG 2), health behaviors (SDG 3), education (SDG 4), reducing inequalities (SDG 10), sustainable cities (SDG 12), and peace (SDG 16) and sustainable consumption (SDG 11) and combating climate change (SDG 13)" [1,6,7].

The American College of Sport Medicine (ACSM) and the World Health Organization (WHO) suggest practicing moderate-intensity aerobic PA for at least 150–300 min, higher intensity (vigorous-intensity aerobic PA) for a reduced amount of time (75–150 min), or an equivalent combination of moderate- and vigorous-intensity activity over a 7-day period to have considerable health benefits [2,8]. Moreover, adults should also include strength-based activities involving all major muscle groups on 2 or more days per week at moderate or greater intensity, to provide additional health benefits [2,8]. The suggested amount of activity may be achieved in a single session or accumulated on different days. Thus, PA guidelines specify that time and intensity are important factors to consider for the accurate estimation of activity and to better investigate the health-related effects of PA [9].

Exercise intensity, used to monitor PA, is usually defined as the energy expenditure per minute to perform a certain task [10]. Standard variables used to prescribe exercise intensity are percentages of maximal heart rate (HRmax) and maximal oxygen uptake (VO_2max) as well as calculated sub-fractions of these variables such as heart rate (HR) reserve (HRR), VO_2 reserve (VO_2R), and the peak oxygen uptake (VO_2peak). HRmax is the highest HR a subject can achieve during an effort to the point of exhaustion, being an important physiological variable for assessing maximal exertion during an exercise. Although it is

widely used for prescribing exercise intensity in PA, Tanaka el al. suggested relative HR, normalized for the theoretical HRmax, as one of the effective methods for monitoring HR pattern to classify PA [11,12]. VO_2max is the maximum amount of oxygen a person can intake, and it is expressed as liters/min as an absolute value or in milliliters/kg/min as a relative value. VO_2max is an accurate measurement of cardio-respiratory fitness and is usually measured during a maximal or submaximal incremental test [13]. In addition to HR or VO_2 monitoring, fatigue and satisfaction from the activity are also useful parameters in prescribing exercise [14]. In fact, while exercise intensity was initially determined using relative percentages, recent approaches have emphasized exercise prescription based on threshold and psychophysiological variables such as the assessment of perceived exertion and the talk test. The talk test is commonly used as a surrogate for maximal testing exercises due to its simplicity, validity, and easy determination of exercise intensity in several populations. It is defined as a subjective measure of exercise intensity which has come to be accepted as an alternative to objective measures (%HRR, %VO_2max) for exercise evaluation and prescription [12,15]. The rating of perceived exertion (RPE), defined as an alternative method to more technological and physiological measurements, holding some insights into accumulated fatigue is a widely accepted method for measuring intensity during exercise [16]. Enjoyment, described as the process of experiencing joy and reflecting general feelings of pleasure, fun, and happiness, has emerged as an important factor for PA levels, representing a good indicator for PA participation [17,18].

In the context of promoting PA and understanding its importance in countering sedentary behavior, it is essential to consider the positive associations between PA and

various physical fitness variables [19]. Physical fitness is defined as a set of measurable health- and skill-related attributes or components, which encompass cardiorespiratory fitness, muscular strength, flexibility, balance, agility, and walking speed [20]. These components play a critical role in determining one's overall well-being and health status. To gauge these facets of physical fitness accurately, various testing protocols have been established, including the Balke protocol [21], Ruffier test [22], and the talk test [12,15]. A comprehensive assessment of physical fitness parameters provides valuable insights into the holistic impact of physical activity and outdoor activities like walking on individual health and well-being [23]. Moreover, to better understand the influence of hiking on sedentary behavior, a focus on the relationship between PA and external and environmental factors is also needed.

Over the past few centuries, both PA and various external or environmental factors, including diet, geographical location, availability of green spaces, and climate conditions, have been undergoing significant changes. These changes have contributed to a rising prevalence of non-communicable diseases [24]. Furthermore, there is an increasing body of evidence suggesting that natural environments hold significant potential for preventing diseases and promoting better health [25]. Promoting outdoor PA, especially walking, not only holds substantial potential to enhance human well-being but also aligns with SDG 13, which emphasizes the mitigation of climate change and its associated consequences. By promoting outdoor activities and reducing reliance on environmentally detrimental transportation methods, we can directly ameliorate our environmental footprint and reduce harmful emissions, thereby actively contributing to climate action [1].

Therefore, considering the positive impact of regular outdoor activities on well-being and their role in supporting climate action, promoting outdoor walking could be a good strategy to reduce SB [5,26,27]. Research on how exactly and to what extent outdoor activities can promote human health is currently limited, although increasing evidence regarding the positive effects of outdoor activities on physical [28,29], mental [28–30], and social [28,31] health exists. Moreover, studies have demonstrated that participants, especially sedentary ones, are more encouraged to start practicing outdoor activities than indoor ones [32]. The exposure to nature while exercising can play a crucial role in physiological [23,33–35], psychological [23,36], biochemical [37], and social [36] levels, giving green exercise a useful role in primary and secondary prevention of disease. In addition, the engagement of sedentary individuals in green exercise could be an effective vehicle in driving behavioral change by improving adherence to PA [38].

Among outdoor activities, walking is considered the most accessible for people of all abilities in terms of the limited skills and equipment needed, as well as the ability for individuals to choose the terrain difficulty and the speed at which they walk [39,40]. It is the most natural and common form of PA and can be practiced from childhood to old age, and it is effective in maintaining and improving adherence to an exercise program. Walking significantly enhances human immune function, reduces the levels of stress hormones such as adrenaline and noradrenaline, increases vigor and decreases anxiety, depression, fatigue, confusion, and anger [2,8]. Additionally, walking demonstrates favorable outcomes in reducing both systolic and diastolic blood pressure, establishing it as a protective element

in the management and prevention of non-communicable diseases, including sarcopenia, type 2 diabetes, fractures, musculoskeletal disorders, and pulmonary diseases [2,8].

The practice of an outdoor activity such as walking dates back to the 16th and 17th centuries, with the start of the practice of the Via Lauretana, St. Francis Way, and the Camino de Santiago. These were initially used for religious purposes only, although people also started to walk in pre-established hikes for tourism [41]. Culture and tourism have always been inextricably linked. Cultural sights, attractions, and events provide an important motivation for travel, and travel itself generates culture. It is only in recent decades that the link between culture and tourism has been more specifically identified as cultural tourism [42], during which the visitor's essential motivation is to learn, discover, experience, and consume the tangible and intangible cultural attractions/products in a touristic destination, adding all the walking benefits. These attractions/products relate to a set of distinctive material, intellectual, spiritual, and emotional features of a society that encompass arts and architecture, historical, cultural, and culinary heritage, literature, music, creative industries, and living cultures with their lifestyles, value systems, beliefs, and traditions [43,44].

With the growth of the phenomenon, there is the need to develop hikes based on the "walkability" principle [45]. To make hiking accessible for everyone, intrinsic and extrinsic factors should be identified, as follows: (1) the presence of necessary services within a walking distance; (2) the attractiveness of the route in terms of architecture and social context; (3) the level of comfort and safety of the route. Although outdoor activities are known to be the starting point of hiking, there is limited research describing hiking utility, the amount and intensity of walking, and motives for using it [46]. Along with the increase

in outdoor activities, the development of different types of hikes and their characterization in terms of distance, time, slope, and degree of difficulty is needed. Therefore, the primary aim of this study protocol is to provide a specific methodology to evaluate hiking difficulty in relation to the energy demand based on (1) metabolic equivalent, (2) HRR, (3) fatigue, and (4) satisfaction while practicing pre-established hikes. The secondary aim is to classify the identified hikes as easy, intermediate, or difficult, based on the primary results and physical fitness parameters.

2. Materials and Methods

2.1. Study Design

The research protocol, designed as a cross-sectional study, was approved on 14 April 2022 by the Institutional Review Board of the Department of Human Sciences, Society, and Health of the University of Cassino and Lazio Meridionale (approval number 6663) in accordance with the Declaration of Helsinki. Participants will receive comprehensive information about the research protocol and will have the option to discontinue their involvement in the study at any point, for any reason, without incurring any adverse consequences. They will also be required to provide their informed consent before participating in the study. In accordance with Regulation (EU) 2016/679 of the European Parliament and the Council, dated 27 April 2016, regarding the protection of individuals in relation to the processing and sharing of personal data, while repealing Directive 95/46/EC (known as the General Data Protection Regulation or GDPR), we will guarantee the security and confidentiality of personal data. In particular, each participant will be assigned a unique identification code to ensure anonymity, and the data will be exclusively utilized for

statistical purposes. Throughout each phase of the study, the study supervisors will oversee all activities. While physical assessments and the outdoor activity program are generally associated with low personal risk, any adverse events will be observed and documented by the research team.

2.2. Participants

Participants of different ages will be recruited by means of flyers, posters, brochures, advertisements on social networks, and word-of-mouth. The inclusion criteria for the study will be the absence of the following conditions: the presence or a known history of neuromuscular disorders, uncontrolled heart failure or hypertension, multiple sclerosis, significant cognitive impairment, acute rheumatoid arthritis, cardiovascular diseases, use of antihypertensive medication, pulmonary dysfunction, uncontrolled metabolic diseases such as diabetes, a prior diagnosis of osteoporosis, or any injury sustained within the past six months. As suggested by previous studies [1,2], ensuring adherence to PA involves incorporating various approaches known for their effectiveness in promoting PA adherence. These approaches encompass preparing participants with informational, behavioral, social, and environmental aspects. Participants will be informed about the benefits of hiking and the associated cardiovascular changes, in addition to the provision of evaluations within the protocol that can offer insights into participants' current health or fitness levels, thereby encouraging active participation. Furthermore, the study integrates group activity programs and interaction with personal trainers or healthcare professionals to provide opportunities for social engagement that enhances participation. Additionally, it

emphasizes the provision of easy access to facilities that promote PA, such as parks, trails, and footpaths, as a fundamental aspect of promoting adherence.

The Italian short version (7 items) of the International Physical Activity Questionnaire (IPAQ) will be administered to assess individual PA levels [47]. According to the IPAQ Scoring Protocol, participants will be categorized into two groups: the Sedentary Group, including individuals reporting no activity or reporting some activity but not enough to meet the 'Minimally Active' category, and the Physically Active Group, including participants meeting at least one of the 'Minimally Active' criteria: 3 or more days of vigorous activity for at least 20 min per day; 5 or more days of moderate-intensity activity or walking for at least 30 min per day; or 5 or more days of any combination of walking, moderate-intensity, or vigorous-intensity activities achieving a minimum of at least 600 MET·min·week−1.

2.3. Procedures

2.3.1. Preliminary Evaluation

Characteristics and PA levels of participants will be assessed one week prior to the initial session. Body weight and height will be determined using a precision instrument that combines a scale and stadiometer accurate to 0.1 kg and 0.1 cm (Seca, model 709, Vogel & Halke, Hamburg, Germany). Additionally, the body mass index (BMI) will be calculated [48]. Waist circumference will be measured at the narrowest point in the abdominal region. In cases where the narrowest point is not clearly distinguishable, the measurement will be taken midway between the 10th rib and the crest of the pelvic bone. Hip circumference will be measured horizontally at the most prominent points on the posterior, lateral, and anterior

sides. The waist-to-hip ratio (WHR) will be subsequently computed. Theoretical HRmax will be calculated for each participant, according to the equation: 220-years (age) [49]. Subsequently, participants will have to perform four different testing procedures to complete the study, including two laboratory tests on a treadmill and two hikes. There will be at least 48 h of rest between each testing day.

During the laboratory testing sessions, all participants will undergo two maximal incremental tests on a treadmill. These tests will include the modified Balke-type protocol with a portable gas analyzer and a modified Balke-type protocol without a portable gas analyzer [21]. The modified Balke-type protocol will be conducted on a treadmill, with the initial speed individually chosen to match a comfortable walking pace during the first 2-min stage. Subsequently, each stage will have increments in workload achieved by increasing the treadmill grade by 2%. During the modified Balke-type protocol without a portable gas analyzer, participants will be asked to recite a standard paragraph composed of 40 words during the final 30 s of each exercise stage [50]. Participants will recite the paragraph out loud, and after completing the recitation, they will be asked the question, 'Can you speak comfortably?' with three possible answers: 'yes' (positive), 'not sure' (equivocal), or 'no' (negative). At the end of each stage, participants will also be asked to provide their RPE by placing a value on the Borg scale (0–10) [51]. The test will be stopped if participants reach voluntary exhaustion. The modified Balke-type protocol with a portable gas analyzer will serve to measure VO2, VO2peak, predict VO2max, and ventilatory thresholds and to calculate energy costs in METs. Respiratory metabolism will be assessed using the VO2 Master Pro analyzer (version 1.1.1) during the modified Balke-

type protocol. The analyzer will be connected to a Hans Rudolph 7450 V2 through the large (L) user piece, with a ventilation display range of 25–250 L/min and an accurate ventilation range of 40–220 L/min. The Flow Sensor will be calibrated using a 3-L syringe. The VO2 Master will automatically calibrate gas concentrations, ambient temperature, humidity, and barometric pressure to the ambient air upon activation. After gas calibration, the VO2 Master will be attached to participants, and they will be instructed to take 10–15 deep breaths for flowmeter calibration. The VO2 Master will transmit data via Bluetooth® to a personal phone, and the GPS Smartwatch Garmin Forerunner® 245 Music will be synchronized with the VO2 Master mobile application for data storage and downloads. Temperature and humidity levels in the laboratory will be recorded during the experimental procedures to ensure consistency between laboratory testing sessions and hikes. These conditions will be maintained within the range of 26–32 °C and 40–65% humidity.

Following the preliminary evaluation, the participants will be divided in groups according to their age, PA level, physical characteristics, cardiorespiratory fitness, and sex.

2.3.2. Route Identification

Hike locations will be determined based on physical-environmental factors and historical-cultural documentation. The main activities will revolve around identifying sites of historical, cultural, and environmental significance, as well as analyzing the connecting and access routes through cartographic analysis. This analysis will involve inspecting potential routes to assess their condition and accessibility. The identification of hikes includes evaluating various parameters such as duration, total length, slope, and energy

demand as per the Club Alpino Italiano (CAI) Manual [52]. Subsequently, the trails will be classified into three hiking difficulty levels: easy, intermediate, or difficult, each associated with specific colors (Table 1).

Table 1. Evaluation criteria for classifying hikes based on hiking difficulty.

Hiking Difficulty	*Duration*	*Total Length*	*Slope*	*Energy Demand*	*Color Scale* *
Easy	≤02 h	≤500 m	≤100 m	Low	Green path
Intermediate	02–05 h	500–1000 m	100–500 m	Medium	Sky blue path
Difficult	≥05 h	≥1000 m	≥500 m	High	Red path

* Overview of the trail color scale (green, sky blue, and red) and the descriptions associated with each level of difficulty (easy, intermediate, and difficult) provided by the Club Alpino Italiano (CAI) Manual.

2.3.3. Hike Evaluation and Data Collection

At the start of each hiking session, comprehensive data on participant characteristics and weather conditions will be collected to ensure the reliability and accuracy of the study's findings. Prior to, during, and after the hiking activities, participants will undergo an evaluation of various physiological and subjective parameters.

Body Mass Measurement: Participants' body mass (in kilograms) will be measured before and after each hike, accounting for any additional weight, such as water and clothing. The additional weight should not exceed 10% of the individual's baseline body mass, as assessed during a preliminary session.

Cardiometabolic Evaluation: Blood pressure (in millimeters of mercury, mmHg) and blood glucose levels (in milligrams per deciliter, mg/dL) will be measured at various time

points: 15 min before the hike, at the conclusion of the hike, and at 15 and 30 min post-hike. This thorough evaluation will allow for the assessment of acute cardiometabolic responses.

Ruffier Test (With and Without Talking): Participants will engage in a standardized protocol that involves performing 30 squats in 45 s [22]. Subsequently, HR will be recorded, and then after a one-minute recovery period, HR will be measured again. The resulting data will be used to calculate the Ruffier index, which serves as an important indicator of participants' effort tolerance, recovery capacity, and cardiovascular response [53]. In the adapted "Talk Test" variation, participants will be further tasked with reciting a standard paragraph of approximately 40 words aloud during the squat exercise. Post-exercise, participants will be asked to express their comfort level with speech, allowing for three possible responses: "yes" (indicating a positive ability to speak comfortably), "not sure" (equivocal), and "no" (indicating discomfort). Additionally, participants will subjectively rate their RPE. This comprehensive assessment of cardiovascular and physiological response will provide insights into participants' fitness levels and their ability to tolerate and recover from physical exertion. The Ruffier test (with and without talking) will be randomly conducted 15 min before each session, contributing to a thorough evaluation of participants' physical fitness and performance capacity.

HR and HR Variability (HRV) Monitoring: Participants will wear Garmin HRM-Pro™ (Garmin International, Kansas City, MO, USA) HR monitors throughout the hiking sessions. These compact modules, measuring 29.4 × 51.4 × 8.5 mm and weighing 59 g, utilize both ANT+® connectivity and Bluetooth® low-energy technology. Positioned just below the xiphoid process on the chest, they will record real-time HR data and track the coordinates

of the hiking route, sampling at a rate of 1 Hz [54,55]. Additionally, continuous HRV monitoring will provide insights into the autonomic nervous system's response to exercise [56].

Spatiotemporal Data Collection: To gather spatiotemporal data during the hike, participants will be equipped with a GPS Smartwatch, specifically the Garmin Forerunner® 245 Music. This smartwatch, measuring 42.3 mm in width, 12.2 mm in thickness, and weighing 38.5g, will be worn on the left wrist. It will display real-time HR and VO2 data, which are directly acquired from the Garmin HRM-Pro™ HR belt and VO2 Master Pro analyzer [55].

Gas Analysis: To measure breath-by-breath ventilation (in liters per minute, L/min), VO2 (in milliliters per kilogram per minute, ml/kg/min), and energy expenditure (in kilocalories, kcal) for each participant during the hike, a portable gas analyzer (VO2 Master Pro analyzer, The VO2 Master Pro, version 1.1.1.) will be utilized. The unit and mask have a combined weight of 0.32 kg and are powered by a single battery. The analyzer will be linked to a Hans Rudolph 7450 V2 over-nose mask using a mask adapter referred to as a 'user piece.' This adapter, which is essentially a plastic tube connecting the analyzer and the mask, includes an exhaust hole for the inflow and outflow of air. To ensure stability, soft headgear will be employed to secure the unit onto the participants' faces. The medium (M) user piece will be used with a ventilation display range of 15–180 L/min and an accurate range of 30–160 L/min. A single-use filter, replaced after each use following the manufacturer's guidelines, will be installed between the user piece and the analyzer. The VO2 Master unit is equipped with a passive, pump-less gas sampling system, a galvanic fuel cell O2 sensor, and a

differential pressure flow sensor (information obtained through personal communications with the manufacturer). The Flow Sensor will be calibrated using a 3-L syringe. Upon activation, the VO2 Master will undergo automatic calibration for gas concentrations, ambient temperature, humidity, and barometric pressure. After gas calibration, the VO2 Master will be affixed to the participants, who will be instructed to perform 10–15 deep breaths to facilitate flowmeter calibration. Data will be transmitted via Bluetooth® to personal smartphones, tablets, and the GPS Smartwatch Garmin Forerunner® 245 Music. These devices are equipped with the VO2 Master mobile application for the storage and retrieval of data [57,58].

RPE: Participants will subjectively evaluate their effort on a scale from 0 to 10 (AU) before the hike, every 10 min during the hike, at the end of the hike, and 30 min following its conclusion.

Session RPE (sRPE): At the end of each hike, sRPE will be calculated by multiplying the overall hike's RPE by the duration of the hike activity (AU). Participants will be asked, "How intense was your hike today?" and rate their effort on a scale ranging from 0 to 10 (AU). This measurement will not only provide insight into the overall hike intensity but also accumulated fatigue [59,60].

Physical Activity Enjoyment Scale (PACES): After completing the hike, participants will fill out the PACES questionnaire to assess their individual satisfaction with the activity. This questionnaire comprises five items evaluated on a seven-point Likert scale (AU). For items 1 and 4, the score ranges from 1 (completely agree) to 7 (completely disagree), while for items 2, 3, and 5, the score ranges from 1 (completely disagree) to 7 (completely agree) [18].

All devices will be utilized in strict accordance with the manufacturers' guidelines. Participants will be equipped with the necessary devices for the entire duration of the hiking sessions. All data will be collected using specialized formats, which can be accessed via personal phones, tablets, and paper sheets. Each participant will complete the same hike at least two times to ensure data reliability and validity.

2.3.4. Statistical Analysis

In this section, we present the statistical methods and analyses that will be applied to investigate the effects of hiking on various physiological and psychological parameters.

Descriptive Statistics

To gain an initial understanding of the data, descriptive statistics will be used to summarize the characteristics of both the dependent and independent variables. This includes calculating measures such as means, standard deviations (SD), medians, ranges, and percentages for the relevant variables. To calculate means, SD, medians, and ranges for several variables, we will aim for a representative sample. Assuming a medium effect size, a sample size of at least 100 participants should be adequate. Furthermore, since this section involves no hypothesis testing, traditional power calculations will not be applied. For example, we will provide the following:

The mean and SD of HR during hiking, as it is a critical physiological response variable (e.g., mean HR during hiking = 125 bpm, SD = 10 bpm).

Frequency of occurrence expressed in percentage for hikes classified by difficulty to understand the distribution of hikes (e.g., easy hikes: 40%, intermediate hikes: 30%, difficult hikes: 30%).

Median and range for participants' age and fitness level to capture the central tendency and variability in these demographics (e.g., median age = 35 years, range = 25–50 years).

Histograms for PACES scores to visualize the distribution of psychological responses.

Normality Testing

Normality assumptions will be assessed to determine whether the data follow a normal distribution. This will guide the selection of appropriate statistical tests. Normality testing does not require specific sample sizes. Similar to descriptive statistics, power calculations are not typically conducted for normality testing. Example:

The Shapiro–Wilk test will be applied to HR data during hiking to assess their normality (Shapiro–Wilk p-value < 0.05, indicating non-normal distribution).

Internal Consistency and Reliability Analysis

To evaluate the consistency and reliability of the measurements, relevant statistical methods will be applied. This may include Cronbach's alpha for scales or test–retest reliability for repeated measures (e.g., Cronbach's alpha for the PACES questionnaire = 0.85, indicating high internal consistency). The sample size required will depend on the number of items in the scale and the desired level of reliability. For example, for a Cronbach's alpha of 0.85, a sample size of 150 participants may be sufficient. Moreover, power calculations will not be conducted for internal consistency analysis.

Validity Assessment

The validity of measurements will also be examined. For example, we may assess the concurrent validity of the Ruffier "Talk Test" index by comparing it to other accepted measures of cardiovascular response (e.g., Ruffier "Talk Test" index shows a strong

correlation with peak HR achieved during hiking, r = 0.75). Assuming a moderate correlation (e.g., r = 0.5), a sample size of around 80 participants may be needed to detect this correlation with adequate power.

Correlation Analysis

We will explore relationships between variables using various correlation techniques. For correlation analysis, the required sample size depends on the expected effect size and significance level. Assuming a moderate effect size (e.g., r = 0.4) and a significance level of 0.05, a sample size of approximately 100 participants might be necessary. A power of 0.80 can be achieved with 100 participants. Example:

Pearson's correlation will be used to investigate the relationship between hike duration (independent variable) and HR (dependent variable) during the hikes (e.g., Pearson's r = 0.42, $p < 0.001$, indicating a moderate positive correlation).

Spearman's rank correlation will be applied to understand the association between the hike difficulty (independent variable) and HR variability (dependent variable) during the hikes (e.g., Spearman's $\varrho = 0.08$, $p = 0.320$, indicating no significant correlation).

Multilevel Mixed-Effect Generalized Linear Model Analysis

To investigate differences in hike classifications and characteristics between groups (e.g., sex, age groups, fitness levels), multilevel mixed-effect generalized linear models will be employed. For instance, we could find that middle-aged participants will be significantly more likely to classify hikes as difficult compared to their younger and older counterparts, after accounting for individual variations within each age group. The multilevel structure will make it possible to examine how these factors influence the likelihood of hike

classifications, considering the nested nature of the data with participants belonging to different age groups. This analysis could provide information about how sex, age, and fitness level interact to affect perceptions of hike difficulty among the study participants. The sample size required for multilevel mixed-effect models highly depends on the complexity of the analysis and the anticipated effect sizes. Assuming moderate effects, a sample size of at least 300 participants, considering the nested structure of the data, may be necessary. Furthermore, with the mentioned parameters, a power of 0.80 can be achieved with around 300 participants.

Generalized Estimating Equation Regression Models

Participants' baseline characteristics, fitness levels, hike features (e.g., slope, length), and hike performance (e.g., speed, total time) will be modeled using generalized estimating equation regression models. For example, a strong positive association between baseline fitness levels and hike performance could be identified, indicating that participants with higher fitness levels completed the hikes more quickly. This modeling approach considers the correlated nature of the data, where multiple measurements will be taken from each participant across different hikes, making it ideal for examining the complex interaction between various factors and their influence on hike-related outcomes. Assuming moderate effects, a sample size of around 200 participants may be required with a power of 0.80.

Survival Analysis

For time-dependent variables, such as the time it takes to complete hikes, we will employ Kaplan–Meier survival curves. For instance, this method will be used to assess the time taken by the participants to complete different hikes within the study. Kaplan–Meier curves

will make it possible to visualize and analyze the probability of event occurrence over time, such as the likelihood of hike completion at various time points. By employing Kaplan–Meier survival curves, we could have information on how participants' completion times vary across different hikes by highlighting the factors that influence hike duration. For survival analysis, the sample size depends on the expected hazard rates and time-to-event data. Assuming a moderate hazard rate, a sample size of at least 150 participants might be necessary, with a power of 0.80.

Nonlinear Regression Models

Nonlinear regression models will be used to investigate complex relationships. The sample size required for nonlinear regression models depends on the complexity of the model and the expected effect sizes. Assuming moderate effects, a sample size of around 120 participants may be needed (power of 0.80). Example:

A nonlinear regression model will be applied to assess the relationship between HR (dependent variable) and independent variables such as age and hike duration (e.g., HR = 160 − 0.5 * age + 5 * hike duration − 0.2 * age * hike duration).

Confounding Variable Management

The statistical analysis encompasses a wide range of methods to ensure the robustness and reliability of the expected research findings. The sample size will range from 100 to 300 participants across different analyses, and, to address other sources of variability, participants will be carefully screened for confounding variables, such as pre-existing medical conditions, medication usage, psychological factors, etc., which might impact the

results. Detailed information will be collected on these potential confounders and will be incorporated as covariates in relevant statistical models.

Statistical Software

STATA 18 (StataCorp LP, College Station, TX, USA) will be used for all the statistical analyses mentioned above. By implementing this comprehensive statistical analysis plan, we aim to provide a deeper understanding of the effects of hiking on physiological and psychological responses, while accounting for various factors and relationships within the dataset.

3. Discussion

This study protocol presents a comprehensive approach to evaluating hiking difficulty in relation to energy demand and fitness parameters, with a focus on both physiological and psychological aspects. The primary aims of this research involve assessing metabolic equivalent, relative HR, fatigue, and satisfaction value during pre-established hikes. Additionally, it seeks to classify these hikes into easy, intermediate, or difficult categories based on the obtained data.

