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Validation and Reliability Protocol of a New Test to Assess Cardiorespiratory Capacity in Brazilian Jiu-Jitsu Practitioners

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Eduardo Baez San Martin¹, Marcelo Tuesta², Ildelfonso Alvear¹

¹Laboratorio de Fisiología Aplicada (FISAP), Instituto de Biomedicina (IBIOMED), Universidad de León, España.;

²Exercise and Rehabilitation Sciences Laboratory, School of Physical Therapy, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago, Chile.



Eduardo Baez San Martin

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Protocol status: Working

We use this protocol and it's working

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Keywords: Cardiorespiratory Fitness, Martial Arts, Oxygen Consumption, Exercise Test, assessing cardiorespiratory capacity, cardiorespiratory capacity in brazilian jiu, cardiorespiratory capacity, cardiorespiratory capacity under field condition, jitsu practitioners this protocol, jitsu athlete, jitsu practitioners of various level, jitsu practitioner, physiological variables such as heart rate variability, heart rate variability, muscle oxygenation, physiological variable, performance evaluation, reproducible tool for performance evaluation, reliability

Abstract

This protocol aims to validate and verify the reliability of a test designed to assess cardiorespiratory capacity in Brazilian Jiu-Jitsu practitioners of various levels. The test incorporates a sequence of standardised guard-passing movements, which simulate the realistic demands of the sport. At the same time, physiological variables such as heart rate variability, muscle oxygenation, and lactate concentration are measured. The expected outcome is that the test will be valid and reliable for assessing cardiorespiratory capacity under field conditions, offering a practical and reproducible tool for performance evaluation in Brazilian Jiu-Jitsu athletes.

Attachments



[BJJ-CRFT Script.txt](#)

OB

Guidelines

1. Ethical Guidelines:

- **Declaration of Helsinki:** Ensure compliance with the ethical principles for medical research involving human subjects as set out in the Declaration of Helsinki. This includes obtaining informed consent from participants and ensuring their well-being throughout the study.
- **Ethics Committee:** Verify that a recognised ethics committee approves the protocol. Ensure any modification or relevant incident during the study is reported to the committee.
- **Participant Confidentiality:** Protect the subjects' identities and personal data. Ensure that the collected information is handled under strict privacy policies.

2. Data Quality Standards:

- **Equipment Calibration:** Ensure that all equipment (scales, lactate meters, heart rate monitors) is correctly calibrated before each testing session to obtain accurate and reproducible measurements.
- **Pre-Testing Verification:** Conduct pilot tests or checks to ensure the entire analysis system works correctly, including synchronising continuous monitoring systems (ventilatory gases, heart rate).

3. Experimental Protocol:

- **Control of Environmental Conditions:** Keep the testing environment under controlled conditions (temperature, humidity) to avoid external factors affecting the results. The laboratory needs to have a stable and regulated environment.
- **Standardisation of Procedures:** Ensure that procedures follow the same order and are applied similarly for each participant. This includes rest periods, auditory signals, and sensor positioning.
- **Participant Fasting and Condition:** Ensure that participants follow pre-test instructions, such as fasting for a minimum of three hours and abstaining from intense physical exercise for 24 hours prior to the tests.

4. Participant Safety:

- **Medical Supervision:** Consider having medical personnel available during the tests, especially during the maximal incremental test, to intervene in case of emergency or extreme fatigue.
- **Continuous Monitoring:** During the tests, continuously monitor critical parameters such as heart rate, oxygen saturation, and perceived exertion to prevent risks of overload or excessive exhaustion.
- **Rest and Safety:** Provide adequate rest periods during evaluations and observe if participants show signs of fatigue. They should be able to withdraw from the study if they feel their health is compromised.

5. Data Analysis and Reporting:

- **Rigorous Data Collection:** All data must be recorded accurately and without bias. Measures should be taken to minimise measurement or data entry errors.

- **Reviews and Verifications:** Ensure that all collected data undergoes a quality review before statistical analysis. This includes detecting outliers, missing values, or inconsistencies.
- **Transparency in Result Reporting:** Study results should be reported objectively without omitting unfavourable outcomes. Any study limitation should be acknowledged and discussed in the final report.

Materials

Electronic scale (SECA, model 803).

Portable stadiometer (SECA, model 213).

HR10 heart rate monitor band (Polar, Kempele, Finland).

Kubios HRV Scientific software (version 4.1.0, Kubios Oy, Kuopio, Finland).

Treadmill (Runrace, Technogym, Italy).

Moxy Monitor (Fortiori Design LLC, Minnesota, USA).

Cortex Metalyzer 3B ventilatory gas analyzer (Cortex Biophysik, Leipzig, Germany).

Lactate meter (Lactate PRO2, ARKRAY, Kyoto, Japan).

Rating of Perceived Exertion (RPE) scale (0-10).

Safety warnings

! Warnings Related to Participant Safety:

1. Risk of Injury or Overexertion During Testing:

- **Warning:** Since the protocol includes maximal effort tests, such as the incremental cardiopulmonary exercise test (CPET) and the Brazilian Jiu-Jitsu Fitness Test (BJJ-CFRT), there is a significant risk of physical overload, extreme fatigue, or even muscle or joint injuries.
- **Preventive action:** Researchers should be vigilant for any signs of fatigue, discomfort, or pain in participants. Testing should be immediately stopped if a participant shows symptoms such as dizziness, disorientation, sharp pain, or breathing difficulties. A clear emergency action plan and a medical professional or first aid team on site is essential.

2. Cardiovascular Complications:

- **Warning:** Maximal incremental exercise tests may pose a cardiovascular risk, particularly if a proper medical assessment has not been conducted beforehand.
- **Preventive action:** Prior to testing, a medical assessment that includes a detailed medical history and, if necessary, preliminary tests such as a resting electrocardiogram is essential to ensure participants do not have underlying heart conditions that could be exacerbated by high-intensity exercise. A clear limit for maximum heart rate should also be established using the formula $HR_{max} = (220 - \text{age})$.

3. Risks Associated with the Lack of Medical Supervision:

- **Warning:** The absence of medical personnel on-site during effort tests may delay necessary intervention in a medical emergency.
- **Preventive action:** The protocol must require the mandatory presence of a sports physician or a healthcare professional capable of performing first aid and using an automated external defibrillator (AED). At least one researcher should be certified in first aid and CPR without medical personnel.

Warnings Related to Data Validity:

1. Equipment Calibration Errors

- **Warning:** Lack of calibration or malfunction of the equipment (scales, ventilatory gas analysers, oxygen sensors) can lead to inaccurate or invalid data.
- **Preventive action:** All equipment must be precisely calibrated before each testing session. Any technical issues detected during calibration or testing should be corrected immediately, and faulty equipment should be replaced if they recur. Record all calibrations to ensure rigorous quality control.

2. Variable Environmental Conditions:

- **Warning:** Variations in environmental conditions (temperature, humidity) during testing can affect results, especially in endurance or prolonged effort tests.
- **Preventive action:** Keep the laboratory at a controlled and constant temperature (approximately 20–22°C) and record environmental conditions during each session. These should be considered when

analysing the results if significant fluctuations are observed.

3. Cumulative Fatigue in Participants:

- **Warning:** Participants may experience cumulative fatigue if tests are conducted too close together, which could affect the results of subsequent evaluations.
- **Preventive action:** As stipulated in the protocol, ensure adequate recovery time between testing sessions (a minimum of 7 days between tests). If participants show signs of prolonged fatigue, rescheduling the tests should be considered.

