



University of Zagreb

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**CONSTRUCTION AND VALIDATION OF
TEST FOR ESTIMATING AEROBIC
CAPACITY IN BALLROOM DANCES**

DOCTORAL THESIS

Zagreb, 2026.



Sveučilište u Zagrebu

Kineziološki fakultet

Tamara Despot

KONSTRUKCIJA I VALIDACIJA TESTA ZA PROCJENU AEROBNOGA KAPACITETA U STANDARDNIM PLESOVIMA

DOKTORSKI RAD

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Supervisor:

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TABLE OF CONTENTS:

1. DECLARATIONS	1
2. SUPERVISOR INFORMATION	2
3. ACKNOWLEDGEMENTS	3
4. LIST OF ABBREVIATIONS	4
5. ABSTRACT	6
6. SAŽETAK	9
7. CHAPTER 1: INTRODUCTION	11
7.1. Context and background	11
7.2. Literature review	16
7.3. List of tables	19
7.4. List of figures	20
7.5. Research aims and questions	21
7.6. List of research studies	22
7.7. Thesis outline	23
8. CHAPTER 2: RESEARCH METHODOLOGY	24
8.1. Study population	24
8.2. Study variables	25
8.3. Testing procedures	26
8.4. Data processing	27
9. CHAPTER 3: ORIGINAL STUDIES	29
9.1. Research study one	29
9.2. Abstract	30
9.3. Introduction	31
9.4. Materials and methods	34
9.5. Results	38
9.6. Discussion	39
9.7. Conclusion	43
9.8. Additional information and declarations	44
9.9. Research study two	44
10. Abstract	45
10.1. Introduction	46
10.2. Materials and Methods	49
10.3. Results	54

10.4. Discussion	58
10.5. Conclusion	60
10.6. Author contributions	61
10.7. Conflicts of interest statement	61
10.8. Institutional review board statement	61
10.9. Informed consent statement	61
11. Data availability statement	61
11.1. Acknowledgments	61
11.2. Conflicts of Interest	61
11.3. Research study three	62
11.4. Abstract	63
11.5. Introduction	64
11.6. Materials and methods	67
11.7. Results	71
11.8. Discussion	74
11.9. Conclusions	78
12. Acknowledgments	78
12.1. Informed consent statement	78
12.2. Ethical committee approval	78
12.3. Topic	78
12.4. Conflicts of interest	79
12.5. Funding	79
12.6. Authors' contribution	79
13. CHAPTER 4: GENERAL CONCLUSION	79
13.1. Strengths and limitations	81
13.2. Perspectives for future research	833
14. REFERENCES	844
15. LIST OF APPENDICES	91
15.1. Study 1	91
15.2. Study 2	106
15.3. Study 3	119
16. BIOGRAPHY OF THE AUTHOR AND LIST OF WORKS	127

1. DECLARATIONS

I, Tamara Despot, hereby declare that this dissertation entitled “Construction and Validation of test for estimating aerobic capacity in ballroom dances” is my original work, and that it does not contain any material previously written or published by me or any other person, apart from the published articles presented in Chapter 3. In the thesis, I have acknowledged all assistance that I have received in this work, and I have presented all relevant sources of information.

This doctoral research is comprised of three studies with interconnected research aims. The studies resulted in scientific articles published in international peer-reviewed journals, which are included in this thesis. All included articles were published after my enrolment in the doctoral programme.

In this thesis, referencing is conducted in accordance with the Publication Manual of the American Psychological Association (7th ed.; American Psychological Association, 2020). References from all chapters are presented alphabetically in the “References” section.

All studies were conducted in accordance with the Declaration of Helsinki. In addition, all participants provided written informed consent to participate in the study. The research was approved by the Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Croatia (ethics code number: 77/2020).

2. SUPERVISOR INFORMATION

Professor Davor Plavec was born in 1962 in Zagreb, Croatia. He graduated from the School of Medicine, University of Zagreb in 1987. He obtained his Master of Science degree in 1991 and his PhD in 1999 at the same institution.

He completed his specialization in Occupational Medicine in 2004 and in Sports Medicine in 2013. In 2009, he was appointed Assistant Professor at the Faculty of Medicine in Osijek, and in 2019 he was promoted to Full Professor at the same institution. In 2024, he was elected Full Professor with permanent appointment at the Faculty of Medicine in Osijek.

Professor Plavec is a Lecturer at the School of Medicine, University of Zagreb (English-language program), and at the Faculty of Dental Medicine and Health in Osijek. He is also an external associate at the Faculty of Kinesiology, University of Zagreb, at the Department of Sports and Exercise Medicine.

Since 2005, he has been working at Srebrnjak Children's Hospital, where he serves as Assistant Director for Quality of Health Care and Head of the Research Department. His professional and research interests include quality improvement in health care, clinical research, sports medicine, allergy and clinical immunology, pulmonology, and cardiopulmonary function diagnostics.

In addition, he currently serves as Director of the health care institution Prima Nova, where he is actively engaged in clinical practice and organizational leadership.

Professor Plavec is the acting president of the Croatian Association of Sports Medicine, a part of the Croatian Medical Association. He is also an active member of several professional societies within the Croatian Medical Association, where he has held responsible leadership positions for multiple terms. Furthermore, he is a member of the European Respiratory Society and the European Academy of Allergy and Clinical Immunology.

Throughout his scientific and professional career, Professor Plavec has authored more than 300 publications, including over 110 articles published in peer-reviewed journals, with more than 2,000 citation.

3. ACKNOWLEDGEMENTS

This doctoral dissertation is the result of years of dedication, perseverance, and belief-belief in science, in creativity, and in the power of continuous growth. I am deeply grateful to everyone who walked alongside me on this journey and helped transform moments of doubt into moments of strength.

My sincere and heartfelt gratitude goes to my supervisor, Prof. Dr. Plavec, for accepting my doctoral project at a time when I felt there was no way forward. His trust in me, constant encouragement, and unwavering support became the wind at my back whenever I hesitated. I was looking for a mentor who would push me forward, believe in my potential, and stand beside me through every challenge, and in him, I found exactly that.

I owe profound thanks to my parents, who planted in me a love for learning and an endless desire for progress. They taught me that knowledge is the one thing that can never be taken away, while everything else in life is fleeting. Their values shaped not only this dissertation, but the person I have become.

I am grateful to my dance community and to all the dancers who gave their time, energy, and trust to participate in this research. Their openness and commitment made this work possible and gave it life beyond the pages of this dissertation. My special thanks go to Nikola Otto and Lovro Štefan, who contributed to the development of the protocol. I am also sincerely thankful to Vanja Vujić and Viktor Szabo, who were always ready to step in and help whenever support was needed.

Above all, I thank my small and joyful family, who continuously support me in all my ideas, dreams, and personal growth. They understand that my creative soul must always explore, create, and move forward, never remaining still. Their love is my foundation and my greatest strength.

Finally, I extend my gratitude to those who did not believe in me. You became the quiet challenge that strengthened my resolve and the spark that ignited my determination. In closing, this dissertation stands not only as an academic achievement, but as a testament to perseverance, support, and the belief that growth is born where passion and resilience meet.

With respect,
Tamara Despot

4. LIST OF ABBREVIATIONS

- AUC – Area Under the Curve
- BAT – Ballroom Aerobic Test
- BF – Breathing Frequency
- BMI – Body Mass Index
- BPM – Bars Per Minute
- bpm – Beats Per Minute
- CI – Confidence Interval
- CV – Coefficient of Variation
- ES – Effect Size
- FN – False Negative
- FP – False Positive
- G*Power – Statistical Power Analysis Software
- HR_{max} – Maximal Heart Rate
- HR_{peak} – Peak Heart Rate
- ICC – Intraclass Correlation Coefficient
- KF1 – Progressive Treadmill Protocol
- LMM – Linear Mixed Model
- Meta Max® 3B – Portable Breath-by-Breath Gas Analyzer
- NLR – Negative Likelihood Ratio
- PLR – Positive Likelihood Ratio
- Quark b2 – Breath-by-Breath Pulmonary Gas Exchange System
- RER – Respiratory Exchange Ratio
- RM ANOVA – Repeated Measures Analysis of Variance
- ROC – Receiver Operating Characteristics
- SD – Standard Deviation
- SEE – Standard Error of Estimate
- SWC – Smallest Worthwhile Change
- TE – Typical Error
- VD/VT – Dead Space to Tidal Volume Ratio
- VE – Minute Ventilation
- VE/VO₂ – Ventilatory Equivalent for Oxygen

- $\dot{V}_E/\dot{V}_{CO_2}$ – Ventilatory Equivalent for Carbon Dioxide
- $\dot{V}O_2$ – Oxygen Uptake
- $\dot{V}O_{2max}$ – Maximal Oxygen Uptake
- $\dot{V}CO_2$ – Carbon Dioxide Production

5. ABSTRACT

Dancesport is a high-intensity intermittent activity that imposes substantial demands on aerobic and anaerobic energy systems. In standard-style ballroom dances, the ability to sustain technical execution under progressive physiological load is strongly associated with aerobic capacity. However, existing aerobic fitness tests in dance are predominantly laboratory-based or developed for ballet and contemporary dance, limiting their ecological validity for standard dancesport couples.

Therefore, the overall aim of this doctoral dissertation was to construct and comprehensively evaluate a novel, dance-specific Ballroom Aerobic Test (BAT) protocol for assessing aerobic capacity in standard-style dancesport athletes.

Study 1 Methods

A within-subject test–retest design was applied. Thirteen advanced standard-style dancesport athletes (age: 20.1 ± 3.8 years) completed two identical BAT sessions separated by seven days. Ventilatory and metabolic variables were recorded using the Meta Max® 3B portable gas analyzer. Reliability was assessed using the intraclass correlation coefficient (ICC, two-way random effects, absolute agreement), coefficient of variation (CV, %), and Cohen’s effect size (ES). Absolute reliability was quantified via typical error (TE), while practical usefulness was evaluated by comparing TE with the smallest worthwhile change ($SWC = 0.2 \times \text{between-subject SD}$). Statistical significance was set at $\alpha = 0.05$. This study was approved by the Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Croatia (No. 77/2020, 29 April 2020).

Study 1 Results

No significant differences were observed between test and retest measurements ($p > 0.05$). ICC values ranged from 0.80 to 0.99, indicating very good to excellent reliability. The CV ranged from 1.63% to 4.85%. Effect sizes were trivial to small ($ES = 0.00\text{--}0.47$). The BAT protocol demonstrated acceptable usefulness for key variables, including speed ($TE = 2.76$ bpm; $SWC = 3.20$ bpm), absolute $\dot{V}O_2$ ($TE = 0.14$ L·min⁻¹; $SWC = 0.15$ L·min⁻¹), and minute ventilation ($TE = 4.87$ L·min⁻¹).

Study 1 Conclusion

The BAT protocol exhibits high reliability and sufficient sensitivity to detect meaningful individual changes in aerobic performance among standard dancesport athletes.

Study 2 Methods

Criterion validity was examined in 24 standard dancesport athletes (12 dance couples; age: 20.4 ± 3.9 years). BAT outcomes were compared with two laboratory-based treadmill protocols (KF1 and Bruce). Absolute and relative $\dot{V}O_{2\max}$, respiratory exchange ratio (RER), minute ventilation (VE), tidal volume (VT), ventilatory equivalents ($VE/\dot{V}O_2$, $VE/\dot{V}CO_2$), and dead space ratio (V_D/V_T) were analyzed. Pearson correlation coefficients (r) were calculated, with interpretation thresholds defined as large ($r \geq 0.50$) and very large ($r \geq 0.70$). Agreement between methods was assessed using Bland–Altman plots and standard error of estimate (SEE).

Study 2 Results

Large to very large correlations were observed between BAT and KF1/Bruce protocols for absolute $\dot{V}O_{2\max}$ ($r = 0.87\text{--}0.88$) and relative $\dot{V}O_{2\max}$ ($r = 0.85\text{--}0.88$). Ventilatory parameters showed correlations ranging from $r = 0.70$ to 0.86 . Bland–Altman analyses demonstrated no systematic or proportional bias between methods. The SEE for relative $\dot{V}O_{2\max}$ was ± 3.36 $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (BAT vs. KF1) and ± 3.75 $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (BAT vs. Bruce).

Study 2 Conclusion

The BAT protocol demonstrates strong criterion validity and satisfactory agreement with established laboratory-based aerobic capacity tests.

Study 3 Methods

Diagnostic accuracy was assessed using receiver operating characteristic (ROC) curve analysis in the same sample of 24 dancesport athletes. Area under the curve (AUC), sensitivity, specificity, false-positive and false-negative rates, as well as positive (PLR) and negative likelihood ratios (NLR), were calculated for BAT outcomes relative to KF1 and Bruce protocols. An AUC threshold of >0.75 was considered indicative of good diagnostic accuracy.

Study 3 Results

The BAT protocol demonstrated good to excellent diagnostic accuracy. AUC values for absolute $\dot{V}O_{2\max}$ ranged from 0.92 to 0.94, while relative $\dot{V}O_{2\max}$ yielded AUC values between 0.94 and 0.95. Sensitivity ranged from 66.7% to 95.1%, and specificity from 60.0% to 100.0%. The highest PLR values were observed for relative $\dot{V}O_{2\max}$ (KF1: 10.31; Bruce: 11.05), indicating strong discriminative power.

Study 3 Conclusion

The BAT protocol is a diagnostically accurate and sensitive tool for identifying aerobic fitness levels in standard-style dancesport athletes.

Key words: dancesport, aerobic capacity, ballroom dances, field-based testing, reliability, validity, diagnostic accuracy, ballroom aerobic test

6. SAŽETAK

Sportski ples predstavlja visokointenzivnu intermitentnu sportsku aktivnost koja nameće značajne zahtjeve aerobnim i anaerobnim energetskim sustavima. U standardnim plesovima, sposobnost održavanja tehničke izvedbe pod progresivnim fiziološkim opterećenjem snažno je povezana s aerobnim kapacitetom. Međutim, postojeći testovi aerobne izdržljivosti u plesu pretežno su laboratorijski ili razvijeni za balet i suvremeni ples, što ograničava njihovu ekološku valjanost za parove standardnih plesova. Stoga je glavni cilj ove doktorske disertacije bio konstruirati i sveobuhvatno procijeniti novi, plesno specifičan protokol testa u plesnoj dvorani (BAT) za procjenu aerobnog kapaciteta kod plesača standardnih plesova.

Metode Studije 1 U Studiji 1 primijenjen je dizajn test-retest unutar uzorka. Trinaest plesača standardnih plesova (dob: $20,1 \pm 3,8$ godina) završilo je dvije identične BAT sesije razdvojene sedam dana. Ventilacijske i metaboličke varijable zabilježene su pomoću prijenosnog analizatora plinova Meta Max® 3B. Pouzdanost je procijenjena pomoću koeficijenta intraklasne korelacije (ICC, dvosmjerni slučajni učinci, apsolutno slaganje), koeficijenta varijacije (CV, %) i Cohenove veličine učinka (ES). Apsolutna pouzdanost kvantificirana je tipičnom pogreškom (TE), dok je praktična korisnost procijenjena usporedbom TE s najmanjom vrijednom promjenom ($SWC = 0,2 \times SD$ između ispitanika). Statistička značajnost postavljena je na $\alpha = 0,05$. Studiju je odobrilo Etičko povjerenstvo Kineziološkog fakulteta Sveučilišta u Zagrebu (br.77/2020;29.travnja 2020).

Rezultati Studije 1 Nisu uočene značajne razlike između testnih i retestnih mjerenja ($p > 0,05$). Vrijednosti ICC-a kretale su se od 0,80 do 0,99, što ukazuje na vrlo dobru do izvrsnu pouzdanost. CV se kretao od 1,63% do 4,85%. Veličine učinaka bile su trivijalne do male ($ES = 0,00-0,47$). BAT protokol pokazao je prihvatljivu korisnost za ključne varijable, uključujući brzinu ($TE = 2,76$ bpm; $SWC = 3,20$ bpm), apsolutni VO_2 ($TE = 0,14$ L·min⁻¹; $SWC = 0,15$ L·min⁻¹) i minutnu ventilaciju ($TE = 4,87$ L·min⁻¹).

Zaključak Studije 1 BAT protokol pokazuje visoku pouzdanost i dovoljnu osjetljivost za otkrivanje značajnih individualnih promjena u aerobnim performansama među plesačima standardnih plesova.

Metode Studije 2 U Studiji 2 kriterijska valjanost ispitana je kod 24 plesača standardnih plesova (12 plesnih parova; dob: $20,4 \pm 3,9$ godina). Ishodi BAT-a uspoređeni su s dva

laboratorijska protokola na traci za trčanje (KF1 i Bruce). Analizirani su apsolutni i relativni $\dot{V}O_{2max}$, omjer respiratorne izmjene (RER), minutna ventilacija (VE), respiracijski volumen (VT), ventilacijski ekvivalenti ($VE/\dot{V}O_2$, $VE/\dot{V}CO_2$) i omjer mrtvog prostora (VD/VT). Izračunati su Pearsonovi koeficijenti korelacije (r), s pragovima interpretacije definiranim kao veliki ($r \geq 0,50$) i vrlo veliki ($r \geq 0,70$). Slaganje između metoda procijenjeno je pomoću Bland-Altmanovih dijagrama i standardne pogreške procjene (SEE).

Rezultati Studije 2 Uočene su velike do vrlo velike korelacije između BAT i KF1/Bruce protokola za apsolutni $\dot{V}O_{2max}$ ($r = 0,87-0,88$) i relativni $\dot{V}O_{2max}$ ($r = 0,85-0,88$). Ventilacijski parametri pokazali su korelacije u rasponu od $r = 0,70$ do $0,86$. Bland-Altmanove analize nisu pokazale sustavnu ili proporcionalnu pristranost između metoda. SEE za relativni $\dot{V}O_{2max}$ iznosio je $\pm 3,36 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (BAT vs. KF1) i $\pm 3,75 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (BAT vs. Bruce).

Zaključak Studije 2 BAT protokol pokazuje snažnu kriterijsku valjanost i zadovoljavajuće slaganje s utvrđenim laboratorijskim testovima aerobnog kapaciteta.

Metode Studije 3 Dijagnostička točnost procijenjena je analizom ROC krivulje u istom uzorku od 24 sportaša plesnog sporta. Površina ispod krivulje (AUC), osjetljivost, specifičnost, stope lažno pozitivnih i lažno negativnih rezultata, kao i omjeri pozitivne (PLR) i negativne vjerojatnosti (NLR), izračunati su za BAT ishode u odnosu na KF1 i Bruce protokole. Prag AUC-a od $>0,75$ smatran je pokazateljem dobre dijagnostičke točnosti.

Rezultati Studije 3 BAT protokol pokazao je dobru do izvrsnu dijagnostičku točnost. Vrijednosti AUC-a za apsolutni $\dot{V}O_{2max}$ kretale su se od $0,92$ do $0,94$, dok je relativni $\dot{V}O_{2max}$ dao vrijednosti AUC-a između $0,94$ i $0,95$. Osjetljivost se kretala od $66,7\%$ do $95,1\%$, a specifičnost od $60,0\%$ do $100,0\%$. Najviše vrijednosti PLR-a uočene su za relativni $\dot{V}O_{2max}$ (KF1: $10,31$; Bruce: $11,05$), što ukazuje na snažnu diskriminativnu moć.

Zaključak Studije 3 BAT protokol je dijagnostički točan i osjetljiv alat za određivanje razine aerobnog kapaciteta kod plesača standardnih plesova.

Ključne riječi: Plesni sport, aerobni kapacitet, standardni plesovi, testiranje na terenu, pouzdanost, valjanost, osjetljivost, dijagnostička točnost, dvoranski aerobni test.

7. INTRODUCTION

7.1.Context and background

Dance has traditionally been perceived primarily as a form of artistic expression; however, contemporary research increasingly recognizes dance as a physically demanding activity that combines artistic performance with substantial physiological requirements. Within this spectrum, dancesport represents a unique discipline characterized by complex choreography, precise motor coordination, and high levels of physical conditioning. Competitive dancesport athletes must simultaneously demonstrate technical mastery, musical interpretation, aesthetic expression, and the physical ability to sustain repeated bouts of intense activity during both training and competition. Consequently, dancers require well-developed physiological capacities to meet the demands of their discipline and maintain performance quality under conditions of fatigue (Koutedakis & Jamurtas, 2004).

The physiological demands of dancesport have been increasingly investigated within the field of sports science, where dance is often classified as a form of intermittent high-intensity physical activity requiring both aerobic and anaerobic energy systems. In addition to technical skills, physical fitness components such as muscular endurance, flexibility, coordination, and cardiorespiratory capacity play a crucial role in determining performance success (Angioi et al., 2009). Among these physiological determinants, aerobic capacity has been identified as one of the key factors enabling dancers to sustain repeated sequences of movements and maintain technical precision throughout performances (Smol & Fredyk, 2012).

Aerobic capacity reflects the ability of the cardiovascular and respiratory systems to deliver oxygen to working muscles and the muscles ability to utilize that oxygen during sustained physical activity. Maximal oxygen uptake ($\dot{V}O_{2\max}$) is widely regarded as the most reliable indicator of aerobic fitness and has therefore been extensively used to assess cardiorespiratory performance in athletes across numerous sports disciplines (Wasserman et al., 1999). Higher levels of aerobic capacity are associated with improved fatigue resistance, faster recovery between bouts of activity, and the ability to maintain higher exercise intensities over prolonged periods of time.

Despite the physiological demands of dancesport, research has consistently demonstrated that dancers often exhibit lower $\dot{V}O_{2\max}$ values compared with athletes participating in endurance and team sports. Previous studies have reported average $\dot{V}O_{2\max}$

values of approximately $48 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in dancesport athletes, whereas athletes in endurance sports such as swimming, rowing, middle-distance running, and triathlon commonly demonstrate $\dot{V}\text{O}_2\text{max}$ values ranging between 55 and $77 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Cohen et al., 1982; Koutedakis & Jamurtas, 2004). Interestingly, these values are only moderately higher than those reported in sedentary populations, suggesting that traditional dance training may provide a limited stimulus for the development of aerobic capacity (Rodrigues-Krause et al., 2015).

One explanation for these findings lies in the structure and objectives of dance training. Dance rehearsals are primarily focused on technical development, choreography learning, artistic interpretation, and performance refinement rather than structured physiological conditioning. As a result, the physiological stimulus provided by dance training may not consistently reach the intensity and duration required to induce significant improvements in aerobic capacity (Wyon et al., 2004). Research indicates that improvements in aerobic fitness typically occur when exercise is performed at intensities between approximately 70% and 80% of an individual's maximal oxygen uptake for durations exceeding 20 minutes (McCord, Nichols & Patterson, 1989). However, dance training sessions are often characterized by intermittent rehearsal segments with frequent pauses for instruction, correction, and repetition of specific movement sequences.

Furthermore, competitive dance performances themselves are typically composed of short routines lasting between one and two minutes, separated by brief recovery periods. While such performance structures require high levels of anaerobic and neuromuscular performance, they may not provide a sufficient aerobic stimulus to significantly enhance cardiorespiratory capacity. As a result, dancers may rely heavily on technical efficiency and neuromuscular coordination rather than physiological endurance to maintain performance quality during competitions.

Given the importance of aerobic capacity for sustaining repeated bouts of activity and supporting recovery processes, objective assessment of cardiorespiratory fitness represents an important component of training management in dancesport athletes. Monitoring physiological variables such as oxygen consumption, heart rate, and ventilatory parameters enables coaches and sport scientists to evaluate training loads, identify potential performance limitations, and design targeted conditioning programs to improve physical performance (Tiemens et al., 2023).

Traditionally, aerobic capacity has been assessed using laboratory-based ergometry protocols, including treadmill and cycle ergometer tests. Such protocols are widely

considered the gold standard for measuring maximal oxygen uptake and associated physiological parameters because they provide controlled conditions and accurate measurement of gas exchange variables (Wasserman et al., 1999). Commonly used protocols such as the Bruce treadmill test or incremental running tests have demonstrated high levels of reliability and validity for assessing aerobic performance in athletic populations.