The protocol places a strong emphasis on outdoor hiking, which offers numerous advantages. It is an inclusive activity accessible to people of all abilities, requiring minimal skills and equipment, and allowing individuals to set their own walking pace [61]. The synergistic effect of walking in a natural environment makes hiking an ideal pursuit for enhancing overall health and well-being. Regular exposure to nature enriches one's lifestyle by providing an array of benefits, including the inhalation of air rich in beneficial organic compounds, engagement in PA, rejuvenation, and the facilitation of social bonds. Among

the benefits of hiking is its impact on cardiovascular health. Hiking demands sustained physical effort, effectively increasing HR and fortifying the cardiovascular system. Engaging in regular hiking can lead to a lowering of blood pressure and enhanced blood circulation [62,63]. These cardiovascular advantages translate into a reduced risk of heart disease, stroke, and other related conditions. Furthermore, hiking serves as an excellent form of aerobic exercise, facilitating weight management and boosting metabolic health. As hikers traverse diverse terrains and elevations, their energy expenditure can significantly increase. Over time, this may result in weight loss or weight maintenance, depending on the duration and intensity of the hike. Additionally, consistent aerobic exercise, such as hiking, has been associated with improved insulin sensitivity, better glucose control, and a reduced risk of developing type 2 diabetes [2,8]. Beyond the physical advantages, hiking also provides a host of mental health benefits. Engaging in outdoor physical activities has been associated with reduced symptoms of stress, anxiety, and depression. The combination of PA, exposure to natural surroundings, and fresh air contributes to a sense of well-being and relaxation.

Hiking provides an opportunity to disconnect from the demands of everyday life and immerse oneself in the beauty of nature, fostering mindfulness and mental revitalization. In modern urban settings, where sedentary lifestyles have become the norm, hiking offers a much-needed respite. Prolonged periods of inactivity, extended periods of sitting, and excessive screen time can result in both physical and mental exhaustion. Hiking offers a rejuvenating solution, inspiring people to be active, inhale fresh air, and connect with the natural world. It offers a shift in pace and an opportunity to reconnect with the senses,

offering a break from the monotony of indoor living. Walking and hiking represent cost-effective and accessible forms of exercise suitable for individuals of all ages and abilities [39,64,65]. They are widely regarded as the most inclusive activities, given the minimal requirements in terms of skill and equipment, along with the freedom for individuals to select the terrain difficulty and their preferred walking speed. Research has shown that individuals with disabilities, who are also at an increased risk of experiencing depression, may benefit from engaging in outdoor recreational activities, potentially reducing that risk [65,66]. Hiking is also considered a good strategy for stimulating social interaction and for providing benefits in terms of flexibility (e.g., advanced motor fitness, including coordination, balance, and agility) among children [39]. Therefore, encouraging individuals to engage in green sustainable tourism and health-focused holidays is a key aspect of this study. By providing easily accessible fitness tests that guide participants towards suitable hiking practices, the study protocol contributes to reducing the risk of overexertion. This proactive approach aims to lower the incidence of cardiovascular events during hiking. By promoting awareness of individual fitness levels and providing personalized hiking recommendations, in line with Goal 3 of the 2030 Agenda for Sustainable Development, which aims to ensure a healthy life and promote well-being for all at every age. Furthermore, it contributes to the broader goals of fostering sustainable tourism that takes into consideration both environmental and health aspects [1].

The practical applications of this study protocol are many, as it combines physiological and psychological assessments and the promotion of outdoor activities. The comprehensive evaluation of hiking difficulty and its potential impacts can benefit various stakeholders:

For individuals interested in hiking, the study protocol provides insights into their fitness levels and helps them understand the difficulty of specific hiking routes. By offering personalized recommendations, it allows hikers to make informed choices and to enjoy their outdoor experiences while minimizing health risks. Moreover, it encourages people to incorporate more outdoor activities into their lives, contributing to overall well-being.

The tourism industry can use the findings of this study protocol to promote green tourism and health-focused holidays. By guiding travelers toward suitable hiking options based on their fitness levels, tour operators can enhance the overall experience and ensure the safety of their clients. The health sector can benefit from the data by promoting hiking as a cost-effective and accessible means of improving physical and mental health.

The research community can use the methods outlined in this protocol to further investigate the impact of outdoor activities on various health parameters. The data can be used to develop evidence-based policies and guidelines for promoting outdoor and hiking activities. It can also inform future research on the physiological and psychological effects of spending time in nature.

Fitness trainers, coaches, and health professionals can incorporate the findings of this study into their practice. By understanding the unique demands of hiking and the benefits it offers, they can provide targeted recommendations to their clients. The data can be used to tailor fitness and training programs, ensuring that individuals are adequately prepared for hiking adventures.

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Comparable blood pressure reductions after indoor and outdoor walking exercise

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Comparable Blood Pressure Reductions After Indoor and Outdoor Walking Exercise

1. Introduction

Physical activity is associated with improved health and quality of life and even minor improvements in fitness have been linked to reduced cardiovascular and all-cause mortality [120–122]. Current physical activity guidelines recognize the importance of fitness and recommend that adults aged 18-65 years engage in at least 150 minutes per week of moderate-intensity exercise or 75 minutes per week of vigorous-intensity exercise [123]. In addition to those benefits, the World Health Organization (WHO) identifies physical activity as a protective factor for the prevention and treatment of cardiovascular diseases [124]. These conditions include a wide range of disorders affecting the cardiac muscle and vascular system, which supply the heart, brain and other vital organs, and are frequently associated with hypertension. In particular, high blood pressure is recognized as a leading risk factor for global mortality, with more than 10 million attributable deaths annually [120]. Since persistent hypertension, together with the absence of drug or physical therapy over time, may cause irreversible cardiovascular damage, the American Heart Association and the American College of Cardiology have defined blood pressure categories [125]. This classification is expressed as ranges that clarify the clinical implications and risks of hypertension, as shown in Table 1.

Table 1. Categories and ranges of blood pressure with corresponding health conditions.

Categories	Conditions
Normal: Systolic Blood Pressure <120 mmHg Diastolic Blood Pressure <80 mmHg	Optimal cardiovascular health, lower risk of cardiovascular disease
Elevated: Systolic Blood Pressure 120-129 mmHg Diastolic Blood Pressure <80 mmHg	Elevated risk for the development of hypertension
Hypertension Stage 1: Systolic Blood Pressure 130-139 mmHg Diastolic Blood Pressure 80-89 mmHg	Mild to moderate elevation in blood pressure levels which warrants lifestyle modifications and possibly pharmacological treatment depending on individual risk factors
Hypertension Stage 2: Systolic Blood Pressure >139 mmHg Diastolic Blood Pressure >89 mmHg	Severe elevation in blood pressure levels requiring pharmacological treatment in addition to lifestyle modifications to reduce the risk of cardiovascular events

Reference values reported in the table were taken from Whelton P.K., et al. (2017) ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA Guideline for the Prevention, Detection, Evaluation, and Management of High Blood Pressure in Adults. J Am Coll Cardiol. 2018;71(19):e127–248. Doi:10.1016/j.jacc.2017.11.006

Hypertension is highly modifiable and can be influenced by various lifestyle factors, including physical activity. Immediately after a single bout of exercise, substantial changes occur in the regulation of arterial blood pressure. This phenomenon, known as post-exercise

hypotension (PEH) [99,126], is considered a relevant non-pharmacological strategy to counteract hypertension risk. Its clinical and preventive relevance lies in its ability to reproduce, after a single exercise session, the chronic reduction in blood pressure usually achieved with pharmacological treatment. PEH typically lasts about 2 hours in healthy individuals and may persist for more than 12 hours in hypertensive patients, representing a valuable preventive mechanism when exercise is performed regularly. Moreover, the magnitude and duration of PEH are strongly influenced by exercise characteristics, particularly session duration, intensity, and frequency. Longer or repeated sessions are associated with more pronounced and sustained blood pressure reductions, highlighting the preventive and therapeutic relevance of structured physical activity in hypertension management [127,128]. PEH has been attributed to several mechanisms, including vasodilation, reduced sympathetic nervous activity, and improved baroreceptor sensitivity. It is commonly associated with indoor exercise (i.e., resistance training, circuit training, and aerobic workouts) which has been shown to significantly reduce blood pressure immediately following the session [99,129,130]. Although indoor exercise is a popular form of physical activity, there has been a growing trend toward outdoor activities, particularly for mental health benefits, given their high salutogenic potential. Salutogenesis refers to the capacity to promote overall health and well-being by enhancing resilience, improving stress management, and fostering positive physical and psychological outcomes through engagement with natural environments [29,131]. Urban green and outdoor environments are the most commonly explored and may provide benefits such as varied terrain, fresh air, and exposure to nature. These factors can enhance the overall exercise experience and

amplify health outcomes [39,132]. In particular, outdoor activities, such as hiking, offer additional benefits beyond physical exercise, including exposure to nature, accessibility for people of different abilities, minimal equipment requirements, cost-effectiveness, and the possibility for individuals to select terrain difficulty and the walking pace. Hiking, defined as walking a substantial distance the outdoors, often over natural terrain with obstacles such as rocks and tree roots, has gained popularity in recent years [26,39,132]. While the increasing popularity of outdoor activities is well documented [131], less is known about their potential beneficial effects on blood pressure compared with indoor exercise. While indoor exercise is well established in inducing PEH, outdoor exercise also holds promise for achieving similar cardiovascular benefits. The choice between indoor and outdoor exercise can therefore be tailored to individual preferences and circumstances, ensuring that the benefits of PEH remain widely accessible. Considering the numerous health benefits of outdoor activities and their potential to enhance hemodynamic responses, exploring outdoor exercise as an alternative to traditional indoor exercise session is relevant. Therefore, this study aims to investigate blood pressure responses and PEH following outdoor exercise compared with indoor exercise.

2. Methods

Participants were recruited by means of flyers, posters, brochures, advertisements on social networks, and word-of-mouth. In line with previous study [87] the inclusion criteria were the absence of the following conditions: the presence or a known history of neuromuscular disorders, uncontrolled heart failure or hypertension, multiple sclerosis, significant cognitive impairment, acute rheumatoid arthritis, cardiovascular diseases, use of

antihypertensive medications, pulmonary dysfunction, uncontrolled metabolic diseases such as diabetes, a prior diagnosis of osteoporosis, a diagnosis of obesity (BMI ≥ 29 kg/m2) or any injury sustained within the past six months.

Forty subjects were included in the study, approved on 14 April 2022 by the Institutional Review Board of the Department of Human Sciences, Society, and Health of the University of Cassino and Lazio Meridionale (approval number 6663) in accordance with the Declaration of Helsinki. Each participant was assigned a unique identification code to ensure anonymity, and the data were exclusively utilized for statistical purposes. Considering that physical activity positively influences cardiometabolic parameters [133], to avoid the influence of physical inactivity, participants were included only if they reported being recreationally active according to the International Physical Activity Questionnaire (IPAQ) [47] and to be in possession of medical clearance to exercise. Since previous research [133] reported a correlation between physical activity level and BMI, in accordance with ACSM guidelines for the clinical classification of participants [121], anthropometric measurements were collected one week prior to the data collection. Body weight and height were measured using a scale and stadiometer accurate to 0.1 kg and 0.1 cm (Seca, model 709, Vogel & Halke, Hamburg, Germany) and the BMI was calculated. Theoretical maximum heart rate (HRmax) was calculated for each participant, according to the equation: 220 - age (years). After one week, participants performed two different testing procedures, including one hiking session and one indoor test on a treadmill, with a minimum of 48h rest between. At the start of each session, weather data were collected to ensure the reliability and accuracy of the study's findings. Temperature and humidity levels

were recorded during the indoor sessions by maintaining the range of 20 – 30 ◦C of temperature and 35 – 55% humidity, to ensure consistency with the temperature (24.2 ± 1.8 ◦C) and humidity (42.8 ± 5.5 %) of outdoor sessions.

Of the 40 participants who began the study, 3 withdrew due to personal reasons. Subsequently 37 participants (Female (n=18): age: 24.7 ± 0.7 years; body mass: 56.3 ± 9.1 kg; body height: 163.4 ± 8.9 cm; BMI: 21.1 ± 2.1 kg/m2; Male (n=19); age:24.9 ± 0.5 years; body mass: 75.5 ± 11.9 kg; body height: 176.5 ± 8.4 cm; BMI: 24.1 ± 2.6 kg/m2) completed all testing and were used for the final analysis.

The hiking session was implemented outdoors in Gaeta, Italy. The location was chosen basing on the similarity (in terms of duration and mean slope) with the indoor session and determined based on walkability principle [134]. The principle was focused on physical-environmental factors and historical-cultural aspect of the course, such as: the presence of necessary services within a walking distance, the attractiveness of the route in terms of architecture and social context, the level of comfort and safety of the route. The identification of the hike included an evaluation of various parameters such as duration, length, slope, and energy demand as per the Club Alpino Italiano (CAI) Manual. Each participant completed the same hike, during the outdoor session, at a self-selected speed.

During the indoor testing session, all participants undergo a maximal incremental walking test on a treadmill (RunRace HC1200, Technogym, Cesena, Italy), incorporating both uphill and downhill walking. Participants were asked to self-select their speed [21,87], trying to replicate their pace during the outdoor session. The initial speed was chosen to match a comfortable walking pace during the first 2-min stage with the slope set at 0%

followed by 2% slope increments every 2-minute stage. When participants reached the maximum exertion, the uphill phase finished and the downhill phase started with 2% slope decrements every stage, until returning to 0% grade.

During both sessions baseline systolic and diastolic blood pressures were measured using a digital sphygmomanometer (Erkameter 3000; Erka, Bad Tolz, Germany). Resting blood pressure values were obtained 15 minutes before the start of each session (PRE), after a 15-minute period of seated rest on a chair with armrests. Blood pressure was also measured immediately after the conclusion (POST), 15 minutes (POST-15) and 30 minutes (POST-30) post-session, to assess acute cardiometabolic responses, as shown in the measurements' timeline (Figure 4).

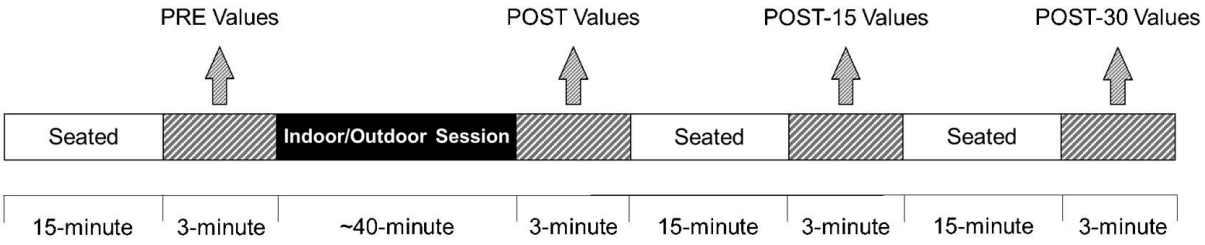

Figure 4. Timeline of the measurements.

Two measurements were recorded and if there was more than 5-mmHg difference between the first and second, an additional measurement was taken. Within each measurement period, the maximum (highest reading) and minimum (lowest reading) value of systolic blood pressure, diastolic blood pressure and heart rate were collected, and average values of measurements were calculated and used for statistical purposes. Post-exercise hypotension was calculated for systolic blood pressure as PRE-POST 30 (mmHg).

Rate pressure product was calculated as Systolic Blood Pressure (mmHg) x Heart Rate (bpm).

Before and during sessions heart rate data were collected using Garmin HRMPro™ (Garmin International, Kansas City, MO, USA) chest strap heart rate monitor, positioned just below the xiphoid process on the chest, they recorded real-time heart rate data and tracked the coordinates of the hiking route, sampling at a rate of 1 Hz.). Resting heart rate data was collected 15 min before the sessions, after a 5-minute seated rest.

Spatiotemporal data were recorded during the sessions. Participants were equipped with a GPS Smartwatch (Garmin Forerunner® 245 Music) worn on the left wrist, displaying real-time heart rate, directly acquired from the Garmin HRM-Pro™ chest strap heart rate monitor.

Statistical analysis was conducted using STATA statistical software version 18 (Stata-Corp, College Station, LLC, Texas, USA). All values are reported as means and standard deviation (±SD) and the average value between measurements are used for the final analysis. Repeated measures mixed models were used to evaluate the hemodynamic responses during and after the maximal incremental walking test on treadmill and the hiking session and to compare with the baseline values for each test. In the model, subjects were considered as random effect, whereas the environment (Indoor vs. Outdoor) and testing time (PRE, POST, POST-15 and POST-30) were treated as fixed effects. Subsequently the contrast method was employed to test whether the means of the dependent variables (i.e., systolic and diastolic blood pressure, heart rate, rate pressure product) for setting (indoor vs outdoor) and time point (PRE, POST, POST-15 and POST-30) were equivalent.

When significant main effects and interactions were found, post hoc analysis was applied using a Bonferroni correction. In order to avoid type 1 error, after Bonferroni correction, for the linear repeated-measures mixed model, significance was set at $p<0.05$ for the main effects and at $p<0.001$ for post hoc pairwise comparisons. Paired t-tests were used for comparisons between the maximal incremental walking test and the hiking session.

3. Results

Outdoor session had a length of ~3800m with the maximum slope at 19% and the mean slope at 5.3%, during the session participants achieved on average the 84% of their theoretical HRmax in 40 minutes of mean duration. Thus, for the indoor session the length was ~2800m, the maximum slope provided from the treadmill was 25% and the mean slope was 8.1%, during the test participant reached on average the 92% of their theoretical HRmax in 41:86 minutes of mean duration. Heart rates from a representative participant during the sessions is shown in Figure 5.

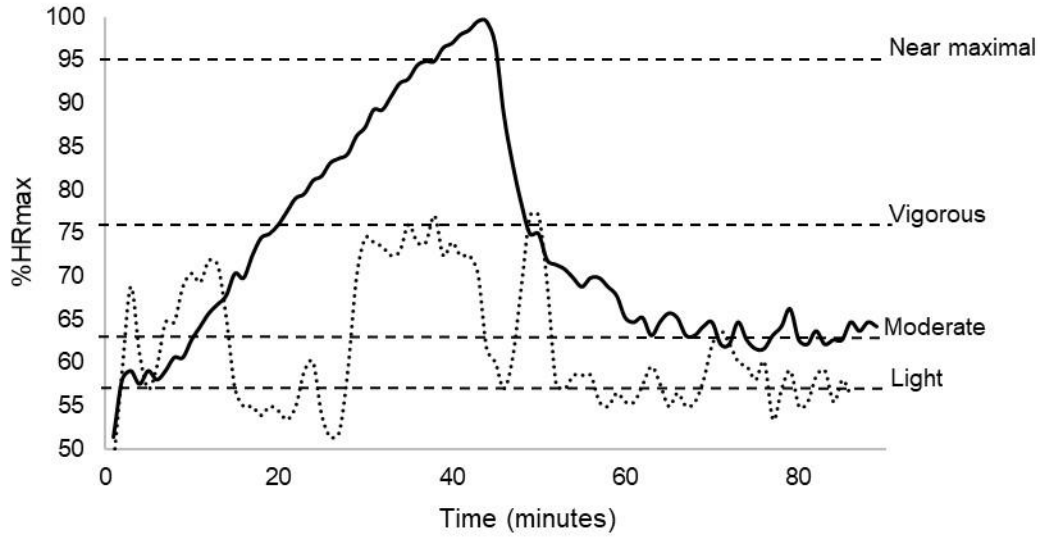

Figure 5. Percentage of heart rate max during indoor (solid line) and outdoor (dotted line) session with horizontal dashed lines identifying threshold of exercise intensities in a representative participant.

Means and standard deviations of the average values and the rate pressure product during outdoor (Table 6) and indoor (Table 7) sessions are shown below.

Table 6. Blood pressure and heart rate response before, during and after outdoor session.

	Outdoor Session			
	Resting	Post	POST-15	POST-30
Average sBP (mmHg)	120 ± 11	118 ± 8	112 ± 9*,#	110 ± 9*,#
Average dBP (mmHg)	77 ± 7	76 ± 8	73 ± 7	73 ± 8*
Average HR (beats·min^{-1})	67 ± 9	81 ± 12*	73 ± 10*,#	72 ± 10#
RPP (mmHg·bpm)	8122±1381	9674±1531*	8257±1262#	7981±1179#

Values are mean ± SD. SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; RPP, rate pressure product. *significantly ($p<0.001$) different from PRE values, #significantly ($p<0.001$) different from POST values.

Table 7. Blood pressure and heart rate response before, during and after indoor session.

	Indoor Session			
	Resting	Post	POST-15	POST-30
Average sBP (mmHg)	120 ±11	112±10*	109 ± 9*	109 ± 9*
Average dBP (mmHg)	75 ± 7	73 ± 7	69 ± 6*	70 ± 7*
Average HR (beats·min^{-1})	70 ± 11	89 ± 13*	80 ± 12*,#	79 ± 11*,#
RPP (mmHg·bpm)	8518±1537	9911±1626*	8881±1255#	8480±1229#

Values are mean ± SD. SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; RPP, rate pressure product. *significantly ($p<0.001$) different from PRE values, #significantly ($p<0.001$) different from POST values.

The repeated measures mixed models showed a significance of model ($p<0.001$) for systolic blood pressure. In particular, significant difference was found for time ($F(7,252)=25.32$; $p=0.02$) with PRE values higher than POST ($p<0.001$), POST-15 ($p<0.001$) and POST-30 ($p<0.001$) for indoor session. While for outdoor session, POST-15 and POST-30 values were lower ($p<0.001$) than PRE and POST, as shown in Figure 6(a). A significant

interaction between time and setting ($F(3, 216)=62.34$; $p<0.001$) was found, but no significant difference emerged for setting ($F(1, 72)=1.71$, $p=0.19$).

Regarding diastolic blood pressure, a main effect was found for time ($F(7, 252)= 11.15$; $p<0.001$), with PRE values significantly higher than POST-15 ($p<0.001$) and POST-30 ($p<0.001$) for indoor session. While for outdoor session POST-30 values were significantly lower ($p<0.001$) than PRE, as shown in Figure 6(b). No significant difference emerged for setting ($F(1,72)= 2.10$; $p=0.03$) and no interaction was found between time and setting ($F(3, 216)= 0.43$; $p=0.66$).

Results revealed a significance of model ($p<0.001$) for heart rate, with a difference for setting ($F(1, 252)=5.10$; $p=0.02$) and time ($F(7,252)=37.73$; $p<0.001$). PRE values were significantly higher than POST ($p<0.001$), POST-15 ($p<0.001$) and POST-30 ($p<0.001$) for indoor session. For outdoor session PRE values were significantly higher than POST ($p<0.001$) and POST-15 ($p<0.001$) and POST values were significantly higher the POST-15 ($p<0.001$) and POST-30 ($p<0.001$) for outdoor session, as shown in Figure 6(c). Regarding time and setting, no significant interactions were found ($F(3, 216)= 1.23$; $p=0.21$).

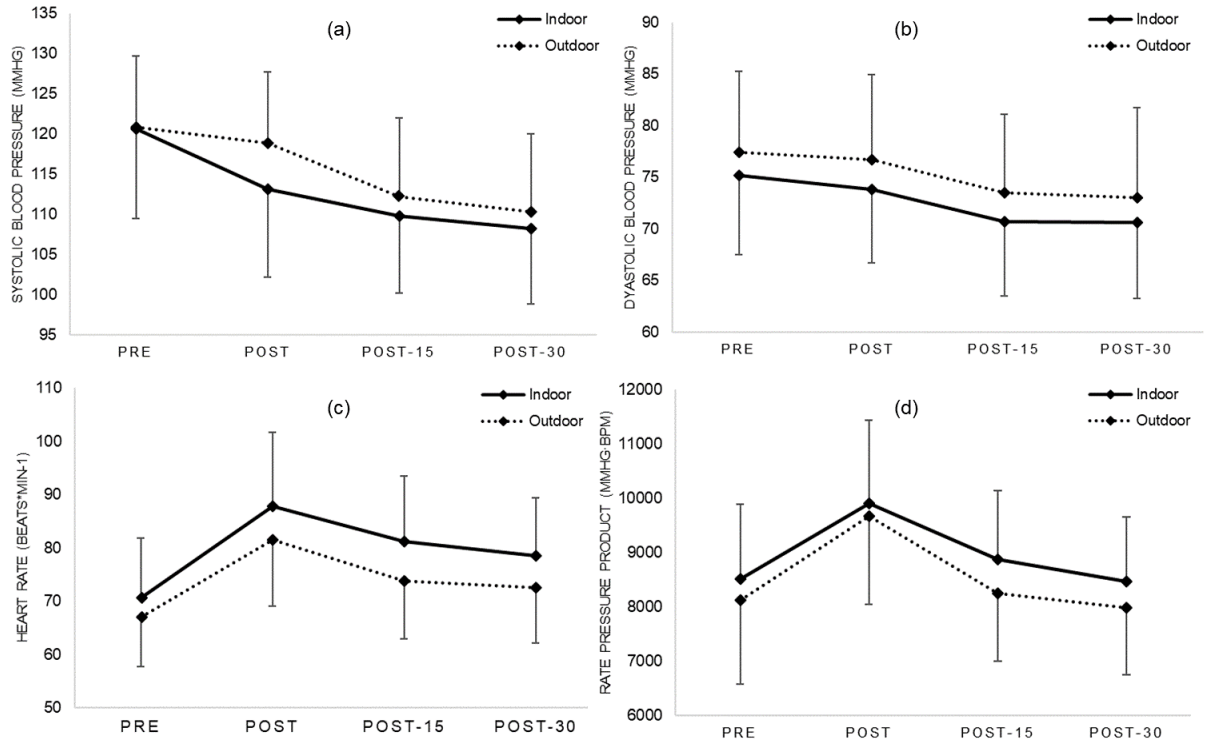

Figure 6. Means and standard deviations of (a) systolic blood pressure, (b) diastolic blood pressure, (c) heart rate and (d) rate pressure product between indoor session (solid lines) and outdoor session (dotted lines) at various time point.

The analysis of rate pressure product showed a significance of model ($p<0.001$), with a significant effect of time ($F(7,252)=23.87$, $p<0.001$). In fact, POST was significantly higher than PRE ($p<0.001$), POST-15 ($p<0.001$) and POST-30 ($p<0.001$) for both sessions, as shown in Figure 3(d). No significant differences were found for setting ($F(1, 252)=3.68$; $p=0.06$) and no interaction between time and settings ($F(3, 216)=0.54$, $p=0.58$).

Lastly, paired t-test showed no significant difference between settings in post-exercise hypotension ($p=0.3658$).

4. Discussion

This study aimed to investigate the effect of a hiking session on post-exercise hypotension, in comparison with an indoor session of approximately the same intensity and

duration. The relevant findings of the present study demonstrated that large hemodynamic changes occur during a maximal walking test and hiking session in recreationally active participants. Independently from proposed activities, systolic blood pressure, diastolic blood pressure and heart rate showed a significant decrease over time, with lowest values occurring in POST-30. The results are in line with previous research [135], confirming the benefits of exercise on acute reduction of blood pressure and offer a new topic to explore. The literature is more focused on the inactive subjects, that usually have worse hypertension and a greater reduction in blood pressure after exercise, the present study included recreationally active adults who also showed a considerable reduction of blood pressure following exercise, reinforcing the value of exercise in the control of blood pressure [135].

The absence of differences in blood pressure response between two settings, despite their difference in term of internal load (%HRmax reached during the sessions), highlights the potential effect of hiking for achieving cardiovascular benefits and highlights the generalizability of the PEH effect.

The systolic blood pressure showed a significant reduction over time, with a higher reduction in POST-30. The analysis also showed a significant interaction between the time point of the measurements and the different settings. This difference is translated in a different hemodynamic response basing on the power of the stimulus. In fact, the systolic blood pressure had two different trends during the sessions, with a greater reduction between POST-15 and POST-30 for the hiking session, and POST and POST-15 ($p<0.001$) for the indoor session. These results could be explained by the different intensity of 2 exercises. Since the indoor session was a maximal incremental walking test, the intensity reached, in

term of % of HRmax, was higher than outdoor session. In fact, during the outdoor session, the increment of the workload was not regular as indoor one (every 2-minutes stage). Previous studies [136] have investigated on the effect of training at high-intensity, where individuals showed significant improvement in systolic blood pressure. Specifically, there was a notable reduction in systolic blood pressure immediately post-exercise, indicating a pronounced cardiovascular response. Study compared the effects of a session of low, moderate, and vigorous intensity exercise among normotensive young adults, reporting that higher exercise intensities elicited the largest acute blood pressure reductions [137]. However, in the current findings, during POST-30, both sessions exhibited lower systolic blood pressure values than at rest, confirming the positive effect of exercise on the management of blood pressure.