Warnings Related to Participants:

1. Failure to Follow Pre-Test Instructions:

- **Warning:** Participants who do not adequately follow pre-test instructions (such as the required three-hour fast or abstaining from intense physical exercise) may alter test results and increase the risk of adverse effects.
- **Preventive action:** Before each test, researchers should verbally confirm with participants that they have followed the pre-test instructions. If they have not, postponing the test or performing an additional evaluation to determine if it is safe to proceed should be considered.

2. Participants with Undeclared Health Conditions:

- **Warning:** Participants who do not adequately disclose their health status (e.g., use of medications or supplements, recent injuries) could put their safety at risk and affect the study's validity.
- **Preventive action:** Conduct a detailed medical interview before the start of the study and request that participants inform researchers of any changes in their health status or medication use during the study period. Implement a health status update form to ensure participants' conditions are appropriately monitored throughout the study.

Warnings Related to Protocol Execution:

1. Failure to Strictly Follow the Protocol

- **Warning:** Deviating from protocol procedures (such as altering rest times, changing exercise cadence, or using different equipment) may compromise the validity and reproducibility of the results.
- **Preventive action:** Researchers must rigorously follow the protocol and document minor modifications or unforeseen events during testing sessions. If adjustments to the protocol are necessary, they should be documented and justified.

2. Lack of Control over Voluntary Fatigue:

- **Warning:** In the Brazilian Jiu-Jitsu Fitness Test (BJJ-CFRT), participants may overestimate their ability to continue, leading to dangerous fatigue levels.
- **Preventive action:** Researchers should carefully monitor participants' perceived exertion (RPE) and heart rate to intervene before subjects reach dangerous levels of fatigue. Clear cut-off points should be established to stop the test if a participant shows signs of extreme exhaustion.



Warnings Related to Data Analysis:

1. Inaccurate Interpretation of Results

- **Warning:** Misinterpreting results, such as incorrectly identifying VO₂max or ventilatory thresholds, can lead to incorrect conclusions about participants' performance and physical capacity.
- **Preventive action:** Ensure researchers perform data analysis experienced in effort tests and ventilatory gas analysis. Use reliable analysis software and review results multiple times before drawing definitive conclusions.

Ethics statement

The research protocol was approved by the Scientific Ethics Committee of the Universidad de Playa Ancha (approval record No. 20-2023) and was conducted in accordance with the ethical guidelines of the Declaration of Helsinki.

Participant Familiarization with the Brazilian Jiu-Jitsu Cardiorespiratory Fitness Test

3d

1 General Explanation of the Test:

6h

Objective: Before starting the test, researchers must provide participants with a clear and detailed explanation of the purpose of the Brazilian Jiu-Jitsu Cardiorespiratory Fitness Test (BJJ-CRFT). This explanation should be comprehensive, ensuring participants understand that the test evaluates physical fitness related to Brazilian Jiu-Jitsu performance through a progressive sequence of technical movements (guard passes).

Test structure: The test's structure must be explained, including five stages with progressive increases in the number of guard passes and the movement cadence (Figure 1). The familiarisation process, a crucial step in ensuring the participants' understanding and comfort, should address the details of each stage.

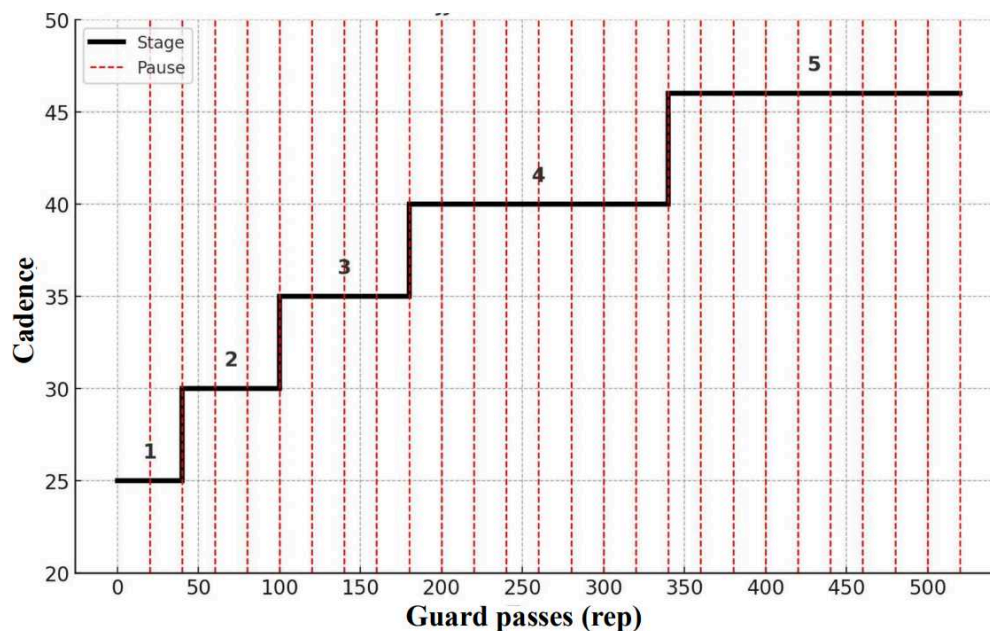


Figure 1. BJJ-CRFT Protocol

Practical Demonstration of the Movements:

The protocol consists of guard pass movements commonly used in BJJ training. The sequence of movements is divided into three positions: initial position (Figure 2 A),

guard pass (Figure 2 B), and return to the initial position (Figure 2 C). A practical demonstration of these movements must be provided. The test is based on a classic multi-stage fitness test. The test involves repeating sequences of 20 guard passes, separated by 5-second pauses. As the test progresses, the volume of completed sequences and the cadence of movements will increase.

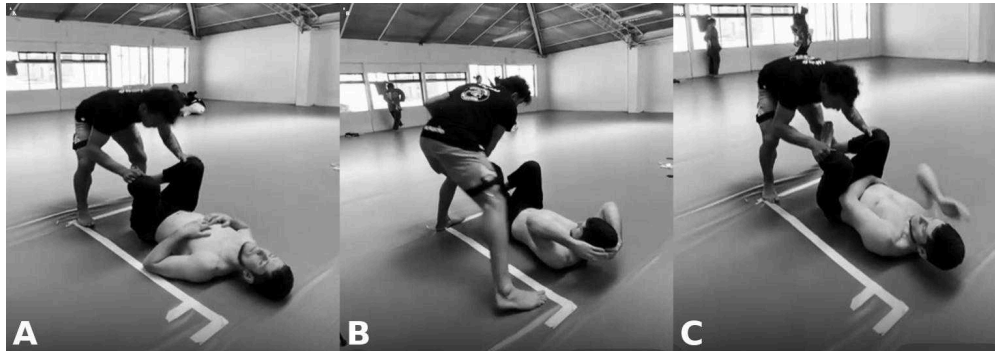


figure 2. Sequence of guard passes in BJJ-CRFT

Citation

Bangsbo, J. laia, F. M. Krstrup, P. (2008)
. The Yo-Yo intermittent recovery test : a useful tool for evaluation of physical performance in intermittent sports.
Sports medicine.

[10.2165/00007256-200838010-00004](https://doi.org/10.2165/00007256-200838010-00004)

[LINK](#)

Citation

Chaabène H, Hachana Y, Franchini E, Mkaouer B, Montassar M, Chamari K (2012)
. Reliability and construct validity of the karate-specific aerobic test.

<https://doi.org/10.1519/JSC.0b013e31824eddda>

[LINK](#)

Guard pass demonstration: Researchers should physically demonstrate the specific guard pass movements used in the test. The demonstrations should focus on proper posture, range of motion, and technique to avoid injuries.