However, the application of these laboratory-based methods to dancers presents several methodological and practical limitations. First, treadmill running does not replicate the complex movement patterns characteristic of dance performance. Dance movements involve multidirectional steps, rotations, and coordinated partner interactions that differ substantially from linear locomotion patterns observed during treadmill running. Consequently, laboratory-based tests may fail to accurately reflect the specific physiological demands of dance activity.

Second, dancers often develop sport-specific biomechanical changes as a result of long-term training. These adaptations include increased external rotation of the hips, limited ankle dorsiflexion, and specific posture-related changes associated with dance technique. Such characteristics may make running uncomfortable or mechanically inefficient for dancers and may even increase the risk of musculoskeletal stress or injury during treadmill testing (Russell, 2013).

Third, laboratory testing requires specialized equipment, trained personnel, and controlled environments, which may limit its accessibility for coaches and practitioners working in dance settings. These logistical constraints highlight the need for practical field-based testing protocols that can be implemented in training environments while still providing valid and reliable estimates of aerobic capacity.

In response to these challenges, researchers have attempted to develop dance-specific field tests that more closely replicate the movement patterns and physiological demands of dance performance. Several testing protocols have been proposed, including the Aerobic Power Index (API) (Wallman et al., 2003), the Ballet-specific Aerobic Fitness Test (B-DAFT) (Twitchett et al., 2011), the Dance Aerobic Fitness Test (DAFT) (Wyon et al., 2004), the High-Intensity Dance Performance Fitness Test (HIDT) (Redding et al., 2009), and the Seifert Assessment of Functional Capacity for Dancers (SAFD) (Seifert et al., 2021).

While these protocols have contributed valuable insights into the physiological characteristics of dancers, several limitations remain. Most of these tests were developed for ballet or contemporary dancers, whose movement patterns and training structures differ substantially from those observed in dancesport athletes. Ballet and contemporary dance

typically involve individual performance, whereas dancesport is fundamentally based on synchronized partner movement within a dance couple.

Ballroom dancesport competitions involve five primary dance styles: English Waltz, Tango, Slowfoxtrot, Viennese Waltz, and Quickstep. Each dance style is characterized by distinct tempo, rhythm, and movement dynamics, which place varying physiological demands on the dancers. In competition settings, dancers must perform multiple routines consecutively, often with minimal recovery between rounds. This competition structure requires dancers to maintain both technical precision and physiological endurance throughout multiple performances.

In addition to these structural differences, the physiological profiles of ballroom dancers may differ from those of ballet or contemporary dancers. Previous research has suggested that ballroom dancers tend to demonstrate higher average $\dot{V}O_{2\max}$ values compared with ballet dancers, as well as different body composition characteristics (Liiv et al., 2014). Ballet dancers generally exhibit lower body fat percentages than contemporary and dancesport dancers. In the study by Liiv et al. (2014), mean body fat percentages were $12.7 \pm 2.9\%$ in male and $17.5 \pm 2.5\%$ in female ballet dancers, $13.0 \pm 1.0\%$ and $21.2 \pm 3.8\%$ in male and female contemporary dancers, and $13.1 \pm 4.3\%$ and $21.9 \pm 3.8\%$ in male and female dancesport dancers, respectively. These differences may reflect distinct aesthetic expectations, training practices, and physiological demands associated with each dance discipline.

Furthermore, ballroom dancing involves specific biomechanical characteristics, including greater hip rotations, increased knee extension torque, and enhanced dynamic balance due to the requirement of synchronized partner movement. These biomechanical features contribute to a unique physiological profile that may not be adequately captured by aerobic fitness tests originally developed for other dance styles.

Another limitation of existing dance-specific tests lies in their methodological validation. Many previously developed protocols focused primarily on correlations between physiological variables measured using the same device rather than comparing field-based testing results with laboratory-based gold-standard methods. In addition, important psychometric properties such as test–retest reliability, measurement error, sensitivity to change, and diagnostic accuracy have rarely been evaluated comprehensively within a single testing protocol (Hopkins, 2004; Buchheit et al., 2011).

In order to address these limitations, a progressive field-based protocol known as the Ballroom Aerobic Test (BAT) was developed specifically for standard dancesport athletes.

The BAT protocol was designed to replicate the movement patterns, tempo progression, and physiological demands of ballroom dance performance while providing a structured and standardized method for assessing aerobic capacity.

The BAT protocol consists of a sequence of progressively increasing dance stages based on the five ballroom dances: English Waltz, Slow Foxtrot, Tango, Viennese Waltz, and Quickstep. Each stage is performed at a predefined tempo controlled by a metronome, with the tempo gradually increasing throughout the test. Dance couples perform basic dance figures during each stage until volitional exhaustion is reached. By integrating authentic dance movements and tempo progression, the BAT protocol was specifically designed to assess aerobic capacity under conditions that reflect the typical movement structure of ballroom dances.

The research presented in this doctoral dissertation represents a comprehensive attempt to develop and scientifically validate the BAT protocol for assessing aerobic capacity in ballroom dancesport athletes. The dissertation follows the Scandinavian model of a publication-based doctoral thesis, where the main body of the thesis consists of several published scientific articles addressing different aspects of the research topic.

Within this framework, the BAT protocol was evaluated through three interconnected studies focusing on reliability, validity, and diagnostic accuracy.

The first study investigated the reliability and practical usefulness of the BAT protocol using a test–retest design in competitive dancesport athletes. Reliability measures such as intraclass correlation coefficients, coefficients of variation, and typical error were calculated to determine the stability and reproducibility of physiological measurements obtained during the test.

The second study examined the criterion validity of the BAT protocol by comparing physiological variables obtained during the test with those measured during established laboratory-based treadmill protocols, including the KF1 and Bruce protocols. Correlation analyses and agreement methods were used to determine the extent to which BAT-derived measures accurately reflect laboratory-based assessments of aerobic capacity.

The third study evaluated the diagnostic accuracy of the BAT protocol using receiver operating characteristic (ROC) analysis, sensitivity and specificity testing, and likelihood ratios. This analysis aimed to determine whether the BAT protocol can effectively distinguish between different levels of cardiorespiratory fitness among dancesport athletes.

Taken together, the findings of these studies provide comprehensive evidence supporting the reliability, validity, and diagnostic usefulness of the Ballroom Aerobic Test as a field-

based assessment tool for evaluating aerobic capacity in dancesport athletes. By integrating sport-specific movement patterns with physiological measurement, the BAT protocol represents an important step toward improving the ecological validity of fitness testing in aesthetic sports.

Furthermore, the development of such sport-specific assessment tools may contribute to improved training monitoring, performance evaluation, and injury prevention strategies within the field of dancesport. Coaches, strength and conditioning specialists, and researchers may utilize the BAT protocol to better understand the physiological demands of dance performance and to design targeted conditioning programs aimed at optimizing dancers physical preparedness.

Ultimately, this dissertation aims to contribute to the growing body of scientific literature addressing the physiological characteristics of aesthetic sports and to provide a practical and scientifically validated testing protocol specifically designed for the unique demands of dancesport performance.

7.2. Literature review

Aerobic Capacity Assessment in Dancesport

Laboratory-based methods, such as treadmill protocols, are considered the gold standard for assessing aerobic capacity. Previous research has shown that protocols like the Bruce test provide valid and reliable measurements of maximal oxygen uptake ($\dot{V}O_{2max}$), allowing precise evaluation of cardiorespiratory fitness (Midgley et al., 2007). However, Wyon et al. (2004) reported that such protocols may not accurately reflect the specific physiological and biomechanical demands of dancers, particularly due to differences in movement patterns and muscle activation.

Field-Based Testing in Dance Populations

To overcome these limitations, several field-based tests have been developed. Early attempts included the Aerobic Power Index (API) (Wallman et al., 2003), which provided initial insights into dance-specific aerobic assessment but showed limited applicability in more complex dance settings. Wyon et al. (2004) introduced the Dance Aerobic Fitness Test (DAFT), reporting moderate to high correlations with $\dot{V}O_{2max}$. Similarly, Twitchett et al. (2011) developed the Ballet-specific Aerobic Fitness Test (B-DAFT), demonstrating

acceptable reliability in ballet dancers. Redding et al. (2009) proposed the High-Intensity Dance Test (HIDT), which was designed to simulate performance conditions and showed appropriate physiological responses during testing.

More recently, Seifert et al. (2021) developed the Seifert Assessment of Functional Capacity for Dancers (SAFD), which aimed to provide a more comprehensive evaluation by integrating functional movement patterns with physiological assessment. However, despite these advancements, the majority of these protocols remain limited to specific dance disciplines and do not fully capture the complexity of partner-based performance in ballroom-style dancesport.

Population-Specific Limitations

Furthermore, most studies have been conducted on ballet or contemporary dancers and primarily at the individual level. Angioi et al. (2009) reported that ballet dancers exhibit lower body fat percentage and different movement patterns compared to other dance populations. In addition, Tiemens et al. (2023) noted that ballroom-style dancesport athletes often demonstrate higher $\dot{V}O_{2\max}$ values compared to ballet dancers, indicating that findings from one population cannot be generalized to another.

Importantly, none of the existing protocols account for partner-based performance, which represents a key characteristic of ballroom dances.

Measurement Properties of Performance Tests

From a methodological perspective, the evaluation of performance tests in dance requires a comprehensive assessment of key measurement properties, including reliability, validity, and diagnostic accuracy. Reliability represents the consistency of repeated measurements and is commonly assessed using intraclass correlation coefficients (ICC), coefficient of variation (CV), and typical error (TE) (Hopkins, 2000; Atkinson & Nevill, 1998). In dance-specific research, several studies have reported acceptable reliability of field-based protocols. For example, Twitchett et al. (2011) demonstrated good test–retest reliability of the Ballet-specific Aerobic Fitness Test (B-DAFT), while Wyon et al. (2004) reported consistent physiological responses using the Dance Aerobic Fitness Test (DAFT). However, despite these findings, reliability outcomes in dance research remain inconsistent and often depend on the type of dance discipline and testing conditions.

Validity reflects the degree to which a test measures what it is intended to measure, typically assessed through comparison with laboratory-based gold standard methods. In dance science, validity has most often been examined through correlations between field-based protocols and $\dot{V}O_{2\max}$ derived from treadmill or cycle ergometer testing (Wyon et al., 2004; Redding et al., 2009). While some studies have reported moderate to high correlations, a systematic review by Tiemens et al. (2023) highlighted substantial variability in validity coefficients (r ranging from -0.12 to 0.91), indicating a lack of consistency in the ability of dance-specific tests to accurately estimate aerobic capacity. More recent approaches, such as the Seifert Assessment of Functional Capacity for Dancers (SAFD) (Seifert et al., 2021), have attempted to integrate functional movement assessment with physiological evaluation. Although this approach enhances ecological validity by incorporating dance-specific movement patterns, its ability to accurately estimate aerobic capacity may be limited due to the absence of direct physiological measurements such as $\dot{V}O_{2\max}$, thereby restricting its validity in comparison with laboratory-based methods.

In addition to reliability and validity, diagnostic accuracy provides further insight into the practical applicability of performance tests by evaluating their ability to correctly classify individuals based on predefined criteria. This includes the assessment of sensitivity, specificity, and area under the curve (AUC) values (Altman & Bland, 1994; Zhou et al., 2011). Despite its importance, diagnostic accuracy has been largely overlooked in dance-related research. Most existing studies have not evaluated the classification ability of field-based tests, limiting their practical use in identifying different levels of aerobic fitness among dancers.

Moreover, previous research has rarely integrated all three measurement properties within a single testing protocol. Instead, studies have typically focused on isolated aspects, such as reliability or validity, without providing a comprehensive evaluation framework. This limitation reduces the overall interpretability and applicability of existing tests, particularly in sport-specific contexts such as standard-style dancesport.

Therefore, there is a clear need for a comprehensive and sport-specific evaluation framework that simultaneously addresses all key measurement properties of performance tests in dance. To the best of the authors' knowledge, no previous study has systematically examined reliability, validity, and diagnostic accuracy within a single field-based protocol tailored to standard-style dancesport athletes.

In response to these limitations, the Ballroom Aerobic Test (BAT) protocol was specifically developed as a progressive, field-based test designed to reflect the physiological,

biomechanical, and performance-specific demands of standard dancesport. By integrating all key measurement properties within a unified framework, the BAT protocol was designed as a comprehensive and practically applicable tool for assessing aerobic capacity in this population.

7.3. List of tables

Study one

Table 1. The BAT dance protocol for every dance style.

Table 2. Basic descriptive statistics of the study participants.

Table 3. Reliability measures for the Meta Max® 3B aerobic outcomes.

Study two

Table 1. The BAT dance protocol for every dance style.

Table 2. Basic descriptive statistics, mean difference (diff.), and ES between the BAT protocol against the KF1 and Bruce protocols.

Study three

Table 1. The BAT dance protocol for every dance style.

Table 2. Classification of the study participants based on the median values of the KF1 protocol against the BAT protocol.

Table 3. Sensitivity, specificity, FP and FN of the BAT protocol against the KF1 and Bruce protocols.

7.4. List of figures

Study two

Figure 1. Bland–Altman plot of differences between the BAT and KF1 protocols (y-axis) and the average of the two measurements (x-axis) for relative $\dot{V}O_{2\max}$.

Figure 2. Bland–Altman plot of differences between the BAT and Bruce protocols (y-axis) and the average of the two measurements (x-axis) for relative $\dot{V}O_{2\max}$.

7.5. Research aims and questions

Looking altogether, previous studies investigating aerobic capacity in dancesport athletes have primarily focused on ballet or contemporary dancers and were mostly conducted at the individual level. Moreover, laboratory-based methods remain the gold standard, although they are often impractical, expensive, and not sport-specific. To the best of the authors' knowledge, there is a lack of comprehensive studies evaluating the reliability, validity, and diagnostic accuracy of a field-based aerobic test specifically designed for standard-style dancesport couples.

Therefore, the main purpose of this doctoral thesis is to examine the measurement properties of a newly developed Ballroom Aerobic Test (BAT) protocol for assessing aerobic capacity in ballroom dancesport athletes. This dissertation is designed according to the Scandinavian model and is divided into three distinct studies with related research questions and aims:

1. Is the BAT protocol a reliable and useful tool for assessing aerobic performance in ballroom dancesport athletes?
2. Is the BAT protocol a valid measure of aerobic capacity when compared to laboratory-based methods (KF1 and Bruce protocols)?
3. What is the diagnostic accuracy of the BAT protocol in classifying aerobic capacity in relation to objective laboratory measures?

7.6. List of research studies

In order to answer the above-mentioned research questions, the current doctoral thesis includes three studies that have been published:

1. **Despot, T., & Plavec, D.** (2026). Application of the Ballroom Aerobic Test protocol for assessing performance in standard-style dancesport athletes. *PeerJ*, 14, e20556. <https://doi.org/10.7717/peerj.20556>
2. **Despot, T., & Plavec, D.** (2025). The criterion validity of a newly developed Ballroom Aerobic Test (BAT) protocol against objective methods. *Sports*, 13, 337. <https://doi.org/10.3390/sports13100337>
3. **Despot, T., Radaš, J., & Plavec, D.** (Ahead of print). The Ballroom Aerobic Test for estimating cardiorespiratory fitness in standard style dancesport athletes: diagnostic accuracy against laboratory measures. *Acta Kinesiologica*. <https://doi.org/10.51371/issn.1840-2976.646>

7.7. Thesis outline

This doctoral thesis is structured according to the Scandinavian article-based model and consists of four main chapters, followed by the included published papers.

Chapter one introduces the thesis and an overview of literature review.

Chapter two presents the methodological framework of the thesis, including the characteristics of the study population, the selected study variables, the testing procedures, and the data processing methods used across the three studies.

Chapter three comprises the scientific articles that constitute the empirical foundation of this doctoral work.

The first study examines the test–retest reliability and practical usefulness of the Ballroom Aerobic Test (BAT) protocol in ballroom dancesport athletes.

The second study investigates the criterion validity of the BAT protocol through comparison with established laboratory-based treadmill protocols (KF1 and Bruce), including correlation analyses, agreement assessment, and estimation of measurement error.

The third study evaluates the diagnostic accuracy of the BAT protocol by analyzing sensitivity, specificity, receiver operating characteristic (ROC) curves, and likelihood ratios in relation to objective laboratory-derived measures of aerobic capacity.

Chapter four provides an integrative synthesis of the findings from the three included studies. The results are discussed within a comprehensive validation framework, demonstrating the methodological progression from reliability assessment to validity confirmation and diagnostic evaluation. The scientific contribution of the BAT protocol as a reliable, valid, and diagnostically accurate field-based tool for assessing cardiorespiratory fitness in standard-style dancesport athletes is highlighted. Strengths and limitations of the thesis are critically examined, and practical implications for training monitoring and performance optimization are outlined.

Finally, directions for future research are proposed.

The published articles are appended in their original form at the end of the thesis.

8. CHAPTER 2: RESEARCH METHODOLOGY

8.1. Study population

This doctoral thesis is based on three studies conducted on standard-style dancesport athletes in order to examine the measurement properties of the newly developed Ballroom Aerobic Test (BAT) protocol.

In Study 1, the sample consisted of 13 advanced standard-style dancesport athletes, including six dance couples and one male participant. Their mean age was 20.1 ± 3.8 years, mean body height was 175.0 ± 8.2 cm, and mean body mass was 64.3 ± 9.7 kg. In Study 2 and Study 3, the sample consisted of 24 standard-style dancesport athletes, that is, 12 dance couples, who competed at national and international level. Their mean age was 20.4 ± 3.9 years, mean body height was 172.1 ± 8.7 cm, mean body mass was 60.1 ± 9.4 kg, and mean training and competitive experience was 8.2 ± 3.4 years.

All participants were members of certified dancesport clubs and were actively involved in regular training and competition.

Before the testing procedures, all participants had to be free from acute or chronic injury, illness, or disease that could affect their performance or prevent them from completing the testing. The inclusion criteria were age between 16 and 35 years, active participation in standard-style dancesport, and completion of all testing procedures. In the studies involving dance couples, all measurements were performed with the athletes' regular dance partners. Before the beginning of the research, all participants signed written informed consent forms agreeing to participate in the study and to allow their data to be used solely for scientific purposes.

The research was conducted anonymously and in accordance with the Declaration of Helsinki. Ethical approval for the studies included in this thesis was granted by the Ethical Committee of the Faculty of Kinesiology on 29 April 2020 under ethical code number 77/2020.

8.2. Study variables

Study 1

In Study 1, the variables used for the analysis were obtained during repeated BAT testing and included: 1) speed expressed in beats per minute (bpm), 2) absolute maximal oxygen uptake ($\dot{V}O_{2\max}$) expressed in $L \cdot \min^{-1}$, 3) relative maximal oxygen uptake ($\dot{V}O_{2\max}$) expressed in $mL \cdot kg^{-1} \cdot \min^{-1}$, 4) respiratory exchange ratio (RER), 5) expiratory ventilation (VE), 6) tidal volume (VT), 7) breathing frequency (BF), 8) normalized oxygen uptake (VO_2 norm), 9) normalized breathing frequency (BF norm), 10) ventilatory equivalent for oxygen (VE/VO_2), 11) ventilatory equivalent for carbon dioxide (VE/VCO_2), and 12) dead space to tidal volume ratio (VD/VT). In addition, effect size (ES), intraclass correlation coefficient (ICC), coefficient of variation (CV), typical error (TE), and smallest worthwhile change (SWC) were calculated.

Study 2

In Study 2, the variables analyzed were ventilatory and metabolic parameters obtained during the BAT protocol and compared with laboratory-based treadmill protocols. The main study variables were: 1) ($\dot{V}O_{2\max}$) expressed in $L \cdot \min^{-1}$, 2) ($\dot{V}O_{2\max}$) expressed in $mL \cdot kg^{-1} \cdot \min^{-1}$, 3) (RER), 4) (VE) expressed in $L \cdot \min^{-1}$, 5) tidal volume (VT) expressed in L, 6) (VE/VO_2), 7) (VE/VCO_2), and 8) (VD/VT).

Study 3

In Study 3, the same ventilatory and metabolic variables were analyzed in order to determine the diagnostic accuracy of the BAT protocol against objective laboratory measures. The variables included: 1) absolute $\dot{V}O_{2\max}$, 2) relative $\dot{V}O_{2\max}$, 3) RER, 4) VE, 5) VT, 6) breathing frequency (BF), 7) VE/VO_2 , 8) VE/VCO_2 , and 9) VD/VT. Based on these variables, sensitivity, specificity, false positive values (FPV), false negative values (FNV), positive likelihood ratio (PLR), negative likelihood ratio (NLR), and area under the curve (AUC) were calculated.

8.3. Testing procedures

Study 1

In Study 1, the BAT protocol was performed on two separate occasions with an interval of one week between measurements in order to determine test–retest reliability and usefulness. All measurements were conducted by the same experienced researcher. During both trials, the participants wore their standard dance equipment, consisting of a light T-shirt, tights, and dance shoes. The testing was carried out under controlled indoor conditions, with air temperature maintained between 22 °C and 24 °C and relative humidity of approximately 55%. Ventilatory and metabolic parameters were obtained using the Meta Max® 3B portable gas analyzer, which was calibrated prior to testing in accordance with the manufacturer's recommendations.

Study 2

In Study 2, the participants performed the Ballroom Aerobic Test (BAT), a newly developed field-based protocol specifically designed for standard-style dancesport athletes. The BAT protocol was standardized across five dances performed in the following order: English Waltz, Slow Foxtrot, Tango, Viennese Waltz, and Quickstep. Each dance consisted of progressively linked levels, and the tempo increased by 7 beats per minute throughout the protocol. At each level, the dance couples performed basic standard dance figures for 30 seconds at a prescribed tempo, following a metronome and without accompanying music. The test began at 75 bpm and continued until volitional exhaustion. After completion of the BAT protocol, the participants also performed two laboratory treadmill protocols, namely the KF1 and Bruce protocols, for the purpose of criterion validation. During both laboratory protocols, ventilatory and metabolic parameters were assessed by means of a breath-by-breath pulmonary gas exchange system. The KF1 protocol began at a speed of 3 km·h⁻¹ with a 1% incline, whereas the Bruce protocol began at a speed of 2.7 km·h⁻¹ with a 10% gradient. In both protocols, workload increased progressively until volitional exhaustion was reached.

Study 3

In Study 3, the same BAT protocol was applied in order to assess the diagnostic accuracy of the field-based test against the KF1 and Bruce treadmill protocols. The dancers performed the BAT under conditions specific to dancesport, while physiological measurements were

collected using the Meta Max® 3B portable gas analyzer. Laboratory measurements obtained from treadmill testing were then used as the reference criteria for sensitivity and specificity analyses.

8.4. Data processing

Study 1

Prior to statistical analysis, all data were checked for completeness, consistency, and suitability for further processing. Only participants who completed both testing sessions were included in the final dataset. Ventilatory and metabolic variables obtained from the MetaMax® 3B system were organized and prepared for analysis, including speed, absolute and relative VO_2 , respiratory exchange ratio, expiratory ventilation, tidal volume, breathing frequency, ventilatory equivalents, and dead space to tidal volume ratio.

The dataset was screened for the assumptions of parametric analysis. Normality was assessed using the Shapiro–Wilk test and Q–Q plot inspection, whereas homogeneity of variance was examined using Levene’s test. Since all variables met the required assumptions, the data were summarized using means, standard deviations, and 90% confidence intervals.

To support the interpretation of repeated measurements, effect size, intraclass correlation coefficient, coefficient of variation, typical error, and smallest worthwhile change were calculated. All data processing and statistical analyses were performed using IBM SPSS Statistics version 27.0, with statistical significance set at $p < 0.05$.