For the diastolic blood pressure, the trend between session was mostly the same. There was a significant reduction of diastolic blood pressure over the time, more prominent between PRE and POST-30 ($p<0.001$) for both sessions. This result aligns with existing literature that reports a lower but more consistent reduction in diastolic blood pressure compared to systolic blood pressure following exercise.

Aerobic exercise has been shown to decrease diastolic blood pressure by a few mmHg, reflecting the beneficial effects of physical activity on cardiovascular health [138]. The reduction in diastolic blood pressure is primarily due to the vasodilatory effects of exercise, which lead to decreased vascular resistance and improved arterial compliance [139].

Results also showed recovery of heart rate after exercise, where significant differences in time were due to increasing of parasympathetic activity, that allowed the return to rest

values [140]. As the systolic blood pressure, the significant difference for heart rate between time, in interaction with settings found explanation in the intensity of the sessions. During the outdoor sessions, participants were only asked to walk with a comfortable pace for ~3800 m with different slopes, instead of the indoor session, where the participants underwent a maximal incremental walking.

Regarding the rate pressure product, the significant effect of time reflects the natural recovery process of the cardiovascular system post-exercise, that decreased significantly from immediately after the conclusion of the sessions to 30 minutes post-exercise. Rate pressure product is a non-invasive prediction of myocardial workload because it is directly related to the oxygen consumption of the heart muscle [141,142]. No differences were found between outdoor and indoor sessions, indicating that both types of exercise could have a similar myocardial workload. Therefore, the similarity in rate pressure product across both sessions suggests that exercising outdoor could be a valid alternative to indoor aerobic exercise (i.e. on treadmill), taking benefits of outdoor activities (high enjoyment, air quality, social relationships).

The findings suggested that outdoor session and indoor maximal incremental walking test showed similar cardiovascular responses, given the absence of statistic differences between both sessions in blood pressure (systolic and diastolic) values and for rate pressure product. This hypothesis can be also confirmed by results about post-exercise hypotension. This result indicates that both the outdoor session and the indoor session effectively reduce blood pressure after exercise, with similar magnitudes of post-exercise hypotension. The

similar reductions in post-exercise suggest that individuals can achieve effective cardiovascular responses and benefits from either exercise modality. Those who prefer outdoor activities like hiking can expect similar improvements in cardiovascular health as those who engage in structured indoor exercises. Therefore, considering the outdoor activities more enjoyable than indoors one, start to practice outdoor activities is an opportunity to replicate traditional physical activity benefits and provide a potentially more sustainable and beneficial approach to improving overall health by reducing cardiovascular stress.

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The Impact of a Multidimensional Physical Activity Intervention on Glycemic Control in Type 1 Diabetes: A Preliminary Study

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The Impact of a Multidimensional Physical Activity Intervention on Glycemic Control in Type 1 Diabetes

1. Introduction

Lifestyle factors, including dietary and physical activity behaviors, are currently targeted to prevent and treat several non-communicable diseases, including diabetes mellitus [67]. Diabetes mellitus is the collective term for heterogeneous metabolic disorders whose primary outcome is chronic hyperglycemia. Hyperglycemia arises from a multifactorial etiology involving genetic, environmental, and behavioral factors and is primarily driven by impaired insulin secretion, impaired insulin action, or a combination of both, with variations across different types of diabetes [68,69]. Diabetes mellitus is the most common metabolic disorder occurring during the lifespan and can be classified into two main types, type 1 and type 2 diabetes. Type 1 diabetes is an autoimmune disorder characterized by the destruction of insulin-producing β cells in the pancreas, leading to absolute insulin deficiency. Common symptoms include polyuria, polydipsia, and weight loss. This metabolic condition disrupts carbohydrate, lipid, and protein metabolism, resulting in acute complications such as diabetic ketoacidosis and chronic complications affecting the cardiovascular, renal, and nervous systems [70,71]. Type 2 diabetes is a metabolic disorder characterized by a state of insulin resistance associated with a progressive loss of β cell function. It is caused by a combination of genetic and biological factors, such as sex and age, and lifestyle factors, including diet, obesity, sedentary behaviors, and consumption of alcohol. This condition is also associated with both acute and chronic complications, including diabetic ketoacidosis, cardiovascular diseases, and diabetic neuropathy [70,71].

Careful control of blood glucose concentration is important for diabetic patients, particularly those with type 1 diabetes mellitus. Regular blood glucose monitoring reduces the risk of hypoglycemia, cardiovascular disease, microvascular and macrovascular complications, and neurological abnormalities. It also helps prevent death, which can result from loss of consciousness and heart failure [72]. Therefore, maintaining blood glucose within safe limits [73] is essential for patients with diabetes.

Blood glucose concentration could be influenced by several factors, such as inadequate duration and poor quality of sleep, both of which increase the risk of impaired glucose regulation and exacerbate diabetes [74]. In fact, sleep duration and quality are important regulators of glucose metabolism. Furthermore, short and long sleep duration, as well as poor sleep quality, have been associated with impaired fasting blood sugar, glucose tolerance, and/or diabetes [74,75]. Sleep restriction activates the sympathetic nervous system, which reduces insulin secretion, promotes insulin resistance, and increases fat accumulation in the liver and muscles. It also alters appetite regulation by lowering leptin levels and raising ghrelin, which increases hunger, especially for carbohydrates. Additionally, reduced physical activity following sleep loss may lead to weight gain [76]. Conversely, excessive sleep may also impair metabolism, influenced by factors such as poor sleep quality, sedentary behavior, and circadian misalignment. It could also reflect comorbidities like depression or hypertension, which are linked to obesity and diabetes, suggesting a potential bidirectional relationship [77].

In addition to sleep, the circadian system could have an influence on glycemic control [74,78,79]. It generates endogenous rhythms of approximately 24 h, the synchronization of

which is vital for healthy bodily function. The timing of many physiological processes, including glucose metabolism, is regulated by these rhythms, and disruptions that desynchronize or misalign them can lead to adverse health outcomes. However, the timing of the circadian system varies considerably across individuals, depending on their chronotype [80]. These individual differences, which reflect how subjects assign their sleep and wake times, could influence several activities of daily living [81], including dietary habits and glycemic control. Individuals with a later chronotype tend to exhibit higher glycated hemoglobin (HbA1c) levels and poorer glycemic control, regardless of sleep duration or quality. This association is partially mediated by a greater proportion of daily caloric intake at dinner, suggesting that dietary and circadian mechanisms are involved [82].

Several "healthy" dietary patterns have been associated with improved glucose regulation in diabetes mellitus. Among them, the Mediterranean diet, rich in plant-based foods and low in animal-based, high-fat, and processed foods, has shown significant benefits for preventing and managing diabetes mellitus and reducing the risks of cardiovascular diseases and mortality [67]. Moreover, regular exercise, a key component of the traditional Mediterranean lifestyle, has been shown to positively impact the reduction of the risk of diabetes [83]. The authors of [84] demonstrated that during exercise, whole-body oxygen consumption can increase by as much as 20-fold, with even greater increases occurring in the working muscles. To meet its energy needs under these circumstances, skeletal muscle uses, at a greatly increased rate, its own stores of glycogen and triglycerides, as well as free fatty acids derived from the breakdown of adipose tissue triglycerides and glucose released from the liver [85]. During exercise, hypoglycemia rarely occurs in

nondiabetic individuals, as metabolic adjustments, in large part mediated by hormonal mechanisms, help maintain normoglycemia [85]. These hormonal adaptations are essentially lost in insulin-deficient patients with type 1 diabetes. As a consequence, when such individuals have too little levels of insulin in their circulation due to inadequate therapy, an excessive release of counterinsulin hormones during exercise might increase the already high levels of glucose and ketone bodies and could even precipitate diabetic ketoacidosis [85]. Conversely, the presence of high levels of insulin, due to exogenous insulin administration, could attenuate or even prevent the increased mobilization of glucose and other substrates induced by exercise, and hypoglycemia might ensue [84]. In summary, practicing physical activity and exercise can help people with diabetes achieve a variety of goals, including increased cardiorespiratory fitness, increased vigor, improved glycemic control, decreased insulin resistance, improved lipid profile, blood pressure reduction, and maintenance of weight loss. Studies have demonstrated that regular physical activity and/or moderate to high cardiorespiratory fitness are associated with reductions in cardiovascular and overall mortality in people with type 1 diabetes [69,86]. The environmental setting in which physical activity takes place could influence individuals with type 1 diabetes. Outdoor exercise, compared to indoor exercise, has been associated with distinct physiological, psychological, and behavioral responses, including differences in perceived exertion, cardiovascular responses, and enjoyment [87]. These factors could also affect acute glycemic control and long-term adherence to physical activity routines. Therefore, it would be interesting to explore how differences in environmental settings may influence glucose regulation in people with type 1 diabetes.

Given the significant impact of exercise on diabetes management and its long-term effects on glucose metabolism, monitoring physical activity is critical in diabetes care. A multidimensional approach that considers factors beyond glucose levels, such as dietary habits, sleep quality, and chronotype, offers valuable insights for personalized management. The hypothesis tested in this study was that, in individuals with type 1 diabetes, glycemic responses to exercise at varying intensities and settings (indoor vs. outdoor) are influenced not only by the exercise itself but also by lifestyle factors such as sleep quality and chronotype. This case report was designed to provide a detailed, individualized analysis of these interactions in a participant with type 1 diabetes, where individual variability in physiological responses to exercise is particularly relevant. By focusing on a single-case report, we aim to gain insights that can inform future research involving larger cohorts with similar clinical profiles, ultimately contributing to more personalized approaches in disease management. Therefore, this case report aims to evaluate glucose trends in response to different exercise intensities and types, using a multidimensional approach that integrates lifestyle and physiological parameters in a young male participant with type 1 diabetes.

2. Materials and Methods

Following the Declaration of Helsinki, the study was approved by the Institutional Review Board of the Department of Human Sciences, Society, and Health of the University of Cassino and Lazio Meridionale (approval number 6663). The study aimed to evaluate the effects of different modalities and exercise intensities on blood glucose regulation in a type 1 diabetes participant. Blood glucose is known to be easily influenced by several internal

and external factors, such as insulin and food intake, sedentary lifestyle or sleep quality. Among these factors, physical activity has been recognized as the most effective. The assessment of the reduction in blood glucose regulation is commonly carried out after generalized strength, resistance, and high interval intensity training (HIIT) [88,89], aimed only to evaluate the reduction of blood glucose levels. However, to the best of our knowledge, no studies have investigated the effect of a prolonged and differentiated intervention (e.g. incremental walking test and hiking exercise), also focusing on the variations in the self-administered insulin units. Therefore, the present case study proposes a new methodological approach and a new intervention, involving both indoor and outdoor activities, allowing for the evaluation of additional influential variables such as daily nutritional intake, adherence to the Mediterranean diet, sleep patterns, chronotype and physical activity levels. To establish whether blood glucose regulation could be acutely affected by different exercise modalities, the evaluation of blood glucose concentration was carried out for during the entire testing period, from the familiarization session and the enrolment day to the last testing session, during which the external and internal factors were controlled.

2.1. Case Description

One 23 years old male with type 1 diabetes since the age of 14 years took part in the study. The participant was a university student regularly enrolled in a master's program, with a 10-year history of playing basketball. He stopped practicing regularly due to academic commitments, which led to a more sedentary lifestyle. He was using a multiple daily injection insulin regimen, taking insulin degludec (Tresiba) at bedtime and insulin lispro

(Humalog) at mealtimes. The participant had medical clearance to exercise, approved by his medical practitioner, and gave his written consent of participation after receiving both written and oral information regarding the procedures. He was informed that he could withdraw from the study at any time without incurring any adverse consequences.

2.2. Procedures

Data collection took place at the Human Performance Lab (HPL) for the indoor sessions and in Gaeta (Lazio, Italy) for the outdoor sessions. The entire testing procedure was conducted in five separate sessions: familiarization session (enrolment day), two indoor sessions and two outdoor sessions. Prior to the baseline evaluations, the participant was familiarized with the experimental protocol. To avoid the influence of individual habits on physiological evaluation, the participant was required to refrain from moderate-to-vigorous physical activity and to abstain from alcohol consumption and caffeine intake for at least 24 hours before the experimental sessions.

Anthropometric measurements were performed by a certified specialist (i.e., level 2 certification of the International Society for the Advancement of Kinanthropometry). Body weight and height were measured using a scale and stadiometer accurate to 0.1 kg and 0.1 cm (Seca, model 709, Vogel & Halke, Hamburg, Germany) and the Body Mass Index (BMI) was calculated. Body circumference measures were made with a tape metric (Holtain Limited, Crymych, UK, 1.5 m Flexible Tape). Waist-to-hip ratio (WHR) was used as a predictor of cardiovascular risk. Waist circumference was measured at the narrowest point in the abdominal region midway between the 10th rib and the crest of the pelvic bone. Hip circumference was measured horizontally at the most prominent points on the posterior,

lateral, and anterior sides. The WHR was subsequently computed. To exclude the hypothesis of the presence of cardiovascular diseases, self-monitoring assessment of blood pressure was applied through multiple daily measurements at various time-points [90]. The participant was instructed to perform duplicate morning and evening measurements after resting for 5 minutes and with 1-minute between recordings. Two succeeding readings were taken to ensure that blood pressure values did not differ by > 5 mmHg from those of a mercury sphygmomanometer (Erkameter 3000; Erka, Bad Tolz, Germany) [90]. Theoretical maximum heart rate (HRmax) was calculated according to the equation [91]:

Theoretical HRmax=220-age (years)

Basal metabolic rate was calculated using the Mifflin-St Jeor predictive equation validated for male subjects with diabetes mellitus [92]:

Basal Metabolic Rate=10* weight (kg)+6.25*height (cm)-5*age (years)+5

In addition, the participant was familiarized with the Borg Category Ratio (CR-10) Rate of Perceived Exertion (RPE) scale, where 0 represented “no exertion at all” and 10 represented “maximal exertion” [93]. During the familiarization session, measurements of glucose history levels, dietary habits, sleep quality and chronotype (fully described in the following section 2.2.3) were collected. The same measurement procedure was repeated during all the testing sessions.

After one week, the participant performed two different testing procedures, including two indoor and two outdoor sessions. The indoor sessions consisted of a maximal walking test while the outdoor sessions consisted of a hike. During one indoor and outdoor session, respiratory gas exchanges were continuously monitored using VO2 Master Pro Analyzer

(VO2 Master Health Sensors Inc., Vernon, British Columbia, CA). To ensure the reliability and accuracy of the study's findings, at the beginning of each session temperature and humidity data were recorded during the indoor sessions by maintaining the range of 20 – 30 °C of temperature and 35 – 55% humidity, to ensure consistency with the temperature (24.2 ± 1.8 °C) and humidity (42.8 ± 5.5 %) of outdoor sessions. Before each exercise session, blood glucose concentrations were also monitored.

The day before and for the entire data collection period (9 days), the participant was asked to take note of his dietary and insulin intake and blood glucose levels.

During the familiarization session and before each session, the participant was asked to complete questionnaires on adherence to the Mediterranean diet, sleep quality, chorotype, and physical activity level. Moreover, blood pressure and recovery index were assessed before each session. The specific parameters evaluated during data collection are described below. After each session, blood pressure, session RPE (sRPE) and enjoyment of the activity were recorded.

During the two indoor testing sessions, the participant underwent a maximal incremental walking test on a treadmill (RunRace HC1200, Technogym, Cesena, Italy), incorporating both uphill and downhill walking. The participant was asked to self-select his speed. The initial speed corresponded to a comfortable walking pace during the first 2-minute stage with the slope set at 0%, followed by 2% slope increments every 2-minute stage. Once the participant reached the maximum exertion, the uphill phase ended and the downhill phase began, with 2% slope decrements at each stage, until returning to 0% grade. Heart rate, RPE and external load (slope %) were monitored throughout the sessions and recorded at the

end of each stage. Thirty minutes after each session, sRPE was collected using the CR-10 scale [12].

The two outdoor sessions were carried out in Gaeta (~3800m in length), Italy. The hiking route was identified based on several parameters such as duration, length, slope, and energy demand according to the Club Alpino Italiano (CAI) Manual. The chosen hike was selected for its similarity to the indoor sessions in terms of duration and mean slope, and it was evaluated according to the walkability principle. The principle considers physical and environmental factors as well as historical and cultural aspects of the route, including the availability of essential services within a walking distance, the attractiveness of the route in terms of architecture and social context, the level of comfort and safety of the route. Thirty minutes after each session, sRPE was asked on a CR-10 scale.

To balance methodological rigor with ecological validity, VO_2 was measured only during two of the four experimental sessions. The remaining sessions were conducted without metabolic equipment to better reflect real-life exercise scenarios. Both indoor and outdoor sessions were performed using the talk test procedure, [94] during which the participant was asked to read aloud the standard 40-word paragraph consisting in the Italian version of the Olympic Oath during the last 30-second of each 2-minute stage for indoor session and every 5-minute for outdoor session. After reading the paragraph, the participant was asked "Can you speak comfortably?", with three possible answers: "yes", which was referred to as "positive" result; "not sure", which was referred to as an "equivocal" result; and "no," which was referred to as a "negative" result. Respiratory gas exchange was assessed using a telemetric open-circuit measurement system (VO2 Master Pro Analyzer, VO2 Master

Health Sensors Inc., Vernon, British Columbia, CA). The following variables were measured: oxygen uptake (VO2), respiratory exchange ratio (RER), and minute ventilation (VE). Additionally, participant's physical activity level during the outdoor session was measured under free-living conditions using triaxial accelerometers (GT9X Link; Actigraph, Pensacola, FL, USA) [68,95]. The Actigraph GT9X provided information on wear time, daily physical activity (e.g., intensity, number of steps, energy expenditure). According to the literature [96,97], the Actigraph GT9X were positioned on both wrists, both ankles and inside a pouch placed on the posterior torso at the level of the inferior angle of the scapulae (Figure 1). The accelerometers were initialized using the ActiLife6 software (version 6.12.1, ActiGraph, Cary, NC, USA), with a sampling frequency of 30 Hz [98].

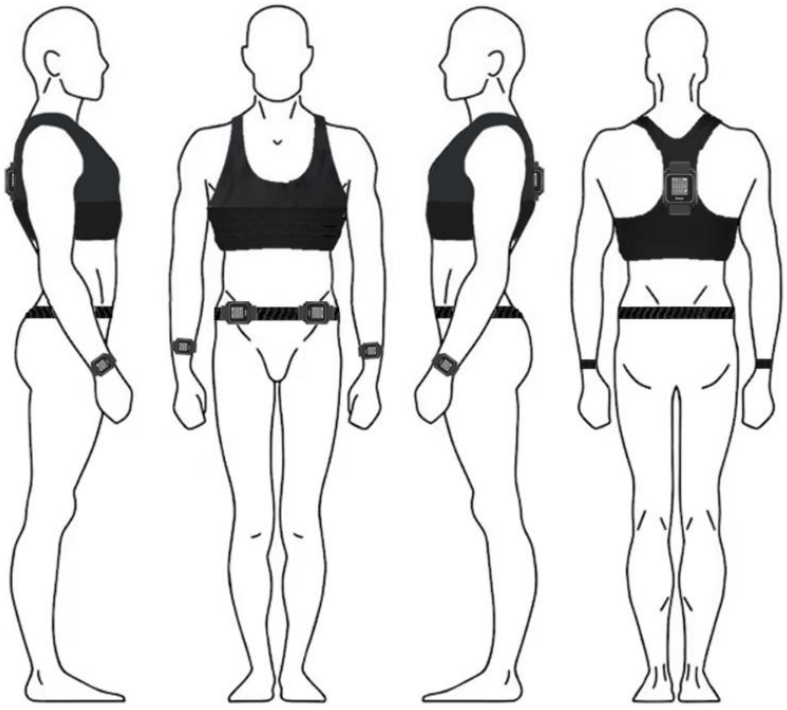

Figure 1. Placement of the Actigraph GT9X accelerometers to evaluate physical activity levels.

2.2.1. Measurements

A multidimensional approach was used to ensure that the four sessions were carried out under consistent conditions and to minimize the influence of external variables on blood glucose levels. During the two indoor and two outdoor sessions the following parameters were assessed:

Blood Pressure (mmHg): baseline systolic and diastolic blood pressures were measured using a digital sphygmomanometer (Erkameter 3000; Erka, Bad Tolz, Germany). Resting values were obtained after a 15-minute period of seated rest, before (PRE) the start of each session. Blood pressure was also measured immediately after the end (POST), and at 15-minute (POST-15) and 30-minute (POST-30) post-sessions. Post exercise hypotension was calculated as the difference between PRE and POST-30 values and rate pressure product was calculated by multiplying systolic blood pressure by heart rate [99].

Blood Glucose (mg/dL): blood glucose was collected using a FreeStyle Libre system (Abbott Diabetes Care, Alameda, CA). The device consists of a coin-size sensor and a reader similar to a conventional glucometer. The sensor is applied to the skin with a special applicator and worn for up to 14 days, requiring scans every eight hours to continuously monitor glucose levels. The sensor was connected via Bluetooth to the FreeStyle Libre App, allowing real-time transmission of glucose data. Data were subsequently downloaded using the FreeStyle Libre computer software. Blood glucose data were collected alongside blood pressure measurements and throughout the exercise sessions. During indoor sessions, glucose readings were taken at the end of each 2-minute stage, while for the outdoor sessions they were recorded every 5 minutes.

Recovery Index by Ruffier Test: the standard version of the Ruffier test was administered during the session that included the respiratory gas exchange measurements. According to the literature [87], a modified version of the test was also used, incorporating the talk test procedure. In this variation, the participant was asked to recite the paragraph (fully described in section 2.2.) while performing a 45-second squat exercise. Post-exercise, the participant was asked whether he could speak comfortably, choosing one of three possible responses: "yes" (positive), "not sure" (equivocal), and "no" (negative). Additionally, RPE was recorded. To calculate the Ruffier index, indicative of the individual effort tolerance, recovery capacity, and cardiovascular response [100], the participant's heart rate was recorded at three given points: at rest (P1), immediately after the 45-second squat exercise (P2) and one minute after the effort (P3). Ruffier index was calculated according to the formula:

$$\text{Ruffier Index}=[(P1+P2+P3)-200]/10$$

Dietary Measures: to monitor participant eating habits and adherence to the Mediterranean diet, the Italian version of the PREvención con Dieta MEDiterránea (PREDIMED) questionnaire was used [101]. PREDIMED is a 14-item questionnaire in which an adequate consumption of typical traditional Mediterranean foods and low consumption of foods that are not characteristic of the traditional Mediterranean diet adds one point. PREDIMED score was calculated as the sum of all the points attributed to the items. According to the score, adherence was categorized as follows: 0–5, lowest adherence; score 6–9, average adherence; and score ≥ 10, highest adherence. PREDIMED was administered before each session. In addition, daily eating behaviors were monitored the day before and

the testing day, using food diary where the participant recorded the time, type and quantity of food consumed [102].

PREvención con DIeta MEDiterranea (PREDIMED)

1. Do you use olive oil as the principal source of fat for cooking?
    a. Yes
    b. No
2. How much olive oil do you consume per day (including that used in frying, meals eaten away from home, salads, etc.)?
    a. <4 tablespoon
    b. ≥4 tablespoon
3. How many servings of vegetables do you consume per day? *(1 serving = 200g)*
    a. <2 portion
    b. ≥2 portion
4. How many pieces of fruit do you consume per day? (not including frozen or dried fruit)
    a. <3 portion
    b. ≥3 portion
5. How many servings of red meat, hamburger, or meat products (ham, sausage, etc.) do you consume per day? (1 serving = 100-150g)
    a. <1 portion
    b. ≥1 portion
6. How many servings of butter, margarine, or cream do you consume per day? (1 serving = 12g)
    a. <1 portion
    b. ≥1 portion
7. How many sugar-sweetened beverages do you drink per day? (1 cup = 100 ml)
    a. <1 portion
    b. ≥1 portion
8. How much wine do you drink per week? (1 glass = 125 ml)
    a. <7 glass
    b. ≥7 glass
9. How many servings of pulses do you consume per week? (1 serving = 150g)
    a. <3 portion
    b. ≥3 portion
10. How many servings of fish or shellfish/seafood do you consume per week? (1 serving = 100-150 g fish, or 4-5 pieces or 200 g shellfish)
    a. <3 portion
    b. ≥3 portion
11. How many times per week do you consume commercial sweets or pastries (not homemade), such as cakes, cookies, biscuits, or custard?
    a. <3 portion
    b. ≥3 portion
12. How many servings of nuts (including peanuts) do you consume per week? (1 serving = 30g)
    a. <3 portion
    b. ≥3 portion
13. Do you prefer to eat chicken, turkey, or rabbit meat instead of beef, pork, hamburgers, or sausages?
    a. Yes
    b. No
14. How many times per week do you consume cooked vegetables, pasta, rice, or other dishes prepared with a sauce of tomato, garlic, onions or leeks sautéed in olive oil (sofrito)?
    a. <2 portion
    b. ≥2 portion

Sleep Quality: the Pittsburgh Sleep Quality Index (PSQI) was used to assess the participant's sleep quality [103]. PSQI is a self-reported questionnaire evaluating subjective sleep quality and disturbances over the previous month. It includes 19 questions grouped into seven components: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbance, use of sleeping medications and daytime dysfunction. Each component is scored on a scale from 0 to 3, with higher scores indicating greater dysfunction. A total score below 5 is indicative of good sleep quality, while scores of 5 or higher suggest poor sleep quality.

Pittsburgh Sleep Quality Index (PSQI)

The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

During the past month, what time have you usually gone to bed at night?
BED TIME _____

During the past month, what time have you usually gotten up in the morning?
GETTING UP TIME_____

1. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?
NUMBERS OF MINUTES _____

2. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.)
HOURS OF SLEEP PER NIGHT_____

For each of the remaining questions, check the one best response. Please answer all questions.

5. During the past month, how often have you had trouble sleeping because you…	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
Cannot get to sleep within 30 minutes				
Wake up in the middle of the night or early morning				
Have to get up to use the bathroom				
Cannot breathe comfortably				
Cough or snore loudly				
Feel too cold				
Feel too hot				
Had bad dreams				
Have pain				

Other reason(s)?

a. Yes
b. No

If yes, please specify:	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
How often during the past month have you had trouble sleeping because of this?				

6. During the past month, how would you rate your sleep quality overall?
   a. Very good
   b. Fairly good
   c. Fairly bad
   d. Very bad

7. During the past month, how often have you taken medicine to help you sleep (prescribed or "over the counter")?
   a. Not during the past month
   b. Less than once a week
   c. Once or twice a week
   d. Three or more times a week

8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?
   a. Not during the past month
   b. Less than once a week
   c. Once or twice a week
   d. Three or more times a week

9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?
   a. No problem at all
   b. Only a very slight problem
   c. Somewhat of a problem
   d. A very big problem

Chronotype: the Morningness-Eveningness Questionnaire (MEQ) is one of the most used in chronobiological and chronopsychological research [104]. It consists of 19 mixed-format items designated to assess an individual's preferred timing of daily activities, particularly sleep and wake behaviors. The questionnaire includes both Likert-type and time-based questions. Likert-type items offer four options, with lower scores indicating stronger evening preference. Time-based items are scored based on selected time intervals over a 7-hour range, with all responses scored from 1 to 5. The total score is the sum of all item scores and it is used to classify chronotype into 5 categories: definitely morning type (70–86), moderately morning type (59–69), neither type (42–58), moderately evening type (31–41), and definitely evening type (16–30).

MORNINGNESS-EVENINGNESS QUESTIONNAIRE (MEQ-SA)

For each question, please select the answer that best describes you by circling the answer that best indicates how you have felt in recent weeks.