Safety zone: Participants should know the 20 cm "safety zone" they must reach with their leading leg during each guard pass. The importance of reaching this zone to complete the test correctly should be emphasised (image 1).

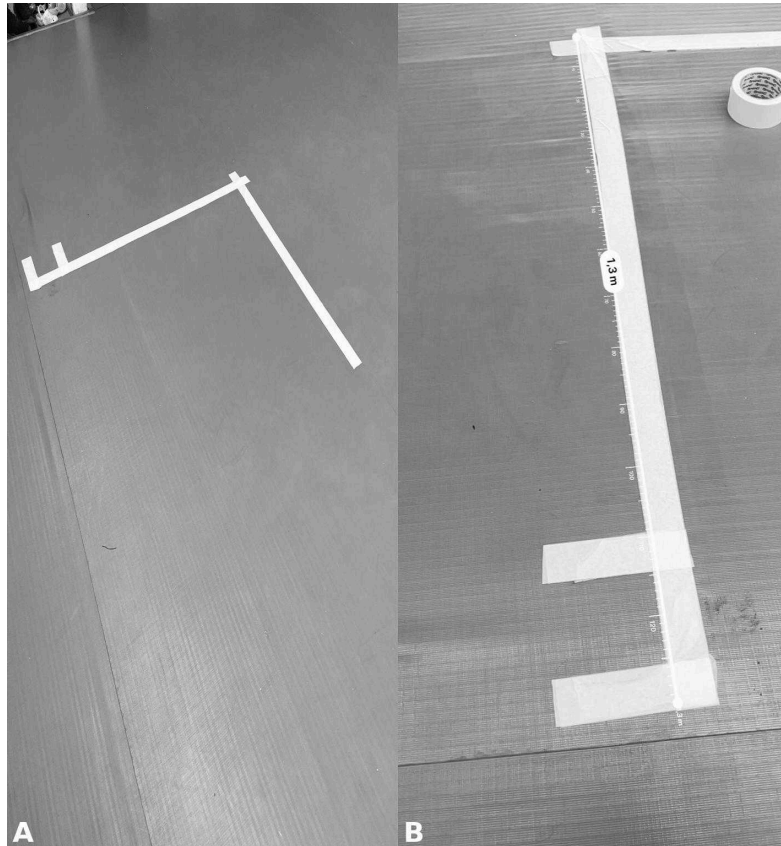


image 1. Safety zone

Auditory signals: The auditory signals were pre-programmed using the Team-Beep-Test Software. The researcher must explain how the auditory signals will indicate the start and pace of each stage and ensure that participants understand how to follow the progressive rhythm of the test.

Software

Team-Beep-Test Software

NAME

Bitworks

DEVELOPER

<https://www.topendsports.com/testing/team-beeptest/index.htm> SOURCE LINK

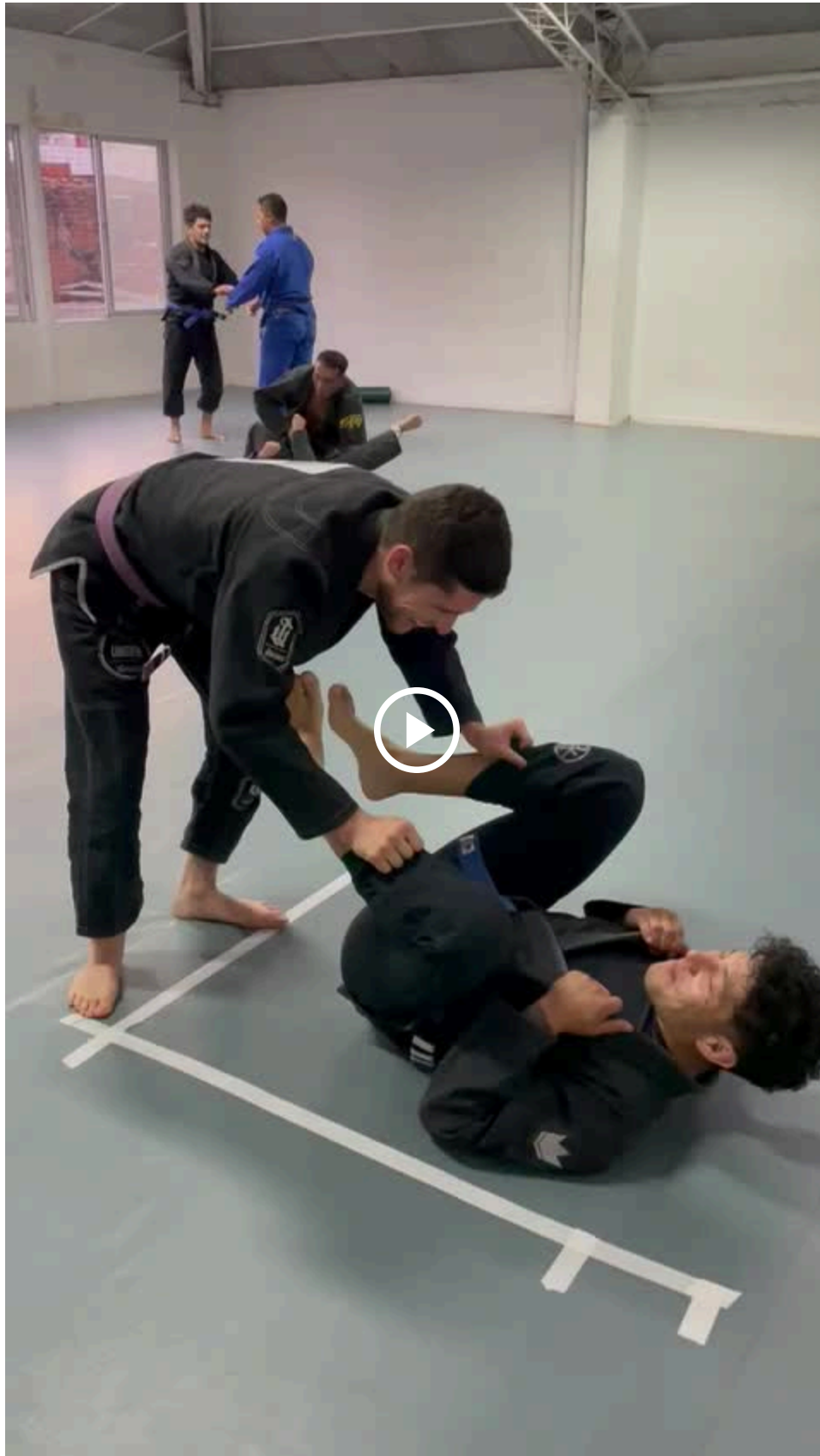


BJJ-CRFT Script.txt

Supervised Practice:

Practice session: Participants should perform one or more practice sessions under the supervision of the researchers. In this practice, they should complete several guard pass sequences at a speed similar to the actual test, starting with the lower-intensity initial stages.

Technique correction: During this practice, researchers should correct any errors in movement technique to ensure participants perform the test correctly and without injury risk.



Adjustment to Cadence and Progression:

Familiarisation with progressive cadence: Participants must experience the progression of movement cadence. They should start with the lowest cadence (25 passes per minute in the first stage) and progressively increase. They should practice with each cadence to adapt to the increasing pace and workload.

Personal pace adjustment: During familiarisation, participants should learn to find a movement pace appropriate to their physical capacities, allowing them to complete each stage without premature overload.



Simulation of Completion Criteria:

Completion criteria: The criteria for terminating the test should be explained: (i) inability to maintain the pace dictated by the auditory signal, (ii) three consecutive failures to reach the safety zone, or (iii) voluntary fatigue.