Study 2

Normality of distribution was assessed using the Shapiro–Wilk test, supported by Q–Q plot inspection, while homogeneity of variance was examined using Levene’s test. Descriptive data were reported as means and standard deviations with 95% confidence intervals. To examine potential dependence within dance couples, a linear mixed-effects model with random intercept for couples was applied. Differences between the BAT, KF1, and Bruce protocols were analysed using repeated-measures analysis of variance. The magnitude of differences was quantified using standardized mean differences expressed as effect sizes. Associations between the BAT protocol and laboratory-based protocols were evaluated using Pearson’s product–moment correlation coefficients. Agreement for relative

$\dot{V}O_{2\max}$ was further examined using Bland–Altman analysis, while Lin’s concordance correlation coefficient was calculated to assess both precision and accuracy relative to the reference methods. In addition, Passing–Bablok regression was used to compare the BAT with the KF1 and Bruce protocols and to detect potential measurement error between methods. All analyses were conducted in IBM SPSS Statistics version 27.0, with statistical significance set at $p < 0.05$.

Study 3

Diagnostic accuracy of the BAT protocol against the KF1 and Bruce protocols was examined using sensitivity, specificity, false positive, false negative, positive likelihood ratio, and negative likelihood ratio. For each ventilatory and metabolic variable, outcomes from the KF1 and Bruce protocols were classified into low and high groups according to the median value, and BAT-derived values were subsequently cross-tabulated against these classifications. Receiver operating characteristic curve analysis was used to assess discriminatory ability, with diagnostic performance quantified by the area under the curve. A linear mixed-effects model with random intercept for couples was applied to test potential dependence within dance couples for the primary outcome. Correlation coefficients and linear regression equations were additionally calculated to examine associations between the BAT and laboratory protocols and to estimate predicted relative $\dot{V}O_{2\max}$ values. All analyses were performed in SPSS version 23, with statistical significance set at $p < .05$.

9. CHAPTER 3: ORIGINAL STUDIES

9.1. Research study one

Article title

Application of the Ballroom Aerobic Test protocol for assesing performance in standard – style dancesport athletes

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9.2. Abstract

Introduction

Although the existing field-based tests to assess functional capacity in dancesport have been developed, most of them have been applied to ballet or contemporary dancesport athletes at the individual level, while little evidence is available for dancesport couples in standard dance disciplines. Therefore, the main purpose of this study was to examine the test-retest reliability and usefulness of the progressive Ballroom Aerobic Test (BAT) protocol for assessing aerobic performance.

Materials and Methods

Thirteen standard dancesport athletes (six pairs and one individual male participant; age: 20.1 ± 3.8 years; height: 175.0 ± 8.2 cm; weight: 64.3 ± 9.7 kg; males; age: 19.9 ± 3.7 years; height: 180.0 ± 4.7 cm; weight: 70.2 ± 8.7 kg; body mass index: 21.5 ± 1.8 kg/m² training experience: 8.6 ± 5.1 years; females; age: 20.3 ± 4.0 years; height: 168.5 ± 6.5 cm; weight: 57.5 ± 5.5 kg; body mass index: 20.2 ± 1.3 kg/m² ; training experience: 8.5 ± 3.4 years) took part in the study. All participants were members of certified dancesport clubs who competed at national and international levels. The BAT protocol consisted of five stages, each corresponding to one of five standard dancesport disciplines (English Waltz, Slow Foxtrot, Tango, Viennese Waltz, and Quickstep). A test-retest design, with one week between trials, was used to examine the reliability measures. Ventilatory and metabolic parameters were derived from MetaMax® 3B, a reliable and valid portable gas analyzer. Reliability measures included Cohen D effect size (ES), intra-class correlation coefficient (ICC), coefficient of variation (CV), typical error (TE) and smallest worthwhile change (SWC).

Results

No significant differences were observed between test and retest sessions ($P > 0.05$). ESs ranged from trivial to small (0.00–0.47) with ‘very good’ to ‘excellent’ reliability (ICC = 0.80–0.99; CV = 1.63–4.85%). The usefulness of the BAT protocol was generally rated as ‘ok’ to ‘good’ for speed (TE = 2.76; SWC = 3.20; <), absolute VO₂ (TE = 0.14; SWC = 0.15;

<), respiratory exchange ratio (RER; TE = 0.02; SWC = 0.02; =), tidal volume (VT = 0.06; SWC = 0.06; =), and dead space to tidal volume ratio (VD/VT; TE = 0.01; SWC = 0.01; =).

Conclusion

Current findings suggest that the BAT protocol is a reliable and useful tool for assessing aerobic capacity in standard-style dancesport athletes. Moreover, the BAT protocol can accurately detect meaningful individual changes, particularly for speed (3.20 bpm), absolute VO_2 ($0.15 \text{ L} \cdot \text{min}^{-1}$), and VE (4.87 L). These results may assist athletes and strength and conditioning coaches in monitoring and tracking ‘real’ time changes to optimize the training process.

Key words: aesthetic sports, the BAT protocol, cardiorespiratory fitness, effect size, coefficient of variation, typical error, smallest worthwhile change

9.3. Introduction

Dancesport performance has been categorized as a high-intensity intermittent exercise requiring high levels of physical fitness (Koutedakis & Jamurtas, 2004). In addition to technical requirements, the complexity of choreography makes physical preparedness just as important as skill development (Ngo et al., 2024), with upper body muscular and cardiovascular endurance identified as the best predictors of aesthetic performance (Angioi et al., 2009). Although dancesport is composed of many disciplines, physiological capabilities are crucial to sustaining the demanding daily schedules of training and competition performance. Evidence suggests that aerobic capacity is one of the key determinants of success in dancesport (Smol & Fredyk, 2012). For example, a study by Rodrigues-Krause, Krause & Reischak-Oliveira (2015) showed that dancers’ cardiorespiratory requirements during both dancesport classes and performances were equally important. However, aerobic capacity during rehearsals and/or classes exhibited lower values than during competition. This suggests that, despite being a crucial factor distinguishing successful from unsuccessful dancesport athletes (Malkogeorgos et al., 2013), the discrepancy between training and competition in dancesport athletes might limit the ability to improve or even maintain higher levels of cardiorespiratory physical fitness (Nam,

Park & Kim, 2024). The ability to efficiently uptake, transport and utilize oxygen through physiological processes has been prioritized, as it directly influences technical achievements, performance quality, and career longevity (Angioi et al., 2012). However, both professional and student dancesport athletes tend to demonstrate lower maximal oxygen uptake ($\dot{V}O_{2\max}$) compared to other athletes (Baldari & Guidetti, 2001; Tiemens et al., 2023). For instance, male dancesport athletes exhibit $\dot{V}O_{2\max}$ of $48.0 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, which is 20 to 50% lower than values reported in cyclic or complex team sport activities (Cohen et al., 1982; Koutedakis & Jamurtas, 2004). Another contributing factor to $\dot{V}O_{2\max}$ improvements in dance may be related to its small ability to stimulate positive cardiorespiratory adaptations (McCord, Nichols & Patterson, 1989). It has been documented that increases in aerobic capacity are not related to class work, but rather to the intensity and duration of performances (Wyon et al., 2004). Since the intensity of specific (dance movements) or general (circuit) training regimes needs to be between 70 and 80% of an individual's $\dot{V}O_{2\max}$ and should last >20 min to enhance aerobic capacity, progressive dance protocols to stimulate cardiorespiratory development are warranted. In dancesport, measuring aerobic capacity with objective tools (heart rate monitors, ergometry) is the cornerstone for planning training programs at the individual level (Tiemens et al., 2023). Because of complex movement patterns and often strenuous training and competition programs, energy pathways for both aerobic and anaerobic requirements should be considered equally important (Maciejczyk & Feć, 2013). On the other hand, literature suggests that physical performance can be a useful indicator of physiological tremor and fatigue (Kruusamäe, Maasalu & Jürimäe, 2016; Mazur-Rózycka et al., 2023), adding its practical ability to detect the level of endurance and deteriorating effects of training and competition on dancesport performance (Ngo et al., 2024). The necessity of determining an individual's cardiovascular and respiratory capabilities may be helpful in dosing the training load and primarily targeting positive aerobic output during preparatory period. On the other hand, examining 'maximal' aerobic levels in dancesport is quite difficult to achieve, because the nature of dance is non-competitive, and the intensity is often set by a choreographer (Chatfield et al., 1990). Unfortunately, well-established objective methods to assess aerobic performance, such as running- or cycling-based ergometers, are expensive, difficult to administer and do not mimic complex dancesport movements. Moreover, dancers may have biomechanical limitations during running or walking, due to their limited dorsiflexion movements in the ankle and a highly developed turn out of the feet, which may cause stress on the knee and hip joints (Russell, 2013). Because of these limitations, previous studies have attempted to

develop on-field aerobic tests for dancesport. According to a systematic review by Tiemens et al. (2023), the most common cardiorespiratory fitness test protocols in dancesport include the Aerobic Power Index (API) (Wallman et al., 2003), the Ballet-specific Aerobic Fitness Test (B-DAFT) (Twitchett et al., 2011), the Dance Aerobic Fitness Test (DAFT) (Wyon et al., 2023), the High-Intensity Dance Performance Fitness Test (HIDT) (Redding et al., 2009), and the Seifert Assessment of Functional Capacity for Dancers (SAFD) (Seifert et al., 2021).

Despite the fact that all tests exhibited ‘good’ to ‘very good’ test-retest reliability properties, findings from these studies cannot be generalized to other dancesport disciplines. Most studies recruited ballet (Twitchett et al., 2011), or contemporary (Wyon et al., 2004) dancesport athletes, whose training routines and movement patterns differ from those of standard dancesport practitioners (Ngo et al., 2024). Standard male ($59.6 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) and female dancers ($51.2 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) tend to have higher average $\dot{V}O_{2\text{max}}$ values (Liiv et al., 2014), compared to ballet or contemporary dancesport athletes (Wyon et al., 2004; Twitchett et al., 2011). Moreover, $\dot{V}O_{2\text{max}}$ has been the most commonly used variable to assess aerobic capacity (Wallman et al., 2003; Redding et al., 2009; Twitchett et al., 2011; Wyon et al., 2023), while data regarding speed, ventilatory and metabolic parameters have been rarely investigated. Finally, available field-based tests have been developed at the individual level, and to the best of the authors’ knowledge, the test-retest properties have not been evaluated simultaneously in dancesport couples. These discrepancies between different dancesport disciplines, type of dancesport athletes and physiological characteristics may affect the reliability properties of a given test. Notably, for the abovementioned tests assessing aerobic performance, neither typical error (TE) nor smallest worthwhile change (SWC) were calculated, limiting their usefulness in real-time settings. TE indicates the random error associated with a measurement protocol, while SWC represents the smallest worthwhile change that is practically relevant to an athlete (Hopkins, 2004; Hopkins, 2007). Both measures allow us to determine if observed performance changes in a certain variable are greater than the TE and the SWC, denoting statistical significance and practical importance. The reliability and usefulness of a newly developed progressive dance test to assess aerobic capacity would be of great importance for standard-style dancesport athletes and their strength and conditioning coaches, allowing them to monitor and track training intensity and duration for maximum efficiency. If results showed appropriate reliability statistics with confirmatory usefulness, the new

progressive test would better reflect the true energetic state of dancesport athletes in both training and competitive conditions. Based on the shortcomings of previously established dancesport tests, the main purpose of this study was to examine the test-retest reliability of the Ballroom Aerobic Test (BAT) for assessing aerobic capacity in dancesport athletes competing in standard dancesport disciplines. The second purpose was to determine its usefulness in accordance with the noise of the test results and measurement uncertainty using the magnitude of the SWC. We hypothesized that the BAT test would yield ‘good’ reliability and could detect meaningful changes in performance.

9.4. Materials and methods

Experimental approach

This observational, within-subject, test-retest sub-study was conducted to examine the reliability properties and usefulness of the BAT in standard dancesport athletes. Portions of this text were previously published as part of a study (Despot & Plavec, 2025). In brief, the study was part of a project titled ‘Construction and Validation of a Test Protocol to Assess Aerobic Capacity in Dancesport Athletes from Standard Dance Styles.’ (Despot & Plavec, 2025). The project was divided into four segments to examine: (i) reliability and usefulness; (ii) validity; (iii) sensitivity; and (iv) pragmatic validity of the BAT. For the purpose of this study, the BAT protocol was performed on two separate occasions, one week apart. The testing procedure was initiated during the preparatory period of dancesport athletes. Measurements were performed by the same experienced researcher to minimize possible measurement error. During both trials, the participants wore their standard dance equipment (light T-shirt, tights, dance shoes). The air temperature conditions of the indoor facility were controlled to be between 22 °C and 24 °C with the humidity of $\approx 55\%$.

Study participants

Thirteen advanced standard dancesport athletes (six pairs and one male participant; age: 20.1 ± 3.8 years; height: 175.0 ± 8.2 cm; weight: 64.3 ± 9.7 kg) with >8 years of training and competing experience participated in the study. As mentioned in a previous study (Despot & Plavec, 2025), all participants were members of certified dancesport clubs who competed at national and international levels. The inclusion criteria to enter the study were: (i) being free from any kind of injury, acute or chronic illness and disease, as confirmed by a certified

dancesport association doctor; (ii) age range between 16 and 35 years; and (iii) completing both measurements for reliability and usefulness properties of the BAT protocol. The a-priori power analysis calculated by the G*Power software ver. 3.1.9.7 (Kang, 2021) showed that by setting the input parameters of a two-tailed $\alpha < 0.05$, a minimum required correlation between two occasions at $r > 0.69$ (Buchheit et al., 2011), and statistical power of $1 - \beta = 0.80$, the required total sample size was $n = 11$. Before the study began, all participants had signed a written informed consent to participate in the study and to allow their data to be used solely for scientific purposes. All procedures in the study were anonymous and conducted in accordance with the Declaration of Helsinki (World Medical Association, 2013). The Ethical Committee of the Faculty of Kinesiology approved the study on 29 April 2020 (ethical code number: 77/2020).

Study variables

The same methodology to examine the psychometric properties of the BAT protocol has been published elsewhere (Despot & Plavec, 2025). To examine the reliability properties of the BAT protocol, we used the MetaMax® 3B (CORTEX Biophysik GmbH, Leipzig, Germany), a reliable and valid portable breath-by-breath ventilatory and metabolic measurement system specifically designed for field- and laboratory-based testing (Macfarlane & Wong, 2012). The device consists of two parts designed to be worn on the chest. By using an electrochemical cell and an infrared analyzer, the MetaMax® 3B was able to calculate O_2 and CO_2 concentrations based on standard metabolic equations (Wasserman et al., 1999). Following the manufacturer's recommendations and previous studies (Macfarlane & Wong, 2012), the system was turned on for at least 20 min and calibrated prior to testing. The calibration process included adjusting the gas analyzers by using reference gas values of O_2 (14.97%), CO_2 (4.96%) and N_2 ($\pm 0.02\%$) and volume with a standardized 3-L syringe (5530 series, Hans Rudolph, Inc., Shawnee, KS, USA). The MetaMax® 3B software generated data regarding absolute ($L \cdot min^{-1}$) and relative $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) and associated variables including speed (bpm), respiratory exchange ratio of CO_2 produced to O_2 consumed during metabolism (RER), expiratory ventilation as the total volume of air inhaled or exhaled per min (VE; $L \cdot min^{-1}$), tidal volume as the volume inhaled or exhaled during a normal breath (VT; L), breathing frequency (BF; bpm), $\dot{V}O_2$ and BF norms calculated from referent values provided by the MetaMax® 3B (%), ventilatory equivalents for O_2 ($VE/\dot{V}O_2$) and CO_2 ($VE/\dot{V}CO_2$) as determinants of breathing efficiency,

and dead space to tidal volume ratio (VD/VT), which indicated the air that failed to participate in O_2 and CO_2 exchange process during breathing.

The BAT protocol

Of note, portions of this text were previously published as part of a study conducted by Despot & Plavec (2025). To assess the level of aerobic capacity of dancesport athletes, we constructed a field-based BAT protocol. The protocol was standardized across five standard dancesport disciplines according to the World DanceSport Federation (Premelč et al., 2019) in the following order: (i) English waltz; (ii) Slow foxtrot; (iii) Tango; (iv) Viennese waltz; and (v) Quickstep. Each dancesport discipline included multiple levels of dancing that were progressively linked, where the speed of dancing (tempo) was defined both by individual beats per minute (bpm), and by beat (bars per minute–BPM) which denote rhythm. The English waltz consisted of six levels, danced in 3/4 time in the range of 25–37 BPM or 75–110 bpm. The Slow foxtrot included five levels, danced in 4/4 time in the range of 29–36 BPM or 117–145 bpm. The Tango had five levels, danced in 4/4 time in the range of 38–45 BPM or 152–180 bpm. The Viennese waltz was performed through

Table 1. The BAT dance protocol for every dance style

Dance styles	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
English waltz						
Beats	75	82	89	96	103	110
Time	30 sec	60 sec	1.5 min	2 min	2.5 min	3 min
Slow fox						
Beats	117	124	131	138	145	
Time	3.5 min	4.0 min	4.5 min	5.0 min	5.5 min	
Tango						
Beats	152	159	166	173	180	
Time	6.0 min	6.5 min	7.0 min	7.5 min	8.0 min	
Viennese waltz						
Beats	187	194	201			
Time	8.5 min	9.0 min	9.5 min			
Quick step						
Beats	208	215	222	229	236	243
Time	10.0 min	10.5 min	11.0 min	11.5 min	12.0 min	12.5 min

three levels, danced in 3/4 time in the range of 62–67 BPM or 187–201 bpm. Finally, the Quickstep consisted of six levels, danced in 4/4 time in the range of 52–60 BPM or 208–243 bpm. At each level, dancesport couples had to perform standard dance figures for 30 s at a prescribed tempo without accompanying music (Table 1). We did not include music, as studies have shown that it may significantly impact both physical and psychological performance, by increasing the ratings of pleasure and emotional arousal during more complex musical pieces (Salimpoor et al., 2009), affecting the autonomic nervous system (Lundqvist et al., 2009), and altering the rhythm of movements (Hu, Li & Liu, 2022), all of which are contributing factors to dancesport performance. The speed expressed in beats progressively increased throughout the protocol by seven BPM. The initial speed of the dancesport protocol was set at 75 bpm. Participants danced to a predefined dance tempo and rhythm using a metronome. The elements of each dancesport discipline were basic and easy to perform, while dancesport couples were free to create their own choreography. The duration of the BAT protocol was cumulatively added up and each pair danced until exhaustion.

Data analysis

Shapiro–Wilk’s (S–W) test was used to assess data normality. Data were checked for critical W values, Q–Q plot inspection, and the homogeneity of the variance was confirmed using the Leven test. If the calculated W value was larger than the tabulated W value, this denoted that we did not reject the null hypothesis. All variables included in further analysis were assumed to follow a hypothetical normal distribution, so data were presented as means and standard deviations (SD) with 90% confidence interval limits (90% CI). The magnitude of change between the two measurements (T0 and T1) were examined using a standardized mean difference with the following effect size (ES) proposed by Hopkins, Schabort & Hawley (2001): trivial ($ES < 0.2$), small ($0.2 < ES < 0.5$), moderate ($0.5 < ES < 0.8$), large ($0.8 < ES < 1.6$), and very large ($ES > 1.6$). The reliability statistics between pre- and post-measurements were determined using three parameters: (i) intraclass correlation coefficient (ICC), (ii) typical error (TE) expressed as coefficient of variation (CV%), and (iii) smallest worthwhile change (SWC), calculated using an Excel spread sheet provided by Hopkins (2007). Based on the 90% CI of the ICC estimate provided by Koo & Li (2016), the ICC strength was described as ‘poor’ ($ICC \leq 0.5$), ‘moderate’ ($0.5 < ICC \leq 0.75$), ‘good’ ($0.75 < ICC \leq 0.9$), and ‘excellent’ ($ICC > 0.9$). The CV% was calculated as the ratio of the SD to the mean and multiplied by 100, while the SWC as the between-subject SD multiplied by 0.2, according to ES. According to Hopkins (2004), the usefulness of a given variable was determined by comparing TE and SWC, and categorized as ‘marginal’ ($TE > SWC$), ‘ok’ ($TE = SWC$), and ‘good’ ($TE < SWC$). The criteria for considering reliability statistics as ‘adequate’ was $CV < 5\%$ and $ICC > 0.69$ (Buchheit et al., 2011). All statistical analyses were performed in SPSS v27.0 software (IBM, Armonk, NY, USA) with an alpha level set a priori at $p < 0.05$ to denote statistical significance.

9.5. Results

Basic descriptive statistics of the study participants are presented in Table 2. Men were significantly taller and heavier compared to women. However, no significant differences were observed in age (t -value = 1.026, $ES = 0.10$), BMI (t -value = 1.374, $ES = 0.72$) and training experience (t -value = 0.029, $ES = 0.02$). Table 3 presents the reliability statistics of aerobic capacity measures obtained by MetaMax® 3B portable spirometric device. Test–retest data showed no significant pre–post differences ($P > 0.05$) in speed (pre = 220.54

± 16.19 bpm; post = 214.92 ± 15.76 bpm), absolute VO_2 (pre = 3.16 ± 0.63 L*min⁻¹; post = 3.06 ± 0.67 L*min⁻¹), relative VO_2 (pre = 49.22 ± 5.84 ml*kg⁻¹*min⁻¹; post = 47.33 ± 6.28 ml*kg⁻¹*min⁻¹), RER (pre = 1.02 ± 0.05 ; post = 1.02 ± 0.05), VE (pre = 102.95 ± 25.09 L*min⁻¹; post = 98.09 ± 23.53 L*min⁻¹), VT (pre = 1.88 ± 0.29 L; post = 1.78 ± 0.29 L), BF (pre = 55.08 ± 9.18 bpm; post = 54.85 ± 8.46 bpm), VO_2 -norm (pre = $117.54 \pm 18.36\%$; post = $112.00 \pm 18.27\%$), BF-norm (pre = $32.31 \pm 9.58\%$; post = $33.62 \pm 9.62\%$), VO/VO_2 (pre = 30.87 ± 2.84 ; post = 29.82 ± 2.34), VO/VCO_2 (pre = 30.27 ± 2.84 ; post = 30.64 ± 3.44) and VD/VT (pre = 0.14 ± 0.02 ; post = 0.14 ± 0.01).

9.6. Discussion

The main purpose of his study was to examine test-retest reliability properties and usefulness of the progressive BAT protocol for assessing aerobic capacity in athletes of standard dancesport disciplines. Findings suggest that the BAT protocol is a reliable new method based on objectively measured ventilatory and metabolic outcomes derived from the the MetaMax® 3B portable device. In general, trivial to small ESs were observed between two occasions. The proposed criteria for ‘adequate’ reliability were met, with CV values for all the study variables $< 5\%$ ($1.63 \leq \text{CV} \leq 4.85$) and ICC values > 0.69 ($0.80\text{--}0.99$). The usefulness analysis of the BAT showed that the majority of variables were rated as ‘ok’ or

Table 2. Basic descriptive statistics of the study participants.

Study variables	Total (n = 13)	Men (n = 7)	Women (n = 6)	<i>P</i> *
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	
Age (years)	20.1 $\pm$ 3.8	20.3 $\pm$ 4.1	19.9 $\pm$ 3.5	0.254
Height (cm)	175.0 $\pm$ 8.2	180.6 $\pm$ 4.7	168.5 $\pm$ 6.5	0.003
Weight (kg)	64.3 $\pm$ 9.7	70.2 $\pm$ 8.7	57.5 $\pm$ 5.5	0.010
BMI (kg/m ²)	20.9 $\pm$ 1.7	21.5 $\pm$ 1.8	20.2 $\pm$ 1.3	0.197
Experience (years)	8.5 $\pm$ 4.2	8.6 $\pm$ 5.1	8.5 $\pm$ 3.4	0.977

*denotes significant differences between men and women ($P < 0.05$)

Table 3. Reliability measures for the MetaMax® 3B aerobic outcomes.