1. Approximately when would you get up if you were entirely free to plan your day?
    a. 5 – 6:30 AM
    b. 6:30 – 7:45 AM
    c. 7:45 – 9:45 AM
    d. 9:45 – 11 AM
    e. 11 AM – 12 noon
2. Approximately what time would you go to bed if you were entirely free to plan your evening?
    a. 8 – 9 PM
    b. 9 – 10:15 PM
    c. 10:15 PM – 12:30 AM
    d. 12:30 – 1:45 AM
    e. 1:45 - 3 AM
3. If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?
    a. Not at all
    b. Slightly
    c. Somewhat
    d. Very much
4. How easy do you find it to get up in the morning when you are not awakened unexpectedly?
    a. Very difficult
    b. Somewhat difficult
    c. Fairly easy
    d. Very easy
5. How alert do you feel during the first half hour after you wake up in the morning?
    a. Not at all alert
    b. Slightly alert
    c. Fairly alert
    d. Very alert
6. How hungry do you feel during the first half hour after you wake up?
    a. Not at all hungry
    b. Slightly hungry
    c. Fairly hungry
    d. Very much hungry
7. During the first half hour after you wake up in the morning, how do you feel?
    a. Very tired
    b. Fairly tired
    c. Fairly refreshed
    d. Very refreshed
8. If you had no commitments the next day, what time would you go to bed compared to your usual bedtime?
    a. Seldom or never later
    b. Less that 1 hour later
    c. 1-2 hours later
    d. More than 2 hours later
9. You have decided to exercise. A friend suggests that you do this for one hour, twice a week, between 7-8 AM (07-08 h). Bearing in mind nothing but your own internal "clock," how do you think you would perform?
    a. Would be in good form
    b. Would be in reasonable form
    c. Would find it difficult
    d. Would find it very difficulr
10. Approximately when would you go to bed if you could sleep when you felt like it?
    a. 8 – 9 PM
    b. 9 – 10:15 PM
    c. 10:15 PM – 12:45 AM
    d. 12:45 – 2 AM
    e. 2 - 3 AM

11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last two hours. You are entirely free to plan your day. Considering only your "internal clock," which one of the four testing times would you choose?
    a. 8 – 10 AM
    b. 11 AM – 1 PM
    c. 3 – 5 PM
    d. 7 – 9 PM
12. If you went to bed at 11 PM (23 h), how tired would you be?
    a. Not at all tired
    b. A little tired
    c. Fairly tired
    d. Very tired
13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which one of the following are you most likely to do?
    a. Wake up at your usual time, but not fall back asleep
    b. Wake up at your usual time, and doze thereafter
    c. Wake up at your usual time, but fall asleep again
    d. Not wake up until later than usual
14. One night you have to remain awake between 4-6 AM (04-06 h) to carry out a night watch. You have no time commitments the next day. Which one of these alternatives would suit you best?
    a. Stay up until the watch is over
    b. Take a nap before the watch, and sleep after
    c. Have a good sleep before the watch, and nap after [
    d. Sleep only before the watch
15. You have two hours of hard physical work. You are entirely free to plan your day. Considering only your internal "clock," which of the following times would you choose?
    a. 8 – 10 AM
    b. 11 AM – 1 PM
    c. 3 – 5 PM
    d. 7 – 9 PM
16. You have decided to exercise. A friend suggests that you do this for one hour twice a week between 10-11 PM (22-23 h). Bearing in mind only your internal "clock," how well do you think you would perform?
    a. Would be in good form
    b. Would be in reasonable form
    c. Would find it difficult
    d. Would find it very difficult
17. Suppose that you can choose your own work hours. Assume that you work a fivehour day (including breaks), your job is interesting, and you are paid based on your performance. At approximately what time would you choose to begin?
    a. 4 – 8 AM
    b. 8 - 9 AM
    c. 9 AM – 2 PM
    d. 2 – 5 PM
    e. 5 PM – 4 AM
18. At approximately what time of day do you usually feel your best?
    a. 5–8 AM
    b. 8–10 AM
    c. 10 AM–5 PM
    d. 5–10 PM
    e. 10 PM–5 AM
19. Are you a "morning type" or an "evening type"?
    a. Definitely a morning type
    b. Rather more a morning type than an evening type
    c. Rather more an evening type than a morning type
    d. Definitely an evening type

Physical Activity Level: the Italian short version (7 items) of the International Physical Activity Questionnaire (IPAQ) was administered to evaluate the individual physical activity level [47]. The IPAQ evaluates the frequency, intensity, and duration of physical activity at various levels: low, moderate, and vigorous, along with total physical activity per week. Additionally, it includes an item regarding daily sitting time to estimate sedentary behaviors [105]. The questionnaire includes both categorical and continuous scores. The categorical scores classify participants into three levels: inactive, minimally active, and health-enhancing physical activity, which denotes activity levels exceeding the minimum public health recommendations, which are associated with greater health benefits. The continuous scores are calculated in metabolic equivalent of task (MET) minutes per week.

Questionario internazionale sull'attività fisica (IPA-Q)

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the last 7 days. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport. Think about all the vigorous activities that you did in the last 7 days. Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

1. During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling?

_____

2. How much time did you usually spend doing vigorous physical activities on one of those days?

_____

Think about all the moderate activities that you did in the last 7 days. Moderate activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the last 7 days, on how many days did you do moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

_____

4. How much time did you usually spend doing moderate physical activities on one of those days?

_____

Think about the time you spent walking in the last 7 days. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the last 7 days, on how many days did you walk for at least 10 minutes at a time?

_____

6. How much time did you usually spend walking on one of those days?

_____

The last question is about the time you spent sitting on weekdays during the last 7 days. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the last 7 days, how much time did you spend sitting on a week day?

Enjoyment: After each session, the participant filled in the Physical Activity Enjoyment Scale (PACES) questionnaire to assess satisfaction with the activity [106]. This questionnaire comprises 5 items evaluated on a seven-point Likert scale (AU). For items 1 and 4, the score ranges from 1 (completely agree) to 7 (completely disagree), while for items 2, 3, and 5, the score ranges from 1 (completely disagree) to 7 (completely agree).

Physical Activity Enjoyment Scale (PACES) 5-items

Please rate how you feel at the moment about the physical activity you have been doing

11 I enjoy it	2	3	4	5	6	7 I hate it
1 I dislike it	2	3	4	5	6	7 I like it
1 It's not fun at all	2	3	4	5	6	7 It's a lot of fun
1 I feel good physically while doing it	2	3	4	5	6	7 I feel bad physically while doing it
1 I am very frustrated by it	2	3	4	5	6	7 I am not frustrated by it

Insulin Intake: During the enrolment and on testing days the participant was asked to track the insulin intake using a diary.

Ruffier test, PREDIMED, PSQI, MEQ and IPAQ were administered before each session. The total duration of each testing session was approximately 2 hours. The timeline of the measurements carried out during the experimental sessions is shown in Figure 2.

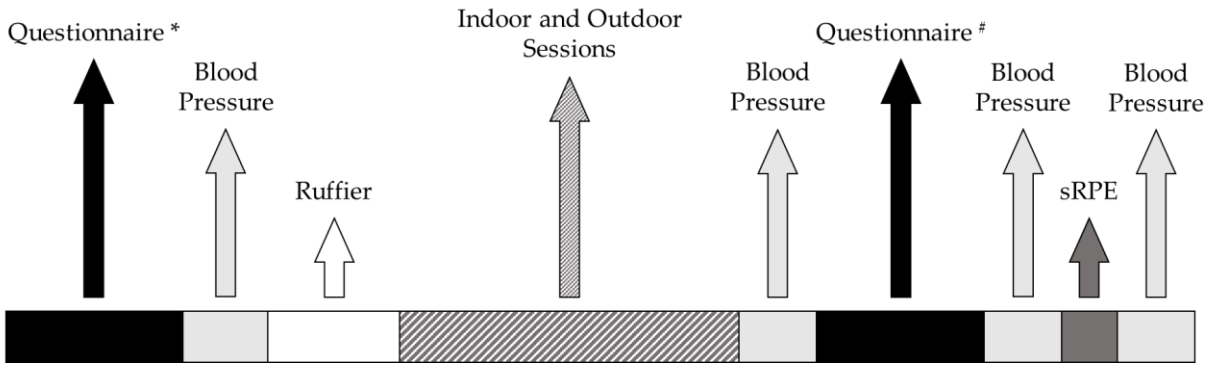

Figure 2. Timeline of the measurements carried out during the experimental sessions. * = PREvención con Dieta MEDiterránea, Pittsburgh Sleep Quality Index, Morningness-Eveningness Questionnaire, International Physical Activity Questionnaire; # = Physical Activity Enjoyment Scale Questionnaire.

2.2.2. Data Extraction and Analysis

To quantify the effect of the exercise intervention on blood glucose levels, raw data from the FreeStyle Libre were downloaded using the FreeStyle Libre computer software. The analysis included data from the following days: the enrolment day (control session), during which the participant became familiar with the protocol through a verbal explanation; the familiarization session, aimed at getting the participant accustomed to the procedures; two indoor sessions and two outdoor sessions.

Data were collected between the end of April (indoor sessions) and the beginning of May (outdoor sessions). The period for the outdoor session was chosen according to the mean temperature and humidity collected during the indoor sessions so that they could be replicated during the outdoor sessions. The time interval analyzed was referred to the testing days, from the first measurement of the day (12:04 AM) to the last (11:59 PM). According to the literature [73,107] ranges of blood glucose levels were identified as follows:

- >250 mg/dL: Very high
- 181-250 mg/dL: High
- 180-70 mg/dL: Normal or Target
- 54-69 mg/dL: Low
- <54 mg/dL: Very low

Data were first analyzed as percentage (%) of the total number identified in the different ranges, then converted in time (hours*day). For the Actigraph data, the raw acceleration data on the three axes (x, y, z) were used to obtain the activity counts for each accelerometer, calculated in 60-s epochs using the ActiLife software (version 6.12.1, ActiGraph, Cary, NC, USA), with the low-frequency extension disabled, and vector magnitude units (VMU) activity counts were calculated as:

$$VMU=\sqrt{(x2+y2+z2)}$$

Energy expenditure and METs were sequentially calculated using algorithms validated by Choi et al. [108] and Freedson et al. [96,109] as follows:

if VMU Counts per Minute were > 2453

kcal/min=0.001064*VMU+0.087512 (body mass)-5.500229

if VMU Counts per Minute were ≤ 2453

kcal/min=Counts per Minute*0.0000191*body mass

Paired t-test was used to compare the mean glucose concentration between control and outdoor and indoor sessions. Statistical significance was set at $p<0.05$.

3. Results

The participant weighed 95 kg, had a height of 1.90 m, a BMI of 26.3 kg/m^2, a WHR of 0.98, a basal metabolic rate of 2015 kcal, an average morning blood pressure of 128-81 mmHg and an average evening blood pressure of 130-88 mmHg, for systolic - diastolic blood pressure, respectively. Data regarding daily caloric intake, adherence to the Mediterranean diet, sleep quality, chronotype, enjoyment across different sessions, IPAQ parameters are presented in Table 2.

Table 2. Summary of daily dietary intake, and lifestyle-related questionnaires (adherence to Mediterranean diet, sleep quality, chronotype, enjoyment, and IPAQ) results collected across the experimental sessions.

Daily Dietary Intake		**Indoor Session 1**	**Indoor Session 2**	**Outdoor Session 1**	**Outdoor Session 2**
CHO (g)		110	196	155	160
PRO (g)		62	72	98	69
FAT (g)		37	24	30	25
Daily Caloric Intake (kcal)		1025	1288	1229	1127
Questionnaire	**Enrolment**	**Indoor Session 1**	**Indoor Session 2**	**Outdoor Session 1**	**Outdoor Session 2**
Mediterranean Diet (AU)	7	8	7	7	7
Sleep Score (AU)	4	3	2	3	4
Chronotype (AU)	63	62	58	58	57

Enjoyment (AU)	N/A	28	20	28	29
IPAQ Parameters					
MET * week (MET)	320	1920	3840	800	1200
Kcal * week (kcal)	1072	4067	8134	2275	2861
Sitting Time (minutes*day)	425	120	150	80	150

CHO: carbohydrates, PRO: proteins; FAT: fats; IPAQ: International Physical Activity Questionnaire; MET: Metabolic Equivalent Task.

According to the VO2 value achieved during the incremental walking test (45.91 mL/kg/min-1), the participant was classified within the "fair" fitness category [14]. To better quantify the overall workload, VO_2 was also measured during the outdoor session (32.75 mL/kg/min), together with physical activity level data (Table 3).

Table 3. Physical Activity Level data recorded during the outdoor session.

Physical Activity Level	**Right wrist**	**Left wrist**	**Back**	**Right waist**	**Left waist**
METs	6.59	6.57	5.92	3.05	3.32
Energy Expenditure (Kcal)	394	383	375	394	383
Activity counts (counts min^{-1})	3936	3937	3929	4384	3937

METs: Metabolic Equivalent Tasks.

During the outdoor sessions, the hike lasted ~44 minutes, with the participant reaching 84% of his theoretical HRmax. In comparison, the indoor sessions lasted ~39 minutes, during which he reached 96% of his theoretical HRmax (Table 4).

Table 4. Psycho-physiological parameters collected during the four experimental sessions.

Psycho-physiological Parameters	**Indoor Session 1**	**Indoor Session 2**	**Outdoor Session 1**	**Outdoor Session 2**
Energy Expenditure (kcal)	197	558	553	296
Recovery Index (AU)	1.6	4	3.2	2.8
Mean Heart Rate (beats·min^{-1})	113	126	119	110
Maximum Heart Rate (beats·min^{-1})	196	183	159	170

sRPE (AU)	4	5	4	4

sRPE: session Rating of Perceived Exertion.

Systolic and diastolic blood pressure, heart rate, post exercise hypotension and rate pressure product values across the experimental sessions are shown in Table 5.

Table 5. Summary of hemodynamic responses collected across the experimental sessions.

Blood Pressure Measurements		**PRE**	**POST**	**POST-15**	**POST-30**
Indoor 1	Systolic (mmHg)	131	130	129	130
	Diastolic (mmHg)	88	80	91	86
	Heart Rate (beats·min^{-1})	65	78	75	78
	Post Exercise Hypotension (mmHg)				1
	Rate pressure product (sBP*HR)				8515
Indoor 2	Systolic (mmHg)	130	129	123	127
	Diastolic (mmHg)	91	92	88	87
	Heart Rate (beats·min^{-1})	65	87	78	82
	Post Exercise Hypotension (mmHg)				3
	Rate pressure product (sBP*HR)				8547
Outdoor 1	Systolic (mmHg)	131	129	131	128
	Diastolic (mmHg)	79	83	79	77
	Heart Rate (beats·min^{-1})	60	80	68	68
	Post Exercise Hypotension (mmHg)				3
	Rate pressure product (sBP*HR)				7890
Outdoor 2	Systolic (mmHg)	130	128	121	116
	Diastolic (mmHg)	82	90	84	75
	Heart Rate (beats·min^{-1})	75	91	84	86
	Post Exercise Hypotension (mmHg)				13
	Rate pressure product (sBP*HR)				9750

sBP: Systolic Blood Pressure, HR: Heart Rate.

Significant ($p<0.0001$) differences in blood glucose were found between the enrolment day (261.2 ± 3.2 mg/dL) and both indoor (Indoor 1: 206.2 ± 4.1 mg/dL; Indoor 2: 192.1 ± 3.6 mg/dL) and outdoor (Outdoor 1: 163.1 ± 3.1 mg/dL; Outdoor 2: 137.9 ± 3.6 mg/dL) sessions. The percentage (%) of time spent by the participant within different blood glucose ranges during the analyzed days and the number of units of insulin intake of Humalog (30, 16, 23, 29, 25 units/mL) and Tresiba (34 units/mL) along the data collection are presented Figure 3.

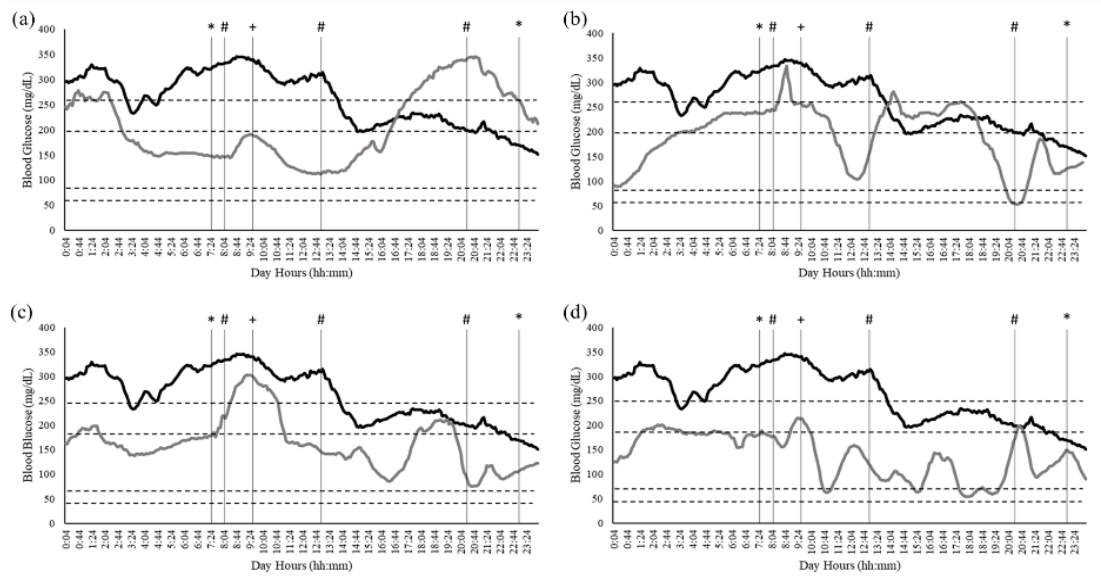

Figure 3. Blood glucose levels in testing days (grey line; (a) Indoor Session 1, (b) Indoor Session 2, (c) Outdoor Session 1, (d) Outdoor Session 2) in comparison with the enrolment day (black line). Horizontal dashed lines identify the glucose thresholds and the vertical solid line identifies different time points.

*the participant wake-up (07:20) and fall asleep (23:10) times

#mealtime and insulin injection

+exercise intervention

4. Discussion

The present study aimed to evaluate the effect of a prolonged exercise intervention on blood glucose regulation in an individual with type 1 diabetes, using a multidimensional approach, in which external variables such as sleep, chronotype, dietary intake and

physical activity levels were monitored. Since type 1 diabetes is a metabolic disease characterized by episodes of hyper or hypoglicemia which could be influenced by several factors, a multidimensional approach was favored to allow regular control of these parameters, ensuring that the experimental sessions were carried out under consistent conditions. Through this new multidimensional approach, the four sessions were conducted when the participant reported an average/good adherence to the Mediterranean diet [101], a good sleep quality [103] and a chronotype between moderately morning and intermediate [104]. Moreover, in each session, the individual met at least the minimum criteria to be classified as "minimally active" according to the IPAQ [47], while on the enrolment day physical activity levels were lower as confirmed also by high duration in sitting time. The findings of this study demonstrated an improvement in glycemic control in the participant with type 1 diabetes following an intervention that combined aerobic exercise, dietary monitoring, and lifestyle assessment. During the intervention, the participant showed better regulation of blood glucose, with a reduction in % of time spent in hyperglycemic ranges (>250 mg/dL and 181–250 mg/dL) and an increase in the time spent in the target range (70–180 mg/dL). According to the literature [110], reduced time in hyperglycemia may result from enhanced insulin action in muscle and liver, which can be modified by acute and regular bouts of exercise. The literature has shown that aerobic exercise is associated with post-exercise reductions in glycemia in individuals with type 1 diabetes, by improving glucose uptake in skeletal muscle and increasing insulin sensitivity [111]. Riddell and Perkins [112] reported that aerobic exercise, particularly at moderate intensity (30-70% maximum

VO2), is effective in lowering blood glucose by enhancing glucose utilization. These findings suggest that physical activity, particularly walking both outdoors and indoors, combined with controlled external variables, such as sleep quality, chronotype and diet, could play a critical role in enhancing glycemic regulation. Walking exercise showed potential benefits for glucose regulation, as reflected by the participant's self-adjusted insulin doses in response to real-time glucose levels.

The literature reported a fundamental role of diet, sleep, chronotype and physical activity levels in blood glucose regulation [97,113,114]. Individuals with type 1 diabetes commonly reported poor sleep quality, irregular sleep patterns, and daytime sleepiness, all of which could negatively affect insulin sensitivity and glucose regulation [115]. Similarly, the circadian system plays a key role in glucose metabolism, with variations in chronotype influencing both dietary habits and physical activity levels [82,102,116]. Adherence to the Mediterranean diet, known for its cardiovascular and metabolic benefits, has been associated with improved glycemic control and reductions in several metabolic risk factors, such as body weight, blood pressure, lipid profiles and HbA1c[113,117]. Additionally, regular exercise, an integral component at the base of the Mediterranean lifestyle pyramid, enhances insulin sensitivity and glucose uptake, contributing to improved glycemic control [85]. Given the combined influence of these variables, adopting a comprehensive and integrated approach is essential for managing diabetes and improving the overall health and well-being of individuals with the condition.

The findings of the present study highlight the acute and chronic effects of aerobic exercise on glycemic control over the four sessions. The participant's blood glucose levels improved from the enrollment date to the final assessment. The time spent in the blood glucose range >250 mg/dL decrease by 56.46%, while time spent in the range 181–250 mg/dL decreased by 11.67%. These results demonstrate the chronic benefits of aerobic exercise, due to improved insulin sensitivity, and enhanced glucose uptake by skeletal muscles. The improvement over time reflects the potential long-term efficacy of incorporating structured exercise in diabetes management. Moreover, the trend of insulin intake strengthens the benefits of aerobic exercise on both glycemic control and insulin treatment. In particular, a 13-unit decrease in insulin dosage was observed during the first week. This reduction was accompanied by improvement glycemic control, with a decrease in time spent in hyperglycemia and an increase in time in the target range (70–180 mg/dL), suggesting acute and chronic improvements in insulin sensitivity due to the increased glucose utilization induced by exercise.

It is interesting to highlight the effect of aerobic exercise performed at different intensities and in different environments on blood glucose control. While the participant achieved on average 84% of his theoretical HRmax during outdoor sessions compared to 96% during indoor sessions, both modalities were effective in reducing time spent in hyperglycemic ranges and increasing time spent in the target range. Despite the lower intensity, outdoor sessions demonstrated comparable benefits in glycemic control and cardiovascular response, as evidenced by similar outcomes in blood glucose, blood pressure and recovery index. These findings suggest that individuals can achieve

effective glycemic improvements from either exercise modality. Those who prefer outdoor activities, such as hiking, can expect similar improvements in insulin action and blood glucose regulation as those who engage in structured indoor exercises. Therefore, in line with our results and the literature [118] which has shown that outdoor exercise is generally perceived as more enjoyable than indoor activities, promoting outdoor exercises may improve adherence to physical activity routines, particularly for diabetic individuals who find indoor exercise less motivating [119]. This could support the long-term maintenance of exercise-related benefits and provide a sustainable strategy to improve blood glucose regulation.

Overall conclusions

The findings from the three studies presented in this article support the idea that socio-cultural tourism can represent a new and effective way to promote physical activity in the general population. This approach combines the physiological benefits of movement with the psychological, social, and environmental value of engaging with heritage and nature. By integrating physical activity into cultural tourism routes, walking trails, and outdoor experiences, it becomes possible to reach individuals who may not be drawn to traditional exercise settings. While the included studies differ in scope and design, they are unified by the overarching objective of evaluating the physiological feasibility and health-related impact of walking performed under both controlled and ecologically valid conditions.

A key finding across the experimental work is that outdoor walking, when performed at a comparable duration and self-selected intensity, elicits cardiovascular responses similar to those observed during structured indoor walking. In particular, both environments induced significant post-exercise hypotension, supporting the effectiveness of walking as a health-enhancing activity regardless of setting. These results contribute to the growing body of evidence suggesting that outdoor physical activity can provide cardiovascular benefits comparable to traditional indoor exercise modalities. Importantly, this thesis does not aim to design or validate specific tourism routes. Rather, it evaluates the physiological responses associated with walking performed in naturalistic and culturally meaningful environments. Cultural and touristic contexts are therefore considered as applied settings in which walking-based physical activity may

occur, rather than as primary outcomes of investigation. This distinction is essential to avoid overstating claims and to maintain methodological rigor.

The standardized protocol proposed in the first study addresses the need for harmonized methodologies in the assessment of hiking and outdoor walking. By integrating laboratory-based and field-based measurements, the protocol enhances ecological validity while maintaining physiological precision. Such an approach may support future research and applied initiatives seeking to promote walking in outdoor environments.

Specifically, the first study demonstrated that it is feasible to collect standardized and reliable physiological data during outdoor activities, which lays the foundation for future research and monitoring in real-world, ecologically valid conditions. Rather than directly designing or testing tourism routes, this work focused on evaluating the physiological feasibility and health-related responses associated with walking performed in culturally and environmentally meaningful contexts.

The second study confirmed that even in individuals with Type 1 Diabetes, lifestyle-based and culturally engaging physical activity programs can support metabolic control and improve physical well-being. Although conclusions regarding clinical populations must be interpreted with caution, the exploratory case study suggests that walking-based physical activity may be feasible and well tolerated in specific clinical contexts.

The third study showed that both indoor and outdoor exercise sessions produce comparable effects on blood pressure and cardiovascular load, reinforcing the health value of outdoor activities even when they are self-paced and less structured.

Taken together, these findings suggest that physical activity, when embedded in socio-cultural experiences, can become more accessible, enjoyable, and sustainable. This model may offer a new paradigm for public health promotion, shifting from prescriptive exercise to integrative and context-based movement that respects individual preferences and enhances community involvement. Cultural and environmental routes, such as historical walking paths, represent a concrete opportunity to align physical activity promotion with territorial development, cultural preservation, and ecological sustainability.

Ultimately, the concept of "Smart Heritage for Health" emerges as a guiding principle. This approach encourages the design of walking paths and tourism experiences that are safe, inclusive, and adapted to diverse populations, while also contributing to the protection and appreciation of local heritage. Socio-cultural tourism, therefore, is not only a tool for leisure or education, but also a meaningful and evidence-based strategy to reduce sedentary behavior and support public health through active engagement with culture and the environment. Overall, the findings support walking as a versatile and accessible form of physical activity capable of eliciting meaningful cardiovascular and metabolic responses across different environments. By combining experimental evidence with applied methodological insights, this doctoral work contributes to the understanding of how walking can be effectively integrated into health promotion strategies in both indoor and outdoor contexts.

Strengths and Limitations

A major strength of this doctoral work lies in its integrated and multidisciplinary approach, combining physiological, perceptual, and environmental assessments across indoor and outdoor walking conditions. The inclusion of both laboratory-based and field-based measurements enhances ecological validity while preserving methodological rigor. The comparison of indoor and outdoor walking under standardized temporal conditions provides novel insights into the cardiovascular effects of walking in naturalistic environments. Another strength is the development of a standardized protocol for the psychophysiological characterization of hiking, addressing a relevant methodological gap in the literature. The use of validated instruments and portable monitoring devices allows for comprehensive assessment of cardiometabolic responses during real-world walking activities.

Several limitations should be acknowledged when interpreting the results. First, some studies involved relatively small sample sizes, which may limit statistical power and generalizability. Second, the clinical component of the thesis is based on a single case study involving an individual with Type 1 Diabetes; therefore, conclusions regarding clinical populations must be interpreted with caution and cannot be generalized. Additionally, while participants were provided with standardized instructions regarding lifestyle behaviors (e.g., nutrition, caffeine intake, and physical activity) prior to testing sessions, these factors were not strictly controlled. Finally, the scope of the thesis did not

include the direct design or validation of cultural or tourism routes; therefore, conclusions regarding tourism-related applications should be considered indirect and contextual rather than outcome-based.