Completion simulation: During practice, participants should simulate situations in which they cannot maintain the pace or reach the safety zone so they understand when to stop the test.

Perceived Exertion Control:

Rating of Perceived Exertion (RPE) scale: Participants should be introduced to the Rating of Perceived Exertion (BORG-CR10) scale, which will be used during the test to measure their subjective fatigue. They should familiarise themselves with the scale and practice reporting their exertion levels at each test stage.

Addressing Questions:

Q&A session: A session should be offered where participants can ask questions regarding the movements, test pace, or measurements. Ensure that no doubts remain before the official test begins.

Acclimatisation to Equipment:

Use of measurement equipment: Participants should also become familiar with the equipment they will use during the test (heart rate monitor band, muscle oxygen saturation sensors). This step includes how the devices will be placed and how they will function during the test to avoid interfering with their performance.



Data Collection: Brazilian Jiu-Jitsu Cardiorespiratory Fitness Test.

1.1 Anthropometric Measurements:

3m

Body weight will be measured while standing using a calibrated electronic scale. Participants will wear bare feet, minimal clothing, and no personal belongings to ensure accuracy. Height will be measured in a standing position using a portable stadiometer. Participants will maintain an upright posture, with heels together and the head aligned according to the Frankfort plane.

Equipment

body weight scale 803

NAME

Anthropometric measurements

TYPE

SECA

BRAND

003

SKU

https://www.seca.com/en_ee/products/all-products/product-details/seca803.html

LINK

Capacity: 150 kg, Graduation (g): 100 g, Measure (W x H x D): 316 × 37 × 326 mm, Net weight: 1.5 kg

SPECIFICATIONS



Equipment

Stadiometer 213

NAME

Anthropometric measurements

TYPE

SECA

BRAND

002

SKU

https://www.seca.com/en_ee/products/all-products/product-details/seca213l.html

LINK

Measuring range in cm: 20 - 205, Graduation [Measuring Rod]: 1 mm,
Measure (W x H x D): 337 × 2.130 × 590 mm, Net weight: 2.4 kg

SPECIFICATIONS

1.2 Resting Lactate Measurement:

5m

In this step, resting lactate levels will be assessed before starting the exercise tests. A capillary blood sample will be taken from the participant's earlobe to measure resting lactate. The procedure will be as follows:

- **Cleaning area:** The earlobe will be disinfected with an isopropyl alcohol wipe to ensure asepsis (image 2).



image 2. Cleaning area.

Capillary puncture: A small puncture will be made in the earlobe using a sterile lancet (image 3).



image 3. Capillary puncture

Sample collection: A drop of blood will be collected on a test strip, which will be inserted into the lactate meter (Lactate PRO2, ARKRAY, Kyoto, Japan) to determine the resting lactate concentration (image 4).

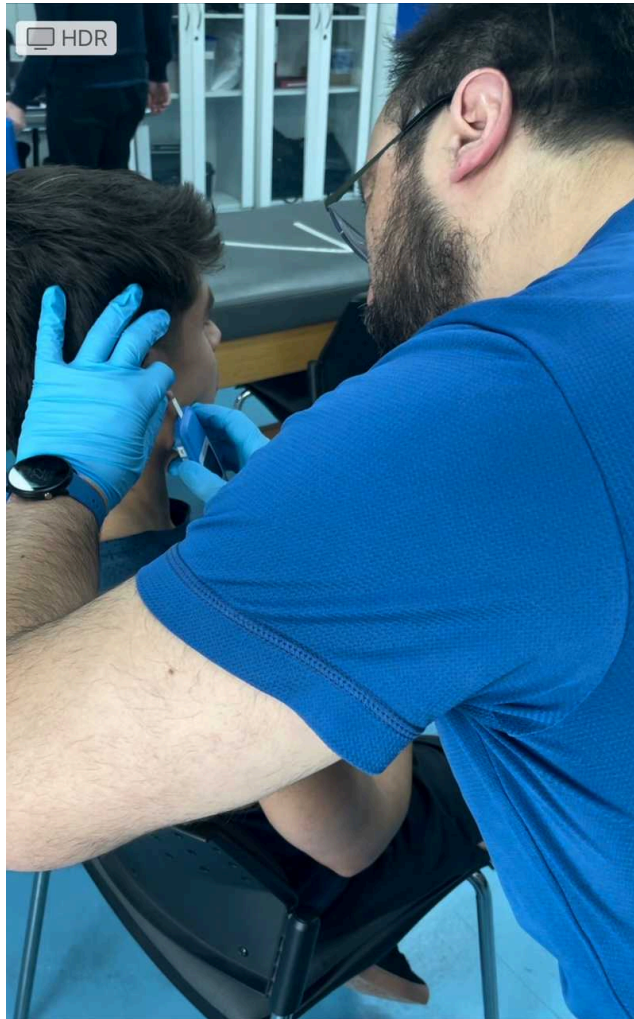


image 4. Sample collection

Equipment

Lactate Pro 2 LT - 1730

NAME

Blood lactate meter

TYPE

ARKRAY

BRAND

005

SKU

<https://www.arkray.eu/english/products/lt-1730.html>

LINK

Sample: Fresh capillary whole blood, Sample size: 3 µL, Test strips: Lactate Pro 2 test strip, Test range: 0.5 - 25.0 mmol/L, Test time: 15 seconds, Dimensions: 50 mm (W) x 100 mm (H) X 12 mm (D)

SPECIFICATIONS

 FILE



1.3 Heart rate variability and Muscle Oxygenation:

20m

Next, heart rate variability (HRV) at rest will be assessed. Participants will remain in a supine position for five minutes. Autonomic balance and resting muscle oxygenation, during which R-R intervals will be recorded using an HR10 heart rate monitor (Polar, Kempele, Finland). Before the measurement, the heart rate monitor will be installed. The heart rate monitor strap will be placed firmly around the participant's chest, just below the sternum, ensuring the sensors have good contact with the skin (image 5). The strap's electrodes will be slightly moistened to improve conductivity and ensure accurate capture of R-R intervals. Before starting the measurement, the device will be checked to confirm that data is transmitted correctly to the recording system.

Heart rate variability will be measured to assess autonomic balance at rest. This variable is important for the reproducibility of measurements on different days.



image 5. Installation of the heart rate strap

Equipment

HR10 Sensor

NAME

heart rate monitor

TYPE

POLAR

BRAND

004

SKU

<https://www.polar.com/us-en/sensors/h10-heart-rate-sensor>

LINK

Bluetooth version: BLE, ANT version: 2.1, USB cable: No, Broadcast range: 9000 cm, CPU speed: 64 MHz, Memory: MB, Storage: MB, Recording mode: Yes, Width: 65 mm, Height: 34 mm, Thickness: 10 mm, Total weight: 60 g.