	ES	Mean diff. (90% CI)	ICC (90% CI)	CV% (90% CI)	TE (90% CI)	SWC (90% CI)	Rating
Speed (bpm)	0.35 (small)	-5.62 (-7.55; -3.68)	0.98 (0.94; 0.99)	1.83 (1.10; 2.48)	2.76 (2.09; 4.19)	3.20 (2.41; 4.84)	Good
Absolute VO2 (L*min⁻¹)	0.15 (trivial)	-0.1 (-0.20; -0.01)	0.96 (0.90; 0.99)	4.40 (2.70; 6.00)	0.14 (0.10; 0.21)	0.15 (0.10; 0.20)	Good
Relative VO2 (ml*kg⁻¹*min⁻¹)	0.31 (small)	-1.90 (-3.40; -0.40)	0.89 (0.71; 0.96)	4.52 (2.90; 6.00)	2.14 (1.61; 3.24)	1.21 (0.92; 1.85)	Marginal
RER	0.00 (trivial)	0.00 (-0.02; 0.01)	0.86 (0.67; 0.95)	1.63 (1.00; 2.30)	0.02 (0.02; 0.03)	0.02 (0.01; 0.03)	Ok
VE (L*min⁻¹)	0.20 (small)	-4.85 (-8.07; -1.63)	0.97 (0.92; 0.99)	4.85 (3.34; 6.40)	4.61 (3.48; 6.98)	4.87 (3.68; 7.37)	Good
VT (L)	0.33 (small)	-0.09 (-0.14; -0.05)	0.96 (0.91; 0.99)	4.32 (3.20; 5.64)	0.06 (0.05; 0.09)	0.06 (0.04; 0.09)	Ok
BF (bpm)	0.03 (trivial)	-0.23 (-2.41; 1.94)	0.90 (0.74; 0.96)	4.57 (2.99; 6.68)	3.11 (2.35; 4.71)	1.77 (1.33; 2.68)	Marginal
VO2 – norm (%)	0.30 (small)	-5.54 (-7.68; -3.40)	0.98 (0.94; 0.99)	3.91 (2.80; 5.00)	3.06 (2.31; 4.64)	3.66 (2.77; 5.55)	Good
BF – norm (%)	0.14 (trivial)	1.31 (0.40; 2.22)	0.99 (0.96; 0.99)	4.71 (3.00; 6.26)	1.30 (0.98; 1.97)	1.92 (1.45; 2.91)	Good
VE / VO2	0.47 (small)	-1.05 (-1.74; -0.37)	0.86 (0.66; 0.94)	3.62 (2.78; 4.38)	0.98 (0.74; 1.49)	0.48 (0.36; 0.72)	Marginal
VE / VCO2	0.10 (trivial)	0.37 (-0.69; 1.43)	0.80 (0.54; 0.92)	3.83 (2.56; 5.40)	1.52 (1.15; 2.30)	0.63 (0.48; 0.96)	Marginal
VD / VT	0.00 (trivial)	0.00 (0.00; 0.01)	0.82 (0.58; 0.83)	4.40 (2.44; 6.38)	0.01 (0.01; 0.01)	0.01 (0.00; 0.02)	Ok

ES = effect size; ICC = intraclass correlation coefficient; CV = coefficient of variation; TE = typical error; SWC = smallest worthwhile change; CI = confidence intervals

‘good’, indicating that the test is sufficiently sensitive to detect the smallest meaningful change. Results from this study were considered in the context of previous studies aiming to develop and investigate the reliability statistics of field-based dancesport tests for measuring aerobic capacity (Wallman et al., 2003; Redding et al., 2009; Twitchett et al., 2011; Seifert et al., 2021; Wyon et al., 2023). In the study by Wallman et al. (2003), the API test showed ‘good’ test-retest reliability for aerobic output (ICC = 0.98; mean diff. = 0.02 ± 0.16 W*kg⁻¹; CV = 3.87%), rate of perceived exertion (RPE; ICC = 0.94, mean diff. = 0.05 ± 2.10 a.u.; CV = 6.74%) and $\dot{V}O_{2\max}$ (ICC = 0.98; mean diff. = 0.41 ± 2.13 ml*kg⁻¹*min⁻¹; CV = 4.63%). In another reliability study, the B-DAFT dancesport protocol produced an almost perfect correlation between the two trials ($r = 0.998$) with the 95% limits of agreement calculated from the Bland-Altman plots to be ± 6.2 ml*kg⁻¹*min⁻¹ (Twitchett et al., 2011). Redding et al. (2009) reported somewhat poorer agreement values for the HIDT, ranging

from 0.80 between bouts of each trial and 0.82 between the four trials for maximal heart rate (HR_{max}), $\dot{V}O_2$ and blood lactate. A 3-min stage SAFD test for collegiate dancers exhibited moderated to excellent reliability for time (ICC = 0.85), $\dot{V}O_{2peak}$ (ICC = 0.92), RER (ICC = 0.50), HR (ICC = 0.86), blood lactate (ICC = 0.52) and RPE (ICC = 0.80) with no significant differences between the two trials (Seifert et al., 2021). In current dancesport practice, the most widely used tool to assess aerobic capacity has been the DAFT (Wyon et al., 2023), a 4-min five stage test with a 5 ml*kg⁻¹*min⁻¹ bandwidth within each stage. Although the authors failed to provide the ICCs for $\dot{V}O_{2max}$ and HR_{max} as the outcome variables of the telemetric gas analyzer (COSMED K4 b2, Italy), the CV for $\dot{V}O_{2max}$ and HR_{max} ranged from 1.4 to 6.0% and 1.5 to 3.5% between stages, indicating adequate reliability (Wyon et al., 2023). Indeed, $\dot{V}O_2$ is the most common functional parameter for assessing consumption in dancesport athletes (Tiemens et al., 2023). Thus, our findings indicated that the ICCs for absolute and relative $\dot{V}O_2$ were 0.96 and 0.89, which is in line with the abovementioned evidence. However, we noted that the CV was <5%, which was somewhat lower than the data reported for the DAFT test. Although some studies have suggested that the guidelines for reliability statistics are ICC > 0.80, moderate CV of ≤ 10%, and small ES (<0.60) (Atkinson & Nevill, 1998; Hopkins, 2000), we additionally strengthened the inclusion criteria to insure the test is reliable and pragmatic in real-time settings. Thus, our newly developed BAT protocol appears to be a reliable measure for testing aerobic capacity and its components. Data from this study also showed that the BAT protocol yielded appropriate sensitivity to detect meaningful changes following performance. Unfortunately, this is the first study to have calculated TE and SWC. When observing the findings in Table 3, ‘ok’ to ‘good’ usefulness was presented for speed, absolute $\dot{V}O_2$, RER, VE, VT, $\dot{V}O_2$ and BF norms and VD/VT, while relative $\dot{V}O_2$, BF, VE/ $\dot{V}O_2$ and VE/VCO₂ were deemed ‘marginally’ useful, as the TE was larger than the SWC. Changes in relative $\dot{V}O_2$ (1.21 ml*kg⁻¹*min⁻¹), BF (1.77 bpm), VE/ $\dot{V}O_2$ (0.48) and VE/VCO₂ (0.63) should be interpreted with caution, as the TE surpassed the SWC for capturing individual changes. Nevertheless, a higher proportion of variables were rated as ‘ok’ or ‘good’, confirming the BAT protocol as a useful test for aerobic performance monitoring. Although this study aimed to examine the test-retest reliability and usefulness of the BAT protocol, it is not without limitations. Sensitivity analysis calculated from the G*Power indicated that the appropriate sample size to detect ICC > 0.69 between the two occasions was n = 11, but we cannot exclude the possibility of insufficient statistical power. Additionally, training experience in dance ranged from 6 to 20 years, increasing the heterogeneity at both individual and dancesport couple levels. Because

of the small sample size, we were unable to examine the differences based on experience. Although dancesport is considered a high-intensity intermittent exercise (Koutedakis & Jamurtas, 2004; Rodrigues-Krause, Krause & Reischak-Oliveira, 2015), dancesport athletes are regarded as a ‘risky’ group of individuals with low level of cardiorespiratory fitness (Tiemens et al., 2023). Evidence regarding the development of aerobic capacity has consistently shown that none of their energy systems have been overly developed (Wyon, 2005). Another problem may be attributed to different energy requirements during the rehearsal and performance period, where the performance period is often accompanied by higher aerobic energy demands and more intense figure routines. Therefore, an advantage of the BAT protocol is that it simulates classical movements from five dancesport disciplines and mimics competition conditions. The current findings have provided evidence of its reliability properties and offer guidelines for the detection of meaningful changes in ventilatory and metabolic parameters. The authors suggest that this test can be implemented within the dancesport training program in preparatory and competitive periods, as it provides important information about changes and usefulness of aerobic performance variables. In terms of its ‘real’ applicability during training and choreography-based stimuli and the associations with long-term cardiovascular adaptations, the findings of the BAT protocol could be useful in enhancing both ventilatory and metabolic parameters related to dancesport activities. From a physiological perspective, the newly established dancesport protocol adequately addresses the most important factors of aerobic capacity in dancesport athletes, including $\dot{V}O_{2max}$. By following the BAT protocol, which consists of gradual increase of exercise intensity and duration every 30 s, positive changes in physiological abilities may be attributed to enhanced vascular tone and parasympathetic modulation of autonomic nervous system (Tomlinson & Naemi, 2025). These beneficial adaptations may contribute to faster recovery and less energy requirements for the same amount of activity, which leads to more sustainable sports performance during training or competition (Tao et al., 2022). Although we obtained promising results demonstrating adequate reliability and usefulness of the BAT protocol, we cannot exclude a few potential limitations. Despite using calculator software with available input to calculate the appropriate sample size (for reference, please see the ‘Study participants’ section), a small sample of $n = 13$ might not be sensitive enough to capture the ‘true’ reliability and usefulness properties of the BAT protocol. This implies that the findings obtained in this sample may not be generalizable to other dancesport athletes from different disciplines and techniques. However, test-retest data indicated extremely high reliability and ability to detect meaningful TE and SWC. Nevertheless, this approach should

be tested in other groups of dancesport athletes to confirm whether the BAT protocol yields satisfactory properties (Despot & Plavec, 2025).

9.7. Conclusion

In summary, the BAT protocol is a reliable and useful progressive test for measuring aerobic capacity in standard discipline dancesport athletes. The test is suitable for administering in large groups indoors and can be completed in a relatively short period of time of $\approx 12\text{--}15$ min. The characteristics through five stages which linearly progress by seven BPM and the duration of 30 s at each stage make this test easy to administer among dancesport couples while mimicking competition conditions. Moreover, by combining several dancesport disciplines (English waltz, Slow foxtrot, Tango, Viennese waltz, and Quickstep), coaches and their teams may be able to monitor and track ‘meaningful’ changes in response to training and/or detraining periods. It should be highlighted that 30-second intervals are capable of accurately capturing small ventilatory and metabolic differences derived from the portable MetaMax® 3B gas analyzer. From a practical perspective, the BAT protocol is able to detect changes as low as $0.15\text{ L}\cdot\text{min}^{-1}$ or $1.21\text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ for absolute and relative VO_2 , providing a useful basis for planning and programming the training process during preparatory and competitive periods.

9.8. Additional information and declarations

Funding

The authors received no funding for this work.

Competing Interests

Davor Plavec is an Academic Editor for PeerJ. Tamara Despot is employed by Dance studio 'Dancespot' and Davor Plavec is employed by Facility for medical care 'Prima Nova'.

Author Contributions

Tamara Despot conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.

Davor Plavec conceived and designed the experiments, authored or reviewed drafts of the article, and approved the final draft.

9.9. Research study two

Article title

The Criterion Validity of a Newly Developed Ballroom Aerobic Test (BAT) Protocol Against Objective Methods

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10. Abstract

Background

Although laboratory testing to assess aerobic capacity has been a ‘gold standard’ in sports science, its high costs and time-consuming protocols may not be feasible for monitoring and tracking progress in limited conditions. In dancesport athletes, several field-based aerobic tests have been proposed, but the majority of them have been developed for ballet or contemporary dancers at the individual level, while the data among dance couples engaging in standard dance styles is lacking. Therefore, the main purpose of this study was to validate a newly developed Ballroom Aerobic Test (BAT) protocol against objective methods.

Methods

Twelve standard dancesport couples (age: 20.4 ± 3.9 years; height: 172.1 ± 8.7 cm; weight: 60.1 ± 9.4 kg) with 8.2 ± 3.4 years of training and competing experience participated in this study. Ventilatory and metabolic parameters were generated using the MetaMax® 3B portable gas analyzer (the BAT), while the KF1 (an increase in speed by $0.5 \text{ km} \cdot \text{h}^{-1}$ by every minute) and Bruce protocols were followed in laboratory-based settings on the running ergometer.

Results

Large to very large correlations were obtained between the BAT and KF1/Bruce protocols for the absolute maximal oxygen uptake ($\dot{V}O_{2\max}$; $r = 0.88$ and 0.87) and relative $\dot{V}O_{2\max}$ ($r = 0.88$ and 0.85), respiratory exchange ratio (RER; $r = 0.78$ and 0.76), minute ventilation (VE; $r = 0.86$ and 0.79), tidal volume (VT; $r = 0.75$; 95% CI = 0.57 – 0.87 ; $p < 0.001$), ventilatory equivalent for O₂ (VE/ $\dot{V}O_2$; $r = 0.81$ and 0.80) and CO₂ (VE/ $\dot{V}CO_2$; $r = 0.78$ and 0.82), and dead space (VD/VT; $r = 0.70$ and 0.74). The Bland–Altman plots indicated no systematic and proportional biases between the BAT and KF1 protocols (standard error of estimate; SEE = $\pm 3.36 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) and the BAT and Bruce protocols (SEE = $\pm 3.75 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$).

Conclusion

This study shows that the BAT exhibits satisfactory agreement properties against objective methods and is a valid dance protocol to accurately estimate aerobic capacity in dancesport athletes participating in standard dance styles.

Key words: dance; field-based test; aerobic capacity; agreement; Bruce protocol; KF1 protocol; MetaMax® 3B portable gas analyzer

10.1. Introduction

Dance has often been defined as a combination of art and sport, with some intermittent intensity elements which are performed at higher levels(1). Regardless of the style of dance, the ability to withstand the training and competition schedules is a prerequisite, and these physiologic capabilities are essential. Evidence suggests that aerobic capacity plays a significant role for success in dance(2). Prioritizing the efficiency of the uptake, transport, and oxygen use efficiently is crucial for dance performance(3). However, it has been noted that both semi-professional and professional dancers tend to have lower levels of maximal oxygen uptake ($\dot{V}O_{2\max}$) in comparison to other athletes(4). The $\dot{V}O_{2\max}$ in dancesport athletes is approximately 30% lower, in comparison to mono-structural and team sport athletes(1). A further explanation for the $\dot{V}O_{2\max}$ hypothesis in dance might relate to the

limited capacity of dance to stimulate positive training adaptations. Research has shown that improvements in aerobic capacity are not linked to rehearsal activities but rather to the intensity and duration of physical performances(5). During specific dance movements or training protocols, the level of $\dot{V}O_{2max}$ should ideally be maintained at a level between 70% and 80% of an individual's $\dot{V}O_{2max}$, and the duration should exceed 20 min in order to effectively boost the aerobic capacity(1). From a practical view, complex dance movements do not necessarily mean intensity but rather complexity. The shortcoming of dance is that there is no methodology for developing aerobic capacity and defined dance structures through which both intensity and duration are achieved. Thus, aerobic endurance is maintained or even increased through multiple repetitions of dance routines and choreography.

In the field of dance, assessing aerobic capacity using objective measures such as heart rate monitors and ergometers is crucial for tailoring training programs at an individual level(4). Determining an individual's cardiovascular and respiratory capabilities is important for effectively managing the training load and focusing on achieving positive aerobic outcomes during the preparatory period. However, evaluating 'maximal' aerobic levels in dance presents challenges due to its non-competitive nature and the predetermined intensity by a choreographer (6). Traditional objective methods for assessing aerobic performance, such as running- or cycling-based ergometers, are not well-suited for dance as they are costly, difficult to administer, and do not replicate the intricate movements involved in dance. Furthermore, dancers may experience biomechanical constraints during running or walking, stemming from limited dorsiflexion movements in the ankle and the highly developed turn out of the feet, leading to potential stress on the knee and hip joints (7). When running, dancers often experience discomfort and pain in the shin area and uneven force distribution between tendons, ligaments, and muscles (especially in the calf area), leading to a higher risk of injuries or strain-related musculoskeletal problems(8). To address these limitations, previous studies have endeavored to develop on-field aerobic tests specifically tailored for dance. A systematic review by Tiemens et al.(4) identified several common cardiorespiratory fitness test protocols in dance, including the Aerobic Power Index (API) (9), the Ballet-Specific Aerobic Fitness Test (B-DAFT) (10), the Dance Aerobic Fitness Test (DAFT) (11), the High-Intensity Dance Performance Fitness Test (HIDT) (12), and the Seifert Assessment of Functional Capacity for Dancers (SAFD) (13).

Although an effort has been made to adequately predict aerobic outcomes derived from objective methods from dance-specific testing protocols (9–13), most previous studies have correlated the $\dot{V}O_{2\max}$ and maximal heart rate ($HR_{\max}$) from a single device (10,11). Also, the agreement between correlation coefficients for the $\dot{V}O_{2\max}$ and associated factors ranged from -0.12 (13) to 0.91 (11), limiting the ‘true’ validity in dancesport athletes. Finally, the available tests have been primarily developed for ballet or contemporary dancers (10–13) at the individual level, while the validity properties in ballroom dance couples engaging in standard dance styles have yet to be investigated. Ballet and contemporary dancers have different training routines and movement patterns compared to the standard dance practitioners(14). Also, ballet dancers have been shown to have an even lower accumulated fat mass %, which often goes below 10%, while ballroom style dancers tend to maintain their fat mass % between 10 and 20%, respectively(15). Standard male and female ballroom dancers tend to have higher average $\dot{V}O_{2\max}$ values (15), compared to ballet or contemporary dancers (10,11). This would imply that higher levels of the $\dot{V}O_{2\max}$ and peak heart rate (HR_{peak}) are generally needed to maintain performance at a high level and to cope with training and competition demands (15). From a sport-specific point of view, ballroom dancesport athletes who come from modern dance typically develop aerobic capacity and maximal performance at different rates, while athletes from other endurance activities tend to increase their aerobic capacities linearly throughout their career (15). On the other hand, by comparing the maximal aerobic capacity of dancers to other endurance sport athletes, the average $\dot{V}O_{2\max}$ is $48.0 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, while it ranges between 55.0 and $77.0 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ in swimmers, middle- and long-distance runners, rowers, and triathlon athletes(1). Interestingly, the $\dot{V}O_{2\max}$ in dancers is similar to sedentary behaviors ($\approx 44.0 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), highlighting that the endurance in dancesport athletes is only developed throughout dance routines, while the development-oriented endurance training has yet to be investigated(1). Thus, aerobic capacities and field-based tests in these athletes cannot be generalized to other dance styles, due to different physiological profiles and training/performance regimes during the preparatory and competition periods (1,4). By examining the regular training and performance by using a specific test to assess aerobic capacity, coaches and choreographers would be able to monitor and track both cardiovascular and respiratory demands of different standard dance styles and could adjust the training volume to tackle physiological enhancements.

Because of the shortcomings from previously developed and validated dance protocols, the primary purpose of this study was to develop and validate a newly established Ballroom Aerobic Test (BAT) protocol specifically designed for dance couples performing in various standard dance styles. A secondary purpose was to establish the typical error of measurement and Bland–Altman agreement between the protocols. Based on the available evidence, we hypothesized that the BAT protocol would yield large to very large criterion validity properties against treadmill-based methods (KF1 and Bruce protocols) for measuring aerobic capacity.

10.2. Materials and Methods

Experimental Approach

In this study, a within subject test–retest sub-study was utilized to examine the validity properties of the BAT in standard dancesport athletes. This study was part of a project entitled ‘Construction and validation of a test protocol to assess aerobic capacity in dancesport athletes from standard dance styles.’ The project was divided into four segments to examine (i) reliability and usefulness; (ii) validity; (iii) sensitivity; and (iv) pragmatic validity of the BAT. For the purpose of this study, two standard progressive treadmill tests (the KF1 and Bruce protocols) were assessed to determine aerobic capacity, followed by the BAT protocol one week later. The testing procedure was initiated during the preparatory period of dancesport athletes. Measurements were conducted by the same experienced researcher to avoid possible measurement errors. During testing, the participants wore their standard dance equipment (light T-shirt, tights, dance shoes). The air temperature conditions of indoor facility and laboratory were controlled to be between 22 °C and 24 °C with a humidity of $\approx 55\%$.

Study Participants

Through a public call between April 2025 and June 2025, a convenience sample of twenty-four standard dancesport athletes (12 dance couples; age: 20.4 ± 3.9 years; height: 172.1 ± 8.7 cm; weight: 60.1 ± 9.4 kg) with 8.2 ± 3.4 years of training and competing experience participated in the study. All participants were members of certified dance clubs who

competed at national and international levels. The inclusion criteria to enter the study were as follows: (i) being free from any kind of injury, acute or chronic illness, and disease, confirmed by a certified dance association doctor; (ii) age range between 16 and 35 years; and (iii) complete both measurements for validity properties of the BAT protocol. The exclusion criteria included having dance experience < 5 years, suffering from musculoskeletal or any other injury that precluded them from entering and completing the testing procedures, being without a training partner, which could not mimic conditions from competition, and not being able to complete the field- and laboratory-based protocols. The a priori power analysis calculated by the G*Power software ver. 3.1.9.7 (16) showed that by setting the input parameters of a two-tailed $\alpha < 0.05$, a minimum required correlation between the two methods at $r > 0.69$, and statistical power of $1 - \beta = 0.95$, the required total sample size was $n = 16$. Because of a possible drop-out rate, we enlarged the sample size by 50% to $n = 24$. Before the study began, all participants had signed a written informed consent form to participate in the study and to use data solely for scientific purposes. All procedures in this study were anonymous and in accordance with the Declaration of Helsinki (17). The Ethical Committee of the Faculty of Kinesiology approved this study on 29 April 2020 (ethical code number: 77/2020).

The BAT Protocol

To assess the level of aerobic capacity of dancesport athletes, we constructed a field-based BAT protocol. The protocol was standardized by 5 standard dance styles with the following order: (i) English waltz; (ii) slow fox; (iii) tango; (iv) Viennese waltz; and (v) quick step. Every dance style had multiple levels of dancing that were progressively linked, where the speed of dancing (tempo) was defined by individual beats per minute (bpm). The English waltz consisted of 6 levels, danced in 3/4 time in the range of 75–110 bpm. The slow fox included 5 levels, danced in 4/4 time in the range of 117–145 bpm. The tango had 5 levels, danced in 4/4 time in the range of 152–180 bpm. The Viennese waltz was carried out through 3 levels, danced in 3/4 time in the range of 187–201 bpm. Finally, the quick step consisted of 6 levels, danced in 4/4 time in the range of 208–243 bpm. At each level, dance couples had to perform standard dance figures for 30 s at a defined speed without the melody (Table 1), while the time was cumulatively summed from the beginning of the BAT protocol. The speed expressed in beats progressively increased throughout the protocol by 7 bpm. The initial speed of the dance protocol was set at 75 bpm. Participants danced to a pre-defined

dance tempo and rhythm by following the metronome. The elements for each dance style were basic and easy to perform, with the freedom of dance couples to create their own choreography. The duration of the BAT protocol was cumulatively added up and each pair danced until exhaustion.

The MetaMax® 3B Outcome

To examine the reliability properties of the BAT protocol, we used the MetaMax® 3B (CORTEX Biophysik GmbH, Leipzig, Germany), a reliable and valid portable breath-by-breath ventilatory and metabolic measurement system specifically designed for field-and laboratory-based testing(18). The device was composed of two parts designed to be worn on the chest. By using an electrochemical cell and an infrared analyzer, the MetaMax® 3B was able to calculate O₂ and CO₂ concentrations based on standard metabolic equations(19). Based on manufacturer's recommendations and previous studies(17), the system was turned on for at least 20 min and calibrated prior to the testing. The calibration process included adjusting the gas analyzers by using reference gas values of O₂ (14.97%), CO₂ (4.96%), and N₂ ($\pm 0.02\%$) and volume with a standardized 3 L syringe (5530 series, Hans Rudolph, Inc., Kansas City, MO, USA). The MetaMax® 3B software generated data regarding absolute (L * min⁻¹) and relative VO_{2max} (mL * kg⁻¹ * min⁻¹) and associated variables including respiratory exchange ratio of CO₂ produced to O₂ consumed during metabolism (RER), expiratory ventilation as the total volume of air inhaled or exhaled per min (VE; L * min⁻¹), tidal volume as the volume inhaled or exhaled during a normal breath (VT; L), ventilatory equivalent for O₂ (VE/VO₂) and CO₂ (VE/VCO₂) as determinants of breathing efficiency, and dead space to tidal volume ratio (VD/VT), which indicated the air that failed to participate in O₂ and CO₂ exchange process during breathing.