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Psychophysiological Data Harmonization for the Sustainability of Outdoor Activities

Olga Papale, Emanuel Festino, Giancarlo Condello, Francesca Di Rocco, Marianna De Maio, Cristina Cortis and Andrea Fusco

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Protocol

Psychophysiological Data Harmonization for the Sustainability of Outdoor Activities

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Abstract: Prolonged sedentary behavior is considered a risk factor for health throughout the human lifespan. Although outdoor activities, such as walking and hiking, can be effective in reducing sedentary behavior, there is a lack of data harmonization on the psychophysiological characteristics of hiking trails. Therefore, this research protocol aims to provide an innovative and uniform methodology to provide a psychophysiological characterization of hiking. Enrolled subjects will be allocated in groups equally distributed for age, physical activity level (physically active vs. sedentary), and sex (male vs. female). Subjects will perform two treadmill tests in laboratory sessions and two hiking tests in field sessions. The Ruffier test will be performed before each session to assess subjects' exercise capacity. During each session, body mass measurement, cardiometabolic evaluation, heart rate and heart rate variability monitoring, rating of perceived exertion, and physical activity enjoyment rate will be assessed. To measure breath-by-breath ventilation, oxygen consumption, and energy expenditure, subjects will be equipped with a portable gas analyzer during one laboratory session and one field session. Findings from the present study protocol have the potential to fill a gap in assessing hiking-related fitness, promoting physical and mental health, and offering a practical way to evaluate fitness for hiking, encouraging outdoor activity. These findings will have the potential to impact tourism, health, and well-being through outdoor experiences.

Keywords: walking; physical inactivity; sedentary lifestyle; hiking; exercise prescription

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1. Introduction

In recent years, the issue of sustainability has gained attention from the public. A well-known pathway to a sustainable future includes the 17 sustainable development goals, in reference to the United Nations 2030 sustainability agenda [1]. The 17 sustainable development goals are not limited to environmental conservation and economic development, but they also extend to improving the quality of human life. In particular, Sustainable Development Goal (SDG) 3 focuses on ensuring healthy lives and promoting well-being for everyone at all ages [1], emphasizing the critical importance of addressing health-related issues, including the alarming rise in sedentary behavior (SB). SB is defined as any waking behavior characterized by an energy expenditure of 1.5 metabolic equivalent of task (METS) or lower while sitting, reclining, or lying down, such as desk-based office work, driving a car, and watching television [2]. In the 21st century, the rate of a sedentary lifestyle in Italy has reached 35.2% of population, with a tendency to increase [3]. Sedentary lifestyles are considered the fourth leading risk factor for global mortality and are associated with poor health outcomes and deteriorating mental and physical health [2]. The key role of physical activity (PA) in reducing SB is well documented [4], and the beneficial effects of PA in enhancing overall health regardless of age confirm that it may contribute to the

maintenance of general well-being, improving postural control and quality of life in general, as well as having an impact on health maintenance and disease prevention [5]. Moreover, PA is not solely an individual health behavior, but it can positively impact planetary health and sustainable development. The literature shows how engagement in PA relates to the different SDGs and outlines how PA can contribute "to improving malnutrition (SDG 2), health behaviors (SDG 3), education (SDG 4), reducing inequalities (SDG 10), sustainable cities (SDG 12), and peace (SDG 16) and sustainable consumption (SDG 11) and combating climate change (SDG 13)" [1,6,7].

The American College of Sport Medicine (ACSM) and the World Health Organization (WHO) suggest practicing moderate-intensity aerobic PA for at least 150–300 min, higher intensity (vigorous-intensity aerobic PA) for a reduced amount of time (75–150 min), or an equivalent combination of moderate- and vigorous-intensity activity over a 7-day period to have considerable health benefits [2,8]. Moreover, adults should also include strength-based activities involving all major muscle groups on 2 or more days per week at moderate or greater intensity, to provide additional health benefits [2,8]. The suggested amount of activity may be achieved in a single session or accumulated on different days. Thus, PA guidelines specify that time and intensity are important factors to consider for the accurate estimation of activity and to better investigate the health-related effects of PA [9].

Exercise intensity, used to monitor PA, is usually defined as the energy expenditure per minute to perform a certain task [10]. Standard variables used to prescribe exercise intensity are percentages of maximal heart rate (HRmax) and maximal oxygen uptake (VO_2max) as well as calculated sub-fractions of these variables such as heart rate (HR) reserve (HRR), VO_2 reserve (VO_2R), and the peak oxygen uptake (VO_2peak). HRmax is the highest HR a subject can achieve during an effort to the point of exhaustion, being an important physiological variable for assessing maximal exertion during an exercise. Although it is widely used for prescribing exercise intensity in PA, Tanaka et al. suggested relative HR, normalized for the theoretical HRmax, as one of the effective methods for monitoring HR pattern to classify PA [11,12]. VO_2max is the maximum amount of oxygen a person can intake, and it is expressed as liters/min as an absolute value or in milliliters/kg/min as a relative value. VO_2max is an accurate measurement of cardio-respiratory fitness and is usually measured during a maximal or submaximal incremental test [13]. In addition to HR or VO_2 monitoring, fatigue and satisfaction from the activity are also useful parameters in prescribing exercise [14]. In fact, while exercise intensity was initially determined using relative percentages, recent approaches have emphasized exercise prescription based on threshold and psychophysiological variables such as the assessment of perceived exertion and the talk test. The talk test is commonly used as a surrogate for maximal testing exercises due to its simplicity, validity, and easy determination of exercise intensity in several populations. It is defined as a subjective measure of exercise intensity which has come to be accepted as an alternative to objective measures (%HRR, %VO_2max) for exercise evaluation and prescription [12,15]. The rating of perceived exertion (RPE), defined as an alternative method to more technological and physiological measurements, holding some insights into accumulated fatigue is a widely accepted method for measuring intensity during exercise [16]. Enjoyment, described as the process of experiencing joy and reflecting general feelings of pleasure, fun, and happiness, has emerged as an important factor for PA levels, representing a good indicator for PA participation [17,18].

In the context of promoting PA and understanding its importance in countering sedentary behavior, it is essential to consider the positive associations between PA and various physical fitness variables [19]. Physical fitness is defined as a set of measurable health- and skill-related attributes or components, which encompass cardiorespiratory fitness, muscular strength, flexibility, balance, agility, and walking speed [20]. These components play a critical role in determining one's overall well-being and health status. To gauge these facets of physical fitness accurately, various testing protocols have been established, including the Balke protocol [21], Ruffier test [22], and the talk test [12,15]. A comprehensive assessment of physical fitness parameters provides valuable insights into

the holistic impact of physical activity and outdoor activities like walking on individual health and well-being [23]. Moreover, to better understand the influence of hiking on sedentary behavior, a focus on the relationship between PA and external and environmental factors is also needed.

Over the past few centuries, both PA and various external or environmental factors, including diet, geographical location, availability of green spaces, and climate conditions, have been undergoing significant changes. These changes have contributed to a rising prevalence of non-communicable diseases [24]. Furthermore, there is an increasing body of evidence suggesting that natural environments hold significant potential for preventing diseases and promoting better health [25]. Promoting outdoor PA, especially walking, not only holds substantial potential to enhance human well-being but also aligns with SDG 13, which emphasizes the mitigation of climate change and its associated consequences. By promoting outdoor activities and reducing reliance on environmentally detrimental transportation methods, we can directly ameliorate our environmental footprint and reduce harmful emissions, thereby actively contributing to climate action [1].

Therefore, considering the positive impact of regular outdoor activities on well-being and their role in supporting climate action, promoting outdoor walking could be a good strategy to reduce SB [5,26,27]. Research on how exactly and to what extent outdoor activities can promote human health is currently limited, although increasing evidence regarding the positive effects of outdoor activities on physical [28,29], mental [28–30], and social [28,31] health exists. Moreover, studies have demonstrated that participants, especially sedentary ones, are more encouraged to start practicing outdoor activities than indoor ones [32]. The exposure to nature while exercising can play a crucial role in physiological [23,33–35], psychological [23,36], biochemical [37], and social [36] levels, giving green exercise a useful role in primary and secondary prevention of disease. In addition, the engagement of sedentary individuals in green exercise could be an effective vehicle in driving behavioral change by improving adherence to PA [38].

Among outdoor activities, walking is considered the most accessible for people of all abilities in terms of the limited skills and equipment needed, as well as the ability for individuals to choose the terrain difficulty and the speed at which they walk [39,40]. It is the most natural and common form of PA and can be practiced from childhood to old age, and it is effective in maintaining and improving adherence to an exercise program. Walking significantly enhances human immune function, reduces the levels of stress hormones such as adrenaline and noradrenaline, increases vigor and decreases anxiety, depression, fatigue, confusion, and anger [2,8]. Additionally, walking demonstrates favorable outcomes in reducing both systolic and diastolic blood pressure, establishing it as a protective element in the management and prevention of non-communicable diseases, including sarcopenia, type 2 diabetes, fractures, musculoskeletal disorders, and pulmonary diseases [2,8].

The practice of an outdoor activity such as walking dates back to the 16th and 17th centuries, with the start of the practice of the Via Lauretana, St. Francis Way, and the Camino de Santiago. These were initially used for religious purposes only, although people also started to walk in pre-established hikes for tourism [41]. Culture and tourism have always been inextricably linked. Cultural sights, attractions, and events provide an important motivation for travel, and travel itself generates culture. It is only in recent decades that the link between culture and tourism has been more specifically identified as cultural tourism [42], during which the visitor's essential motivation is to learn, discover, experience, and consume the tangible and intangible cultural attractions/products in a touristic destination, adding all the walking benefits. These attractions/products relate to a set of distinctive material, intellectual, spiritual, and emotional features of a society that encompasses arts and architecture, historical, cultural, and culinary heritage, literature, music, creative industries, and living cultures with their lifestyles, value systems, beliefs, and traditions [43,44].

With the growth of the phenomenon, there is the need to develop hikes based on the "walkability" principle [45]. To make hiking accessible for everyone, intrinsic and extrinsic

factors should be identified, as follows: (1) the presence of necessary services within a walking distance; (2) the attractiveness of the route in terms of architecture and social context; (3) the level of comfort and safety of the route. Although outdoor activities are known to be the starting point of hiking, there is limited research describing hiking utility, the amount and intensity of walking, and motives for using it [46]. Along with the increase in outdoor activities, the development of different types of hikes and their characterization in terms of distance, time, slope, and degree of difficulty is needed. Therefore, the primary aim of this study protocol is to provide a specific methodology to evaluate hiking difficulty in relation to the energy demand based on (1) metabolic equivalent, (2) HRR, (3) fatigue, and (4) satisfaction while practicing pre-established hikes. The secondary aim is to classify the identified hikes as easy, intermediate, or difficult, based on the primary results and physical fitness parameters.

2. Materials and Methods

2.1. Study Design

The research protocol, designed as a cross-sectional study, was approved on 14 April 2022 by the Institutional Review Board of the Department of Human Sciences, Society, and Health of the University of Cassino and Lazio Meridionale (approval number 6663) in accordance with the Declaration of Helsinki. Participants will receive comprehensive information about the research protocol and will have the option to discontinue their involvement in the study at any point, for any reason, without incurring any adverse consequences. They will also be required to provide their informed consent before participating in the study. In accordance with Regulation (EU) 2016/679 of the European Parliament and the Council, dated 27 April 2016, regarding the protection of individuals in relation to the processing and sharing of personal data, while repealing Directive 95/46/EC (known as the General Data Protection Regulation or GDPR), we will guarantee the security and confidentiality of personal data. In particular, each participant will be assigned a unique identification code to ensure anonymity, and the data will be exclusively utilized for statistical purposes. Throughout each phase of the study, the study supervisors will oversee all activities. While physical assessments and the outdoor activity program are generally associated with low personal risk, any adverse events will be observed and documented by the research team.

2.2. Participants

Participants of different ages will be recruited by means of flyers, posters, brochures, advertisements on social networks, and word-of-mouth. The inclusion criteria for the study will be the absence of the following conditions: the presence or a known history of neuromuscular disorders, uncontrolled heart failure or hypertension, multiple sclerosis, significant cognitive impairment, acute rheumatoid arthritis, cardiovascular diseases, use of antihypertensive medication, pulmonary dysfunction, uncontrolled metabolic diseases such as diabetes, a prior diagnosis of osteoporosis, or any injury sustained within the past six months. As suggested by previous studies [47,48], ensuring adherence to PA involves incorporating various approaches known for their effectiveness in promoting PA adherence. These approaches encompass preparing participants with informational, behavioral, social, and environmental aspects. Participants will be informed about the benefits of hiking and the associated cardiovascular changes, in addition to the provision of evaluations within the protocol that can offer insights into participants' current health or fitness levels, thereby encouraging active participation. Furthermore, the study integrates group activity programs and interaction with personal trainers or healthcare professionals to provide opportunities for social engagement that enhances participation. Additionally, it emphasizes the provision of easy access to facilities that promote PA, such as parks, trails, and footpaths, as a fundamental aspect of promoting adherence.

The Italian short version (7 items) of the International Physical Activity Questionnaire (IPAQ) will be administered to assess individual PA levels [49]. According to the IPAQ

Scoring Protocol, participants will be categorized into two groups: the Sedentary Group, including individuals reporting no activity or reporting some activity but not enough to meet the 'Minimally Active' category, and the Physically Active Group, including participants meeting at least one of the 'Minimally Active' criteria: 3 or more days of vigorous activity for at least 20 min per day; 5 or more days of moderate-intensity activity or walking for at least 30 min per day; or 5 or more days of any combination of walking, moderate-intensity, or vigorous-intensity activities achieving a minimum of at least 600 MET·min·week^{-1}.

2.3. Procedures

2.3.1. Preliminary Evaluation

Characteristics and PA levels of participants will be assessed one week prior to the initial session. Body weight and height will be determined using a precision instrument that combines a scale and stadiometer accurate to 0.1 kg and 0.1 cm (Seca, model 709, Vogel & Halke, Hamburg, Germany). Additionally, the body mass index (BMI) will be calculated [50]. Waist circumference will be measured at the narrowest point in the abdominal region. In cases where the narrowest point is not clearly distinguishable, the measurement will be taken midway between the 10th rib and the crest of the pelvic bone. Hip circumference will be measured horizontally at the most prominent points on the posterior, lateral, and anterior sides. The waist-to-hip ratio (WHR) will be subsequently computed. Theoretical HRmax will be calculated for each participant, according to the equation: 220-years (age) [51]. Subsequently, participants will have to perform four different testing procedures to complete the study, including two laboratory tests on a treadmill and two hikes. There will be at least 48 h of rest between each testing day.

During the laboratory testing sessions, all participants will undergo two maximal incremental tests on a treadmill. These tests will include the modified Balke-type protocol with a portable gas analyzer and a modified Balke-type protocol without a portable gas analyzer [21]. The modified Balke-type protocol will be conducted on a treadmill, with the initial speed individually chosen to match a comfortable walking pace during the first 2-min stage. Subsequently, each stage will have increments in workload achieved by increasing the treadmill grade by 2%. During the modified Balke-type protocol without a portable gas analyzer, participants will be asked to recite a standard paragraph composed of 40 words during the final 30 s of each exercise stage [52]. Participants will recite the paragraph out loud, and after completing the recitation, they will be asked the question, 'Can you speak comfortably?' with three possible answers: 'yes' (positive), 'not sure' (equivocal), or 'no' (negative). At the end of each stage, participants will also be asked to provide their RPE by placing a value on the Borg scale (0–10) [53]. The test will be stopped if participants reach voluntary exhaustion. The modified Balke-type protocol with a portable gas analyzer will serve to measure VO_2, VO_2peak, predict VO_2max, and ventilatory thresholds and to calculate energy costs in METs. Respiratory metabolism will be assessed using the VO_2 Master Pro analyzer (version 1.1.1) during the modified Balke-type protocol. The analyzer will be connected to a facemask (7450 V2 series, Hans Rudolph, Shawnee, KS, USA) through the large (L) user piece, with a ventilation display range of 25–250 L/min and an accurate ventilation range of 40–220 L/min. The Flow Sensor will be calibrated using a 3-L syringe. The VO_2 Master will automatically calibrate gas concentrations, ambient temperature, humidity, and barometric pressure to the ambient air upon activation. After gas calibration, the VO_2 Master will be attached to participants, and they will be instructed to take 10–15 deep breaths for flowmeter calibration. The VO_2 Master will transmit data via Bluetooth® to a personal phone, and the GPS Smartwatch (Forerunner® 245 Music, Garmin, Olathe, KS, USA) will be synchronized with the VO_2 Master mobile application for data storage and downloads. Temperature and humidity levels in the laboratory will be recorded during the experimental procedures to ensure consistency between laboratory testing sessions and hikes. These conditions will be maintained within the range of 26–32 °C and 40–65% humidity.

Following the preliminary evaluation, the participants will be divided in groups according to their age, PA level, physical characteristics, cardiorespiratory fitness, and sex.

2.3.2. Route Identification

Hike locations will be determined based on physical-environmental factors and historical-cultural documentation. The main activities will revolve around identifying sites of historical, cultural, and environmental significance, as well as analyzing the connecting and access routes through cartographic analysis. This analysis will involve inspecting potential routes to assess their condition and accessibility. The identification of hikes includes evaluating various parameters such as duration, total length, slope, and energy demand as per the Club Alpino Italiano (CAI) Manual [54]. Subsequently, the trails will be classified into three hiking difficulty levels: easy, intermediate, or difficult, each associated with specific colors (Table 1).

Table 1. Evaluation criteria for classifying hikes based on hiking difficulty.

Hiking Difficulty	Duration	Total Length	Slope	Energy Demand	Color Scale *
Easy	≤2 h	≤500 m	≤100 m	Low	Green path
Intermediate	2–5 h	500–1000 m	100–500 m	Medium	Sky blue path
Difficult	≥5 h	≥1000 m	≥500 m	High	Red path

* Overview of the trail color scale (green, sky blue, and red) and the descriptions associated with each level of difficulty (easy, intermediate, and difficult) provided by the Club Alpino Italiano (CAI) Manual.

2.3.3. Hike Evaluation and Data Collection

At the start of each hiking session, comprehensive data on participant characteristics and weather conditions will be collected to ensure the reliability and accuracy of the study's findings. Prior to, during, and after the hiking activities, participants will undergo an evaluation of various physiological and subjective parameters.

Body Mass Measurement: Participants' body mass (in kilograms) will be measured before and after each hike, accounting for any additional weight, such as water and clothing. The additional weight should not exceed 10% of the individual's baseline body mass, as assessed during a preliminary session.

Cardiometabolic Evaluation: Blood pressure (in millimeters of mercury, mmHg) and blood glucose levels (in milligrams per deciliter, mg/dL) will be measured at various time points: 15 min before the hike, at the conclusion of the hike, and at 15 and 30 min post-hike. This thorough evaluation will allow for the assessment of acute cardiometabolic responses.

Ruffier Test (With and Without Talking): Participants will engage in a standardized protocol that involves performing 30 squats in 45 s [22]. Subsequently, HR will be recorded, and then after a one-minute recovery period, HR will be measured again. The resulting data will be used to calculate the Ruffier index, which serves as an important indicator of participants' effort tolerance, recovery capacity, and cardiovascular response [55]. In the adapted "Talk Test" variation, participants will be further tasked with reciting a standard paragraph of approximately 40 words aloud during the squat exercise. Post-exercise, participants will be asked to express their comfort level with speech, allowing for three possible responses: "yes" (indicating a positive ability to speak comfortably), "not sure" (equivocal), and "no" (indicating discomfort). Additionally, participants will subjectively rate their RPE. This comprehensive assessment of cardiovascular and physiological response will provide insights into participants' fitness levels and their ability to tolerate and recover from physical exertion. The Ruffier test (with and without talking) will be randomly conducted 15 min before each session, contributing to a thorough evaluation of participants' physical fitness and performance capacity.

HR and HR Variability (HRV) Monitoring: Participants will wear Garmin HRM-Pro™ (Garmin International, Kansas City, MO, USA) HR monitors throughout the hiking sessions. These compact modules, measuring 29.4 × 51.4 × 8.5 mm and weighing 59 g, utilize both ANT+® connectivity and Bluetooth® low-energy technology. Positioned just

below the xiphoid process on the chest, they will record real-time HR data and track the coordinates of the hiking route, sampling at a rate of 1 Hz [56,57]. Additionally, continuous HRV monitoring will provide insights into the autonomic nervous system's response to exercise [58].

Spatiotemporal Data Collection: To gather spatiotemporal data during the hike, participants will be equipped with a GPS Smartwatch, specifically the Garmin Forerunner® 245 Music. This smartwatch, measuring 42.3 mm in width, 12.2 mm in thickness, and weighing 38.5 g, will be worn on the left wrist. It will display real-time HR and VO_2 data, which are directly acquired from the Garmin HRM-Pro™ HR belt and VO_2 Master Pro analyzer [57].

Gas Analysis: To measure breath-by-breath ventilation (in liters per minute, L/min), VO_2 (in milliliters per kilogram per minute, mL/kg/min), and energy expenditure (in kilocalories, kcal) for each participant during the hike, a portable gas analyzer (VO_2 Master Pro analyzer, The VO_2 Master Pro, version 1.1.1.) will be utilized. The unit and mask have a combined weight of 0.32 kg and are powered by a single battery. The analyzer will be linked to a Hans Rudolph 7450 V2 over-nose mask using a mask adapter referred to as a 'user piece.' This adapter, which is essentially a plastic tube connecting the analyzer and the mask, includes an exhaust hole for the inflow and outflow of air. To ensure stability, soft headgear will be employed to secure the unit onto the participants' faces. The medium (M) user piece will be used with a ventilation display range of 15–180 L/min and an accurate range of 30–160 L/min. A single-use filter, replaced after each use following the manufacturer's guidelines, will be installed between the user piece and the analyzer. The VO_2 Master unit is equipped with a passive, pump-less gas sampling system, a galvanic fuel cell O_2 sensor, and a differential pressure flow sensor (information obtained through personal communications with the manufacturer). The Flow Sensor will be calibrated using a 3-L syringe. Upon activation, the VO_2 Master will undergo automatic calibration for gas concentrations, ambient temperature, humidity, and barometric pressure. After gas calibration, the VO_2 Master will be affixed to the participants, who will be instructed to perform 10–15 deep breaths to facilitate flowmeter calibration. Data will be transmitted via Bluetooth® to personal smartphones, tablets, and the GPS Smartwatch Garmin Forerunner® 245 Music. These devices are equipped with the VO_2 Master mobile application for the storage and retrieval of data [59,60].

RPE: Participants will subjectively evaluate their effort on a scale from 0 to 10 (AU) before the hike, every 10 min during the hike, at the end of the hike, and 30 min following its conclusion.

Session RPE (sRPE): At the end of each hike, sRPE will be calculated by multiplying the overall hike's RPE by the duration of the hike activity (AU). Participants will be asked, "How intense was your hike today?" and rate their effort on a scale ranging from 0 to 10 (AU). This measurement will not only provide insight into the overall hike intensity but also accumulated fatigue [61,62].

Physical Activity Enjoyment Scale (PACES): After completing the hike, participants will fill out the PACES questionnaire to assess their individual satisfaction with the activity. This questionnaire comprises five items evaluated on a seven-point Likert scale (AU). For items 1 and 4, the score ranges from 1 (completely agree) to 7 (completely disagree), while for items 2, 3, and 5, the score ranges from 1 (completely disagree) to 7 (completely agree) [18].

All devices will be utilized in strict accordance with the manufacturers' guidelines. Participants will be equipped with the necessary devices for the entire duration of the hiking sessions. All data will be collected using specialized formats, which can be accessed via personal phones, tablets, and paper sheets. Each participant will complete the same hike at least two times to ensure data reliability and validity.

2.3.4. Statistical Analysis

In this section, we present the statistical methods and analyses that will be applied to investigate the effects of hiking on various physiological and psychological parameters.

Descriptive Statistics

To gain an initial understanding of the data, descriptive statistics will be used to summarize the characteristics of both the dependent and independent variables. This includes calculating measures such as means, standard deviations (SD), medians, ranges, and percentages for the relevant variables. To calculate means, SD, medians, and ranges for several variables, we will aim for a representative sample. Assuming a medium effect size, a sample size of at least 100 participants should be adequate. Furthermore, since this section involves no hypothesis testing, traditional power calculations will not be applied.

For example, we will provide the following:

- The mean and SD of HR during hiking, as it is a critical physiological response variable (e.g., mean HR during hiking = 125 bpm, SD = 10 bpm).
- Frequency of occurrence expressed in percentage for hikes classified by difficulty to understand the distribution of hikes (e.g., easy hikes: 40%, intermediate hikes: 30%, difficult hikes: 30%).
- Median and range for participants' age and fitness level to capture the central tendency and variability in these demographics (e.g., median age = 35 years, range = 25–50 years).
- Histograms for PACES scores to visualize the distribution of psychological responses.

Normality Testing

Normality assumptions will be assessed to determine whether the data follow a normal distribution. This will guide the selection of appropriate statistical tests. Normality testing does not require specific sample sizes. Similar to descriptive statistics, power calculations are not typically conducted for normality testing. Example:

- The Shapiro–Wilk test will be applied to HR data during hiking to assess their normality (Shapiro–Wilk p-value < 0.05, indicating non-normal distribution).

Internal Consistency and Reliability Analysis

To evaluate the consistency and reliability of the measurements, relevant statistical methods will be applied. This may include Cronbach's alpha for scales or test–retest reliability for repeated measures (e.g., Cronbach's alpha for the PACES questionnaire = 0.85, indicating high internal consistency). The sample size required will depend on the number of items in the scale and the desired level of reliability. For example, for a Cronbach's alpha of 0.85, a sample size of 150 participants may be sufficient. Moreover, power calculations will not be conducted for internal consistency analysis.

Validity Assessment

The validity of measurements will also be examined. For example, we may assess the concurrent validity of the Ruffier "Talk Test" index by comparing it to other accepted measures of cardiovascular response (e.g., Ruffier "Talk Test" index shows a strong correlation with peak HR achieved during hiking, r = 0.75). Assuming a moderate correlation (e.g., r = 0.5), a sample size of around 80 participants may be needed to detect this correlation with adequate power.

Correlation Analysis

We will explore relationships between variables using various correlation techniques. For correlation analysis, the required sample size depends on the expected effect size and significance level. Assuming a moderate effect size (e.g., r = 0.4) and a significance level of 0.05, a sample size of approximately 100 participants might be necessary. A power of 0.80 can be achieved with 100 participants. Example:

- Pearson's correlation will be used to investigate the relationship between hike duration (independent variable) and HR (dependent variable) during the hikes (e.g., Pearson's r = 0.42, p < 0.001, indicating a moderate positive correlation).

- Spearman's rank correlation will be applied to understand the association between the hike difficulty (independent variable) and HR variability (dependent variable) during the hikes (e.g., Spearman's $\rho = 0.08$, $p = 0.320$, indicating no significant correlation).

Multilevel Mixed-Effect Generalized Linear Model Analysis

To investigate differences in hike classifications and characteristics between groups (e.g., sex, age groups, fitness levels), multilevel mixed-effect generalized linear models will be employed. For instance, we could find that middle-aged participants will be significantly more likely to classify hikes as difficult compared to their younger and older counterparts, after accounting for individual variations within each age group. The multilevel structure will make it possible to examine how these factors influence the likelihood of hike classifications, considering the nested nature of the data with participants belonging to different age groups. This analysis could provide information about how sex, age, and fitness level interact to affect perceptions of hike difficulty among the study participants. The sample size required for multilevel mixed-effect model highly depends on the complexity of the analysis and the anticipated effect sizes. Assuming moderate effects, a sample size of at least 300 participants, considering the nested structure of the data, may be necessary. Furthermore, with the mentioned parameters, a power of 0.80 can be achieved with around 300 participants.

Generalized Estimating Equation Regression Models

Participants' baseline characteristics, fitness levels, hike features (e.g., slope, length), and hike performance (e.g., speed, total time) will be modeled using generalized estimating equation regression models. For example, a strong positive association between baseline fitness levels and hike performance could be identified, indicating that participants with higher fitness levels completed the hikes more quickly. This modeling approach considers the correlated nature of the data, where multiple measurements will be taken from each participant across different hikes, making it ideal for examining the complex interaction between various factors and their influence on hike-related outcomes. Assuming moderate effects, a sample size of around 200 participants may be required with a power of 0.80.

Survival Analysis

For time-dependent variables, such as the time it takes to complete hikes, we will employ Kaplan–Meier survival curves. For instance, this method will be used to assess the time taken by the participants to complete different hikes within the study. Kaplan–Meier curves will make it possible to visualize and analyze the probability of event occurrence over time, such as the likelihood of hike completion at various time points. By employing Kaplan–Meier survival curves, we could have information on how participants' completion times vary across different hikes by highlighting the factors that influence hike duration. For survival analysis, the sample size depends on the expected hazard rates and time-to-event data. Assuming a moderate hazard rate, a sample size of at least 150 participants might be necessary, with a power of 0.80.