SPECIFICATIONS



Software

Kubios HRV Scientific

NAME

Kubios Oy

DEVELOPER

<https://www.kubios.com/hrv-scientific/>

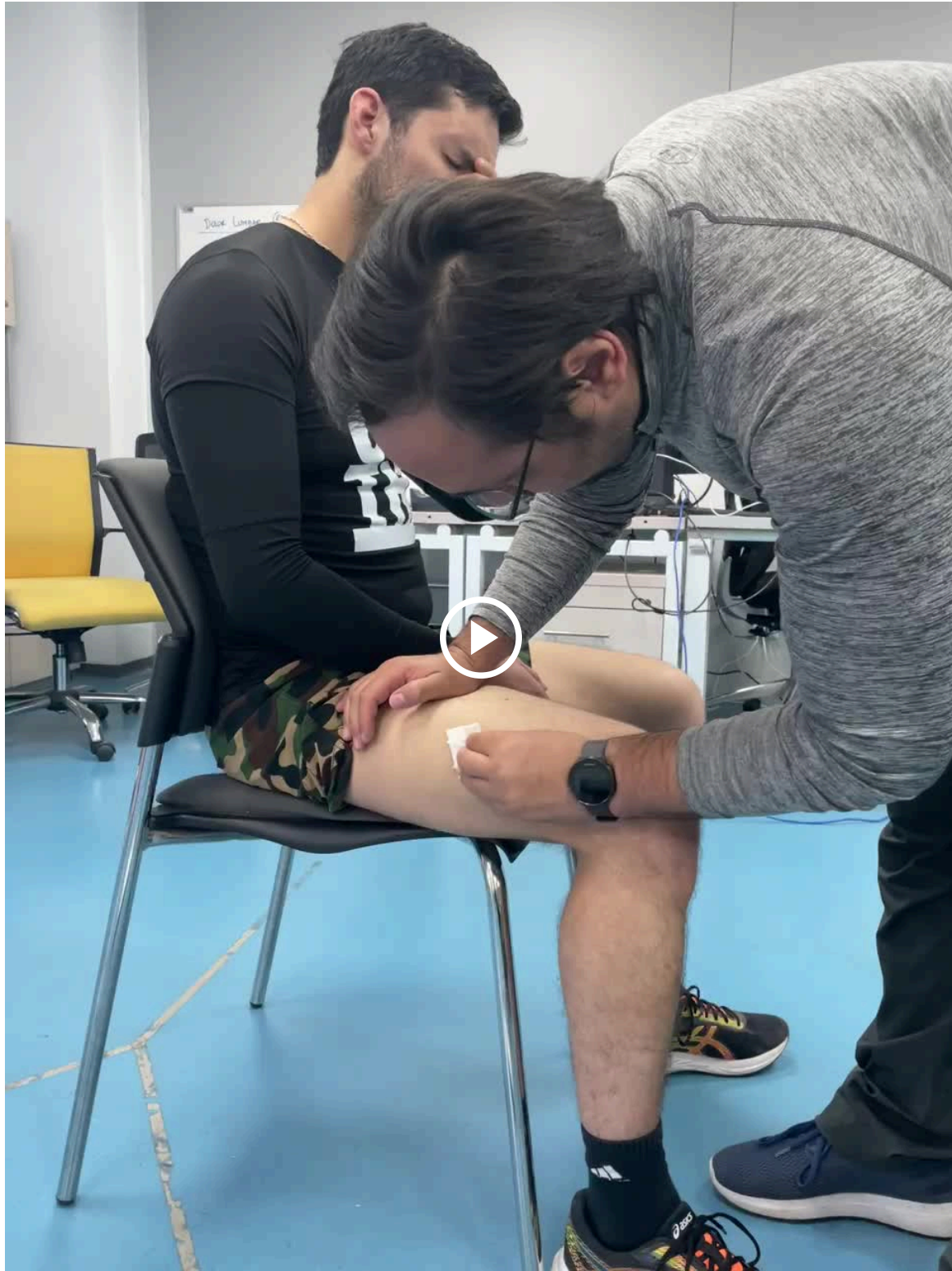
SOURCE LINK

Moxy Monitor Installation and Muscle Oxygenation Measurement:

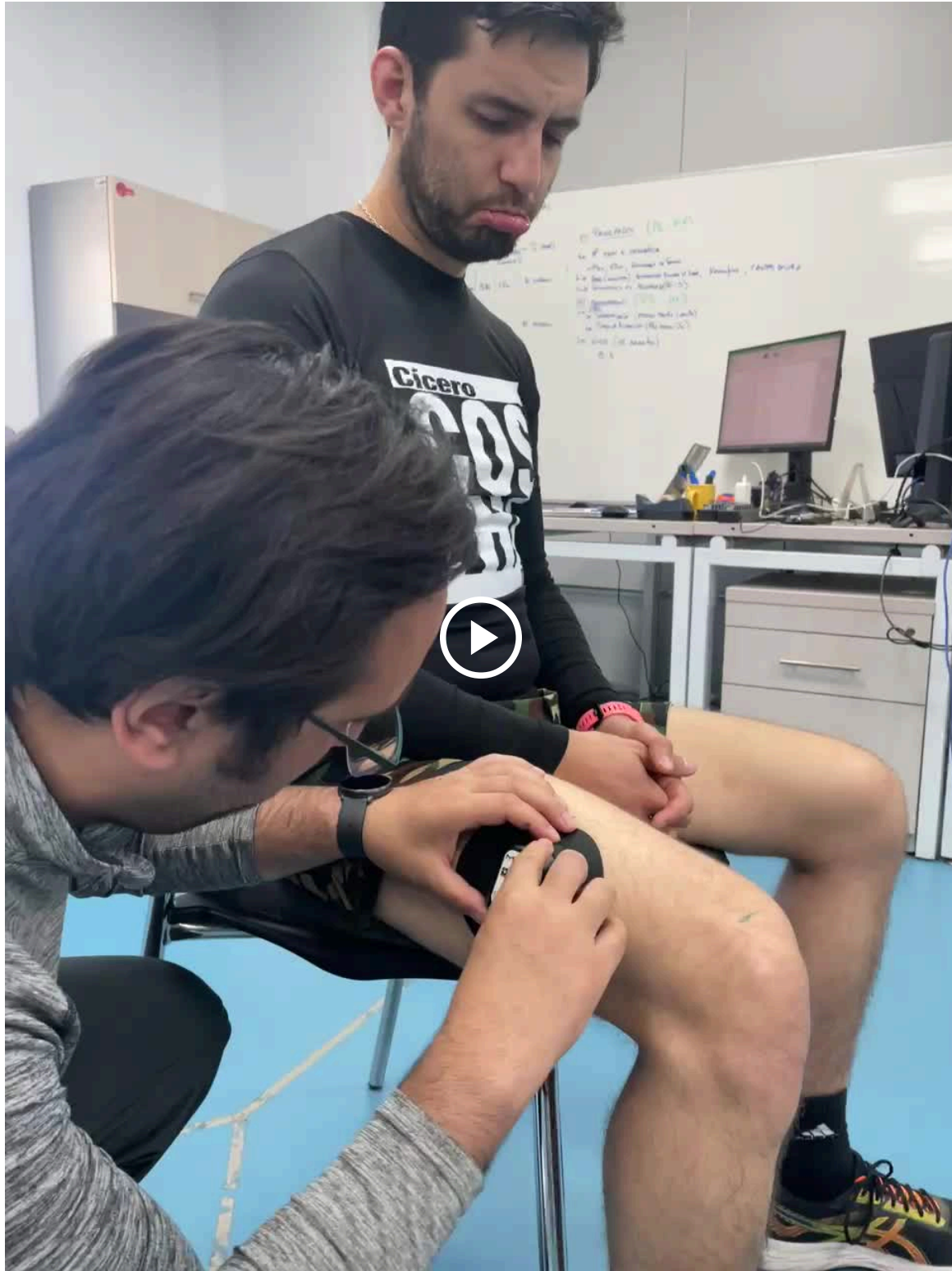
Next, the Moxy Monitor will be installed to measure muscle oxygenation in the vastus lateralis muscle.