Table 1. The BAT dance protocol for every dance style

Dance styles	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
<i>English waltz</i>						
Beats	75	82	89	96	103	110
Time	30 sec	60 sec	1.5 min	2 min	2.5 min	3 min
<i>Slow fox</i>						
Beats	117	124	131	138	145	
Time	3.5 min	4.0 min	4.5 min	5.0 min	5.5 min	
<i>Tango</i>						
Beats	152	159	166	173	180	
Time	6.0 min	6.5 min	7.0 min	7.5 min	8.0 min	
<i>Viennese waltz</i>						
Beats	187	194	201			
Time	8.5 min	9.0 min	9.5 min			
<i>Quick step</i>						
Beats	208	215	222	229	236	243
Time	10.0 min	10.5 min	11.0 min	11.5 min	12.0 min	12.5 min

Time = cumulative time from BAT start.

The testing procedure indicated that both male and female dancers (one dance couple) were simultaneously measured with the MetaMax® 3B in order to simulate conditions from competitions in real-life settings. Although the order of trial was fixed, where dance couples first had to be tested for the BAT protocol and 48h after with the KF1 and 72 h after the KF1 protocol with the Bruce protocol in laboratory conditions, the possibility of a learning effect was vastly diminished. Each dance couple was tested individually to other dance couples for both field-and laboratory-based protocols. Also, they were told to keep the dance protocols and procedures to themselves and not to unveil them to the next dance couple. The BAT protocol was performed in an environment specific to dance, regarding the floor and dance attire that needed to be worn, while the KF1 and Bruce protocols were examined in laboratory conditions.

The KF1 and Bruce Testing Protocols

$\dot{V}O_{2max}$ and associated ventilatory and metabolic parameters were assessed by a breath-by-breath pulmonary gas exchange system (Quark b2, COSMED, Roma, Italy) during an incremental treadmill test (KF1 and Bruce). KF1 is a standard test for the assessment of aerobic and anaerobic energy capacity (20). The starting speed of the KF1 was 3 km * h⁻¹ at a slope of 1% (continuous) for a duration of 2 min, after which the speed increased by 0.5 km * h⁻¹ at the end of the third min and after that every 30 s until volitional exhaustion.

During recovery after each test protocol, the subjects walked at 5 km * h⁻¹ for 3 min. In the Bruce protocol, the participants started exercising at a treadmill speed of 2.7 km * h⁻¹ and an incline of 10% gradient for 3 min. Workloads (speed and inclination) were subsequently increased each 3 min period in a simultaneous way until volitional exhaustion was reached(21). Both protocols generated equal cardiorespiratory data as the MetaMax® 3B, which were filtered and averaged on a 5 s basis.

Data Analysis

Shapiro–Wilk’s (S-W) test was used to assess data normality. Data were checked for the critical W values, Q-Q plot inspection and the homogeneity of the variance was confirmed using the Leven test. If a calculated W value was larger than tabulated W value, this denoted that we did not reject the null hypothesis. All variables included in further analysis came from a hypothetical normal distribution, so data were presented as means and standard deviations (SDs) with 95% confidence interval limits (95% CI). To examine whether there was a couple dependence present during the BAT protocol, we utilized a linear-mixed effects model (LMM) with random intercept for couples and showed that there was no dependence effect within each couple for $\dot{V}O_{2max}$, as our primary outcome of the study ($F = 1.533$, $p = 0.244$). Differences between each protocol were examined with repeated measures analysis of variance (RM ANOVA). The magnitude of the change between the two measurements (the BAT protocol vs. KF1 and Bruce protocols) was examined with a standardized mean difference and the following effect sizes (ESs) proposed by Hopkins et al.(22): trivial ($ES < 0.2$), small ($0.2 < ES < 0.5$), moderate ($0.5 < ES < 0.8$), large ($0.8 < ES < 1.6$), and very large ($ES > 1.6$). Degree of coherence between ventilatory and metabolic parameters of the BAT protocol vs. KF1 and Bruce protocols was assessed using Pearson’s product–moment correlation (r). Correlation values denoted association between variables and tests as small ($r = 0.1–0.3$), moderate ($r = 0.3–0.5$), large ($r = 0.5–0.7$), very large ($r = 0.7–0.9$), and almost perfect ($r = 0.9–1.0$)(23). Since $\dot{V}O_{2max}$ is considered as one of the most important determinants of performance in dancesport athletes(1,4,5), a Bland–Altman plot was created to present a graphical visualization of the agreement between the BAT and KF1/Bruce protocols for relative $\dot{V}O_{2max}$. In brief, the difference between the BAT and KF1 (BAT and Bruce) protocol was calculated on the y-axis, while the average of the two measurements was presented on the x-axis. To be able to determine the mean difference ideally close to (0) and the upper and lower limits of agreement (± 1.96 SD), we created three horizontal lines.

Based on data representation, we were able to (i) determine visual agreement between the two methods; (ii) identify possible bias where the mean difference was significantly different from 0; (iii) assess the presence of magnitude of random error; and (iv) establish the limits of agreement to confirm whether the differences between the two methods were clinically meaningful(24). Finally, we calculated Lin's concordance coefficient of correlation (ρ_c), an analysis which tests both precision and accuracy of bivariate pairs of observations relative to a 'gold standard' or another set of data. According to Altman(25), the cut-off points for 'poor' vs. 'excellent' agreement were <0.20 and >0.80 . In addition, a Passing–Bablok regression analysis was considered as a non-parametric technique for comparing the BAT with the KF1 and Bruce protocols to observe a potential error in both measurements(26). All statistical analyses were performed in SPSS v27.0 software (IBM, Armonk, NY, USA), with an alpha level set a priori at $p < 0.05$ to denote statistical significance.

10.3. Results

Primary Outcomes

According to the objective termination criteria of an $RER \geq 1.10$, of the 24 participants, the proportion of the participants who reached this cut-off was 20.8% for the BAT protocol and 45.8% and 37.5% for the KF1 and Bruce protocols. Basic descriptive statistics of the study participants are presented in Table 2. No significant differences between the KF1 and BAT nor between the Bruce and BAT protocols were observed for the absolute $\dot{V}O_{2max}$ ($F_{1,3} = 0.206$; $p = 0.816$; $\eta^2_p = 0.02$) and relative $\dot{V}O_{2max}$ ($F_{1,3} = 1.502$; $p = 0.245$; $\eta^2_p = 0.12$), RER ($F_{1,3} = 2.272$; $p = 0.094$; $\eta^2_p = 0.24$), VE ($F_{1,3} = 1.956$; $p = 0.165$; $\eta^2_p = 0.15$), VT ($F_{1,3} = 2.833$; $p = 0.065$; $\eta^2_p = 0.31$), VE/ $\dot{V}O_2$ ($F_{1,3} = 2.514$; $p = 0.104$; $\eta^2_p = 0.19$) and VE/ $\dot{V}CO_2$ ($F_{1,3} = 2.737$; $p = 0.087$; $\eta^2_p = 0.20$), and VD/VT ($F_{1,3} = 2.878$; $p = 0.078$; $\eta^2_p = 0.21$). ESs showed trivial to small changes. Large to very large correlations were calculated between the KF1 and BAT protocols for absolute $\dot{V}O_{2max}$ ($r = 0.88$; 95% CI = 0.75–0.95; $p < 0.001$) and relative $\dot{V}O_{2max}$ ($r = 0.88$; 95% CI = 0.76–0.95; $p < 0.001$), RER ($r = 0.78$; 95% CI = 0.59–0.90; $p < 0.001$), VE ($r = 0.86$; 95% CI = 0.62–0.96; $p < 0.001$), VT ($r = 0.75$; 95% CI = 0.57–0.87; $p < 0.001$), VE/ $\dot{V}O_2$ ($r = 0.81$; 95% CI = 0.55–0.91; $p < 0.001$) and VE/ $\dot{V}CO_2$ ($r = 0.78$; 95% CI = 0.65–0.94; $p < 0.001$), and VD/VT ($r = 0.70$; 95% CI = 0.40–0.87; $p < 0.001$). Large to very large correlations were obtained between the Bruce and BAT protocols for absolute $\dot{V}O_{2max}$ ($r = 0.87$; 95% CI = 0.72–0.95; $p < 0.001$) and relative $\dot{V}O_{2max}$

($r = 0.85$; 95% CI = 0.71–0.93; $p < 0.001$), RER ($r = 0.76$; 95% CI = 0.50–0.91; $p < 0.001$), VE ($r = 0.79$; 95% CI = 0.50–0.94; $p < 0.001$), VT ($r = 0.83$; 95% CI = 0.71–0.91; $p < 0.001$), VE/VO₂ ($r = 0.80$; 95% CI = 0.64–0.92; $p < 0.001$) and VE/VCO₂ ($r = 0.82$; 95% CI = 0.75–0.94; $p < 0.001$), and VD/VT ($r = 0.74$; 95% CI = 0.44–0.89; $p < 0.001$).

Table 2. Basic descriptive statistics, mean difference (diff.) and ES between the BAT protocol against the KF1 and Bruce protocols.

Study variables	KF1	Bruce	BAT	Absolute diff. (95% CI)		Relative diff. (%)		ES	
	Mean±SD	Mean ±SD	Mean ±SD	KF1 - BAT	Bruce - BAT	KF1 - BAT	Bruce - BAT	KF1 - BAT	Bruce - BAT
Absolute VO₂ (L*min ⁻¹)	3.05 ± 0.74	3.05 ± 0.75	3.00 ± 0.65	-0.05 (-0.19 – 0.10)	-0.05 (-0.20 – 0.11)	1.64%	1.64%	0.07 (trivial)	0.07 (trivial)
Relative VO₂ (ml*kg ⁻¹ *min ⁻¹)	50.92 ± 7.47	49.98 ± 7.55	50.21 ± 5.96	-0.71 (-2.24 – 0.83)	0.23 (-1.47 – 1.93)	1.39%	0.46%	0.11 (trivial)	0.03 (trivial)
RER	1.09 ± 0.05	1.08 ± 0.04	1.07 ± 0.06	-0.02 (-0.03 – 0.02)	-0.01 (-0.02 – 0.02)	1.83%	0.93%	0.36 (small)	0.20 (small)
VE (L*min ⁻¹)	110.21 ± 28.43	110.43 ± 28.75	104.20 ± 26.37	-6.01 (-12.22 – 0.20)	-6.23 (-13.83 – 1.37)	5.45%	5.64%	0.22 (small)	0.23 (small)
VT (L)	1.93 ± 0.42	1.98 ± 0.54	1.77 ± 0.36	-0.16 (-0.28 – 0.04)	-0.22 (-0.54 – -0.28)	8.29%	11.11%	0.41 (small)	0.46 (small)
VE / VO₂	33.65 ± 3.82	33.85 ± 3.46	32.93 ± 2.93	-0.71 (-1.67 – 0.24)	-0.91 (-1.78 – 0.04)	2.11%	2.69%	0.21 (small)	0.29 (small)
VE / VCO₂	30.90 ± 3.83	30.16 ± 2.67	31.04 ± 3.51	0.14 (-0.89 – 1.17)	0.88 (-0.03 – 1.73)	0.45%	2.92%	0.04 (trivial)	0.28 (small)
VD / VT	0.15 ± 0.03	0.14 ± 0.03	0.15 ± 0.02	0.003 (-0.005 – 0.01)	0.009 (-0.001 – 0.02)	2.00%	6.43%	0.01 (trivial)	0.39 (small)

Lin's analysis indicated an excellent concordance between the KF1 and BAT protocols for the absolute $\dot{V}O_{2\max}$ ($\rho_c = 0.93$; 95% CI = 0.84–0.97) and relative $\dot{V}O_{2\max}$ ($\rho_c = 0.92$; 95% CI = 0.82–0.97), RER ($\rho_c = 0.86$; 95% CI = 0.68–0.94), VE ($\rho_c = 0.92$; 95% CI = 0.82–0.97), VT ($\rho_c = 0.85$; 95% CI = 0.66–0.94), VE/VO₂ ($\rho_c = 0.88$; 95% CI = 0.71–0.95) and VE/VCO₂ ($\rho_c = 0.88$; 95% CI = 0.71–0.95), and VD/VT ($\rho_c = 0.81$; 95% CI = 0.57–0.92). Similarly, the data showed an excellent concordance between the Bruce and BAT protocols for the absolute $\dot{V}O_{2\max}$ ($\rho_c = 0.93$; 95% CI = 0.83–0.97) and relative $\dot{V}O_{2\max}$ ($\rho_c = 0.90$; 95% CI = 0.78–0.96), RER ($\rho_c = 0.83$; 95% CI = 0.62–0.93), VE ($\rho_c = 0.88$; 95% CI = 0.73–0.95), VT ($\rho_c = 0.87$; 95% CI = 0.70–0.94), VE/VO₂ ($\rho_c = 0.89$; 95% CI = 0.73–0.95) and VE/VCO₂ ($\rho_c = 0.88$; 95% CI = 0.73–0.95), and VD/VT ($\rho_c = 0.84$; 95% CI = 0.63–0.93).

Secondary Outcomes

Figure 1 shows the Bland–Altman scatterplot of the $\dot{V}O_{2\max}$ agreement between the BAT and KF1 protocols. The mean difference between the two methods yielded a value of -0.71 , indicating no measurement bias ($p > 0.05$). Although a negative linear trend was observed, a linear regression analysis showed no potential proportional bias ($\beta = -0.24$; 95% CI -0.46 – 0.02 ; $p = 0.066$), with a standard error for the estimate (SEE) of $3.36 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. The linear regression equation to predict the relative $\dot{V}O_{2\max}$ from the KF1 protocol was as follows: $\dot{V}O_{2\max}\text{KF1} (\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) = -4.305 + (1.100 \cdot \dot{V}O_{2\max}\text{BAT})$ ($R^2 = 0.77$; $p < 0.001$). The slope coefficient between the BAT and KF1 protocols was $b = 1.625$ with a 95% CI ($0.90, 2.25$), while the intercept coefficient was $a = -18.43$ with a 95% confidence interval ($-64.65, 42.13$). According to Passing and Bablok(26), if one was included in the CI for the slope and zero was included for the intercept, the BAT procedure yielded similar measurements to the KF1 procedure.

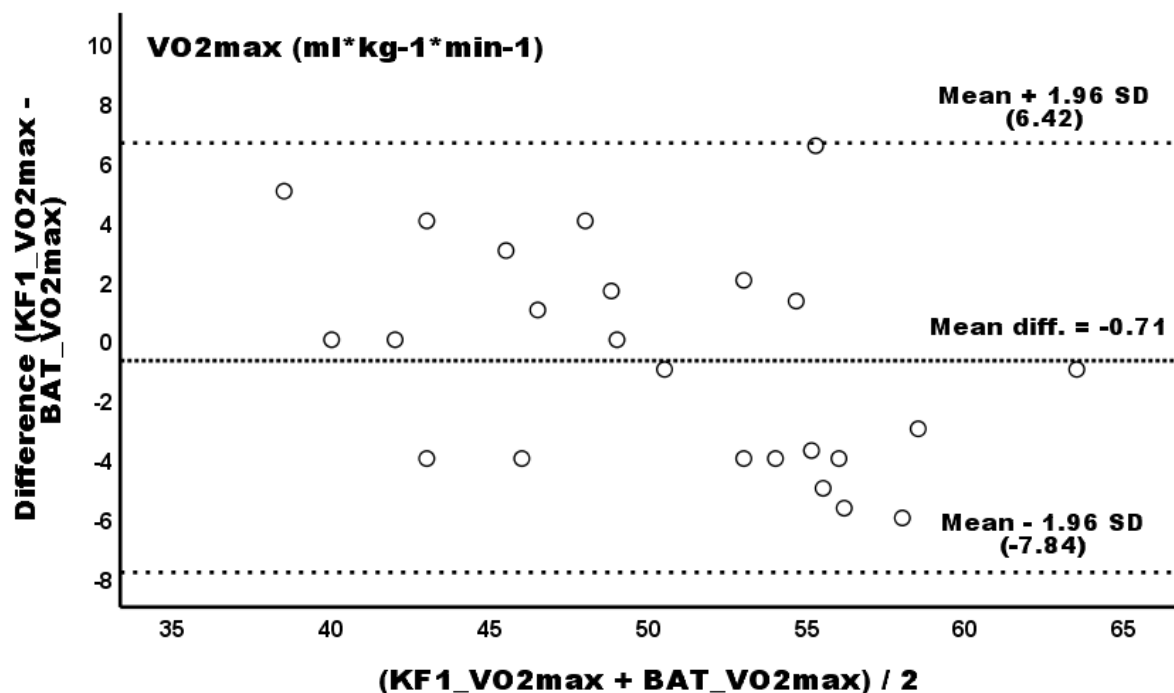


Figure 1. Bland–Altman plot of differences between the BAT and KF1 protocols (y-axis) and the average of the two measurements (x-axis) for relative $\dot{V}O_{2\max}$.

The Bland–Altman scatterplot of the $\dot{V}O_{2\max}$ agreement between the BAT and Bruce protocols is presented in Figure 2. The mean difference between the two methods yielded a

value of 0.23, indicating no measurement bias ($p > 0.05$). Similarly to the BAT-KF1, a negative linear trend between the BAT and Bruce protocols was observed; however, no potential proportional bias was shown ($\beta = -0.26$; 95% CI -0.51 – 0.15 ; $p = 0.087$). The generated SEE of the $\dot{V}O_{2\max}$ was $3.75 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Similarly to the KF1 protocol, the linear regression equation to predict the relative $\dot{V}O_{2\max}$ from the Bruce protocol was as follows: $\dot{V}O_{2\max}\text{BRUCE} (\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) = -3.996 + (1.075 \cdot \dot{V}O_{2\max}\text{BAT})$ ($R^2 = 0.72$; $p < 0.001$). The slope coefficient between the BAT and KF1 protocols was $b = 1.10$ with a 95% CI (0.80, 1.30), while the intercept coefficient was $a = -1.05$ with a 95% confidence interval ($-10.17, 9.90$), indicating that the BAT protocol yielded similar measurements to the Bruce protocol.

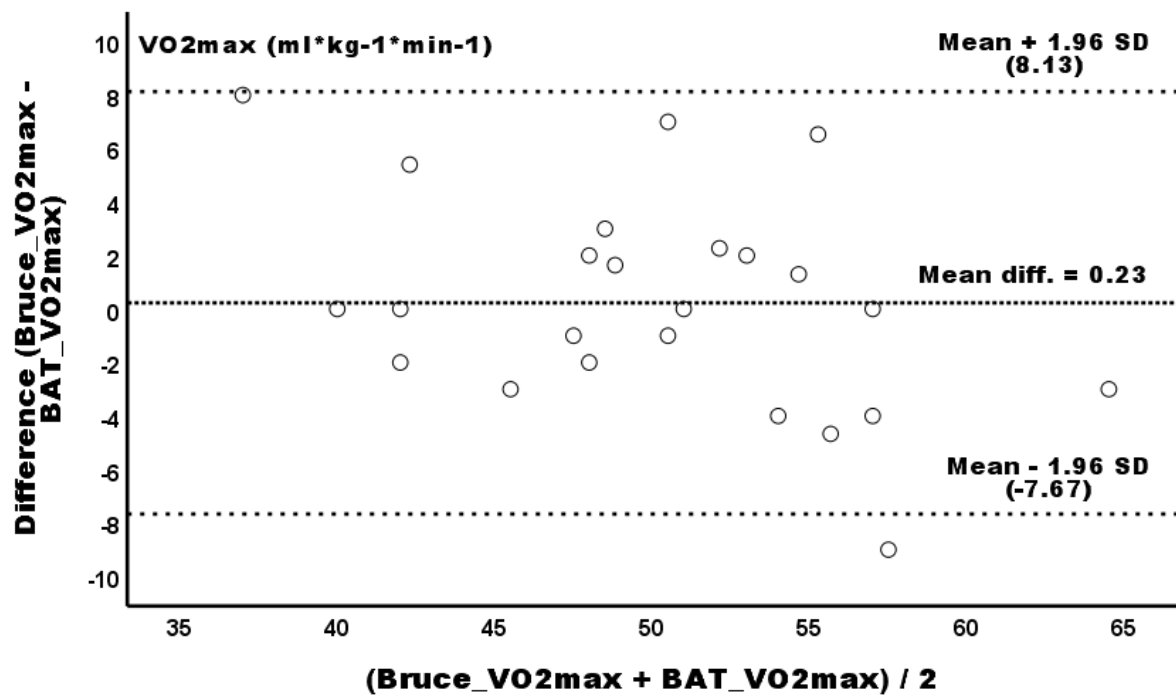


Figure 2. Bland-Altman plot of differences between the BAT and Bruce protocols (y-axis) and the average of the two measurements (x-axis) for relative $\dot{V}O_{2\max}$.

10.4. Discussion

The main purpose of this study was to develop and examine the criterion validity and Bland–Altman agreement of the BAT protocol against the KF1 and Bruce laboratory protocols in dancesport athletes performing in standard dance styles. Findings suggest that the ventilatory and metabolic parameters derived from the MetaMax® 3B portable gas analyzer during the BAT protocol correlate as large to very large with the KF1 and Bruce aerobic outcomes. The level of agreement calculated from the Bland–Altman plots for the relative $\dot{V}O_{2\max}$ shows no systematic nor proportional biases between the two methods with the SEE of $3.36 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (KF1) and $3.75 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (Bruce). To the best of the authors' knowledge, this is the first study examining the development and validity of a progressive test to assess aerobic capacity in standard dancesport athletes. Our results should be interpreted in light of previous studies. To date, several progressive field-based tests to assess the level of aerobic capacity in dance have been proposed and validated against more objective methods. For example, a study by Wallmann et al.(9) showed that the API submaximal exercise fitness test correlated well with the $\dot{V}O_{2\max}$ ($r = 0.89$ and 0.90), with a technical error of measurement (TEM) of a power output $= 0.07 \text{ W} \cdot \text{kg}^{-1}$ and $\dot{V}O_{2\max} = 0.71 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Another dance protocol designed for ballet dancers indicated that the mean squared root (sw2) for the test was 5.01, with a SEE of $6.20 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (10). One of the most common fitness protocols to examine aerobic capacity is the DAFT, a five-stage 4 min progressive test(10). In a study by Wyon et al.(11), data generated from the portable telemetric gas analyzer (Cosmed K4 b2, Italy) indicated that the $HR_{\max}$ and $\dot{V}O_{2\max}$ correlated very strongly for the test ($r = 0.91$; $SEE = 5.60 \text{ b} \cdot \text{min}^{-1}$). Similar observations were noted for the HIDT dance protocol, where five participants ($n = 5$) undertook both the treadmill and dance tests to estimate the $\dot{V}O_{2\max}$ (12). During the treadmill protocol, the mean $\dot{V}O_{2\max}$ was $46.40 \pm 3.60 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, and during the HIDT, the $\dot{V}O_{2\max}$ value was $51.00 \pm 6.60 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. A pairwise comparison between the treadmill and dance protocols showed no significant differences in $\dot{V}O_{2\max}$ ($p = 0.100$) (12). The same study also showed that the mean % of the $HR_{\max}$ was significantly lower in the HIDT compared to the treadmill test (97.50 vs. 101.00%, $p = 0.020$), while the validity of blood lactate values were high (HIDT $= 6.10 \pm 1.90 \text{ mmol} \cdot \text{L}^{-1}$ vs. treadmill $= 6.30 \pm 1.70 \text{ mmol} \cdot \text{L}^{-1}$, $p = 0.860$) (12). The most recent SAFD test to evaluate the functional capacity of collegiate dancers revealed large to very large correlations with the peak treadmill test for the relative $\dot{V}O_{2\max}$ ($r = 0.78$), $HR_{\max}$ ($r = 0.85$), blood lactate ($r = 0.72$), and rate of perceived exertion (RPE; r

= 0.84), while trivial to moderate correlations were found for time ($r = 0.60$) and the RER ($r = -0.12$) (13).