Nonlinear Regression Models

Nonlinear regression models will be used to investigate complex relationships. The sample size required for nonlinear regression models depends on the complexity of the model and the expected effect sizes. Assuming moderate effects, a sample size of around 120 participants may be needed (power of 0.80). Example:

- A nonlinear regression model will be applied to assess the relationship between HR (dependent variable) and independent variables such as age and hike duration (e.g., $HR = 160 - 0.5 \times \text{age} + 5 \times \text{hike duration} - 0.2 \times \text{age} \times \text{hike duration}$).

Confounding Variable Management

The statistical analysis encompasses a wide range of methods to ensure the robustness and reliability of the expected research findings. The sample size will range from 100 to 300 participants across different analyses, and, to address other sources of variability, participants will be carefully screened for confounding variables, such as pre-existing medical conditions, medication usage, psychological factors, etc., which might impact the results. Detailed information will be collected on these potential confounders and will be incorporated as covariates in relevant statistical models.

Statistical Software

STATA 18 (StataCorp LP, College Station, TX, USA) will be used for all the statistical analyses mentioned above. By implementing this comprehensive statistical analysis plan, we aim to provide a deeper understanding of the effects of hiking on physiological and psychological responses, while accounting for various factors and relationships within the dataset.

3. Discussion

This study protocol presents a comprehensive approach to evaluating hiking difficulty in relation to energy demand and fitness parameters, with a focus on both physiological and psychological aspects. The primary aims of this research involve assessing metabolic equivalent, relative HR, fatigue, and satisfaction value during pre-established hikes. Additionally, it seeks to classify these hikes into easy, intermediate, or difficult categories based on the obtained data.

The protocol places a strong emphasis on outdoor hiking, which offers numerous advantages. It is an inclusive activity accessible to people of all abilities, requiring minimal skills and equipment, and allowing individuals to set their own walking pace [63]. The synergistic effect of walking in a natural environment makes hiking an ideal pursuit for enhancing overall health and well-being. Regular exposure to nature enriches one's lifestyle by providing an array of benefits, including the inhalation of air rich in beneficial organic compounds, engagement in PA, rejuvenation, and the facilitation of social bonds. Among the benefits of hiking is its impact on cardiovascular health. Hiking demands sustained physical effort, effectively increasing HR and fortifying the cardiovascular system. Engaging in regular hiking can lead to a lowering of blood pressure and enhanced blood circulation [64,65]. These cardiovascular advantages translate into a reduced risk of heart disease, stroke, and other related conditions. Furthermore, hiking serves as an excellent form of aerobic exercise, facilitating weight management and boosting metabolic health. As hikers traverse diverse terrains and elevations, their energy expenditure can significantly increase. Over time, this may result in weight loss or weight maintenance, depending on the duration and intensity of the hike. Additionally, consistent aerobic exercise, such as hiking, has been associated with improved insulin sensitivity, better glucose control, and a reduced risk of developing type 2 diabetes [2,8]. Beyond the physical advantages, hiking also provides a host of mental health benefits. Engaging in outdoor physical activities has been associated with reduced symptoms of stress, anxiety, and depression. The combination of PA, exposure to natural surroundings, and fresh air contributes to a sense of well-being and relaxation.

Hiking provides an opportunity to disconnect from the demands of everyday life and immerse oneself in the beauty of nature, fostering mindfulness and mental revitalization. In modern urban settings, where sedentary lifestyles have become the norm, hiking offers a much-needed respite. Prolonged periods of inactivity, extended periods of sitting, and excessive screen time can result in both physical and mental exhaustion. Hiking offers a rejuvenating solution, inspiring people to be active, inhale fresh air, and connect with the natural world. It offers a shift in pace and an opportunity to reconnect with the senses, offering a break from the monotony of indoor living. Walking and hiking represent cost-effective and accessible forms of exercise suitable for individuals of all ages and abilities [39,66,67].

They are widely regarded as the most inclusive activities, given the minimal requirements in terms of skill and equipment, along with the freedom for individuals to select the terrain difficulty and their preferred walking speed. Research has shown that individuals with disabilities, who are also at an increased risk of experiencing depression, may benefit from engaging in outdoor recreational activities, potentially reducing that risk [67,68]. Hiking is also considered a good strategy for stimulating social interaction and for providing benefits in terms of plasticity (e.g., advanced motor fitness, including coordination, balance, and agility) among children [39]. Therefore, encouraging individuals to engage in green sustainable tourism and health-focused holidays is a key aspect of this study. By providing easily accessible fitness tests that guide participants towards suitable hiking practices, the study protocol contributes to reducing the risk of overexertion. This proactive approach aims to lower the incidence of cardiovascular events during hiking. By promoting awareness of individual fitness levels and providing personalized hiking recommendations, in line with Goal 3 of the 2030 Agenda for Sustainable Development, which aims to ensure a healthy life and promote well-being for all at every age. Furthermore, it contributes to the broader goals of fostering sustainable tourism that takes into consideration both environmental and health aspects [1].

The practical applications of this study protocol are many, as it combines physiological and psychological assessments and the promotion of outdoor activities. The comprehensive evaluation of hiking difficulty and its potential impacts can benefit various stakeholders:

- For individuals interested in hiking, the study protocol provides insights into their fitness levels and helps them understand the difficulty of specific hiking routes. By offering personalized recommendations, it allows hikers to make informed choices and to enjoy their outdoor experiences while minimizing health risks. Moreover, it encourages people to incorporate more outdoor activities into their lives, contributing to overall well-being.
- The tourism industry can use the findings of this study protocol to promote green tourism and health-focused holidays. By guiding travelers toward suitable hiking options based on their fitness levels, tour operators can enhance the overall experience and ensure the safety of their clients. The health sector can benefit from the data by promoting hiking as a cost-effective and accessible means of improving physical and mental health.
- The research community can use the methods outlined in this protocol to further investigate the impact of outdoor activities on various health parameters. The data can be used to develop evidence-based policies and guidelines for promoting outdoor and hiking activities. It can also inform future research on the physiological and psychological effects of spending time in nature.
- Fitness trainers, coaches, and health professionals can incorporate the findings of this study into their practice. By understanding the unique demands of hiking and the benefits it offers, they can provide targeted recommendations to their clients. The data can be used to tailor fitness and training programs, ensuring that individuals are adequately prepared for hiking adventures.

4. Conclusions

This study addresses a gap in the assessment of hiking-specific exercise capacities and offers a holistic approach to promoting both physical and mental health. By providing a valid and practical method for evaluating fitness levels in the context of hiking, it encourages individuals to embrace outdoor activities and gain the numerous benefits they offer. Findings from this research have the potential to influence tourism, health, and fitness practices, and contribute to the broader goal of enhancing well-being through outdoor experiences. We anticipate that the initial concrete outcomes of our study may manifest in the domain of cardiometabolic evaluations, including the measurement of blood pressure and blood glucose levels at various time points during hiking. These initial tangible outcomes in the realm of cardiometabolic assessments may serve as a foundation

for subsequent investigations into the enhancement of physiological parameters such as HR, HRV, and VO_2. This comprehensive evaluation will facilitate the examination of acute cardiometabolic responses, with a focus on the impact of the cardiometabolic aspect of the study.

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Informed Consent Statement: Informed consent will be obtained from all participants willing to be involved in the study.

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Comparable blood pressure reductions after indoor and outdoor walking exercise

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ABSTRACT: Although there is a trend toward outdoor activities, limited research has examined the effects of outdoor exercise on blood pressure. This study aimed to compare the Systolic (sBP) and Diastolic (dBP) Blood Pressure, Heart Rate (HR) response, Post-Exercise Hypotension (PEH) and Rate Pressure Product (RPP) following indoor and outdoor activities. Thirty-seven participants (18 females = age: 24.7 ± 0.7 years, BMI: 21.1 ± 2.1 kg/m^2, MET*week: 3779 ± 3037; 19 males = age: 24.9 ± 0.5 years, BMI: 24.1 ± 2.6 kg/m^2, MET*week: 3000 ± 730) completed an outdoor hike (H) (~3800 m) and an indoor maximal walking test (MWT). During both sessions, sBP, dBP and HR were measured 15-min before (PRE), immediately after (POST), 15-min (POST-15) and 30-min (POST-30) after the sessions. Mean differences and standard deviations of all variables, along with PEH and RPP, were determined. Repeated-measures mixed models evaluate the effects of indoor and outdoor sessions on hemodynamic variables. Paired t-tests compared PEH between settings. Regardless of sessions PRE measurements were higher ($p < 0.0001$) than POST-30 for sBP (H: 10.4 ± 2.1 mmHg; MWT: 12.3 ± 2.3 mmHg), dBP (H: 4.3 ± 1.9 mmHg; MWT: 4.5 ± 1.7 mmHg), HR (H: -5.4 ± 2.2 bpm; MWT: -7.8 ± 2.5 bpm) and RPP (H: 140.6 ± 296.6 mmHg*bpm; MWT: 38.6 ± 323.5 mmHg*bpm). No significant difference in PEH (0.9 ± 11.3 mmHg) was found between sessions. PEH occurred regardless of PRE values, confirming the positive effect of physical activity on reducing BP.

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INTRODUCTION

Physical activity is associated with improved health and quality of life, and even minor improvements in fitness have been linked to reduced cardiovascular and all-cause mortality [1–3]. Current physical activity guidelines recognize the importance of fitness and recommend that adults aged 18–65 years engage in at least 150 minutes per week of moderate-intensity exercise or 75 minutes per week of vigorous-intensity exercise [4]. In addition to those benefits, the World Health Organization (WHO) identifies physical activity as a protective factor for the prevention and treatment of cardiovascular diseases [5]. These conditions include a wide range of disorders affecting the cardiac muscle and vascular system, which supply the heart, brain and other vital organs, and are frequently associated with hypertension. In particular, high blood pressure is recognized as a leading risk factor for global mortality, with more than 10 million attributable deaths annually [1]. Since persistent hypertension, together with the absence of drug or physical therapy over time, may cause irreversible cardiovascular damage, the American Heart Association and the American College of Cardiology have defined blood pressure categories [6]. This classification is expressed as ranges that clarify the clinical implications and risks of hypertension, as shown in Table 1.

Hypertension is highly modifiable and can be influenced by various lifestyle factors, including physical activity. Immediately after a single bout of exercise, substantial changes occur in the regulation of arterial blood pressure. This phenomenon, known as Post-Exercise Hypotension (PEH) [7, 8], is considered a relevant non-pharmacological strategy to counteract hypertension risk. Its clinical and preventive relevance lies in its ability to reproduce, after a single exercise session, the chronic reduction in blood pressure usually achieved with pharmacological treatment. PEH typically lasts about 2 hours in healthy individuals and may persist for more than 12 hours in hypertensive patients, representing a valuable preventive mechanism when exercise is performed regularly. Moreover, the magnitude

TABLE 1. Categories and ranges of blood pressure with corresponding health conditions.

Categories	Conditions
Normal: Systolic Blood Pressure < 120 mmHg Diastolic Blood Pressure < 80 mmHg	Optimal cardiovascular health, lower risk of cardiovascular disease
Elevated: Systolic Blood Pressure 120–129 mmHg Diastolic Blood Pressure < 80 mmHg	Elevated risk for the development of hypertension
Hypertension Stage 1: Systolic Blood Pressure 130–139 mmHg Diastolic Blood Pressure 80–89 mmHg	Mild to moderate elevation in blood pressure levels which warrants lifestyle modifications and possibly pharmacological treatment depending on individual risk factors
Hypertension Stage 2: Systolic Blood Pressure > 139 mmHg Diastolic Blood Pressure > 89 mmHg	Severe elevation in blood pressure levels requiring pharmacological treatment in addition to lifestyle modifications to reduce the risk of cardiovascular events

Note: Reference values reported in the table were taken from Whelton PK, Carey RM, Aronow WS, et al. 2017 ACC/AHA/AAPA/ABC/ACPM /AGS/APhA/ASH/ASPC/NMA/PCNA Guideline for the prevention, detection, evaluation, and management of high blood pressure in adults. J Am Coll Cardiol. 2018; 71(19):e127–e248.

and duration of PEH are strongly influenced by exercise characteristics, particularly session duration, intensity, and frequency. Longer or repeated sessions are associated with more pronounced and sustained blood pressure reductions, highlighting the preventive and therapeutic relevance of structured physical activity in hypertension management [9, 10]. PEH has been attributed to several mechanisms, including vasodilation, reduced sympathetic nervous activity, and improved baroreceptor sensitivity. It is commonly associated with indoor exercise (e.g., resistance training, circuit training, and aerobic workouts), which has been shown to significantly reduce blood pressure immediately following the session [8, 11, 12]. Although indoor exercise is a popular form of physical activity, there has been a growing trend toward outdoor activities, particularly for mental health benefits, given their high salutogenic potential. Salutogenesis refers to the capacity to promote overall health and well-being by enhancing resilience, improving stress management, and fostering positive physical and psychological outcomes through engagement with natural environments [13, 14]. Urban green and outdoor environments are the most commonly explored and may provide benefits such as varied terrain, fresh air, and exposure to nature. These factors can enhance the overall exercise experience and amplify health outcomes [15, 16]. In particular, outdoor activities, such as hiking, offer additional benefits beyond physical exercise, including exposure to nature, accessibility for people of different abilities, minimal equipment requirements, cost-effectiveness, and the possibility for individuals to select terrain difficulty and the walking pace. Hiking, defined as walking a substantial distance in the outdoors, often over natural terrain with obstacles such as rocks and tree roots, has gained popularity in recent years [15–17]. While the increasing popularity of outdoor activities is well documented [13], less is known about their potential beneficial effects on blood pressure compared with indoor exercise. While indoor exercise is well established in inducing PEH, outdoor exercise also holds promise for achieving similar cardiovascular benefits. The choice between indoor and outdoor exercise can therefore be tailored to individual preferences and circumstances, ensuring that the benefits of PEH remain widely accessible. Considering the numerous health benefits of outdoor activities and their potential to enhance hemodynamic responses, exploring outdoor exercise as an alternative to traditional indoor exercise sessions is relevant. Therefore, this study aims to investigate blood pressure responses and PEH following outdoor exercise compared with indoor exercise.

MATERIALS AND METHODS

Participants were recruited by means of flyers, posters, brochures, advertisements on social networks, and word-of-mouth. In line with the literature [18] the inclusion criteria were the absence of the following conditions: the presence or a known history of neuromuscular disorders, uncontrolled heart failure or hypertension, multiple sclerosis, significant cognitive impairment, acute rheumatoid arthritis, cardiovascular diseases, use of antihypertensive medications, pulmonary dysfunction, uncontrolled metabolic diseases such as diabetes, a prior diagnosis of osteoporosis, a diagnosis of obesity (Body Mass Index [BMI] $\geq$ 29 kg/m^2) or any injury sustained within the past six months.

Forty participants were included in the study, approved on 14 April 2022 by the Institutional Review Board of the Department of Human Sciences, Society, and Health of the University of Cassino and Lazio Meridionale (approval number 6663) in accordance with the Declaration of Helsinki. Each participant was assigned a unique

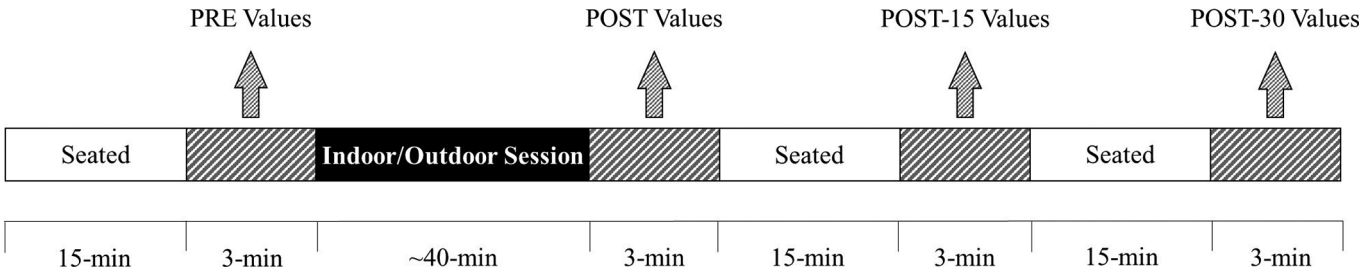

FIG. 1. Timeline of the measurements.

identification code to ensure anonymity, and the data were used exclusively for statistical purposes. Considering that physical activity positively influences cardiometabolic parameters [19], to avoid the influence of physical inactivity, participants were included only if they reported being recreationally active according to the International Physical Activity Questionnaire (IPAQ) [20] and possessed medical clearance to exercise. Since previous research [19] reported a correlation between physical activity level and BMI, and in accordance with the American College of Sports Medicine guidelines for the clinical classification of participants [2], anthropometric measurements were collected one week prior to the data collection. Body weight and height were measured using a scale and stadiometer accurate to 0.1 kg and 0.1 cm (Seca, model 709, Vogel & Halke, Hamburg, Germany), and BMI was calculated. Theoretical maximum heart rate (HRmax) was calculated for each participant, according to the equation: 220 – age (years). After one week, participants performed two different testing procedures, including one hiking session and one indoor test on a treadmill, with a minimum of 48 h recovery in between. At the start of each session, weather data were collected to ensure the reliability and accuracy of the study's findings. To ensure consistency and confirm the absence of significant environmental differences, temperature (indoor: 24.6 ± 2.8°C, outdoor: 24.2 ± 1.8°C), humidity (indoor: 41.1 ± 4.1 %, outdoor: 42.1 ± 1.8 %) and barometric pressure (indoor: 1012.0 ± 5.1 hPa, outdoor: 1008.1 ± 4.9 hPa) levels were recorded during both sessions.

Of the 40 participants who began the study, 3 withdrew due to personal reasons. Subsequently 37 participants (18 females, age: 24.7 ± 0.7 years; body mass: 56.3 ± 9.1 kg; body height: 163.4 ± 8.9 cm; BMI: 21.1 ± 2.1 kg/m^2; 19 males, age: 24.9 ± 0.5 years; body mass: 75.5 ± 11.9 kg; body height: 176.5 ± 8.4 cm; BMI: 24.1 ± 2.6 kg/m^2) completed all testing and data were used for the final analysis.

The hiking session took place outdoors in Gaeta, Italy. The location was selected based on the similarity (in terms of duration and mean slope) with the indoor session and determined according to the walkability principle [21]. This principle considers physical-environmental and historical-cultural aspects of the route, such as: the presence of necessary services within walking distance, the attractiveness of the route in terms of architecture and social context, and the level of comfort and safety of the route. The identification of the hike included an evaluation of various parameters such as duration, length, slope, and energy demand as per the Club Alpino Italiano Manual. During the outdoor session, each participant completed the same hike at a self-selected speed.

During the indoor session, all participants performed a maximal incremental walking test on a treadmill (RunRace HC1200, Technogym, Cesena, Italy), incorporating both uphill and downhill walking. Participants were asked to self-select their speed [18, 22], trying to replicate their pace during the outdoor session. The initial speed was chosen to match a comfortable walking pace during the first 2-min stage, with the slope set at 0% followed by 2% slope increments every 2-min stage. When participants reached the maximum exertion, the uphill phase finished and the downhill phase started with 2% slope decrements every stage, until returning to 0% grade.

During both sessions baseline systolic and diastolic blood pressures were measured using a digital sphygmomanometer (Erkameter 3000, Erka, Bad Tolz, Germany). Resting blood pressure values were obtained 15 minutes before the start of each session (PRE), after a 15-min period of seated rest on a chair with armrests. Blood pressure was also measured immediately after the conclusion (POST), 15 minutes (POST-15) and 30 minutes (POST-30) after the sessions, to assess acute cardiometabolic responses, as shown in the measurement timeline (Figure 1).

Two measurements were recorded at each time point, and if there was more than a 5-mmHg difference between them, an additional measurement was taken. Within each measurement period, the maximum (highest reading) and minimum (lowest reading) value of systolic blood pressure, diastolic blood pressure and heart rate were collected, and average values of measurements were calculated and used for statistical purposes. PEH was calculated for systolic blood pressure as PRE – POST-30 (mmHg). Rate pressure product was calculated as systolic blood pressure (mmHg) multiplied by heart rate (bpm).

Before and during the sessions, a Garmin HRM-Pro™ (Garmin International, Kansas City, MO, USA) chest strap monitor, positioned just below the xiphoid process, was used to record real-time (at a sampling rate of 1 Hz) heart rate data and track the coordinates of the hiking route. Resting heart rate data were collected 15 minutes before each session, after a 5-min seated rest. Spatiotemporal data were

TABLE 2. Blood pressure and heart rate response before, during and after outdoor and indoor sessions.

Outdoor Session	**PRE**	**POST**	**POST-15**	**POST-30**
Average sBP (mmHg)	120 ± 11	118 ± 8	112 ± 9$^{*,\#}$	110 ± 9$^{*,\#}$
Average dBP (mmHg)	77 ± 7	76 ± 8	73 ± 7	73 ± 8*
Average HR (beats · min^{-1})	67 ± 9	81 ± 12*	73 ± 10$^{*,\#}$	72 ± 10$^{\#}$
RPP (mmHg · bpm)	8122 ± 1381	9674 ± 1531*	8257 ± 1262$^{\#}$	7981 ± 1179$^{\#}$
Indoor Session	**PRE**	**POST**	**POST-15**	**POST-30**
Average sBP (mmHg)	120 ± 11	112 ± 10*	109 ± 9*	109 ± 9*
Average dBP (mmHg)	75 ± 7	73 ± 7	69 ± 6*	70 ± 7*
Average HR (beats · min^{-1})	70 ± 11	89 ± 13*	80 ± 12$^{*,\#}$	79 ± 11$^{*,\#}$
RPP (mmHg · bpm)	8518 ± 1537	9911 ± 1626*	8881 ± 1255$^{\#}$	8480 ± 1229$^{\#}$

Note: Values are mean ± SD. sBP, systolic blood pressure; dBP, diastolic blood pressure; HR, heart rate; RPP, rate pressure product. *significantly ($p < 0.0001$) different from PRE values, $^{\#}$significantly ($p < 0.0001$) different from POST values.

recorded using a GPS Smartwatch (Garmin Forerunner® 245 Music) worn on the left wrist, which was used to display real-time heart rate acquired from the Garmin HRM-Pro™ chest strap monitor.

Statistical analysis was conducted using STATA statistical software version 18 (Stata-Corp, College Station, LLC, Texas, USA). All values are reported as means and standard deviation (± SD) and the average values across measurements were used for the final analysis. Repeated-measures mixed models were used to evaluate the hemodynamic responses during and after the maximal incremental walking test on a treadmill and the hiking session and to compare with the baseline values for each test. In the model, subjects were considered as random effects, whereas the environment (indoor vs. outdoor) and testing time (PRE, POST, POST-15 and POST-30) were treated as fixed effects. Subsequently, the contrast method was employed to test whether the means of the dependent variables (i.e., systolic and diastolic blood pressure, heart rate, rate pressure product) for setting (indoor vs. outdoor) and time point (PRE, POST, POST-15 and POST-30) were equivalent. When significant main effects and interactions were found, post hoc analysis was applied using a Bonferroni correction. To avoid type 1 error, after Bonferroni correction, for the linear repeated-measures mixed model, significance was set at $p < 0.05$ for the main effects and at $p < 0.0017$ for post hoc pairwise comparisons. Cohen's d (*d*) was used to evaluate the power of all the primary comparisons. Paired t-tests were used for comparisons between the maximal incremental walking test and the hiking session.

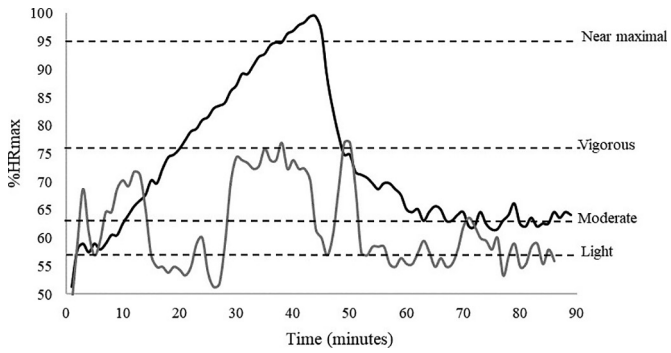

FIG. 2. Percentage of heart rate max during indoor (black line) and outdoor (grey line) session with horizontal dashed lines identifying threshold of exercise intensities in a representative participant.

RESULTS

The outdoor session had a length of ~3800 m with the maximum slope at 19% and the mean slope at 5.3%. During the session participants achieved on average 84% of their theoretical HRmax over a mean duration of 40 minutes. For the indoor session the length was ~2800 m, the maximum slope provided from the treadmill was 25% and the mean slope 8.1%. During the session participants reached on average 92% of their theoretical HRmax in 41.86 minutes of mean duration. Heart rate from a representative participant during the sessions is shown in Figure 2.

Means and standard deviations of the average values and the rate pressure product during outdoor and indoor sessions are shown in Table 2.

The repeated-measures mixed models showed a significance of model ($F_{(7,252)} = 25.32$; $p < 0.0001$) for systolic blood pressure. In particular, significant differences were found for time ($F_{(3,216)} = 26.34$; $p < 0.0001$) with PRE values higher than POST ($d = 0.68$), POST-15 ($d = 1.04$) and POST-30 ($d = 1.19$) for indoor session. For outdoor session (Figure 3a), POST-15 was significantly lower than PRE ($d = 0.91$) and POST ($d = 0.71$), and POST-30 was significantly lower than PRE ($d = 1.12$) and POST ($d = 0.91$). A significant interaction between time and setting ($F_{(3,216)} = 62.34$; $p < 0.02$) was found, although no significant differences emerged for setting ($F_{(1,72)} = 1.71$; $p = 0.19$).

Regarding diastolic blood pressure, a main effect was found for time ($F_{(3,216)}$ = 20.72; p < 0.0001), with PRE values significantly higher than POST-15 (d = 0.59) and POST-30 (d = 0.61) in the indoor session. For the outdoor session (Figure 3b) POST-30 values were significantly lower than PRE (d = 0.52). No significant difference emerged for setting ($F_{(1,72)}$ = 2.69; p = 0.1) and no interaction was found between time and setting ($F_{(3,216)}$ = 0.10; p = 0.95).

The overall model was statistically significant (p < 0.0001) for heart rate, with a difference for setting ($F_{(1,72)}$ = 5.85; p = 0.01) and time ($F_{(3,216)}$ = 94.33; p < 0.0001). PRE values were significantly lower than POST (d = 1.36), POST-15 (d = 0.90) and POST-30 (d = 0.71) for indoor session. For outdoor session (Figure 3c) PRE values were significantly lower than POST (d = 1.31) and POST-15 (d = 0.66) and POST values were significantly higher the POST-15 (d = 0.66) and POST-30 (d = 0.78). Regarding time and setting, no significant interactions were found ($F_{(3,216)}$ = 1.49; p = 0.21).

The overall model for rate pressure product was statistically significant ($F_{(7,252)}$ = 23.87; p < 0.0001), with a significant effect of time ($F_{(3,216)}$ = 61.52; p < 0.0001). POST values were significantly higher than PRE (indoor d = 0.87, outdoor d = 1.06), POST-15 (indoor d = 0.71, outdoor d = 1.01) and POST-30 (indoor d = 0.99, outdoor d = 1.23) for both sessions (Figure 3d). No significant differences were found for setting ($F_{(1,72)}$ = 2.47; p = 0.12) and no interaction between time and settings ($F_{(3,216)}$ = 0.78; p = 0.51). Lastly, paired t-test showed no significant difference between settings for PEH (p = 0.36).