Equipment		
Moxy monitor		NAME
Muscle oxygen saturation (SmO2) in real time, using near-infrared spectroscopy (NIRS) technology.		TYPE
MOXY		BRAND
001		SKU
Depth: Measures through up to 15mm of skin and fat, Update Rate: 0.5 Hz to 2 Hz, Smoothing: 10 seconds or None, Physical Size (with Light Shield): 128 × 115 x 30 mm, Weight (with Light Shield): 59 g, Environment: 40°F (15°C) to 95°F (35°C) ambient con		LINK
PNG 		

Skin preparation: Before placing the monitor, the vastus lateralis area will be cleaned with an alcohol wipe to ensure the skin is free of sweat or oils, which could interfere with the device's readings.



Moxy Monitor placement: The Moxy sensor will be placed in a central point of the vastus lateralis muscle of the participant's dominant leg.



Adjustment and fixation: The sensor will be secured using hypoallergenic medical tape or an elastic band. The fixation should be firm but comfortable for the participant, ensuring the sensor maintains good skin contact.



Signal verification: The signal from the Moxy sensor will be checked to ensure proper transmission to the receiving device (via ANT+ or Bluetooth), ensuring that muscle oxygen saturation (SmO₂) and total hemoglobin (THb) data are recorded correctly.

Resting muscle oxygenation measurement: Once the sensor is installed and signal transmission is verified, the resting muscle oxygenation measurement will be performed for approximately 5 minutes (image 6). The collected data will include muscle oxygen saturation (SmO₂) and total hemoglobin (THb) levels, providing information about the muscle's oxygenation status at rest.



figure 4. Autonomic balance and resting muscle oxygenation

1.4 Brazilian Jiu Jitsu Cardiorespiratory Fitness Test:

BJJ-CRFT will be conducted in this step to assess the participants' cardiorespiratory capacity. The test will consist of a progressive sequence of guard-passing movements performed with increasing cadence under controlled conditions.

BJJ-CRFT Application:

Participants will begin the test from the initial position and perform sequences of guard-passing movements. The test will consist of repeating sequences of 20 movements, with brief pauses between sequences, while the cadence increases progressively. Researchers will closely monitor physiological variables and the participant's response. The test will conclude when any of the termination criteria is met.

Test Termination Criteria:

The test will be terminated when at least one of the following criteria is met:

- **Inability to maintain the cadence:** The participant will be unable to sustain the pace set by the auditory signal, which dictates the cadence of the movements.
- **Three consecutive failures to reach the safety zone:** The safety zone, located 110 cm from the starting zone (initial position), must be reached with the leading leg in each guard pass movement. Three consecutive failures to reach this zone will terminate the test.
- **Voluntary fatigue:** The participant can voluntarily stop the test by reporting fatigue using the Rating of Perceived Exertion (BORG-CR10) scale.

Criteria for Considering the Test as Maximal Effort:

The test will be considered a maximal effort if at least one of the following criteria is met:

- **Maximum heart rate (HR_{max}):** Achieving a maximum heart rate within ten beats per minute of the theoretical maximum, calculated using the $HR_{max} = (220 - \text{age})$ formula.
- **Capillary lactate concentration ≥ 8.0 mmol/L:** A post-exercise lactate sample will be taken, and if levels exceed this threshold, the test will be considered maximal.



Citation

R. Beneke, R. M. Leithäuser and O. Ochentel (2011)
. Blood Lactate Diagnostics in Exercise Testing and Training.
International Journal of Sports Physiology and Performance.

<https://doi.org/10.1123/ijsp.6.1.8>

LINK

Recorded Variables During the Test:

During the BJJ-CRFT, the following key physiological variables will be recorded:

- **Heart rate and heart rate variability (HRV):** Heart rate and HRV will be measured in real-time using an HR10 heart rate monitor (Polar, Kempele, Finland).
- **Muscle oxygen saturation:** Muscle oxygen saturation in the vastus lateralis will be measured using the Moxy Monitor (Fortiori Design LLC, Minnesota, USA), allowing real-time monitoring of muscle oxygenation during the movements.
- **Peak post-exercise lactate:** One minute after the test, a capillary lactate sample will be collected using the Lactate PRO2 meter (ARKRAY, Kyoto, Japan) to measure peak lactate levels.
- **Rating of Perceived Exertion (BORG-CR10):** The participants' subjective perception of effort will be recorded using a scale from 0 to 10, where 0 indicates "no effort" and 10 indicates "maximum effort."

- 1.5 To ensure the test's reliability, steps 1.1, 1.2, 1.3, and 1.4 must be repeated one week after the initial measurement under similar environmental and experimental conditions. Includes maintaining consistent factors such as temperature, humidity, time of day, and subject preparation, which are crucial for minimising variability. Repeating the test under these controlled conditions allows for the assessment of test-retest reliability, ensuring that any observed changes in the data are due to true physiological variations rather than external influences or measurement inconsistencies.

53m



Data Collection: Cardiopulmonary exercise test

1h 3m

- 2 Participant Preparation Participants will attend the laboratory in the morning after a minimum three-hour fast and avoid intense physical activity for 24 hours prior, ensuring standard conditions for the cardiopulmonary exercise test (CPET).



2.1 Anthropometric Measurements:

3m

Body weight will be measured while standing using a calibrated electronic scale. Participants will wear bare feet, minimal clothing, and no personal belongings to ensure accuracy. Height will be measured in a standing position using a portable stadiometer. Participants will maintain an upright posture, with heels together and the head aligned according to the Frankfort plane.

2.2 Resting Lactate Measurement:

5m

In this step, resting lactate levels will be assessed before starting the exercise tests. A capillary blood sample will be taken from the participant's earlobe to measure resting lactate. The procedure will be as follows:

- **Cleaning area:** The earlobe will be disinfected with an isopropyl alcohol wipe to ensure asepsis.
- **Capillary puncture:** A small puncture will be made in the earlobe using a sterile lancet.
- **Sample collection:** A drop of blood will be collected on a test strip, which will be inserted into the lactate meter (Lactate PRO2, ARKRAY, Kyoto, Japan) to determine the resting lactate concentration.

2.3 Heart rate variability and Muscle Oxygenation:

20m

Next, heart rate variability (HRV) at rest will be assessed. Participants will remain in a supine position for five minutes. Autonomic balance and resting muscle oxygenation, during which R-R intervals will be recorded using an HR10 heart rate monitor (Polar, Kempele, Finland). Before the measurement, the heart rate monitor will be installed. The heart rate monitor strap will be placed firmly around the participant's chest, just below the sternum, ensuring the sensors have good contact with the skin (image 5). The strap's electrodes will be slightly moistened to improve conductivity and ensure accurate capture of R-R intervals. Before starting the measurement, the device will be checked to confirm that data is transmitted correctly to the recording system. Heart rate variability will be measured to assess autonomic balance at rest. This variable is important for the reproducibility of measurements on different days.

Moxy Monitor Installation and Muscle Oxygenation Measurement:

Next, the Moxy Monitor will be installed to measure muscle oxygenation in the vastus lateralis muscle.

- **Skin preparation:** Before placing the monitor, the vastus lateralis area will be cleaned with an alcohol wipe to ensure the skin is free of sweat or oils, which could interfere

with the device's readings.

- **Moxy Monitor placement:** The Moxy sensor will be placed in a central point of the vastus lateralis muscle of the participant's dominant leg.
- **Adjustment and fixation:** The sensor will be secured using hypoallergenic medical tape or an elastic band. The fixation should be firm but comfortable for the participant, ensuring the sensor maintains good skin contact.
- **Signal verification:** The signal from the Moxy sensor will be checked to ensure proper transmission to the receiving device (via ANT+ or Bluetooth), ensuring that muscle oxygen saturation (SmO₂) and total hemoglobin (THb) data are recorded correctly.
- **Resting muscle oxygenation measurement:** Once the sensor is installed and signal transmission is verified, the resting muscle oxygenation measurement will be performed for approximately 5 minutes (figure 4). The collected data will include muscle oxygen saturation (SmO₂) and total hemoglobin (THb) levels, providing information about the muscle's oxygenation status at rest.