Although the existing progressive dance protocols to assess aerobic capacity exhibited satisfactory validity properties against objective measures (9–13), our newly developed BAT protocol yielded high agreements with the treadmill test following two protocols (KF1 and Bruce). The incremental difference and the novelty between our and other dance protocols lies in the fact that it is specifically designed for dance couples who engage in standard dance styles. This is very important, because both individuals need to cope with each other during the rehearsal/training or competition. This would suggest that their aerobic capacity needs to be at equal level in order to keep up with the partner. Despite the fact that the $\dot{V}O_{2\max}$ tends to be low in dancesport athletes, compared to other athletes (4–6), the intention of the BAT protocol is to enhance the aerobic system and to physiologically prepare for stress during training and/or performance. Dance movements in standard dance styles are often characterized by sway components and the interplay between rises and falls, which are considered key elements for preserving or increasing functional performance in competitive dancesport athletes (27). Moreover, the complexity of figures and faster pace during training and competition in standard dance styles is not comparable to ballet or contemporary dance styles, where the movements are often performed in static conditions, emphasizing esthetic rather than functional components of dance. Therefore, the BAT protocol can serve as an avenue for screening and tracking aerobic capacity within the narrow niche of standard style dance athletes.

The practical application of the BAT protocol is reflected in the development of a completely new model for measuring aerobic capacity and an algorithm for estimating the $\dot{V}O_{2\max}$ in standard dances under the conditions of the sport-specific activity. This enables a realistic assessment of physical and energy loads specific to the activity, in comparison with the existing tests for assessing aerobic capacity. Since standard dance styles have been often categorized as high-intensity physical activities that need aerobic and anaerobic energy systems to perform (28), the newly established dance protocol would be able to increase aerobic capacity and to optimize dance training. Indeed, correct and timely diagnostic procedures for measuring and/or assessing energy capacities in dance are needed to achieve primary goals and positive trends towards sports success (1,4).

This study is not without limitations. First, a cross-sectional design prevents us from confirming a causal relationship between field- and laboratory-based testing protocols for

assessing aerobic capacity. Second, we did not include the HR_{max} nor blood lactate parameters as indicators of aerobic and anaerobic capacities, limiting our findings to data generated from the MetaMax® 3B and treadmill devices. Previous studies have shown a strong relationship between HR_{max} and $\dot{V}O_{2max}$ (10,11) and adequate sensitivity in HR_{max} and blood lactate changes following the dance protocol (13). Third, a relatively small sample size might have underpowered the validity properties of the BAT protocol. Although we performed a sample size calculation (for more information, please see the ‘Study Participants’ section), we cannot exclude the lack of statistical power. Fourth, we failed to examine the rate of perceived exertion (RPE) and collect blood samples for lactate concentrations following the BAT, KF1, and Bruce protocols. These physiological measures have been constantly used as potential markers for determining fatigue and should be considered in further research in dancesport athletes. Fifth, the BAT protocol was measured with the MetaMax® 3B, while the treadmill tests used COSMED Quark b2. The difference in devices could introduce systematic errors independent of the protocol. Finally, the BAT protocol was not cross-validated in other athletes from different dance styles (ballet, contemporary, or Latin American), limiting its applicability. Nevertheless, the authors suggest that the BAT protocol is a valid training and performance tool for measuring aerobic capacity and associated factors in dancesport athletes from standard dance styles.

10.5. Conclusion

In summary, this study shows that the BAT protocol has a strong to excellent criterion validity against the KF1 and Bruce protocols. Also, the Bland–Altman analysis indicated that the SEE for the KF1 and Bruce protocols against the BAT protocol was $3.36 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and $3.75 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. The advantage of the BAT protocol is that it simulates classical movements from five dance styles and mimics competition conditions. The current findings have provided evidence of its validity properties and potential guidelines for monitoring and tracking ventilatory and metabolic parameter changes under different training conditions. The authors suggest that this test can be implemented within the dance training program in preparatory and competitive periods, as it gives important and valid information about the agreement between field and laboratory aerobic performance variables among standard dancesport athletes.

10.6. Author contributions: TD and DP designed the study and collected and analyzed the data. All authors contributed to interpretation of the data, drafting, and revising the manuscript, and approved the final version of the manuscript.

10.7. Conflicts of interest statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

10.8. Institutional review board statement: The study was conducted in accordance with the Declaration of Helsinki, and the Ethical Committee of the Faculty of Kinesiology approved the study on the 29th of April 2020 (ethical code number: 77/2020).

10.9. Informed Consent Statement: A written informed consent was obtained from all subjects involved in the study.

11. Data Availability Statement: The data that support the findings of this study are available upon reasonable request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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11.2. Conflicts of Interest: Author Tamara Despot is professionally engaged through her own company, Dancespot d.o.o. The company served solely as the legal entity through which the author conducts her professional activities and has no financial, commercial, or other interests that could be considered a potential conflict of interest in relation to the present study. Author Davor Plavec is employed at Polyclinic Prima Nova. The institution had no financial, commercial, or other involvement that could be construed as a potential conflict of interest in relation to the present study.

11.3. Research study three

Article title

The Ballroom Aerobic Test for estimating cardiorespiratory fitness in standard style dancesport athletes: Diagnostic accuracy against laboratory measures

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11.4. Abstract

Background

The main purpose of the study was to investigate the sensitivity properties of a newly developed Ballroom Aerobic Test (BAT) protocol for cardiorespiratory fitness against objective methods.

Methods

Twenty-four young dancesport couple athletes who competed at international level were recruited (age 20.40 ± 3.90 years; stature 172.10 ± 8.70 cm; body mass 60.10 ± 9.40 kg; 50.00% women). Physiological parameters from the field-based BAT protocol were evaluated using the MetaMax® 3B portable gas analyzer, while objective data were generated on the running ergometer following the KF1 and Bruce protocols. The area under the curve (AUC), sensitivity, specificity, false positive (FP), false negative (FN), positive likelihood ratio (PLR) and negative likelihood ratio (NLR) were calculated.

Results

The AUC for the BAT against the KF1 and Bruce protocols yielded satisfactory values of $> .75$, with the largest agreements for absolute (AUC = .92; 95% CI .82 – 1.00 and .94; 95% CI .90 – 1.00) and relative maximal oxygen uptake ($\dot{V}O_{2\max}$; AUC = .94; 95% CI .90 – 1.00 and .95; 95% CI .86 – 1.00). Other ventilatory and metabolic parameters yielded somewhat lower AUC values ($.65 \leq \text{AUC} \leq .93$). Sensitivity and specificity analyses exhibited acceptable agreement percentages between the BAT and KF1/Bruce protocols, ranging from 67% to 95% for sensitivity and 60% to 100% for specificity. The largest PLRs were shown for relative $\dot{V}O_{2\max}$ in both KF1 (10.31) and Bruce (11.05) protocols.

Conclusion

This study shows that the BAT protocol may be considered as a good diagnostic tool for evaluating ventilatory and metabolic parameters of standard style dancesport athletes.

Key words: diagnostic testing; dance; physiological parameters; sensitivity; specificity.

11.5. Introduction

Dance is often seen as a vigorous form of exercise that demands higher levels of muscular and cardiorespiratory capacities.¹ Being able to handle the rigors of training and competition in dance is essential, underscoring the importance of physiological capabilities.² Research indicates that having a strong aerobic capacity is vital for success in dance. It's crucial for dancers to be efficient in how they take in, transport, and use oxygen to enhance their performance.³ Interestingly, studies show that both semi-professional and professional dancers typically have lower maximal oxygen uptake ($\dot{V}O_{2\max}$) compared to athletes from other sports. In fact, dancers in competitive dance sports exhibit a $\dot{V}O_{2\max}$ that is about 30% lower than that of athletes involved in mono-structural and team sports.⁴ One possible reason for this lower $\dot{V}O_{2\max}$ in dancers may be linked to the limited ability of dance training to induce significant training adaptations. Findings suggest that improvements in aerobic capacity are more related to the intensity and duration of physical performance rather than rehearsal activities. This approach is key to effectively boosting their aerobic performance. From a practical view, complex dance movements do not necessarily mean intensity, but rather complexity. The shortcoming of dance is a lack of standardized or sport-specific protocols integrated into routine training and defined dance structures through which both intensity and duration are achieved. Thus, aerobic endurance is maintained or even increased through multiple repetitions of dance routines and choreography.⁵

In the realm of dance, it is essential to evaluate aerobic capacity using objective tools like heart rate monitors and ergometers to customize training programs for each individual.⁶ Assessing an athlete's cardiovascular and respiratory abilities is vital for effectively regulating the training load and aiming for beneficial aerobic results during the preparatory phase. Nonetheless, measuring 'maximal' aerobic levels in dance is challenging due to its

non-competitive aspects and the predetermined intensity set by the choreographer. Conventional objective techniques for measuring aerobic performance, such as running- or cycling-based ergometers, are not ideal for dance because they are expensive, complicated to implement, and fail to mimic the complex movements required in dance.^{7,8} In a complex, aesthetic, and skill-based discipline (like dance or parkour), where traditional testing is inadequate, reinforcing the need for ecologically valid tests is warranted.^{8,9} To address these limitations, previous studies have endeavored to develop on-field aerobic tests specifically tailored for dance. A systematic review by Tiemens et al.⁴ identified several common cardiorespiratory fitness test protocols in dance, including the Aerobic Power Index (API),¹⁰ the Ballet-specific Aerobic Fitness Test (B-DAFT),¹¹ the Dance Aerobic Fitness Test (DAFT),¹² the High-Intensity Dance Performance Fitness Test (HIDT),¹³ and the Seifert Assessment of Functional Capacity for Dancers (SAFD).¹⁴

Despite attempts to accurately forecast aerobic results based on objective methods from dance-specific testing protocols,¹⁰⁻¹⁴ the majority of earlier studies have linked $\dot{V}O_{2\max}$ and maximal heart rate ($HR_{\max}$) using a single device.^{13,14} Ultimately, the tests that are available have mostly been created for ballet or contemporary dancers¹²⁻¹⁵ on a personal basis, whereas the diagnostic aspects in ballroom dance pairs participating in standard dance styles have not been explored. Ballet and contemporary dancers follow distinct training regimens and movement styles in contrast to traditional dance performers.¹⁶ From a biomechanical point of view, ballroom dancers tend to have higher knee extension torque movements, accompanied by greater hip external and internal rotations, and hip extension, opposed to more traditional dance disciplines.^{16,17} Also, studies have shown that ballroom dancers, being more competitive and sport-related comparison to ballet and contemporary dancers, have more hamstring muscle length and dynamic balance, indicating higher levels of physical fitness.¹⁷ Lower mobility in the pelvis region found in ballet dancers might indicate more intra-articular lesions, followed by discomfort and pain more frequently.¹⁷ The biomechanical problem in the lumbo-sacral region may also indicate a complex association with altered gait biomechanics, specifically kinematics and kinetics of the dance movements. Greater dynamic balance in ballroom dancesport athletes leads to a lower risk of sport-related lower limb injury rate. Moreover, ballet dancers exhibit an even lower percentage of accumulated fat mass, often falling below 10%, whereas ballroom dancers typically keep their fat mass percentage between 10 and 20%, respectively.¹⁷ From a physiological point of view, typical male and female ballroom dancers generally exhibit higher average $\dot{V}O_{2\max}$

values¹⁶ when compared to ballet or contemporary dancers.¹⁰⁻¹⁴ This suggests that elevated $\dot{V}O_{2\max}$ and peak heart rate (HR_{peak}) are usually required to sustain high-level performance and meet the challenges of training and competition demands.¹⁷ From a discipline-specific perspective, ballroom dancesport competitors originating from modern dance usually enhance their aerobic capacity and peak performance at varying rates, whereas those from other endurance sports generally see a gradual increase in their aerobic abilities throughout their careers.¹⁷ Conversely, when examining the maximal aerobic capacity of dancers relative to other endurance sport athletes, the mean $\dot{V}O_{2\max}$ is recorded at $48.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, whereas it varies from 55.0 to $77.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ among swimmers, middle- and long-distance runners, rowers, and triathletes.¹ Notably, the $\dot{V}O_{2\max}$ in dancers aligns with sedentary activities ($\approx 44.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), emphasizing that the endurance of dancesport athletes is cultivated solely during dance performances, while endurance training designed for improvement remains unexplored.¹ Consequently, aerobic capacities and field tests in these dancers cannot be applied to other dance forms, as a result of varied physiological profiles and training/competition routines throughout the preparatory and competitive phases.^{1,4} Through the analysis of consistent training and performance with a designated test to evaluate aerobic capacity, coaches and choreographers can oversee and record the cardiovascular and respiratory requirements of various standard dance styles and can modify training volume to address physiological improvements. Therefore, the main purpose of the study was to examine the sensitivity properties of a newly developed Ballroom Aerobic Test (BAT) protocol for cardiorespiratory fitness against objective methods. We hypothesized that the BAT protocol would yield satisfactory sensitivity and specificity values in comparison to laboratory-based aerobic capacity tests.

11.6. Materials and methods

Experimental approach

This observational sub-study, conducted within subjects, aimed to assess the diagnostic characteristics of the BAT in standard dancesport athletes. The research was a component of a project titled 'Development and validation of a testing protocol to evaluate aerobic capacity in dancesport competitors from standard dance styles.' The project was split into four segments to investigate: i) reliability and utility; ii) validity; iii) diagnostic accuracy; and iv) practical validity of the BAT. Portions of the text have been published recently regarding the validity properties of the BAT protocol, where we used continuous data to evaluate correlations and Bland-Altman analyses between the BAT against the KF1/ Bruce protocols. Of note, the standard error of estimate (SEE) for relative $\dot{V}O_{2\max}$ was 3.36 ml·kg⁻¹·min⁻¹ (KF1) and 3.75 ml·kg⁻¹·min⁻¹ (Bruce).¹⁸ In this study, two standard progressive treadmill tests (the KF1 and Bruce protocols) were evaluated to measure aerobic capacity, with the BAT protocol conducted one week later. The testing process commenced during the training phase of dancesport competitors. Assessments were carried out by the same skilled researcher to prevent potential measurement inaccuracies. During the tests, the participants donned their usual dance gear (light T-shirt, tights, dance shoes). The indoor facility and laboratory's air temperature was maintained between 22°C and 24°C, with a humidity level of approximately 55%.

Study participants

Twenty-four standard dancesport athletes (12 dance couples; age 20.4±3.9 years; stature 172.1±8.7 cm; body mass 60.1±9.4 kg) with 8.2±3.4 years of training and competing experience participated in the study. All participants were members of certified dance clubs who competed at national and international level. The inclusion criteria to enter the study were: i) being free from any kind of injury, acute or chronic illness and disease confirmed by a certified dance association doctor; ii) age range between 16 and 35 years; and iii) complete both measurements for validity properties of the BAT protocol. The a-priori power analysis calculated by the G*Power software ver. 3.1.9.719 showed that by setting the input parameters of a two-tailed $P < .05$, a minimum required correlation between the two methods at $R > .69$, and statistical power of $1 - \beta = .95$, the required total sample size was $n = 16$. Because

of a possible drop-out rate, we enlarged the sample size by 50% to n=24. Before the study began, all participants had signed a written informed consent to participate in the study and to use data solely for scientific purposes. All procedures in the study were anonymous and in accordance with the Declaration of Helsinki.²⁰

The BAT protocol

To assess the level of aerobic capacity of dance sport athletes, we constructed a field-based BAT protocol. The protocol was standardized by 5 standard dance styles with the following order: i) English waltz; ii) Slow fox; iii) Tango; iv) Viennese waltz; and v) Quick step. Every dance style had multiple level of dancing that were progressively linked, where the speed of dancing (tempo) was defined by individual beats per minute (b·pm⁻¹), and by beat (bars per minute – BPM) denoting rhythm. The English waltz consisted of 6 levels, danced in 3/4 time in the range of 25–37 BPM or 75–110 BPM. The Slow fox included 5 levels, danced in 4/4 time in the range of 29–36 BPM or 117– 145 BPM. The Tango had 5 levels, danced in 4/4 time in the range of 38–45 BPM or 152–180 bpm. The Viennese waltz was carried out through 3 levels, danced in 3/4 time in the range of 62-67 BPM or 187–201 BPM. Finally, the Quick step consisted of 6 levels, danced in 4/4 time in the range of 52-60 BPM or 208–243 BPM. At each level, dance couples had to perform standard dance figures for 30 sec at a defined speed without the melody (Table 1). The speed expressed in beats progressively increased throughout the protocol by 7 BPM. The initial speed of the dance protocol was set at 75 BPM. Participants danced on a pre-defined dance tempo and rhythm by following the metronome. The elements for each dance style were basic and easy to perform, with the freedom of dance couples to create their own choreography. The duration of the BAT protocol was cumulatively added up and each pair danced until exhaustion.

The MetaMax® 3B outcomes

To examine the reliability properties of the BAT protocol, we used the MetaMax® 3B (CORTEX Biophysik GmbH, Leipzig, Germany), a reliable and valid portable breath-by-breath ventilatory and metabolic measurement system specifically

Table 1. The BAT dance protocol for every dance style

Dance styles	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
<i>English waltz</i>						
Beats	75	82	89	96	103	110
Time	30 sec	60 sec	1.5 min	2 min	2.5 min	3 min
<i>Slow fox</i>						
Beats	117	124	131	138	145	
Time	3.5 min	4.0 min	4.5 min	5.0 min	5.5 min	
<i>Tango</i>						
Beats	152	159	166	173	180	
Time	6.0 min	6.5 min	7.0 min	7.5 min	8.0 min	
<i>Viennese waltz</i>						
Beats	187	194	201			
Time	8.5 min	9.0 min	9.5 min			
<i>Quick step</i>						
Beats	208	215	222	229	236	243
Time	10.0 min	10.5 min	11.0 min	11.5 min	12.0 min	12.5 min

Note: Ballroom Aerobic Test (BAT).

designed for field- and laboratory-based testing.²¹ The device was composed of two parts designed to be worn on the chest. By using an electrochemical cell and an infrared analyzer, the MetaMax® 3B was able to calculate O₂ and CO₂ concentrations based on standard metabolic equations.²² Based on manufacturer's recommendations and previous studies,²¹ the system was turned on for at least 20 min and calibrated prior to the testing. The calibration process included adjusting the gas analyzers by using reference gas values of O₂ (14.97%), CO₂ (4.96%) and N₂ ($\pm 0.02\%$) and volume with a standardized 3-L syringe (5530 series, Hans Rudolph, Inc., MO, USA). The MetaMax® 3B software generated data regarding absolute ($\text{l}\cdot\text{min}^{-1}$) and relative $\dot{V}\text{O}_{2\text{max}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and associated variables including respiratory exchange ratio of CO₂ produced to O₂ consumed during metabolism (RER), expiratory ventilation as the total volume of air inhaled or exhaled per min (VE; $\text{l}\cdot\text{min}^{-1}$), tidal volume as the volume inhaled or exhaled during a normal breath (VT; L), ventilatory equivalent for O₂ (VE/ $\dot{V}\text{O}_2$) and CO₂ (VE/ $\dot{V}\text{CO}_2$) as determinants of breathing

efficiency, and dead space to tidal volume ratio (VD/VT), which indicated the air that failed to participate in O₂ and CO₂ exchange process during breathing.

The KF1 and Bruce testing protocols

$\dot{V}O_{2\max}$ and metabolic parameters were assessed by a breath-by-breath pulmonary gas exchange system (Quark b2, COSMED, Italy) during an incremental treadmill tests (KF1 and Bruce). KF1 is a standard test for the assessment of aerobic and anaerobic energy capacity.²³ The starting speed of the KF1 was 3 km·h⁻¹ at a slope of 1% (continuous) for a duration of 2 min, after which the speed increased by 0.5 km·h⁻¹ at the end of the third min and after that every 30 sec until volitional exhaustion. During recovery after each test protocol, the subjects walked at 5 km·h⁻¹ for 3 min. In the Bruce protocol, the participants started exercising at a treadmill speed of 2.7 km·h⁻¹ and an incline of 10% gradient for 3 min. Workloads (speed and inclination) were subsequently increased each 3-minute period in a simultaneous way until volitional exhaustion was reached.²³ Both protocols generated equal cardiorespiratory data as the MetaMax® 3B, which were filtered and averaged on a 5-second basis.

Statistical analysis

Diagnostic accuracy of outcome measures derived from the BAT protocol against the KF1 and Bruce protocols included sensitivity, specificity, false positive (FP) and false negative (FN) values, and the level of positive likelihood ratio (PLR) and negative likelihood ratio (NLR). The outcome was every variable derived from the KF1 and Bruce protocols categorized as ‘low’ (below the 50th percentile) and ‘high’ (above the 50th percentile) according to the median value. Such approach has been previously used for soccer players and general population to determine the level of physical fitness.^{24,25} Based on the two groups for each variable, we cross-tabulated the values from the MetaMax® 3B portable device and calculated the abovementioned statistical procedures. Sensitivity represented the proportion of individuals with the ‘true’ positive test, while specificity denoted those with the ‘true’ negative test. Sensitivity and specificity equations were as follows: sensitivity = (true positives)/(true positives + FN) and specificity = (true negatives)/(true negatives + FP). Individuals categorized in the ‘high’ group for the KF1 and Bruce protocols, but ‘low’ for

the BAT protocol and vice versa represented FP and FN. Likelihood ratios determined the utility of the BAT protocol. PLR was calculated as sensitivity/(1-specificity), while NLR was calculated as (1-sensitivity)/specificity. To examine the discriminatory ability of the ventilatory and metabolic outcomes derived from the MetaMax® 3B portable device to predict the same variables from the KF1 and Bruce protocols, we used receiver operating characteristics (ROC) curves quantified by the area under the curve (AUC). ROC curves analyses were designed to test the discriminatory power. The AUC represented the diagnostic power of a test classified as small (AUC= .55 – .62), moderate (AUC= .63 - .71) and large (AUC> .71). Two-sided values of P were used, and significance was set at P< .05. All the analyses were calculated in Statistical Packages for Social Sciences v.23 (SPSS, Chicago, IL, United States).

11.7. Results

Before the examination of diagnostic accuracy of the BAT protocol against the KF1 and Bruce protocols, we determined if a couple dependence was present during the testing procedures, by utilizing a linear-mixed effects model (LMM) with random intercept for couples. Data showed no dependence effect within each couple for $\dot{V}O_{2max}$, as our primary outcome of the study ($F= 1.533$, $P= .244$). As previously stated¹⁸, the proportion of the participants who reached the cut-off of $RER \geq 1.10$ was 20.8% for the BAT protocol and 45.8% and 37.5% for the KF1 and Bruce protocols. Ventilatory and metabolic parameters obtained from the MetaMax® 3B portable device yielded great diagnostic properties in terms of sensitivity and specificity (Table 2). The AUCs exhibited were the largest for the absolute and relative $\dot{V}O_{2max}$, followed by VE and VT. The lowest AUCs were presented for VE/ $\dot{V}O_2$ and VE/ $\dot{V}CO_2$. Nevertheless, all AUCs were mostly categorized as ‘large’.

Table 3 shows the sensitivity, specificity, FP and FN, and PLR and NLR properties of the ventilatory and metabolic parameters from the BAT protocol against the KF1 and Bruce protocols. Similar to AUCs, the largest sensitivity and specificity properties were generated for the absolute and relative $\dot{V}O_{2max}$. Again, VE/ $\dot{V}O_2$ and VE/ $\dot{V}CO_2$ exhibited somewhat lower diagnostic properties. However, all parameters showed PLR greater than 1, indicating that the participants categorized in either ‘low’ or ‘high’ categories of the BAT protocol were more likely to be categorized in the same category of the KF1 and BAT protocols. The lowest PLRs were obtained for the VE/ $\dot{V}CO_2$ in the KF1 protocol (1.68) and VD/VT for the Bruce

protocol (1.92). The BAT protocol yielded large to very large correlations with the KF1 and Bruce protocols for both absolute ($R = .88$ and $.87$) and relative $\dot{V}O_{2\max}$ ($R = .88$ and $.85$), RER ($R = .78$ and $.76$), VE ($R = .86$ and $.79$), VT ($R = .75$ and $.83$), VE/ $\dot{V}O_2$ ($R = .81$ and $.80$) and VE/ $\dot{V}CO_2$ ($R = .78$ and $.82$), and VD/VT ($R = .70$ and $.74$).