DISCUSSION

This study aimed to investigate the effect of a hiking session on blood pressure and PEH compared with an indoor session of approximately the same intensity and duration. The main findings indicated that large hemodynamic changes occur during both maximal walking test and hiking session in recreationally active participants. Regardless the proposed activities, systolic blood pressure, diastolic blood pressure and heart rate showed significant decreases over time, with lowest values observed at POST-30. These results are consistent with previous research [23], confirming the benefits of the exercise

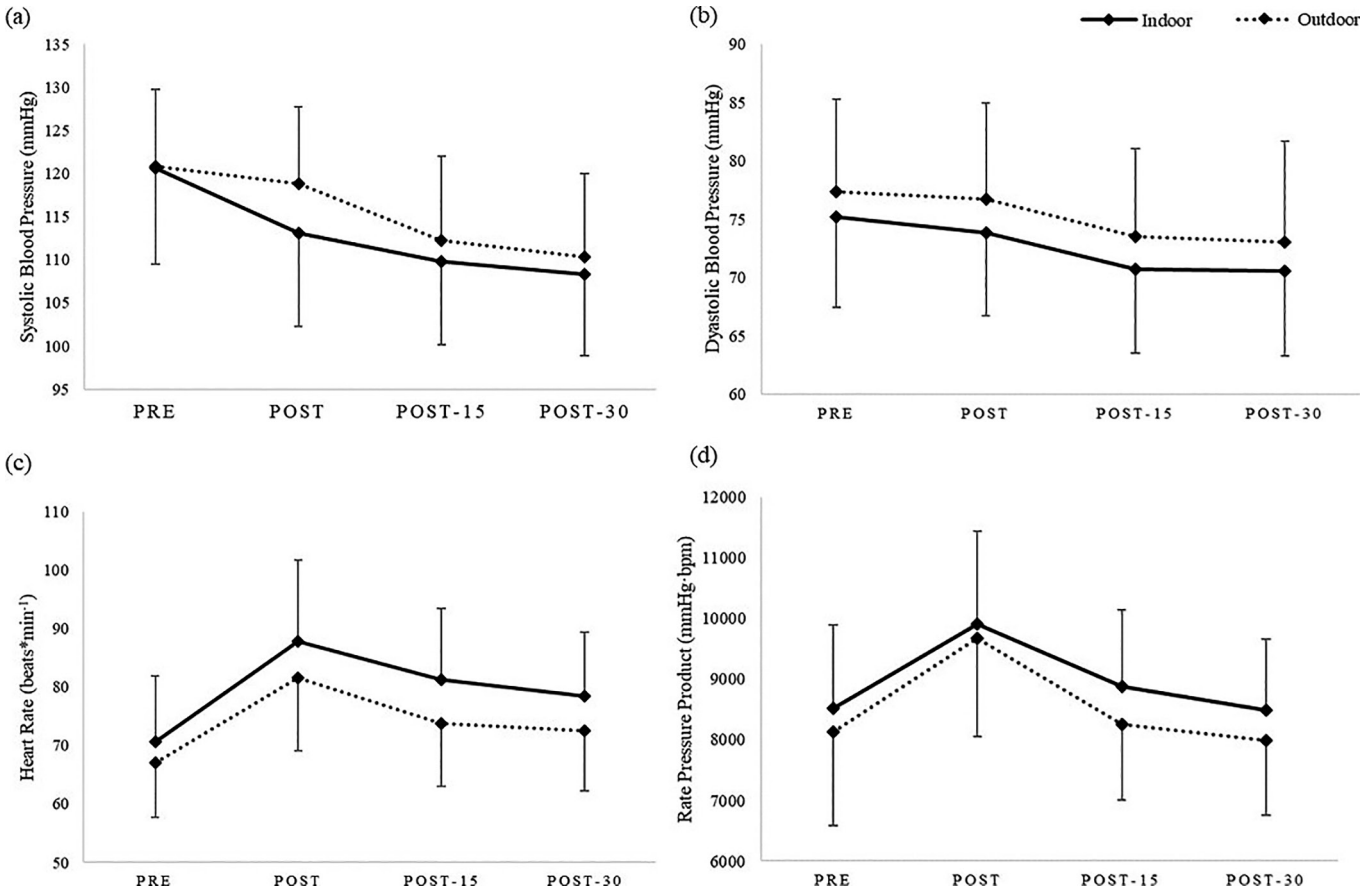

FIG. 3. Means and standard deviations of (a) systolic blood pressure, (b) diastolic blood pressure, (c) heart rate and (d) rate pressure product between indoor session (solid lines) and outdoor session (dotted lines). All reported differences were statistically significant (p < 0.0001). (a) For the indoor session, PRE values were higher than POST, POST-15, and POST-30. For the outdoor session, POST-15 and POST-30 values were lower than PRE and POST. (b) For the indoor session, PRE was higher than POST-15 and POST-30. For the outdoor session, POST-30 was lower than PRE. (c) For the indoor session, PRE was higher than POST, POST-15, and POST-30. For the outdoor session, PRE was lower than POST and POST-15, and POST was higher than POST-15 and POST-30. (d) For both indoor and outdoor sessions POST values were higher than PRE, POST-15, and POST-30.

on acute reduction of blood pressure and offering a new perspective for investigation. While most of the literature focuses on inactive individuals, who typically present with higher blood pressure and a greater reduction in blood pressure after exercise, the present study found that recreationally active adults also experienced considerable decreases, reinforcing the value of exercise for blood pressure control [23, 24]. The lack of differences in blood pressure responses between the two settings, despite variations in internal load (%HRmax reached during the sessions), highlights the potential of hiking for cardiovascular benefits and emphasizes the generalizability of the PEH effect.

The systolic blood pressure showed a significant reduction over time, with a higher reduction in POST-30. The analysis also revealed a significant interaction between the time points and exercise settings, indicating different hemodynamic responses based on the stimulus intensity. Specifically, the systolic blood pressure had two different trends during the sessions, with a greater reduction between POST-15 and POST-30 in the hiking session, and between POST and POST-15 in the indoor session. These results can be explained by the different intensities of two exercises. Since the indoor session was a maximal incremental walking test, the reached intensity, in terms of % of HRmax, was higher than outdoor session. Conversely, during the outdoor session, the increment of the workload was not as regular as the indoor one (every 2-min stage). Examining the effects of high-intensity training, the literature [25] reported significant improvements in systolic blood pressure, with notable reductions immediately post-exercise, indicating a pronounced cardiovascular response. Moreover, comparing the effects of low, moderate, and vigorous intensity exercise sessions among normotensive young adults higher exercise intensities have been found to elicit the largest acute reductions in blood pressure [26]. However, in the present study, during POST-30, both sessions exhibited lower systolic blood pressure values than at rest, confirming the positive effect of exercise on the management of blood pressure.

For diastolic blood pressure, the trends between sessions were largely similar. A significant reduction was observed over time, particularly between PRE and POST-30 ($p < 0.001$) in both sessions. This findings align with existing literature, which reports smaller but more consistent reductions in diastolic compared with systolic blood pressure after exercise.

Aerobic exercise has been shown to lower diastolic blood pressure by a few mmHg, reflecting beneficial effects on cardiovascular health [27]. This reduction is primarily attributed to the vasodilatory effects of exercise, which decrease vascular resistance and improve arterial compliance [28]. These results highlight the preventive role of PEH in healthy young populations. Although participants in this study were recreationally active young adults, elevated blood pressure during youth and early adulthood has been associated with an increased risk of vascular alterations and progression to hypertension later in life [29, 30]. Moreover, PEH reflects vascular adaptations such as improved arterial compliance, enhanced endothelial function, and reduced peripheral resistance [7, 8]. Demonstrating that this effect also occurs in healthy young individuals reinforces the preventive role of regular physical activity in promoting cardiovascular health across the lifespan. This suggests that PEH may serve as an early preventive mechanism, even in healthy populations, by counteracting the gradual vascular changes that can lead to hypertension later in life.

Heart rate recovery after exercise reflected significant time effects, explained by increasing parasympathetic activity leading to a return to resting values [31]. Differences in heart rate between settings, similar to those observed for systolic blood pressure, can be attributed to session intensity.

For rate pressure product, the significant time effect reflected the natural recovery process of the cardiovascular system, with values significantly decreasing from immediately after the end of the sessions to 30 minutes post-exercise. Rate pressure product is a non-invasive predictor of myocardial workload, as it is directly related to myocardical oxygen consumption [32, 33]. No differences were found between outdoor and indoor sessions, suggesting that both exercises could have a similar myocardial workload. Therefore, the similarity in rate pressure product across both sessions suggests that exercising outdoors could be a valid alternative to indoor aerobic exercise (e.g., on treadmill), taking the advantages of outdoor activities (high enjoyment, air quality, social relationships).

The findings suggested that outdoor hiking session and indoor walking test showed similar cardiovascular responses, given the absence of statistic differences between both sessions in blood pressure (systolic and diastolic) values and for rate pressure product. These results are further supported by the PEH findings, indicating that both sessions effectively reduce blood pressure after exercise with similar magnitudes of PEH. The similar reductions in post-exercise suggest that individuals can achieve effective cardiovascular responses and benefits from either exercise modality. Those who prefer outdoor activities like hiking can expect similar improvements in cardiovascular health as those who engage in structured indoor exercises. Given that outdoor activities are often perceived as more enjoyable [34], opportunity to promote them may provide a sustainable and engaging way to replicate the benefits of traditional physical activity while further supporting cardiovascular health. The novelty of this study lies in directly comparing indoor and outdoor walking-based exercise in recreationally active young adults, a group less frequently examined in PEH research. Our results demonstrate that significant reductions in systolic and diastolic blood pressure also occur in this population, reinforcing the preventive role of exercise. Moreover, the comparison between an indoor maximal incremental walking test and an outdoor hiking session provides evidence that PEH is not limited to laboratory-based protocols but also extends to real-world outdoor settings. This expands the generalizability of PEH and underlines the potential of enjoyable, low-cost activities, such as hiking, to promote cardiovascular health.

CONCLUSIONS

Findings from this study suggest that while significant variations in physiological parameters over time occur, the environment (indoor vs. outdoor) does not significantly influence these changes. Both indoor treadmill and outdoor hiking sessions induced a clear post-exercise hypotensive effect lasting up to 30 minutes after exercise, confirming the relevance of PEH as a short-term protective mechanism against hypertension. These findings align with existing literature and confirm the positive effect of physical activity on reducing blood pressure [3, 35]. From a practical perspective, our results suggest that young, recreationally active individuals can achieve similar cardiovascular benefits regardless of whether exercise is performed indoors or outdoors. However, outdoor activities may offer additional advantages, such as lower perceived exertion and greater long-term adherence, which could further support cardiovascular health. This enhancement is linked to the lower internal load observed during outdoor activities, suggesting a protective cardiovascular effect, even with similar exercise characteristics. Outdoor activities replicate traditional physical activity while offering a potentially more sustainable and beneficial approach to improving overall health by reducing cardiovascular stress. Practically, this indicates that a single 40-min walking session, whether indoors or outdoors, is sufficient to induce a clinically relevant short-term reduction in blood pressure, reinforcing the value of integrating regular exercise into daily routines. Therefore, incorporating outdoor exercise sessions, when feasible, represents a sustainable and accessible strategy to promote regular physical activity and reinforce the protective effects of PEH in daily life.

Limitations

Several limitations should be considered when interpreting these findings. The observation window was limited to 30 minutes post-exercise, preventing conclusions regarding the longer-term persistence of PEH. The assessment did not include measures of subjective enjoyment or affective responses, which might have provided additional insight into the broader impact of indoor and outdoor exercise. The sample consisted exclusively of young, recreationally active adults, limiting the generalizability of the results to other populations, such as sedentary individuals, older adults, or those with hypertension. In addition, although temperature and humidity were controlled to minimize environmental variability, other contextual factors, such as noise, light exposure, or social interactions, were not systematically monitored and may have influenced cardiovascular responses.

Future Research Directions

Future research should address these limitations and expand the current findings in several directions. Longer follow-up periods are warranted to determine the persistence of PEH and to explore potential differences in recovery between exercise modalities. Investigating the role of subjective enjoyment, psychological well-being, and adherence in response to indoor versus outdoor activities could provide valuable insights into long-term exercise adoption. Additionally, studies should include more diverse populations, such as older adults, individuals with hypertension, or clinical groups, to enhance external validity. Future investigations might also examine environmental and seasonal influences, such as thermal stress, solar radiation, or air quality, to better understand how outdoor conditions affect cardiovascular and perceptual responses to exercise. Finally, comparing different types of outdoor environments (e.g., urban vs. natural settings) may help clarify the specific contribution of nature exposure to cardiovascular health. Such investigations would build on the current findings by clarifying how contextual and environmental factors modulate the magnitude and persistence of PEH.

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The Impact of a Multidimensional Physical Activity Intervention on Glycemic Control in Type 1 Diabetes: A Preliminary Study

Olga Papale [1], Emanuel Festino [1], Francesca Di Rocco [1], Carl Foster [2], Iris Prestanti [3], Sofia Serafini [3], Pascal Izzicupo [3], Cristina Cortis [1,*] and Andrea Fusco [3]

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Abstract: Objectives: Type 1 diabetes is characterized by hyperglycemic episodes influenced by diet, sleep quality, chronotype, and physical activity, among others. While aerobic exercise is known to improve glycemic control, its effect on blood glucose regulation remains underexplored. Thus, this case study aimed to evaluate the effects of a prolonged and differentiated indoor and outdoor exercise intervention on glycemic control in an individual with type 1 diabetes. **Methods**: The participant (age: 23 years; weight: 95 kg; height: 1.90 m; Body Mass Index: 26.3 kg/m^2; waist to hip ratio: 0.98; basal metabolic rate: 2015 kcal; Heart Rate Maximum (HRmax): 197 beats·min^{-1}) completed two outdoor (~3800 m) and two indoor sessions with self-selected speed, in the initial 2 min stage, at a 0% grade slope. The grade increased by 2% at each stage during the uphill phase until reaching volitional fatigue, followed by a 2% decrease at each stage during the downhill phase until returning to a 0% grade. Blood pressure was assessed before and after each session. Daily nutrition intake, insulin intake, and blood glucose were continuously monitored. Dietary adherence (PREvención con DIeta MEDiterránea), sleep quality (Pittsburgh Sleep Quality Index), chronotype (Morningness–Eveningness Questionnaire), and physical activity levels (International Physical Activity Questionnaire) were assessed before each session. The Physical Activity Enjoyment Scale was used to measure enjoyment after each session. **Results**: The sessions were completed in ~44 and ~39 min with the participant achieving 84% (outdoor) and 96% (indoor) of their theoretical HRmax. The intervention resulted in glycemic improvements, with time spent in hyperglycemia (>250 mg/dL) decreasing from 56.46% to 0%, while time in the normal range (70–180 mg/dL) increased to 63.96%. A 47% reduction in insulin units showed that insulin sensitivity also improved. **Conclusions**: Despite differences in intensity, indoor and outdoor activities yielded comparable benefits, with outdoor activities being perceived as more enjoyable (outdoor: 28.5 ± 0.7; indoor: 24.0 ± 5.6) and positively impacting glycemic control, thus supporting the need for tailored strategies in diabetes management.

Keywords: blood glucose; mediterranean diet; sleep quality; chronotype; physical activity

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1. Introduction

Lifestyle factors, including dietary and physical activity behaviors, are currently targeted to prevent and treat several non-communicable diseases, including diabetes mellitus [1]. Diabetes mellitus is the collective term for heterogeneous metabolic disorders whose primary outcome is chronic hyperglycemia. Hyperglycemia arises from a multifactorial etiology involving genetic, environmental, and behavioral factors and is primarily driven by impaired insulin secretion, impaired insulin action, or a combination of both, with variations across different types of diabetes [2,3]. Diabetes mellitus is the most common metabolic disorder occurring during the lifespan and can be classified into two main types, type 1 and type 2 diabetes. Type 1 diabetes is an autoimmune disorder characterized by the destruction of insulin-producing β cells in the pancreas, leading to absolute insulin deficiency. Common symptoms include polyuria, polydipsia, and weight loss. This metabolic condition disrupts carbohydrate, lipid, and protein metabolism, resulting in acute complications such as diabetic ketoacidosis and chronic complications affecting the cardiovascular, renal, and nervous systems [4,5]. Type 2 diabetes is a metabolic disorder characterized by a state of insulin resistance associated with a progressive loss of β cell function. It is caused by a combination of genetic and biological factors, such as sex and age, and lifestyle factors, including diet, obesity, sedentary behaviors, and consumption of alcohol. This condition is also associated with both acute and chronic complications, including diabetic ketoacidosis, cardiovascular diseases, and diabetic neuropathy [4,5]. Careful control of blood glucose concentration is important for diabetic patients, particularly those with type 1 diabetes mellitus. Regular blood glucose monitoring reduces the risk of hypoglycemia, cardiovascular disease, microvascular and macrovascular complications, and neurological abnormalities. It also helps prevent death, which can result from loss of consciousness and heart failure [6]. Therefore, maintaining blood glucose within safe limits [7] is essential for patients with diabetes.

Blood glucose concentration could be influenced by several factors, such as inadequate duration and poor quality of sleep, both of which increase the risk of impaired glucose regulation and exacerbate diabetes [8]. In fact, sleep duration and quality are important regulators of glucose metabolism. Furthermore, short and long sleep duration, as well as poor sleep quality, have been associated with impaired fasting blood sugar, glucose tolerance, and/or diabetes [8,9]. Sleep restriction activates the sympathetic nervous system, which reduces insulin secretion, promotes insulin resistance, and increases fat accumulation in the liver and muscles. It also alters appetite regulation by lowering leptin levels and raising ghrelin, which increases hunger, especially for carbohydrates. Additionally, reduced physical activity following sleep loss may lead to weight gain [10]. Conversely, excessive sleep may also impair metabolism, influenced by factors such as poor sleep quality, sedentary behavior, and circadian misalignment. It could also reflect comorbidities like depression or hypertension, which are linked to obesity and diabetes, suggesting a potential bidirectional relationship [11].

In addition to sleep, the circadian system could have an influence on glycemic control [8,12,13]. It generates endogenous rhythms of approximately 24 h, the synchronization of which is vital for healthy bodily function. The timing of many physiological processes, including glucose metabolism, is regulated by these rhythms, and disruptions that desynchronize or misalign them can lead to adverse health outcomes. However, the timing of the circadian system varies considerably across individuals, depending on their chronotype [14]. These individual differences, which reflect how subjects assign their sleep and wake times, could influence several activities of daily living [15], including dietary habits and glycemic control. Individuals with a later chronotype tend to exhibit higher glycated hemoglobin (HbA1c) levels and poorer glycemic control, regardless of sleep duration or

quality. This association is partially mediated by a greater proportion of daily caloric intake at dinner, suggesting that dietary and circadian mechanisms are involved [16].

Several "healthy" dietary patterns have been associated with improved glucose regulation in diabetes mellitus. Among them, the Mediterranean diet, rich in plant-based foods and low in animal-based, high-fat, and processed foods, has shown significant benefits for preventing and managing diabetes mellitus and reducing the risks of cardiovascular diseases and mortality [1]. Moreover, regular exercise, a key component of the traditional Mediterranean lifestyle, has been shown to positively impact the reduction of the risk of diabetes [17]. The authors of [18] demonstrated that during exercise, whole-body oxygen consumption can increase by as much as 20-fold, with even greater increases occurring in the working muscles. To meet its energy needs under these circumstances, skeletal muscle uses, at a greatly increased rate, its own stores of glycogen and triglycerides, as well as free fatty acids derived from the breakdown of adipose tissue triglycerides and glucose released from the liver [19]. During exercise, hypoglycemia rarely occurs in nondiabetic individuals, as metabolic adjustments, in large part mediated by hormonal mechanisms, help maintain normoglycemia [19]. These hormonal adaptations are essentially lost in insulin-deficient patients with type 1 diabetes. As a consequence, when such individuals have too little levels of insulin in their circulation due to inadequate therapy, an excessive release of counterinsulin hormones during exercise might increase the already high levels of glucose and ketone bodies and could even precipitate diabetic ketoacidosis [19]. Conversely, the presence of high levels of insulin, due to exogenous insulin administration, could attenuate or even prevent the increased mobilization of glucose and other substrates induced by exercise, and hypoglycemia might ensue [18]. In summary, practicing physical activity and exercise can help people with diabetes achieve a variety of goals, including increased cardiorespiratory fitness, increased vigor, improved glycemic control, decreased insulin resistance, improved lipid profile, blood pressure reduction, and maintenance of weight loss. Studies have demonstrated that regular physical activity and/or moderate to high cardiorespiratory fitness are associated with reductions in cardiovascular and overall mortality in people with type 1 diabetes [3,20]. The environmental setting in which physical activity takes place could influence individuals with type 1 diabetes. Outdoor exercise, compared to indoor exercise, has been associated with distinct physiological, psychological, and behavioral responses, including differences in perceived exertion, cardiovascular responses, and enjoyment [21]. These factors could also affect acute glycemic control and long-term adherence to physical activity routines. Therefore, it would be interesting to explore how differences in environmental settings may influence glucose regulation in people with type 1 diabetes.

Given the significant impact of exercise on diabetes management and its long-term effects on glucose metabolism, monitoring physical activity is critical in diabetes care. A multidimensional approach that considers factors beyond glucose levels, such as dietary habits, sleep quality, and chronotype, offers valuable insights for personalized management. The hypothesis tested in this study was that, in individuals with type 1 diabetes, glycemic responses to exercise at varying intensities and settings (indoor vs. outdoor) are influenced not only by the exercise itself but also by lifestyle factors such as sleep quality and chronotype. This case report was designed to provide a detailed, individualized analysis of these interactions in a participant with type 1 diabetes, where individual variability in physiological responses to exercise is particularly relevant. By focusing on a single-case report, we aim to gain insights that can inform future research involving larger cohorts with similar clinical profiles, ultimately contributing to more personalized approaches in disease management. Therefore, this case report aims to evaluate glucose trends in response to different exercise intensities and types, using a multidimensional approach that integrates lifestyle and physiological parameters in a young male participant with type 1 diabetes.

2. Materials and Methods

In accordance with the Declaration of Helsinki, the study was approved by the Institutional Review Board of the Department of Human Sciences, Society, and Health of the University of Cassino and Lazio Meridionale (approval number 6663). The study aimed to evaluate the effects of different modalities and exercise intensities on blood glucose regulation in a type 1 diabetes participant. Blood glucose is known to be easily influenced by several internal and external factors, such as insulin and food intake, sedentary lifestyle, or sleep quality. Among these factors, physical activity has been recognized as the most effective. The assessment of the reduction in blood glucose regulation is commonly carried out after generalized strength, resistance, and high-intensity interval training (HIIT) [22,23], aimed only at evaluating the reduction in blood glucose levels. However, to the best of our knowledge, no studies have investigated the effect of a prolonged and differentiated intervention (e.g., incremental walking test and hiking exercise), also focusing on the variations in the self-administered insulin units. Therefore, the present case study proposes a new methodological approach and a new intervention, involving both indoor and outdoor activities, allowing for the evaluation of additional influential variables such as daily nutritional intake, adherence to the Mediterranean diet, sleep patterns, chronotype, and physical activity levels. To establish whether blood glucose regulation could be acutely affected by different exercise modalities, the evaluation of blood glucose concentration was carried out during the entire testing period, from the familiarization session and the enrolment day to the last testing session, during which the external and internal factors were controlled.

2.1. Case Description

One 23-year-old male with type 1 diabetes since the age of 14 years took part in the study. The participant was a university student regularly enrolled in a master's program, with a 10-year history of playing basketball. They stopped practicing regularly due to academic commitments, which led to a more sedentary lifestyle. They were using a multiple daily injection insulin regimen, taking insulin degludec (Tresiba) at bedtime and insulin lispro (Humalog) at mealtimes. The participant had medical clearance to exercise, approved by their medical practitioner, and gave their written consent to participation after receiving both written and oral information regarding the procedures. They were informed that they could withdraw from the study at any time without incurring any adverse consequences.

2.2. Procedures

Data collection took place at the Human Performance Lab (HPL) for the indoor sessions and in Gaeta (Lazio, Italy) for the outdoor sessions. The entire testing procedure was conducted in five separate sessions: a familiarization session (enrolment day), two indoor sessions, and two outdoor sessions. Prior to the baseline evaluations, the participant was familiarized with the experimental protocol. To avoid the influence of individual habits on physiological evaluation, the participant was required to refrain from moderate-to-vigorous physical activity and to abstain from alcohol consumption and caffeine intake for at least 24 h before the experimental sessions.

Anthropometric measurements were performed by a certified specialist (i.e., level 2 certification of the International Society for the Advancement of Kinanthropometry). Body weight and height were measured using a scale and stadiometer accurate to 0.1 kg and 0.1 cm, respectively, (Seca, model 709, Vogel & Halke, Hamburg, Germany) and the Body Mass Index (BMI) was calculated. Body circumference measures were made with a tape metric (Holtain Limited, Crymych, UK, 1.5 m Flexible Tape). Waist-to-hip ratio (WHR) was used as a predictor of cardiovascular risk. Waist circumference was measured at the narrowest point in the abdominal region midway between the 10th rib and the crest of

the pelvic bone. Hip circumference was measured horizontally at the most prominent points on the posterior, lateral, and anterior sides. The WHR was subsequently computed. To exclude the hypothesis of the presence of cardiovascular diseases, self-monitoring assessment of blood pressure was applied through multiple daily measurements at various time points [24]. The participant was instructed to perform duplicate morning and evening measurements after resting for 5 min and with 1 min between recordings. Two succeeding readings were taken to ensure that blood pressure values did not differ by >5 mmHg from those of a mercury sphygmomanometer (Erkameter 3000; Erka, Bad Tolz, Germany) [24]. Theoretical maximum heart rate (HRmax) was calculated according to the equation [25]:

$$\text{Theoretical HRmax} = 220 - \text{age (years)}$$

Basal metabolic rate was calculated using the Mifflin–St Jeor predictive equation validated for male subjects with diabetes mellitus [26]:

$$\text{Basal Metabolic Rate} = 10 \times \text{weight (kg)} + 6.25 \times \text{height (cm)} - 5 \times \text{age (years)} + 5$$

In addition, the participant was familiarized with the Borg Category Ratio (CR-10) Rate of Perceived Exertion (RPE) scale, where 0 represented "no exertion at all" and 10 represented "maximal exertion" [27]. During the familiarization session, measurements of glucose history levels, dietary habits, sleep quality, and chronotype (fully described in the following Section 2.2.1 were collected. The same measurement procedure was repeated during all the testing sessions.

After one week, the participant performed two different testing procedures, including two indoor and two outdoor sessions. The indoor sessions consisted of a maximal walking test while the outdoor sessions consisted of a hike. During one indoor and outdoor session, respiratory gas exchanges were continuously monitored using a VO_2 Master Pro Analyzer (VO_2 Master Health Sensors Inc., Vernon, BC, Canada). To ensure the reliability and accuracy of the study's findings, at the beginning of each session temperature and humidity data were recorded during the indoor sessions by maintaining the range of 20–30 °C of temperature and 35–55% humidity, to ensure consistency with the temperature (24.2 ± 1.8 °C) and humidity (42.8 ± 5.5%) of outdoor sessions. Before each exercise session, blood glucose concentrations were also monitored.

The day before and for the entire data collection period (9 days), the participant was asked to take note of their dietary and insulin intake and blood glucose levels.

During the familiarization session and before each session, the participant was asked to complete questionnaires on adherence to the Mediterranean diet, sleep quality, chorotype, and physical activity level. Moreover, blood pressure and recovery index were assessed before each session. The specific parameters evaluated during data collection are described below. After each session, blood pressure, session RPE (sRPE), and enjoyment of the activity were recorded.

During the two indoor testing sessions, the participant underwent a maximal incremental walking test on a treadmill (RunRace HC1200, Technogym, Cesena, Italy), incorporating both uphill and downhill walking. The participant was asked to self-select their speed. The initial speed corresponded to a comfortable walking pace during the first 2 min stage with the slope set at 0%, followed by 2% slope increments every 2 min stage. Once the participant reached the maximum exertion, the uphill phase ended and the downhill phase began, with 2% slope decrements at each stage, until returning to a 0% grade. Heart rate, RPE, and external load (slope %) were monitored throughout the sessions and recorded at the end of each stage. Thirty minutes after each session, sRPE was collected using the CR-10 scale [28].