2.4 Calibration of metabolic cart:

Before each evaluation, it is crucial to calibrate the metabolic cart (Metalyzer 3B, Cortex-Medical, Germany) ergospirometer to ensure accurate measurements of ventilatory gases and volume. The calibration process consists of the following steps:

Atmospheric pressure calibration:

Before starting each evaluation, the atmospheric pressure calibration will be performed on the Metalyzer 3B ergospirometer. To do the device must be turned on and properly connected. The procedure will follow these steps:

- Access the Metalyzer calibration menu and select the atmospheric pressure calibration option.
- Verify the current atmospheric pressure using an external barometer.
- Manually enter the atmospheric pressure value into the Metalyzer software, or if the device has the function, allow it to adjust the value automatically.
- Confirm that the calibration has been successful and that the values match the current environmental conditions.

Gas Calibration:

- The gas analyser will be calibrated using a known reference gas mixture (e.g., 15% O₂ and 5% CO₂).
- Connect the gas tank to the metabolic cart and allow the analyser to sample the reference gas for a few minutes.

5m



- Verify that the measured gas concentrations match the known values of the reference mixture and adjust if necessary.

Volume Calibration:

- A 3-litre calibration syringe will be used to verify the accuracy of the volume measurements.

The syringe will be connected to the metabolic cart, and a series of strokes (pushing and pulling the syringe) will be performed at varying flow rates.

- The metabolic cart will compare the injected volumes with the actual readings to ensure they are within the acceptable range.
- Performing gas and volume calibration is essential before each test to ensure the reliability and accuracy of the measurements during the CPET.

Equipment

METALYZER® 3B

NAME

Metabolic cart

TYPE

CORTEX

BRAND

010

SKU

<https://cortex-medical.com/EN/METALYZER-3B-en.htm>

LINK

O2 Sensor · type: electro-chemical fuel cell · range: ≤ 25 Vol % · accuracy: ± 0.1 Vol % · calibration: every 14 days CO2 Sensor · type: Infrared (NDIR) · range: ≤ 13 Vol % · accuracy: ± 0.1 Vol % · calibration: 1x per month Volume Turbine, Reusable · flow: ≤ 20 l/s · accuracy: ± 2 % · resistance PEF: ≤ 0.30 kPa/l/s @ 20 l/s · calibration: 1x daily Volume Turbine, Disposable · flow: ≤ 14 l/s · accuracy: ± 3 % · resistance PEF: ≤ 0.36 kPa/l/s @ 14 l/s · calibration: not necessary Heart Rate · smart BT | 3-lead ECG (optional) 12-lead ECG (optional) Operating Conditions · temperature: $+10^{\circ}$ to $+35^{\circ}\text{C}$ · ambient pressure: 500 to 1,050 mbar · at atmospheres: ≤ 25 % O2 · relative humidity: ≤ 95 % (non condensing) Physical Specifications · dimension (LxWxH): 240 × 210 x 90 mm · weight: 940 g

SPECIFICATIONS



FILE

2.5 Cardiopulmonary Exercise Test (CPET):

30m

Participants will perform a maximal incremental test on a treadmill (Runrace, Technogym, Italy). The test will start at a walking speed of 6 km/h and increase by 1 km/h each minute until the participant reaches exhaustion. The treadmill incline will remain constant at 1% throughout the test.

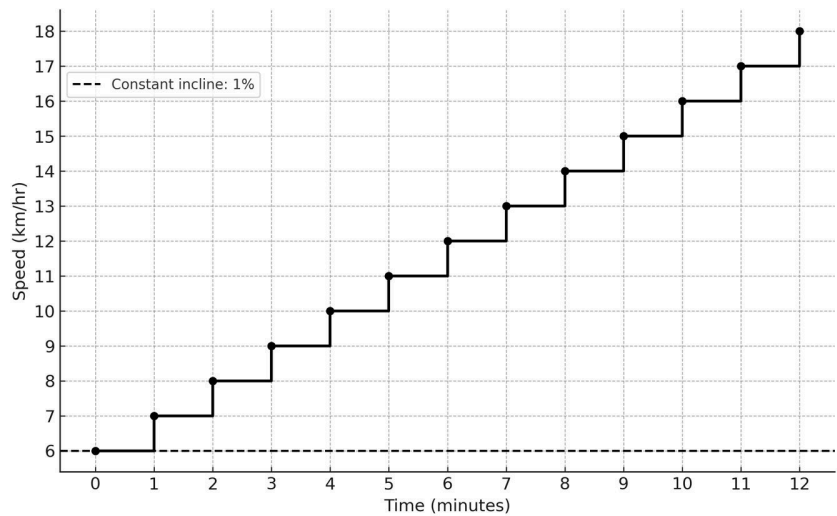


Figure 3. Ramp Running for VO2max Measurement

Equipment	
Runrace	NAME
treadmill	TYPE
Technogym	BRAND
009	SKU
https://www.technogym.com/en-INT/	LINK
Technical Specifications of the Technogym Runrace: Motor Power: High-performance motor providing a smooth and consistent running experience. Speed Range: From 0.5 km/h to 25 km/h. Inclination Range: From 0% to 15% incline to simulate varied terrains. Running Surface: Spacious running area approximately 160 cm long x 58 cm wide. Maximum User Weight: Up to 180 kg.	
SPECIFICATIONS	
FILE	

Citation

Wasserman, K Whipp, B J Koyl, S N Beaver, W L (1973)
. Anaerobic threshold and respiratory gas exchange during exercise.
Journal of Applied Physiology.

[10.1152/jappl.1973.35.2.236](https://doi.org/10.1152/jappl.1973.35.2.236)

[LINK](#)

The respiratory mask will be carefully adjusted to the participant's face to ensure a proper seal, preventing air leaks. Once the mask is securely fitted, the participant will sit on a chair and rest for 2 minutes. During this time, the respiratory exchange ratio (RER) will be monitored, and the test will begin when the RER approaches resting values between 0.7 and 0.8.



image 7. Rest before the CPET

Criteria for Maximal Effort:

The test will be considered maximal if at least two of the following criteria are met:

- Stabilisation in oxygen consumption (VO_2) despite a continuous increase in workload is considered a classic criterion for determining VO_2 max. This plateau in VO_2 , generally defined as an increase of less than $2 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ in oxygen consumption with progressive increases in workload, indicates the inability of the cardiorespiratory system to meet a higher oxygen demand, reflecting the subject's physiological limit.
- Maximum heart rate (HR_{max}) within ten beats per minute of the theoretical maximum calculated with $\text{HR}_{\text{max}} = (220 - \text{age})$ formula.
- Respiratory exchange ratio (RER) greater than 1.10

Citation

Taati B, Arazi H, Bridge CA, Franchini E (2022)

. A new taekwondo-specific field test for estimating aerobic power, anaerobic fitness, and agility performance.