The linear regression equation to predict the relative $\dot{V}O_{2\max}$ from the KF1 protocol was as follows: $\dot{V}O_{2\max}\text{-KF1 (ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) = -4.305 + (1.100 \cdot \dot{V}O_{2\max}\text{-BAT})$ ($R^2 = .77$). The slope coefficient between the BAT and KF1 protocols was $\beta = 1.625$ with a 95% CI (.90, 2.25), while the intercept coefficient was $a = -18.43$ with a 95% confidence interval (−64.65, 42.13), indicating no proportional bias. Similarly, the linear regression equation to predict the relative $\dot{V}O_{2\max}$ from the Bruce protocol was as follows: $\dot{V}O_{2\max}\text{-BRUCE (ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) = -3.996 + (1.075 \cdot \dot{V}O_{2\max}\text{-BAT})$ ($R^2 = .72$). The slope coefficient between the BAT and KF1 protocols was $\beta = 1.10$ with a 95% CI (.80, 1.30), while the intercept coefficient was $a = -1.05$ with a 95% confidence interval (−10.17, 9.90).

Table 2. Classification of the study participants based on the median values of the KF1 protocol against the BAT protocol

Study variables	Protocol	AUC (95% CI)	Std. error	Significance
$\dot{V}O_{2\text{max-absolute}}$ ($L \cdot \text{min}^{-1}$)	KF1	.92 (.82 – 1.00)	.053	$P < .001$
	Bruce	.93 (.83 – 1.00)	.050	$P < .001$
$\dot{V}O_{2\text{max-relative}}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	KF1	.94 (.90 – 1.00)	.021	$P < .001$
	Bruce	.95 (.86 – 1.00)	.047	$P < .001$
RER	KF1	.81 (.63 - .99)	.091	$P = .010$
	Bruce	.85 (.69 – 1.00)	.080	$P = .004$
VE ($L \cdot \text{min}^{-1}$)	KF1	.87 (.70 – 1.00)	.086	$P = .002$
	Bruce	.86 (.69 – 1.00)	.087	$P = .003$
VT (L)	KF1	.85 (.70 – 1.00)	.078	$P = .003$
	Bruce	.93 (.83 – 1.00)	.054	$P < .001$
BF (bpm)	KF1	.84 (.69 – 1.00)	.080	$P = .004$
	Bruce	.88 (.74 – 1.00)	.069	$P = .002$
VE/ $\dot{V}O_2$	KF1	.84 (.68 – 1.00)	.083	$P = .005$
	Bruce	.76 (.56 – 0.96)	.103	$P = .033$
VE/ $\dot{V}CO_2$	KF1	.65 (.43 - .87)	.114	$P = .214$
	Bruce	.80 (.60 – 1.00)	.102	$P = .012$
VD/VT	KF1	.76 (.57 - .96)	.099	$P = .030$
	Bruce	.82 (.66 - .99)	.084	$P = .014$

NOTE: Ballroom Aerobic Test (BAT)

Table 3. Sensitivity, specificity, FP and FN of the BAT protocol against the KF1 and Bruce protocols

The BAT protocol	Protocol	Sensitivity	Specificity	FP	FN	PLR	NLR
$\dot{V}O_{2max}$ (L*min ⁻¹)	KF1	83.3%	75.0%	16.7%	25.0%	3.33	0.22
	Bruce	91.70%	75.00%	8.30%	25.00%	3.67	0.11
$\dot{V}O_{2max}$ (ml*kg ⁻¹ *min ⁻¹)	KF1	95.90%	90.70%	4.10%	9.30%	10.31	0.05
	Bruce	91.70%	91.70%	8.30%	8.30%	11.05	0.09
RER	KF1	76.90%	72.70%	23.10%	27.30%	2.82	0.32
	Bruce	76.90%	81.80%	23.10%	18.20%	4.23	0.28
VE (L*min ⁻¹)	KF1	80.00%	100.00%	20.00%	0.00%	4.00	0.00
	Bruce	83.30%	83.30%	16.70%	16.70%	4.99	0.20
VT (L)	KF1	76.90%	81.80%	23.10%	18.20%	4.23	0.28
	Bruce	84.60%	90.90%	15.40%	9.10%	9.30	0.93
BF (bpm)	KF1	80.00%	71.40%	20.00%	28.60%	2.80	0.28
	Bruce	73.30%	88.90%	26.70%	11.10%	6.60	0.30
VE/ $\dot{V}O_2$	KF1	81.80%	76.90%	18.20%	23.10%	3.54	0.24
	Bruce	73.30%	88.90%	26.70%	11.10%	6.60	0.30
VE/ $\dot{V}CO_2$	KF1	66.70%	60.00%	33.30%	40.00%	1.68	0.56
	Bruce	81.80%	76.90%	18.20%	23.10%	3.54	0.24
VD/VT	KF1	70.60%	85.70%	29.40%	14.30%	4.94	0.34
	Bruce	82.40%	57.10%	17.60%	42.90%	1.92	0.31

Note: Ballroom Aerobic Test (BAT), The area under the curve (AUC), sensitivity, specificity, false positive (FP), false negative (FN), positive likelihood ratio (PLR) and negative likelihood ratio (NLR).

proportional bias. Similarly, the linear regression equation to predict the relative $\dot{V}O_{2max}$ from the Bruce protocol was as follows: $\dot{V}O_{2max}\text{-BRUCE (ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) = -3.996 + (1.075 \cdot \dot{V}O_{2max}\text{-BAT})$ ($R^2 = .72$). The slope coefficient between the BAT and KF1 protocols was $\beta = 1.10$ with a 95% CI (.80, 1.30), while the intercept coefficient was $a = -1.05$ with a 95% confidence interval (-10.17, 9.90).

11.8. Discussion

The main purpose of the study was to develop and examine the diagnostic accuracy of the BAT protocol against the KF1 and Bruce laboratory protocols in dancesport athletes performing in standard dance styles. Findings suggest that the ventilatory and metabolic parameters derived from the MetaMax® 3B portable gas analyzer during the BAT protocol yield large to very large sensitivity and specificity properties with the KF1 and Bruce aerobic outcomes. The level of AUC indicates satisfactory discriminative power between ‘low’ vs. ‘high’ groups in each parameter with high PLRs and low NLRs.

As far as the author is aware, this is the initial research investigating the creation and reliability of a progressive exam to evaluate aerobic capacity in standard dancesport competitors. Our findings ought to be understood in the context of earlier research. So far, multiple advanced field tests to evaluate aerobic capacity in dance have been suggested and confirmed through more objective methods. A study conducted by Wallmann et al.⁹ demonstrated that the API submaximal exercise fitness test had a strong correlation with $\dot{V}O_{2\max}$ ($R = .89$ and $.90$), along with a technical error of measurement (TEM) of power output = $.07 \text{ W}\cdot\text{kg}^{-1}$ and $\dot{V}O = .71 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. A different dance protocol aimed at ballet dancers showed that the mean squared root (sw2) for the test was 5.01, and the SEE was $6.20 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.¹⁰ A frequently used fitness protocol to assess aerobic capacity is the DAFT, a 5-stage progressive test lasting 4 minutes.¹¹

A study conducted by Wyon et al.¹¹ showed that data from the portable telemetric gas analyzer (Cosmed K4 b2, Italy) demonstrated a very strong correlation between $HR_{\max}$ and $\dot{V}O_{2\max}$ for the test ($R = .91$; $SEE = 5.60 \text{ b}\cdot\text{min}^{-1}$). Comparable findings were observed for the HIDT dance protocol, with five individuals ($n=5$) participating in both the treadmill and dance assessments to evaluate $\dot{V}O_{2\max}$.¹¹ In the treadmill protocol, the average $\dot{V}O_{2\max}$ recorded was $46.4 \pm 3.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, while in the HIDT, the $\dot{V}O_{2\max}$ value reached $51.0 \pm 6.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. A comparison between the treadmill and dance protocols indicated no notable differences in $\dot{V}O_{2\max}$.¹² The identical research indicated that the average %HRmax was notably less in the HIDT when compared to the treadmill assessment (97.5 vs. 101.0 %), while the accuracy of blood lactate measurements was elevated (HIDT = $6.1 \pm 1.9 \text{ mmol}\cdot\text{L}^{-1}$ vs. treadmill = $6.3 \pm 1.7 \text{ mmol}\cdot\text{L}^{-1}$).¹²

The latest SAFD assessment measuring the functional ability of collegiate dancers showed substantial to very substantial correlations with the peak treadmill evaluation for relative $\dot{V}O_{2\max}$ ($R = .78$), $HR_{\max}$ ($R = .85$), blood lactate ($R = .72$), and rate of perceived exertion (RPE; $R = .84$), whereas trivial to moderate correlations were observed for time ($R = .60$) and RER ($R = -.12$).¹³

Despite the current progressive dance protocols for evaluating aerobic capacity showing acceptable validity compared to objective measures,⁹⁻¹³ our recently created BAT protocol demonstrated strong correlations with the treadmill test after two protocols (KF1 and Bruce). The unique aspect and distinction of our dance protocols compared to others is that they are tailored specifically for dance couples practicing standard dance styles. This is crucial, as both partners must support one another during practice or competition. This implies that

comparable fitness levels may be beneficial for performance. Although $\dot{V}O_{2\max}$ is generally lower in dancesport athletes in comparison to other athletes,^{4,6} the aim of the BAT protocol is to improve the aerobic system and to physiologically prepare them for stress during training and/or competition.

Standard dance styles frequently feature movements defined by sway elements and the interaction of rises and falls, regarded as crucial factors for maintaining or enhancing functional performance in competitive dancesport competitors.²⁶ Additionally, the intricate figures and quicker tempo during training and competition in standard dance styles cannot be compared to ballet or contemporary dance styles, where movements are frequently executed in static settings, focusing more on aesthetics than on the functional aspects of dance. Consequently, the BAT protocol can act as a method for assessing and monitoring aerobic capacity within the limited group of standard style dance competitors.

This research has its limitations. Initially, a cross-sectional design inhibits our ability to validate causal relationships between field- and laboratory-based testing methods for evaluating aerobic capacity. Second, we omitted $HR_{\max}$ and blood lactate measures as indicators of aerobic and anaerobic abilities, restricting our results to data obtained from the MetaMax® 3B and treadmill equipment. Earlier research has demonstrated a significant connection between $HR_{\max}$ and $\dot{V}O_{2\max}$ ^{10,11} and sufficient sensitivity in $HR_{\max}$ and blood lactate variations after the dance protocol.^{27,28} The reasons for not considering these measures were the lack of time and devices for collecting and analyzing blood sampling. Third, a relatively limited sample size may have weakened the validity characteristics of the BAT protocol. Even though we conducted a sample size calculation (for additional details, refer to the ‘Study participants’ section), we cannot rule out the possibility of inadequate statistical power. Fourth, statistical analyses indicated that objectively measured ventilatory and metabolic parameters were split by a median into two groups (low vs. high), which could have led to a lack of statistical power and hypothetical significance. Thus, we re-calculated the continuous data and presented with the coefficients of correlation between the BAT and KF1/Bruce protocols and a set of regression equations to estimate predicted $\dot{V}O_{2\max}$. Also, previous studies have used the same approach to define the participants with low. vs. high physical fitness levels, based on cardiorespiratory data.^{24,25} Ultimately, the BAT protocol was not cross validated in athletes from various dance styles (ballet, contemporary, or Latin-American), which constrains its applicability. The authors indicate that the BAT protocol serves as a legitimate training and performance instrument for assessing aerobic capacity

and related factors in dancesport athletes engaged in standard dance styles. Finally, while the tempo was controlled, this freedom introduced potential variability in movement economy and energy expenditure between couples, which could influence the results.

Practical Applications

The practical use of the BAT protocol is shown in creating a brand-new model to assess aerobic capacity and an algorithm for estimating $\dot{V}O_{2\max}$ in competitive standard dances within sport-specific activity conditions. This allows for an accurate evaluation of physical and energy demands related to the activity, in contrast to current tests for measuring aerobic capacity. Given that conventional dance styles are frequently identified as high-intensity physical activities requiring both aerobic and anaerobic energy systems for execution, the newly introduced dance protocol could enhance aerobic capacity and improve dance training. Accurate and promptly executed diagnostic methods for evaluating and/or measuring energy capacities in dance are essential to reach primary objectives and foster positive trends toward athletic success.^{1,4} On the other hand, data from the BAT protocol could be used in both clinical and coaching environment to test specific aerobic capacity related to dancesport performance. Health-related professionals and strength and conditioning coaches should include the BAT protocol to evaluate, monitor and track cardiorespiratory fitness and to adjust training and choreography regimes for maximal performance output and persistence of high ventilatory and metabolic parameters for future health. However, given the nature of the study, future research should consider establishing the minimal detectable change (MDC), which is critical for coaches to determine if an observed change in performance is a true improvement or simply measurement error.²⁹ This would improve practical ability of the test and denote whether changes in performance occur intentionally or by chance.

11.9. Conclusions

In conclusion, this research demonstrates that the BAT protocol exhibits excellent diagnostic accuracy properties when compared to the KF1 and Bruce protocols. The benefit of the BAT protocol lies in its ability to replicate classical movements from five dance styles while imitating competition environments. The present results have demonstrated sensitivity and specificity characteristics and possible recommendations for overseeing and observing changes in ventilatory and metabolic parameters across various training conditions. The authors propose that this assessment can be incorporated into the dance training regimen during preparatory and competitive phases, as it provides crucial and reliable insights into the correlation between field and laboratory aerobic performance metrics among standard dancesport competitors. As mentioned in the 'Practical application' section, MDC should be the next critical step for validating the BAT protocol for practical use. Since it tests the smallest change that is unlikely to be due to the measurement error, evaluating the MDC may be helpful for targeting a 'real' change. This can help coaches in planning the target ventilatory and metabolic outcomes to reach high confidence levels and to adjust the training program for enhancing aerobic capacity.

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12.1. Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

12.2. Ethical Committee approval

The Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Zagreb, Croatia; approved the study on the 29th of April 2020 (ethical code number: 77/2020).

12.3. Topic

Sport science

12.4. Conflicts of interest

The authors have no conflicts of interest to declare.

12.5. Funding

No funding was received for this investigation.

12.6. Authors' contribution

Conceptualization, T.D.; methodology, T.D.; software, T.D.; validation, T.D.; formal analysis, T.D.; investigation, T.D.; resources, T.D. and D.P.; data curation, T.D.; writing—original draft preparation, T.D., J.R. and D.P.; writing—review and editing, T.D., J.R. and D.P.; visualization, T.D.; supervision, D.P.; project administration, T.D. All authors have read and agreed to the published version of the manuscript.

13. CHAPTER 4: GENERAL CONCLUSION

This doctoral thesis addressed a significant methodological gap in dancesport science, namely the lack of valid, reliable, and sport-specific tools for assessing aerobic capacity in standard-style dancesport athletes, particularly at the level of dance couples. Existing assessment protocols have predominantly relied on laboratory-based testing or general field-based methods, which do not adequately reflect the specific physiological demands of dancesport performance.

Previous research has attempted to develop dance-specific protocols for assessing aerobic capacity, primarily within ballet and contemporary dance populations. Among the most commonly used field-based tests are the Aerobic Power Index (API), the Ballet-Specific Aerobic Fitness Test (B-DAFT), the Dance Aerobic Fitness Test (DAFT), the High-Intensity Dance Performance Fitness Test (HIDT), and the Seifert Assessment of Functional Capacity for Dancers (SAFD). These protocols have been designed to assess cardiorespiratory fitness using dance-specific movements and progressive workloads, demonstrating varying levels of validity and reliability. However, they have predominantly been developed for individual dancers and specific dance styles, with limited applicability to standard-style dancesport athletes and couple-based performance settings. Furthermore, inconsistencies in methodological approaches and validity outcomes across studies have limited their broader applicability. Consequently, there has been a clear need for a standardized and sport-specific

protocol tailored to standard-style dancesport athletes (Despot & Plavec, 2025; Despot & Plavec, 2026).

In line with these limitations, this doctoral thesis developed and systematically evaluated the Ballroom Aerobic Test (BAT) as a novel field-based protocol specifically designed for standard-style dancesport athletes. Across the included studies, the BAT protocol demonstrated consistent evidence of scientific robustness and practical applicability for assessing cardiorespiratory fitness.

In terms of criterion validity, the BAT protocol showed strong agreement with established laboratory-based methods, including treadmill protocols such as KF1 and Bruce. Large to very large correlations were observed for key physiological variables, particularly absolute and relative maximal oxygen uptake ($\text{VO}_{2\text{max}}$), as well as selected ventilatory parameters. Additionally, the absence of systematic bias and acceptable limits of agreement further support the validity of the BAT protocol as an alternative method for estimating aerobic capacity outside controlled laboratory conditions (Despot & Plavec, 2025).

The reliability and usefulness of the BAT protocol were confirmed through a test–retest design, demonstrating trivial to small effect sizes, high intraclass correlation coefficients, and low coefficients of variation across measured variables. Furthermore, the relationship between typical error and the smallest worthwhile change indicated that the BAT protocol is capable of detecting meaningful changes in performance, supporting its applicability for monitoring training adaptations and performance progression in dancesport athletes (Despot & Plavec, 2026).

In addition to validity and reliability, the diagnostic accuracy of the BAT protocol was evaluated against laboratory-based measures. The findings revealed satisfactory to high discriminatory power, with area under the curve (AUC) values exceeding acceptable thresholds for most variables, particularly $\text{VO}_{2\text{max}}$. Sensitivity and specificity analyses further demonstrated that the BAT protocol can effectively classify athletes according to their aerobic performance levels (Despot et al., in press)

From a practical perspective, the BAT protocol offers a feasible, time-efficient, and easily implementable method for coaches, practitioners, and clinicians. Its ability to provide objective and sensitive measures of ventilatory and metabolic responses enables more precise monitoring of training load and performance development in standard-style dancesport athletes.

Despite these strengths, certain limitations should be acknowledged. The relatively small sample sizes and the focus on standard-style dancesport athletes may limit the generalizability of the findings to other dance disciplines or populations. Future research should aim to further validate the BAT protocol across different dance styles, performance levels, and age groups and sexes as well as to establish normative values and minimal detectable changes.

In conclusion, this doctoral thesis integrates existing knowledge on aerobic capacity assessment in dance with newly generated empirical evidence, providing strong support for the Ballroom Aerobic Test (BAT) as a valid, reliable, and diagnostically accurate field-based protocol for standard-style dancesport athletes. The BAT protocol represents a meaningful advancement in dancesport performance diagnostics and offers a practical tool for both scientific and applied use.

13.1. Strengths and limitations

A major strength of this doctoral thesis is its cumulative, article-based design, which allowed the Ballroom Aerobic Test (BAT) protocol to be examined from several complementary perspectives, including reliability, validity, and diagnostic accuracy. This provided a more comprehensive evaluation of the protocol than would have been possible within a single study. Another important strength is that the BAT protocol was specifically developed for ballroom-style dancesport athletes, a population that remains underrepresented in the existing literature, while the testing procedure itself more closely reflects actual dancesport performance conditions. In addition, the use of objective physiological measurements obtained from portable and laboratory-based gas analysis systems strengthened the methodological quality of the thesis and enabled direct comparison between field-based and laboratory-based outcomes. Finally, the application of several statistical approaches across the three studies contributed to a detailed evaluation of the protocol and increased both the scientific value and practical relevance of the findings for monitoring aerobic performance in ballroom-style dancesport athletes.

Several limitations of this doctoral thesis should be acknowledged. Although the initial doctoral proposal was broader in scope, the final article-based thesis primarily focused on the key measurement properties of the BAT protocol, namely reliability, criterion validity, and diagnostic accuracy. Consequently, some components of the original research plan,

particularly the broader pragmatic validation of the test and the full development of a predictive algorithm for maximal oxygen uptake, were not addressed to the same extent and remain important directions for future research. Applicability of the findings may also have been influenced by partner selection. In the present sample, this aspect was documented only anecdotally, indicating that dancers should ideally be tested in the same pairing in which they usually train and compete.

In addition, although anthropometric and morphological variables were collected in accordance with the original doctoral design, not all of them were included in the final analyses. The published studies were intentionally centred on the evaluation of the BAT protocol itself, while the broader dataset needs to be complemented from a larger sample size and broader age group, but offers further analytical potential, particularly for examining additional determinants of aerobic performance and refining predictive models.

The studies were also conducted on relatively small samples of ballroom-style dancesport athletes. Although this was appropriate given the specific nature of the investigated population, the sample size still limits the statistical strength of the findings and indicates the need for further verification in larger groups within the same discipline.

It should also be noted that the BAT protocol was specifically developed for ballroom-style dancesport athletes and reflects the technical, biomechanical, and physiological demands of this discipline. For this reason, its applicability to other dance forms was not examined, as their movement structure and performance demands differ substantially.

Finally, since the thesis is based predominantly on methodological and cross-sectional studies, the findings support the measurement quality and practical relevance of the BAT protocol, but do not yet provide evidence on longitudinal training adaptations, responsiveness to interventions, or long-term monitoring of all features that need to be examined further in future.

13.2. Perspectives for future research

Future research should extend the evaluation of the BAT protocol beyond its current methodological framework. Although the present thesis established its reliability, criterion validity, and diagnostic accuracy, further studies should examine its pragmatic validity in real training environments, particularly in relation to training monitoring, performance progression, and decision-making in practice. Such work would provide a stronger basis for its routine use in standard-style dancesport.

An additional direction for future research is the further use of the broader dataset collected within the doctoral thesis project. Since anthropometric and morphological variables were measured but not fully incorporated into the published analyses, future studies could investigate their relationship with BAT outcomes and their contribution to the prediction of maximal oxygen uptake. This would also support the refinement of predictive models originally envisaged in the doctoral thesis proposal.

Future studies should also include larger samples with wider age range of ballroom style dancesport athletes in order to strengthen the statistical stability of the findings and confirm the applicability of the BAT protocol within the same discipline. Also, different practical algorithms should be developed and tested on larger samples to enable accurate prediction of aerobic capacity, thereby allowing field – based assessment without the need to directly measure physiological parameters ($\dot{V}O_{2\max}$, etc.). This would considerably broaden applicability of this field test. In addition, longitudinal and intervention-based studies are needed to determine whether the BAT protocol is sensitive to training-induced adaptations and whether it can be used for long-term monitoring of aerobic performance.

Finally, future research should examine additional physiological and perceptual indicators that were envisaged in the initial doctoral thesis design, such as heart rate and ratings of perceived exertion, in order to provide a more comprehensive understanding of the demands captured by the BAT protocol. Together, these directions would further strengthen the scientific and practical value of the test in standard-style dancesport athletes.

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15. LIST OF APPENDICIES

15.1. Study 1

Despot, T., & Plavec, D. (2026). Application of the Ballroom Aerobic Test protocol for assessing performance in standard-style dancesport athletes. PeerJ, 14, e20556. <https://doi.org/10.7717/peerj.20556>



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Application of the Ballroom Aerobic Test protocol for assessing performance in standard-style dancesport athletes

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ABSTRACT

Background. Although the existing field-based tests to assess functional capacity in dancesport have been developed, most of them have been applied to ballet or contemporary dancesport athletes at the individual level, while little evidence is available for dancesport couples in standard dance disciplines. Therefore, the main purpose of this study was to examine the test-retest reliability and usefulness of the progressive Ballroom Aerobic Test (BAT) protocol for assessing aerobic performance.