The two outdoor sessions were carried out in Gaeta (~3800 m in length), Italy. The hiking route was identified based on several parameters such as duration, length, slope, and energy demand according to the Club Alpino Italiano (CAI) Manual. The chosen hike was selected for its similarity to the indoor sessions in terms of duration and mean slope, and it was evaluated according to the walkability principle. The principle considers physical and environmental factors as well as historical and cultural aspects of the route, including the availability of essential services within walking distance, the attractiveness of the route in terms of architecture and social context, and the level of comfort and safety of the route. Thirty minutes after each session, sRPE was asked on a CR-10 scale.

To balance methodological rigor with ecological validity, VO_2 was measured only during two of the four experimental sessions. The remaining sessions were conducted without metabolic equipment to better reflect real-life exercise scenarios. Both indoor and outdoor sessions were performed using the talk test procedure [29], during which the participant was asked to read aloud the standard 40-word paragraph consisting of the Italian version of the Olympic Oath during the last 30 s of each 2 min stage for indoor sessions and every 5 min for outdoor sessions. After reading the paragraph, the participant was asked "Can you speak comfortably?", with three possible answers: "yes", which was referred to as a "positive" result; "not sure", which was referred to as an "equivocal" result; and "no", which was referred to as a "negative" result. Respiratory gas exchange was assessed using a telemetric open-circuit measurement system (VO_2 Master Pro Analyzer, VO_2 Master Health Sensors Inc., Vernon, BC, Canada). The following variables were measured: oxygen uptake (VO_2), respiratory exchange ratio (RER), and minute ventilation (VE). Additionally, the participant's physical activity level during the outdoor session was measured under free-living conditions using triaxial accelerometers (GT9X Link; Actigraph, Pensacola, FL, USA) [2,30]. The Actigraph GT9X accelerometers provided information on wear time and daily physical activity (e.g., intensity, number of steps, energy expenditure). According to the literature [31,32], the Actigraph GT9X accelerometers were positioned on both wrists, both ankles, and inside a pouch placed on the posterior torso at the level of the inferior angle of the scapulae (Figure 1). The accelerometers were initialized using the ActiLife6 software (version 6.12.1, ActiGraph, Cary, NC, USA), with a sampling frequency of 30 Hz [33].

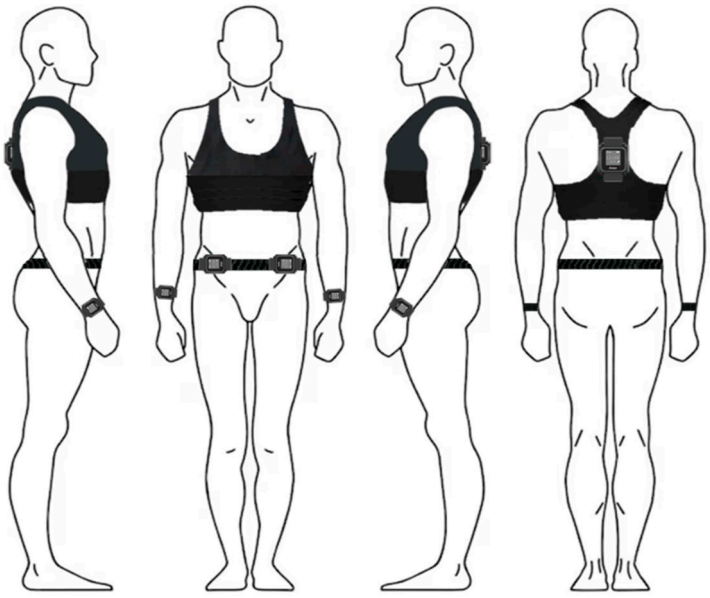

Figure 1. Placement of the Actigraph GT9X accelerometers to evaluate physical activity levels.

2.2.1. Measurements

A multidimensional approach was used to ensure that the four sessions were carried out under consistent conditions and to minimize the influence of external variables on blood glucose levels. During the two indoor and two outdoor sessions, the following parameters were assessed:

Blood Pressure (mmHg): baseline systolic and diastolic blood pressures were measured using a digital sphygmomanometer (Erkameter 3000; Erka, Bad Tolz, Germany). Resting values were obtained after a 15 min period of seated rest, before (PRE) the start of each session. Blood pressure was also measured immediately after the end (POST) and at 15 min (POST-15) and 30 min (POST-30) post-sessions. Post-exercise hypotension was calculated as the difference between PRE and POST-30 values and rate pressure product was calculated by multiplying systolic blood pressure by heart rate [34].

Blood Glucose (mg/dL): blood glucose was collected using a FreeStyle Libre system (Abbott Diabetes Care, Alameda, CA, USA). The device consists of a coin-size sensor and a reader similar to a conventional glucometer. The sensor is applied to the skin with a special applicator and worn for up to 14 days, requiring scans every eight hours to continuously monitor glucose levels. The sensor was connected via Bluetooth to the FreeStyle Libre App, allowing real-time transmission of glucose data. Data were subsequently downloaded using FreeStyle Libre computer software (version 2.12). Blood glucose data were collected alongside blood pressure measurements and throughout the exercise sessions. During indoor sessions, glucose readings were taken at the end of each 2 min stage, while for the outdoor sessions, they were recorded every 5 min.

Recovery Index by Ruffier Test: the standard version of the Ruffier test was administered during the session that included the respiratory gas exchange measurements. According to the literature [21], a modified version of the test was also used, incorporating the talk test procedure. In this variation, the participant was asked to recite the paragraph (fully described in Section 2.2) while performing a 45 s squat exercise. Post-exercise, the participant was asked whether they could speak comfortably, choosing one of three possible responses: "yes" (positive), "not sure" (equivocal), or "no" (negative). Additionally, RPE was recorded. To calculate the Ruffier index, indicative of the individual effort tolerance, recovery capacity, and cardiovascular response [35], the participant's heart rate was recorded at three given points: at rest (P1), immediately after the 45 s squat exercise (P2) and one minute after the effort (P3). Ruffier index was calculated according to the formula:

$$\text{Ruffier Index} = [(P1 + P2 + P3) - 200]/10$$

Dietary Measures: to monitor participant eating habits and adherence to the Mediterranean diet, the Italian version of the PREvención con Dieta MEDiterránea (PREDIMED) questionnaire was used [36]. PREDIMED is a 14-item questionnaire in which an adequate consumption of typical traditional Mediterranean foods and low consumption of foods that are not characteristic of the traditional Mediterranean diet adds one point. PREDIMED score was calculated as the sum of all the points attributed to the items. According to the score, adherence was categorized as follows: 0–5, lowest adherence; score 6–9, average adherence; and score $\geq$ 10, highest adherence. PREDIMED was administered before each session. In addition, daily eating behaviors were monitored the day before and the testing day, using a food diary where the participant recorded the time, type, and quantity of food consumed [37].

Sleep Quality: the Pittsburgh Sleep Quality Index (PSQI) was used to assess the participant's sleep quality [38]. PSQI is a self-reported questionnaire evaluating subjective sleep quality and disturbances over the previous month. It includes 19 questions grouped

into seven components: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbance, use of sleeping medications, and daytime dysfunction. Each component is scored on a scale from 0 to 3, with higher scores indicating greater dysfunction. A total score below 5 is indicative of good sleep quality, while scores of 5 or higher suggest poor sleep quality.

Chronotype: the Morningness–Eveningness Questionnaire (MEQ) is one of the most used in chronobiological and chronopsychological research [39]. It consists of 19 mixed-format items designated to assess an individual's preferred timing of daily activities, particularly sleep and wake behaviors. The questionnaire includes both Likert-type and time-based questions. Likert-type items offer four options, with lower scores indicating stronger evening preference. Time-based items are scored based on selected time intervals over a 7-h range, with all responses scored from 1 to 5. The total score is the sum of all item scores and it is used to classify chronotype into 5 categories: definitely morning type (70–86), moderately morning type (59–69), neither type (42–58), moderately evening type (31–41), and definitely evening type (16–30).

Physical Activity Level: the Italian short version (7 items) of the International Physical Activity Questionnaire (IPAQ) was administered to evaluate the individual physical activity level [40]. The IPAQ evaluates the frequency, intensity, and duration of physical activity at various levels, namely, low, moderate, and vigorous, along with total physical activity per week. Additionally, it includes an item regarding daily sitting time to estimate sedentary behaviors [41]. The questionnaire includes both categorical and continuous scores. The categorical scores classify participants into three levels, namely, inactive, minimally active, and health-enhancing physical activity, which denotes activity levels exceeding the minimum public health recommendations, which are associated with greater health benefits. The continuous scores are calculated in metabolic equivalent of task (MET) minutes per week.

Enjoyment: After each session, the participant filled in the Physical Activity Enjoyment Scale (PACES) questionnaire to assess satisfaction with the activity [42]. This questionnaire comprises 5 items evaluated on a seven-point Likert scale (AU). For items 1 and 4, the score ranges from 1 (completely agree) to 7 (completely disagree), while for items 2, 3, and 5, the score ranges from 1 (completely disagree) to 7 (completely agree).

Insulin Intake: During the enrolment and on testing days the participant was asked to track the insulin intake using a diary.

Ruffier test, PREDIMED, PSQI, MEQ, and IPAQ were administered before each session. The total duration of each testing session was approximately 2 h. The timeline of the measurements carried out during the experimental sessions is shown in Figure 2.

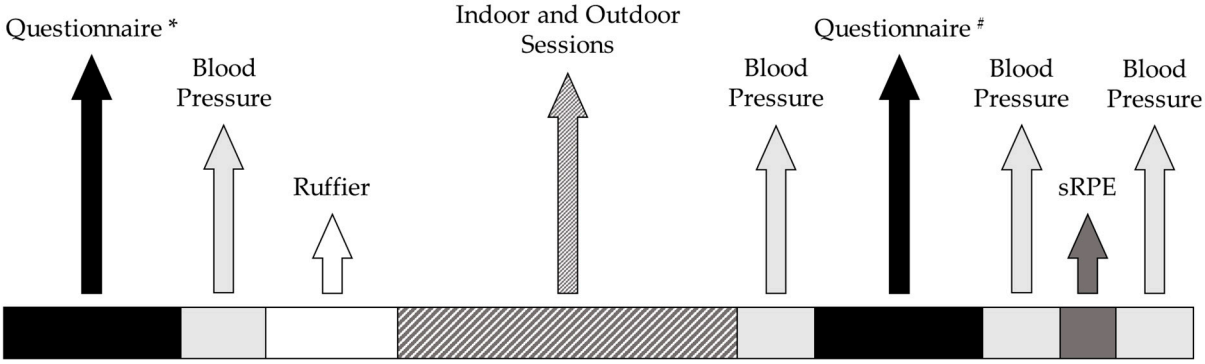

Figure 2. Timeline of the measurements carried out during the experimental sessions. * = PREvención con Dieta MEDiterránea, Pittsburgh Sleep Quality Index, Morningness-Eveningness Questionnaire, International Physical Activity Questionnaire; # = Physical Activity Enjoyment Scale Questionnaire.

2.2.2. Data Extraction and Analysis

To quantify the effect of the exercise intervention on blood glucose levels, raw data from the FreeStyle Libre were downloaded using FreeStyle Libre computer software. The analysis included data from the following days: the enrolment day (control session), during which the participant became familiar with the protocol through a verbal explanation; the familiarization session, aimed at accustoming the participant to the procedures; two indoor sessions and two outdoor sessions.

Data were collected between the end of April (indoor sessions) and the beginning of May (outdoor sessions). The period for the outdoor session was chosen according to the mean temperature and humidity collected during the indoor sessions so that they could be replicated during the outdoor sessions. The time interval analyzed was referred to the testing days, from the first measurement of the day (12:04 a.m.) to the last (11:59 p.m.). According to the literature [7,43] ranges of blood glucose levels were identified as follows:

- >250 mg/dL: Very high;
- 181–250 mg/dL: High;
- 180–70 mg/dL: Normal or Target;
- 54–69 mg/dL: Low;
- <54 mg/dL: Very low.

Data were first analyzed as percentage (%) of the total number identified in the different ranges, then converted in time (hours x day). For the Actigraph data, the raw acceleration data on the three axes (x, y, z) were used to obtain the activity counts for each accelerometer, calculated in 60 s epochs using the ActiLife software (version 6.12.1, ActiGraph, Cary, NC, USA), with the low-frequency extension disabled, and vector magnitude units (VMU) activity counts were calculated as:

$$\text{VMU} = \sqrt{(x^2 + y^2 + z^2)}$$

Energy expenditure and METs were sequentially calculated using algorithms validated by Choi et al. [44] and Freedson et al. [31,45] as follows:

if VMU Counts per Minute were >2453

$$\text{kcal/min} = 0.001064 \times \text{VMU} + 0.087512 \text{ (body mass)} - 5.500229$$

if VMU Counts per Minute were $\leq$2453

$$\text{kcal/min} = \text{Counts per Minute} \times 0.0000191 \times \text{body mass}$$

Paired *t*-test was used to compare the mean glucose concentration between control and outdoor and indoor sessions. Statistical significance was set at $p < 0.05$.

3. Results

The participant weighed 95 kg, had a height of 1.90 m, a BMI of 26.3 kg/m^2, a WHR of 0.98, a basal metabolic rate of 2015 kcal, an average morning blood pressure of 128–81 mmHg, and an average evening blood pressure of 130–88 mmHg, for systolic—diastolic blood pressure, respectively. Data regarding daily caloric intake, adherence to the Mediterranean diet, sleep quality, chronotype, enjoyment across different sessions, and IPAQ parameters are presented in Table 1.

Table 1. Summary of daily dietary intake, and lifestyle-related questionnaires (adherence to a Mediterranean diet, sleep quality, chronotype, enjoyment, and IPAQ) results collected across the experimental sessions.

Daily Dietary Intake		Indoor Session 1	Indoor Session 2	Outdoor Session 1	Outdoor Session 2
CHO (g)		110	196	155	160
PRO (g)		62	72	98	69
FAT (g)		37	24	30	25
Daily Caloric Intake (kcal)		1025	1288	1229	1127
Questionnaire	**Enrolment**	**Indoor Session 1**	**Indoor Session 2**	**Outdoor Session 1**	**Outdoor Session 2**
Mediterranean Diet (AU)	7	8	7	7	7
Sleep Score (AU)	4	3	2	3	4
Chronotype (AU)	63	62	58	58	57
Enjoyment (AU)	N/A	28	20	28	29
IPAQ Parameters					
MET × week (MET)	320	1920	3840	800	1200
Kcal × week (kcal)	1072	4067	8134	2275	2861
Sitting Time (minutes × day)	425	120	150	80	150

CHO: carbohydrates, PRO: proteins; FAT: fats; N/A: not applicable; IPAQ: International Physical Activity Questionnaire; MET: Metabolic Equivalent Task.

According to the VO_2 value achieved during the incremental walking test (45.91 mL/kg/min^{-1}), the participant was classified within the "fair" fitness category [46]. To better quantify the overall workload, VO_2 was also measured during the outdoor session (32.75 mL/kg/min), together with physical activity level data (Table 2).

Table 2. Physical Activity Level data recorded during the outdoor session.

Physical Activity Level	Right Wrist	Left Wrist	Back	Right Waist	Left Waist
METs	6.59	6.57	5.92	3.05	3.32
Energy Expenditure (Kcal)	394	383	375	394	383
Activity counts (counts min^{-1})	3936	3937	3929	4384	3937

METs: Metabolic Equivalent Tasks.

During the outdoor sessions, the hike lasted ~44 min, with the participant reaching 84% of their theoretical HRmax. In comparison, the indoor sessions lasted ~39 min, during which they reached 96% of their theoretical HRmax (Table 3).

Table 3. Psycho-physiological parameters collected during the four experimental sessions.

Psycho-Physiological Parameters	Indoor Session 1	Indoor Session 2	Outdoor Session 1	Outdoor Session 2
Energy Expenditure (kcal)	197	558	553	296
Recovery Index (AU)	1.6	4	3.2	2.8
Mean Heart Rate (beats·min^{-1})	113	126	119	110
Maximum Heart Rate (beats·min^{-1})	196	183	159	170
sRPE (AU)	4	5	4	4

sRPE: session Rating of Perceived Exertion.

Systolic and diastolic blood pressure, heart rate, post-exercise hypotension, and rate pressure product values across the experimental sessions are shown in Table 4.

Table 4. Summary of hemodynamic responses collected across the experimental sessions.

Blood Pressure Measurements		PRE	POST	POST-15	POST-30
Indoor 1	Systolic (mmHg)	131	130	129	130
	Diastolic (mmHg)	88	80	91	86
	Heart Rate (beats·min^{-1})	65	78	75	78
	Post-Exercise Hypotension (mmHg)				1
	Rate pressure product (sBP × HR)				8515
Indoor 2	Systolic (mmHg)	130	129	123	127
	Diastolic (mmHg)	91	92	88	87
	Heart Rate (beats·min^{-1})	65	87	78	82
	Post-Exercise Hypotension (mmHg)				3
	Rate pressure product (sBP × HR)				8547
Outdoor 1	Systolic (mmHg)	131	129	131	128
	Diastolic (mmHg)	79	83	79	77
	Heart Rate (beats·min^{-1})	60	80	68	68
	Post-Exercise Hypotension (mmHg)				3
	Rate pressure product (sBP × HR)				7890
Outdoor 2	Systolic (mmHg)	130	128	121	116
	Diastolic (mmHg)	82	90	84	75
	Heart Rate (beats·min^{-1})	75	91	84	86
	Post-Exercise Hypotension (mmHg)				13
	Rate pressure product (sBP × HR)				9750

sBP: Systolic Blood Pressure, HR: Heart Rate.

Significant ($p < 0.0001$) differences in blood glucose were found between the enrolment day (261.2 ± 3.2 mg/dL) and both indoor (Indoor 1: 206.2 ± 4.1 mg/dL; Indoor 2: 192.1 ± 3.6 mg/dL) and outdoor (Outdoor 1: 163.1 ± 3.1 mg/dL; Outdoor 2: 137.9 ± 3.6 mg/dL) sessions. The percentage (%) of time spent by the participant within different blood glucose ranges during the analyzed days and the number of units of insulin intake of Humalog (30, 16, 23, 29, 25 units/mL) and Tresiba (34 units/mL) along the data collection are presented Figure 3.

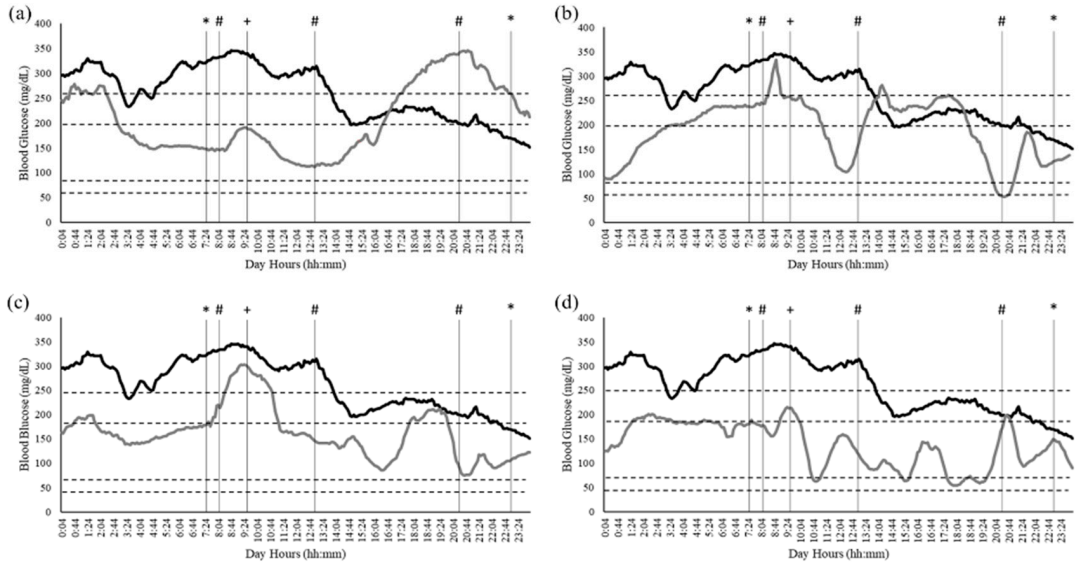

Figure 3. Blood glucose levels in testing days (grey line; (**a**) Indoor Session 1, (**b**) Indoor Session 2, (**c**) Outdoor Session 1, (**d**) Outdoor Session 2) in comparison with the enrolment day (black line). Horizontal dashed lines identify the glucose thresholds and the vertical solid line identifies different time points. * the participant's wake-up (07:20) and fall asleep (23:10) times; # mealtime and insulin injection; + exercise intervention.

4. Discussion

The present study aimed to evaluate the effect of a prolonged exercise intervention on blood glucose regulation in an individual with type 1 diabetes, using a multidimensional approach, in which external variables such as sleep, chronotype, dietary intake, and physical activity levels were monitored. Since type 1 diabetes is a metabolic disease characterized by episodes of hyper- or hypoglycemia which could be influenced by several factors, a multidimensional approach was favored to allow regular control of these parameters, ensuring that the experimental sessions were carried out under consistent conditions. Through this new multidimensional approach, the four sessions were conducted when the participant reported an average/good adherence to the Mediterranean diet [36], a good sleep quality [38], and a chronotype between moderately morning and intermediate [39]. Moreover, in each session, the individual met at least the minimum criteria to be classified as "minimally active" according to the IPAQ [40], while on the enrolment day physical activity levels were lower as confirmed also by high duration in sitting time. The findings of this study demonstrated an improvement in glycemic control in the participant with type 1 diabetes following an intervention that combined aerobic exercise, dietary monitoring, and lifestyle assessment. During the intervention, the participant showed better regulation of blood glucose, with a reduction in % of time spent in hyperglycemic ranges (>250 mg/dL and 181–250 mg/dL) and an increase in the time spent in the target range (70–180 mg/dL). According to the literature [47], reduced time in hyperglycemia may result from enhanced insulin action in muscle and liver, which can be modified by acute and regular bouts of exercise. The literature has shown that aerobic exercise is associated with post-exercise reductions in glycemia in individuals with type 1 diabetes, by improving glucose uptake in skeletal muscle and increasing insulin sensitivity [48]. Riddell and Perkins [49] reported that aerobic exercise, particularly at moderate intensity (30–70% maximum VO_2), is effective in lowering blood glucose by enhancing glucose utilization. These findings suggest that physical activity, particularly walking both outdoors and indoors, combined with controlled external variables, such as sleep quality, chronotype, and diet, could play a critical role in enhancing glycemic regulation. Walking exercise showed potential benefits for glucose regulation, as reflected by the participant's self-adjusted insulin doses in response to real-time glucose levels.

The literature reported a fundamental role of diet, sleep, chronotype, and physical activity levels in blood glucose regulation [32,50,51]. Individuals with type 1 diabetes commonly reported poor sleep quality, irregular sleep patterns, and daytime sleepiness, all of which could negatively affect insulin sensitivity and glucose regulation [52]. Similarly, the circadian system plays a key role in glucose metabolism, with variations in chronotype influencing both dietary habits and physical activity levels [16,37,53]. Adherence to the Mediterranean diet, known for its cardiovascular and metabolic benefits, has been associated with improved glycemic control and reductions in several metabolic risk factors, such as body weight, blood pressure, lipid profiles, and HbA1c [50,54]. Additionally, regular exercise, an integral component at the base of the Mediterranean lifestyle pyramid, enhances insulin sensitivity and glucose uptake, contributing to improved glycemic control [19]. Given the combined influence of these variables, adopting a comprehensive and integrated approach is essential for managing diabetes and improving the overall health and well-being of individuals with the condition.

The findings of the present study highlight the acute and chronic effects of aerobic exercise on glycemic control over the four sessions. The participant's blood glucose levels improved from the enrollment date to the final assessment. The time spent in the blood glucose range >250 mg/dL decreased by 56.46%, while time spent in the range 181–250 mg/dL decreased by 11.67%. These results demonstrate the chronic benefits of aerobic exercise,

due to improved insulin sensitivity, and enhanced glucose uptake by skeletal muscles. The improvement over time reflects the potential long-term efficacy of incorporating structured exercise in diabetes management. Moreover, the trend of insulin intake strengthens the benefits of aerobic exercise on both glycemic control and insulin treatment. In particular, a 13-unit decrease in insulin dosage was observed during the first week. This reduction was accompanied by improved glycemic control, with a decrease in time spent in hyperglycemia and an increase in time in the target range (70–180 mg/dL), suggesting acute and chronic improvements in insulin sensitivity due to the increased glucose utilization induced by exercise.

It is interesting to highlight the effect of aerobic exercise performed at different intensities and in different environments on blood glucose control. While the participant achieved on average 84% of their theoretical HRmax during outdoor sessions compared to 96% during indoor sessions, both modalities were effective in reducing time spent in hyperglycemic ranges and increasing time spent in the target range. Despite the lower intensity, outdoor sessions demonstrated comparable benefits in glycemic control and cardiovascular response, as evidenced by similar outcomes in blood glucose, blood pressure, and recovery index. These findings suggest that individuals can achieve effective glycemic improvements from either exercise modality. Those who prefer outdoor activities, such as hiking, can expect similar improvements in insulin action and blood glucose regulation as those who engage in structured indoor exercises. Therefore, in line with our results and the literature [55], which has shown that outdoor exercise is generally perceived as more enjoyable than indoor activities, promoting outdoor exercises may improve adherence to physical activity routines, particularly for diabetic individuals who find indoor exercise less motivating [56]. This could support the long-term maintenance of exercise-related benefits and provide a sustainable strategy to improve blood glucose regulation.

Limitations and Future Studies

This study presents several limitations that must be acknowledged when interpreting the findings. First, the single-participant case report design limits the generalizability of the results. Although detailed monitoring allowed for an in-depth and individualized analysis, the findings cannot be extrapolated to the broader population of individuals with type 1 diabetes. Moreover, the study did not assess the long-term effects of the intervention. Future studies should investigate whether similar exercise protocols can be sustained over time and contribute to long-term improvements in glycemic control.

In this study, a multidimensional approach was used to evaluate key lifestyle and physiological factors known to influence glycemic control. To this end, several validated instruments were used (e.g., PSQI, PREDIMED, MEQ, IPAQ, dietary intake, and insulin dose management). While these are self-reported measures and may be subject to participant bias, they are widely validated and commonly used in studies involving clinical populations, including individuals with diabetes. Additionally, the participant's daily caloric intake during the monitored sessions was below the estimated basal metabolic rate. Although this was not an intentional component of the study design, it may have influenced various physiological parameters, including glucose fluctuations, physical performance, and recovery. Future research should consider implementing more rigorous control or monitoring of nutritional intake to minimize potential confounding effects.

Building upon the findings of this single-case study, future investigations should aim to include larger sample sizes to improve external validity. Furthermore, alternative assessment methods should be explored. The digitalization of self-reported measures may enhance data reliability through the use of tools such as actigraphy for sleep, continuous glucose and insulin monitoring systems, and digital food tracking platforms. Finally, future

research should aim to confirm the benefits of both indoor and outdoor exercise modalities on glycemic control by including larger and more diverse populations of individuals with type 1 diabetes.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved on 9 June 2021 by the Institutional Review Board of the Department of Human Sciences, Society, and Health of the University of Cassino and Lazio Meridionale (approval Number 6663, 9 June 2021).

Informed Consent Statement: Written informed consent has been obtained from the patient to publish this paper.

Data Availability Statement: Data available in a publicly accessible repository: The original data presented in the study are openly available at https://github.com/ccortis/Dataset (accessed on 5 May 2025).

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

HIIT	High-Intensity Interval Training
WHR	Waist-to-Hip Ratio
RPE	Rate of Perceived Exertion
PREDIMED	PREvención con Dieta MEDiterránea
PSQI	Pittsburgh Sleep Quality Index
IPAQ	International Physical Activity Questionnaire
MeQ	Morningness–Eveningness Questionnaire
sRPE	Session Rate of Perceived Exertion
VO_2	Oxygen Uptake
CAI	Club Alpino Italiano
RER	Respiratory Exchange Ratio
VE	Minute Ventilation
MET	Metabolic Equivalent Task
PACES	Physical Activity Enjoyment Scale
HbA1c	Glycated hemoglobin

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