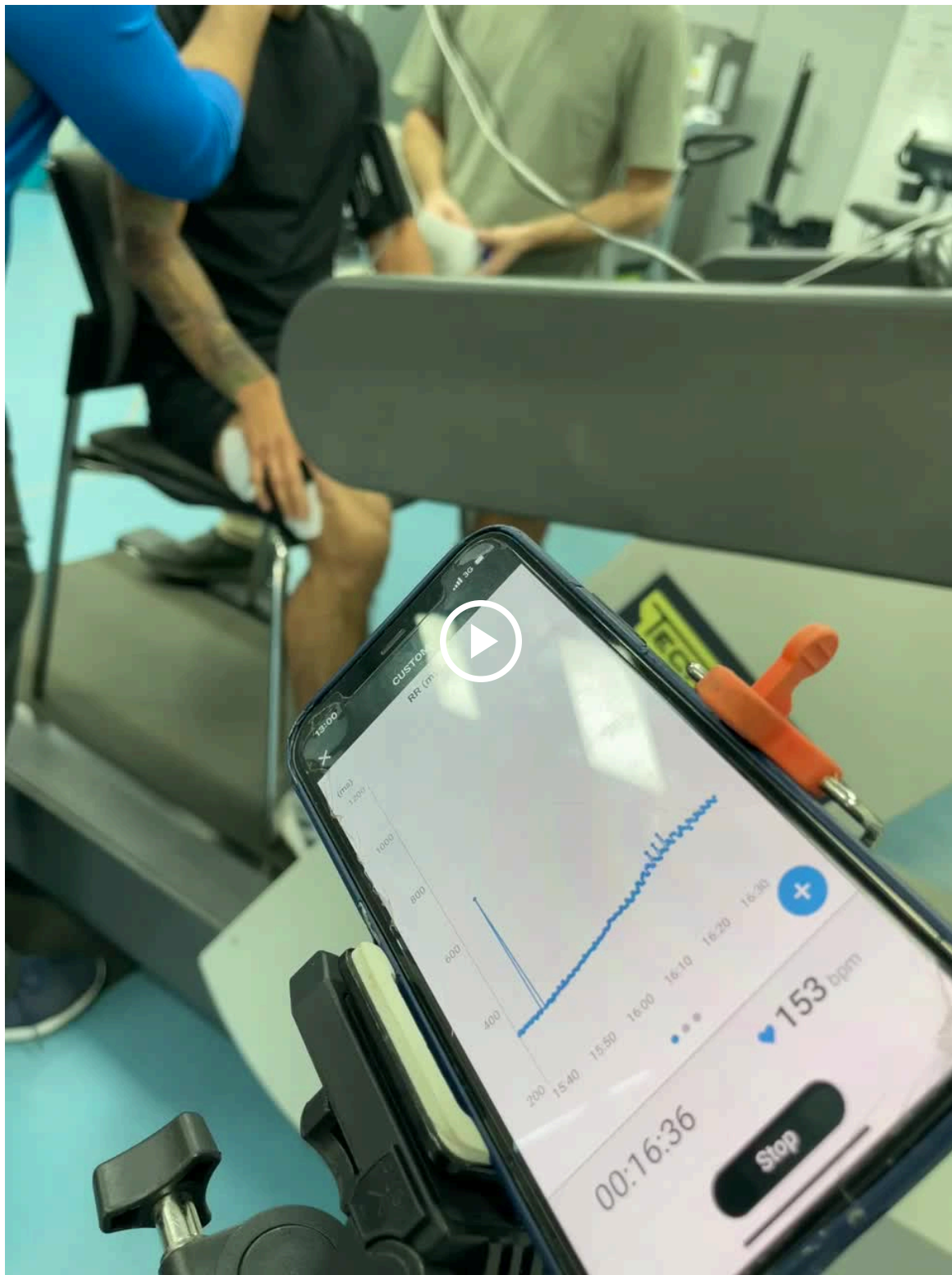
<https://doi.org/10.1371/journal.pone.0264910>

LINK

Variables Recorded During the Test:

During the test and the recovery phase, the following variables will be measured continuously:

- Heart rate and heart rate variability (HRV) using the Polar HR10 heart rate monitor (Kempele, Finland).
- Muscle oxygen saturation was measured with a Moxy Monitor (Fortiori Design LLC, Minnesota, USA) placed on the vastus lateralis muscle.
- Ventilatory gas analysis was performed using a Cortex Metalyzer 3B (Cortex Biophysik, Leipzig, Germany) to measure VO_2 , VCO_2 , and other respiratory parameters.
- Peak post-exercise lactate was measured one minute after the test using the Lactate PRO2 meter (ARKRAY, Kyoto, Japan).
- Rating of Perceived Exertion (RPE), assessed using a scale from 0 to 10, where 0 is "no effort" and 10 is "maximum effort."



Statistical analysis.

1w



- 3 To analyse the data obtained from the BJJ-CRFT and other measurements, the following statistical methods will be applied:

The analysis will begin using the **Shapiro-Wilk test** to check if the data is normally distributed before conducting correlation and reliability analyses. This will help determine the appropriate statistical methods for further analyses based on the data's normality.

Next, the **Pearson correlation coefficient** will be used to examine the relationship between maximum oxygen consumption (VO₂max) and performance in the BJJ-CRFT. This will provide insights into how closely the participants' cardiorespiratory capacity is linked to their performance in the sport-specific test.

The intraclass **correlation coefficient (ICC)** will be calculated to assess the consistency of the participants' performance across repeated measures under similar conditions. This will offer insights into the relative reliability between test and retest results. For absolute reliability, the **typical error of measurement (TEM)** will be used to quantify the degree of variability or error in the measurements obtained. This will help understand the precision and repeatability of the test.

Employing these statistical methods aims to comprehensively evaluate the test's validity and reliability, providing valuable insights into the measurements' reproducibility and relationship to key physiological variables.

Citation

Chaabene H, Negra Y, Bouguezzi R, Capranica L, Franchini E, Prieske O, Hbacha H, Granacher U
(2018)

. Tests for the Assessment of Sport-Specific Performance in Olympic Combat Sports: A Systematic Review With Practical Recommendations.

<https://doi.org/10.3389/fphys.2018.00386>

LINK



Citation

Yogev A, Arnold J, Nelson H, Clarke DC, Guenette JA, Sporer BC, Koehle MS (2023)
. Comparing the reliability of muscle oxygen saturation with common performance and physiological markers across cycling exercise intensity.

<https://doi.org/10.3389/fspor.2023.1143393>

LINK



Citations

Step 1

Chaabène H, Hachana Y, Franchini E, Mkaouer B, Montassar M, Chamari K. Reliability and construct validity of the karate-specific aerobic test

<https://doi.org/10.1519/JSC.0b013e31824eddda>

Step 1

Bangsbo, J. Iaia, F. M. Krstrup, P.. The Yo-Yo intermittent recovery test : a useful tool for evaluation of physical performance in intermittent sports

[10.2165/00007256-200838010-00004](https://doi.org/10.2165/00007256-200838010-00004)

Step 1.4

R. Beneke, R. M. Leithäuser and O. Ochentel. Blood Lactate Diagnostics in Exercise Testing and Training

<https://doi.org/10.1123/ijsspp.6.1.8>

Step 2.5

Taati B, Arazi H, Bridge CA, Franchini E. A new taekwondo-specific field test for estimating aerobic power, anaerobic fitness, and agility performance.

<https://doi.org/10.1371/journal.pone.0264910>

Step 2.5

Wasserman, K Whipp, B J Koyl, S N Beaver, W L. Anaerobic threshold and respiratory gas exchange during exercise

[10.1152/jappl.1973.35.2.236](https://doi.org/10.1152/jappl.1973.35.2.236)

Step 3

Chaabene H, Negra Y, Bouguezzi R, Capranica L, Franchini E, Prieske O, Hbacha H, Granacher U. Tests for the Assessment of Sport-Specific Performance in Olympic Combat Sports: A Systematic Review With Practical Recommendations.

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Step 3

Yogev A, Arnold J, Nelson H, Clarke DC, Guenette JA, Sporer BC, Koehle MS. Comparing the reliability of muscle oxygen saturation with common performance and physiological markers across cycling exercise intensity.

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