Methods. Thirteen standard dancesport athletes (six pairs and one individual male participant; age: 20.1 ± 3.8 years; height: 175.0 ± 8.2 cm; weight: 64.3 ± 9.7 kg; males; age: 19.9 ± 3.7 years; height: 180.0 ± 4.7 cm; weight: 70.2 ± 8.7 kg; body mass index: 21.5 ± 1.8 kg/m² training experience: 8.6 ± 5.1 years; females; age: 20.3 ± 4.0 years; height: 168.5 ± 6.5 cm; weight: 57.5 ± 5.5 kg; body mass index: 20.2 ± 1.3 kg/m²; training experience: 8.5 ± 3.4 years) took part in the study. All participants were members of certified dancesport clubs who competed at national and international levels. The BAT protocol consisted of five stages, each corresponding to one of five standard dancesport disciplines (English Waltz, Slow Foxtrot, Tango, Viennese Waltz, and Quickstep). A test-retest design, with one week between trials, was used to examine the reliability measures. Ventilatory and metabolic parameters were derived from MetaMax[®] 3B, a reliable and valid portable gas analyzer. Reliability measures included Cohen D effect size (ES), intra-class correlation coefficient (ICC), coefficient of variation (CV), typical error (TE) and smallest worthwhile change (SWC). **Results.** No significant differences were observed between test and retest sessions ($P > 0.05$). ESs ranged from trivial to small (0.00–0.47) with 'very good' to 'excellent' reliability (ICC = 0.80–0.99; CV = 1.63–4.85%). The usefulness of the BAT protocol was generally rated as 'ok' to 'good' for speed (TE = 2.76; SWC = 3.20; <), absolute VO₂ (TE = 0.14; SWC = 0.15; <), respiratory exchange ratio (RER; TE = 0.02; SWC = 0.02; =), tidal volume (VT = 0.06; SWC = 0.06; =), and dead space to tidal volume ratio (VD/VT; TE = 0.01; SWC = 0.01; =).

Conclusion. Current findings suggest that the BAT protocol is a reliable and useful tool for assessing aerobic capacity in standard-style dancesport athletes. Moreover, the BAT protocol can accurately detect meaningful individual changes, particularly for speed (3.20 bpm), absolute VO₂ ($0.15 \text{ L} \cdot \text{min}^{-1}$), and VE (4.87 L). These results may assist athletes and strength and conditioning coaches in monitoring and tracking 'real' time changes to optimize the training process.

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INTRODUCTION

Dancesport performance has been categorized as a high-intensity intermittent exercise requiring high levels of physical fitness (*Koutedakis & Jamurtas, 2004*). In addition to technical requirements, the complexity of choreography makes physical preparedness just as important as skill development (*Ngo et al., 2024*), with upper body muscular and cardiovascular endurance identified as the best predictors of aesthetic performance (*Angioi et al., 2009*). Although dancesport is composed of many disciplines, physiological capabilities are crucial to sustaining the demanding daily schedules of training and competition performance. Evidence suggests that aerobic capacity is one of the key determinants of success in dancesport (*Smol & Fredyk, 2012*). For example, a study by *Rodrigues-Krause, Krause & Reischak-Oliveira (2015)* showed that dancers' cardiorespiratory requirements during both dancesport classes and performances were equally important. However, aerobic capacity during rehearsals and/or classes exhibited lower values than during competition. This suggests that, despite being a crucial factor distinguishing successful from unsuccessful dancesport athletes (*Malkogeorgos et al., 2013*), the discrepancy between training and competition in dancesport athletes might limit the ability to improve or even maintain higher levels of cardiorespiratory physical fitness (*Nam, Park & Kim, 2024*). The ability to efficiently uptake, transport and utilize oxygen through physiological processes has been prioritized, as it directly influences technical achievements, performance quality, and career longevity (*Angioi et al., 2012*). However, both professional and student dancesport athletes tend to demonstrate lower maximal oxygen uptake (VO_2max) compared to other athletes (*Baldari & Guidetti, 2001*; *Tiemens et al., 2023*). For instance, male dancesport athletes exhibit VO_2max of $48.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, which is 20 to 50% lower than values reported in cyclic or complex team sport activities (*Cohen et al., 1982*; *Koutedakis & Jamurtas, 2004*). Another contributing factor to VO_2max improvements in dance may be related to its small ability to stimulate positive cardiorespiratory adaptations (*McCord, Nichols & Patterson, 1989*). It has been documented that increases in aerobic capacity are not related to class work, but rather to the intensity and duration of performances (*Wyon et al., 2004*). Since the intensity of specific (dance movements) or general (circuit) training regimes needs to be between 70 and 80% of an individual's VO_2max and should last >20 min to enhance aerobic capacity, progressive dance protocols to stimulate cardiorespiratory development are warranted.

In dancesport, measuring aerobic capacity with objective tools (heart rate monitors, ergometry) is the cornerstone for planning training programs at the individual level (*Tiemens et al., 2023*). Because of complex movement patterns and often strenuous training and competition programs, energy pathways for both aerobic and anaerobic requirements should be considered equally important (*Maciejczyk & Feć, 2013*). On the other hand, literature suggests that physical performance can be a useful indicator of

physiological tremor and fatigue (*Kruusamäe, Maasalu & Jürimäe, 2016; Mazur-Rózycka et al., 2023*), adding its practical ability to detect the level of endurance and deteriorating effects of training and competition on dancesport performance (*Ngo et al., 2024*). The necessity of determining an individual's cardiovascular and respiratory capabilities may be helpful in dosing the training load and primarily targeting positive aerobic output during preparatory period. On the other hand, examining 'maximal' aerobic levels in dancesport is quite difficult to achieve, because the nature of dance is non-competitive, and the intensity is often set by a choreographer (*Chatfield et al., 1990*). Unfortunately, well-established objective methods to assess aerobic performance, such as running- or cycling-based ergometers, are expensive, difficult to administer and do not mimic complex dancesport movements. Moreover, dancers may have biomechanical limitations during running or walking, due to their limited dorsiflexion movements in the ankle and a highly developed turn out of the feet, which may cause stress on the knee and hip joints (*Russell, 2013*). Because of these limitations, previous studies have attempted to develop on-field aerobic tests for dancesport. According to a systematic review by *Tiemens et al. (2023)*, the most common cardiorespiratory fitness test protocols in dancesport include the Aerobic Power Index (API) (*Wallman et al., 2003*), the Ballet-specific Aerobic Fitness Test (B-DAFT) (*Twitchett et al., 2011*), the Dance Aerobic Fitness Test (DAFT) (*Wyon et al., 2023*), the High-Intensity Dance Performance Fitness Test (HIDT) (*Redding et al., 2009*), and the Seifert Assessment of Functional Capacity for Dancers (SAFD) (*Seifert et al., 2021*).

Despite the fact that all tests exhibited 'good' to 'very good' test-retest reliability properties, findings from these studies cannot be generalized to other dancesport disciplines. Most studies recruited ballet (*Twitchett et al., 2011*), or contemporary (*Wyon et al., 2004*) dancesport athletes, whose training routines and movement patterns differ from those of standard dancesport practitioners (*Ngo et al., 2024*). Standard male ($59.6 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) and female dancers ($51.2 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) tend to have higher average VO_2max values (*Liiv et al., 2014*), compared to ballet or contemporary dancesport athletes (*Wyon et al., 2004; Twitchett et al., 2011*). Moreover, VO_2max has been the most commonly used variable to assess aerobic capacity (*Wallman et al., 2003; Redding et al., 2009; Twitchett et al., 2011; Wyon et al., 2023*), while data regarding speed, ventilatory and metabolic parameters have been rarely investigated. Finally, available field-based tests have been developed at the individual level, and to the best of the authors' knowledge, the test-retest properties have not been evaluated simultaneously in dancesport couples. These discrepancies between different dancesport disciplines, type of dancesport athletes and physiological characteristics may affect the reliability properties of a given test. Notably, for the abovementioned tests assessing aerobic performance, neither typical error (TE) nor smallest worthwhile change (SWC) were calculated, limiting their usefulness in real-time settings. TE indicates the random error associated with a measurement protocol, while SWC represents the smallest worthwhile change that is practically relevant to an athlete (*Hopkins, 2004; Hopkins, 2007*). Both measures allow us to determine if observed performance changes in a certain variable are greater than the TE and the SWC, denoting statistical significance and practical importance.

The reliability and usefulness of a newly developed progressive dance test to assess aerobic capacity would be of great importance for standard-style dancesport athletes and their strength and conditioning coaches, allowing them to monitor and track training intensity and duration for maximum efficiency. If results showed appropriate reliability statistics with confirmatory usefulness, the new progressive test would better reflect the true energetic state of dancesport athletes in both training and competitive conditions. Based on the shortcomings of previously established dancesport tests, the main purpose of this study was to examine the test-retest reliability of the Ballroom Aerobic Test (BAT) for assessing aerobic capacity in dancesport athletes competing in standard dancesport disciplines. The second purpose was to determine its usefulness in accordance with the noise of the test results and measurement uncertainty using the magnitude of the SWC. We hypothesized that the BAT test would yield 'good' reliability and could detect meaningful changes in performance.

MATERIALS AND METHODS

Experimental approach

This observational, within-subject, test-retest sub-study was conducted to examine the reliability properties and usefulness of the BAT in standard dancesport athletes. Portions of this text were previously published as part of a study (Despot & Plavec, 2025). In brief, the study was part of a project titled 'Construction and Validation of a Test Protocol to Assess Aerobic Capacity in Dancesport Athletes from Standard Dance Styles.' (Despot & Plavec, 2025). The project was divided into four segments to examine: (i) reliability and usefulness; (ii) validity; (iii) sensitivity; and (iv) pragmatic validity of the BAT. For the purpose of this study, the BAT protocol was performed on two separate occasions, one week apart. The testing procedure was initiated during the preparatory period of dancesport athletes. Measurements were performed by the same experienced researcher to minimize possible measurement error. During both trials, the participants wore their standard dance equipment (light T-shirt, tights, dance shoes). The air temperature conditions of the indoor facility were controlled to be between 22 °C and 24 °C with the humidity of $\approx 55\%$.

Study participants

Thirteen advanced standard dancesport athletes (six pairs and one male participant; age: 20.1 ± 3.8 years; height: 175.0 ± 8.2 cm; weight: 64.3 ± 9.7 kg) with >8 years of training and competing experience participated in the study. As mentioned in a previous study (Despot & Plavec, 2025), all participants were members of certified dancesport clubs who competed at national and international levels. The inclusion criteria to enter the study were: (i) being free from any kind of injury, acute or chronic illness and disease, as confirmed by a certified dancesport association doctor; (ii) age range between 16 and 35 years; and (iii) completing both measurements for reliability and usefulness properties of the BAT protocol. The *a-priori* power analysis calculated by the G*Power software ver. 3.1.9.7 (Kang, 2021) showed that by setting the input parameters of a two-tailed $\alpha < 0.05$, a minimum required correlation between two occasions at $r > 0.69$ (Buchheit et al., 2011), and statistical power of $1 - \beta = 0.80$, the required total sample size was $n = 11$. Before the

study began, all participants had signed a written informed consent to participate in the study and to allow their data to be used solely for scientific purposes. All procedures in the study were anonymous and conducted in accordance with the Declaration of Helsinki ([World Medical Association, 2013](#)). The Ethical Committee of the Faculty of Kinesiology approved the study on 29 April 2020 (ethical code number: 77/2020).

Study variables

The same methodology to examine the psychometric properties of the BAT protocol has been published elsewhere ([Despot & Plavec, 2025](#)). To examine the reliability properties of the BAT protocol, we used the MetaMax[®] 3B (CORTEX Biophysik GmbH, Leipzig, Germany), a reliable and valid portable breath-by-breath ventilatory and metabolic measurement system specifically designed for field- and laboratory-based testing ([Macfarlane & Wong, 2012](#)). The device consists of two parts designed to be worn on the chest. By using an electrochemical cell and an infrared analyzer, the MetaMax[®] 3B was able to calculate O₂ and CO₂ concentrations based on standard metabolic equations ([Wasserman et al., 1999](#)). Following the manufacturer's recommendations and previous studies ([Macfarlane & Wong, 2012](#)), the system was turned on for at least 20 min and calibrated prior to testing. The calibration process included adjusting the gas analyzers by using reference gas values of O₂ (14.97%), CO₂ (4.96%) and N₂ ($\pm 0.02\%$) and volume with a standardized 3-L syringe (5530 series, Hans Rudolph, Inc., Shawnee, KS, USA). The MetaMax[®] 3B software generated data regarding absolute ($L \cdot \text{min}^{-1}$) and relative VO₂max ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) and associated variables including speed (bpm), respiratory exchange ratio of CO₂ produced to O₂ consumed during metabolism (RER), expiratory ventilation as the total volume of air inhaled or exhaled per min (VE; $L \cdot \text{min}^{-1}$), tidal volume as the volume inhaled or exhaled during a normal breath (VT; L), breathing frequency (BF; bpm), VO₂ and BF norms calculated from referent values provided by the MetaMax[®] 3B (%), ventilatory equivalents for O₂ (VE/VO₂) and CO₂ (VE/VCO₂) as determinants of breathing efficiency, and dead space to tidal volume ratio (VD/VT), which indicated the air that failed to participate in O₂ and CO₂ exchange process during breathing.

The BAT protocol

Of note, portions of this text were previously published as part of a study conducted by [Despot & Plavec \(2025\)](#). To assess the level of aerobic capacity of dancesport athletes, we constructed a field-based BAT protocol. The protocol was standardized across five standard dancesport disciplines according to the World DanceSport Federation ([Premelč et al., 2019](#)) in the following order: (i) English waltz; (ii) Slow foxtrot; (iii) Tango; (iv) Viennese waltz; and (v) Quickstep. Each dancesport discipline included multiple levels of dancing that were progressively linked, where the speed of dancing (tempo) was defined both by individual beats per minute (bpm), and by beat (bars per minute-BPM) which denote rhythm. The English waltz consisted of six levels, danced in 3/4 time in the range of 25–37 BPM or 75–110 bpm. The Slow foxtrot included five levels, danced in 4/4 time in the range of 29–36 BPM or 117–145 bpm. The Tango had five levels, danced in 4/4 time in the range of 38–45 BPM or 152–180 bpm. The Viennese waltz was performed through

Table 1 The BAT dance protocol for every dance style.

Dance styles	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
<i>English waltz</i>						
Beats	75	82	89	96	103	110
Time	30 s	60 s	1.5 min	2 min	2.5 min	3 min
<i>Slow fox</i>						
Beats	117	124	131	138	145	
Time	3.5 min	4.0 min	4.5 min	5.0 min	5.5 min	
<i>Tango</i>						
Beats	152	159	166	173	180	
Time	6.0 min	6.5 min	7.0 min	7.5 min	8.0 min	
<i>Viennese waltz</i>						
Beats	187	194	201			
Time	8.5 min	9.0 min	9.5 min			
<i>Quick step</i>						
Beats	208	215	222	229	236	243
Time	10.0 min	10.5 min	11.0 min	11.5 min	12.0 min	12.5 min

three levels, danced in 3/4 time in the range of 62–67 BPM or 187–201 bpm. Finally, the Quickstep consisted of six levels, danced in 4/4 time in the range of 52–60 BPM or 208–243 bpm. At each level, dancesport couples had to perform standard dance figures for 30 s at a prescribed tempo without accompanying music (Table 1). We did not include music, as studies have shown that it may significantly impact both physical and psychological performance, by increasing the ratings of pleasure and emotional arousal during more complex musical pieces (Salimpoor et al., 2009), affecting the autonomic nervous system (Lundqvist et al., 2009), and altering the rhythm of movements (Hu, Li & Liu, 2022), all of which are contributing factors to dancesport performance. The speed expressed in beats progressively increased throughout the protocol by seven BPM. The initial speed of the dancesport protocol was set at 75 bpm. Participants danced to a predefined dance tempo and rhythm using a metronome. The elements of each dancesport discipline were basic and easy to perform, while dancesport couples were free to create their own choreography. The duration of the BAT protocol was cumulatively added up and each pair danced until exhaustion.

Data analysis

Shapiro–Wilk’s (S–W) test was used to assess data normality. Data were checked for critical W values, Q–Q plot inspection, and the homogeneity of the variance was confirmed using the Leven test. If the calculated W value was larger than the tabulated W value, this denoted that we did not reject the null hypothesis. All variables included in further analysis were assumed to follow a hypothetical normal distribution, so data were presented as means and standard deviations (SD) with 90% confidence interval limits (90% CI). The magnitude of change between the two measurements (T0 and T1) were examined using a standardized mean difference with the following effect size (ES) proposed by Hopkins, Schabort & Hawley (2001): trivial ($ES < 0.2$), small ($0.2 < ES < 0.5$), moderate ($0.5 < ES < 0.8$), large

($0.8 < ES < 1.6$), and very large ($ES > 1.6$). The reliability statistics between *pre*- and *post*- measurements were determined using three parameters: (i) intraclass correlation coefficient (ICC), (ii) typical error (TE) expressed as coefficient of variation (CV%), and (iii) smallest worthwhile change (SWC), calculated using an Excel spreadsheet provided by Hopkins (2007). Based on the 90% CI of the ICC estimate provided by Koo & Li (2016), the ICC strength was described as 'poor' ($ICC \leq 0.5$), 'moderate' ($0.5 < ICC \leq 0.75$), 'good' ($0.75 < ICC \leq 0.9$), and 'excellent' ($ICC > 0.9$). The CV% was calculated as the ratio of the SD to the mean and multiplied by 100, while the SWC as the between-subject SD multiplied by 0.2, according to ES. According to Hopkins (2004), the usefulness of a given variable was determined by comparing TE and SWC, and categorized as 'marginal' ($TE > SWC$), 'ok' ($TE = SWC$), and 'good' ($TE < SWC$). The criteria for considering reliability statistics as 'adequate' was $CV < 5\%$ and $ICC > 0.69$ (Buchheit et al., 2011). All statistical analyses were performed in SPSS v27.0 software (IBM, Armonk, NY, USA) with an alpha level set a priori at $p < 0.05$ to denote statistical significance.

RESULTS

Basic descriptive statistics of the study participants are presented in Table 2. Men were significantly taller and heavier compared to women. However, no significant differences were observed in age (t -value = 1.026, $ES = 0.10$), BMI (t -value = 1.374, $ES = 0.72$) and training experience (t -value = 0.029, $ES = 0.02$).

Table 3 presents the reliability statistics of aerobic capacity measures obtained by MetaMax[®] 3B portable spiroergometric device. Test-retest data showed no significant *pre-post* differences ($P > 0.05$) in speed (*pre* = 220.54 ± 16.19 bpm; *post* = 214.92 ± 15.76 bpm), absolute $\dot{V}O_2$ (*pre* = 3.16 ± 0.63 L $\cdot$ min⁻¹; *post* = 3.06 ± 0.67 L $\cdot$ min⁻¹), relative $\dot{V}O_2$ (*pre* = 49.22 ± 5.84 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹; *post* = 47.33 ± 6.28 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹), RER (*pre* = 1.02 ± 0.05 ; *post* = 1.02 ± 0.05), $\dot{V}E$ (*pre* = 102.95 ± 25.09 L $\cdot$ min⁻¹; *post* = 98.09 ± 23.53 L $\cdot$ min⁻¹), $\dot{V}T$ (*pre* = 1.88 ± 0.29 L; *post* = 1.78 ± 0.29 L), $\dot{B}F$ (*pre* = 55.08 ± 9.18 bpm; *post* = 54.85 ± 8.46 bpm), $\dot{V}O_2$ -norm (*pre* = $117.54 \pm 18.36\%$; *post* = $112.00 \pm 18.27\%$), $\dot{B}F$ -norm (*pre* = $32.31 \pm 9.58\%$; *post* = $33.62 \pm 9.62\%$), $\dot{V}O/\dot{V}O_2$ (*pre* = 30.87 ± 2.84 ; *post* = 29.82 ± 2.34), $\dot{V}O/\dot{V}CO_2$ (*pre* = 30.27 ± 2.84 ; *post* = 30.64 ± 3.44) and $\dot{V}D/\dot{V}T$ (*pre* = 0.14 ± 0.02 ; *post* = 0.14 ± 0.01).

DISCUSSION

The main purpose of his study was to examine test-retest reliability properties and usefulness of the progressive BAT protocol for assessing aerobic capacity in athletes of standard dancesport disciplines. Findings suggest that the BAT protocol is a reliable new method based on objectively measured ventilatory and metabolic outcomes derived from the the MetaMax[®] 3B portable device. In general, trivial to small ESs were observed between two occasions. The proposed criteria for 'adequate' reliability were met, with CV values for all the study variables $< 5\%$ ($1.63 \leq CV \leq 4.85$) and ICC values > 0.69 ($0.80-0.99$). The usefulness analysis of the BAT showed that the majority of variables were rated as 'ok' or

Table 2 Basic descriptive statistics of the study participants.

Study variables	Total (n = 13) Mean ± SD	Men (n = 7) Mean ± SD	Women (n = 6) Mean ± SD	P*
Age (years)	20.1 ± 3.8	20.3 ± 4.1	19.9 ± 3.5	0.254
Height (cm)	175.0 ± 8.2	180.6 ± 4.7	168.5 ± 6.5	0.003
Weight (kg)	64.3 ± 9.7	70.2 ± 8.7	57.5 ± 5.5	0.010
BMI (kg/m ²)	20.9 ± 1.7	21.5 ± 1.8	20.2 ± 1.3	0.197
Experience (years)	8.5 ± 4.2	8.6 ± 5.1	8.5 ± 3.4	0.977

Notes.

*denotes significant differences between men and women ($P < 0.05$).

Table 3 Reliability measures for the MetaMax[®] 3B aerobic outcomes.

	ES	Mean diff. (90% CI)	ICC (90% CI)	CV% (90% CI)	TE (90% CI)	SWC (90% CI)	Rating
Speed (bpm)	0.35 (small)	-5.62 (-7.55; -3.68)	0.98 (0.94; 0.99)	1.83 (1.10; 2.48)	2.76 (2.09; 4.19)	3.20 (2.41; 4.84)	Good
Absolute VO ₂ (L·min ⁻¹)	0.15 (trivial)	-0.1 (-0.20; -0.01)	0.96 (0.90; 0.99)	4.40 (2.70; 6.00)	0.14 (0.10; 0.21)	0.15 (0.10; 0.20)	Good
Relative VO ₂ (ml·kg ⁻¹ ·min ⁻¹)	0.31 (small)	-1.90 (-3.40; -0.40)	0.89 (0.71; 0.96)	4.52 (2.90; 6.00)	2.14 (1.61; 3.24)	1.21 (0.92; 1.85)	Marginal
RER	0.00 (trivial)	0.00 (-0.02; 0.01)	0.86 (0.67; 0.95)	1.63 (1.00; 2.30)	0.02 (0.02; 0.03)	0.02 (0.01; 0.03)	Ok
VE (L·min ⁻¹)	0.20 (small)	-4.85 (-8.07; -1.63)	0.97 (0.92; 0.99)	4.85 (3.34; 6.40)	4.61 (3.48; 6.98)	4.87 (3.68; 7.37)	Good
VT (L)	0.33 (small)	-0.09 (-0.14; -0.05)	0.96 (0.91; 0.99)	4.32 (3.20; 5.64)	0.06 (0.05; 0.09)	0.06 (0.04; 0.09)	Ok
BF (bpm)	0.03 (trivial)	-0.23 (-2.41; 1.94)	0.90 (0.74; 0.96)	4.57 (2.99; 6.68)	3.11 (2.35; 4.71)	1.77 (1.33; 2.68)	Marginal
VO ₂ -norm (%)	0.30 (small)	-5.54 (-7.68; -3.40)	0.98 (0.94; 0.99)	3.91 (2.80; 5.00)	3.06 (2.31; 4.64)	3.66 (2.77; 5.55)	Good
BF-norm (%)	0.14 (trivial)	1.31 (0.40; 2.22)	0.99 (0.96; 0.99)	4.71 (3.00; 6.26)	1.30 (0.98; 1.97)	1.92 (1.45; 2.91)	Good
VE/VO ₂	0.47 (small)	-1.05 (-1.74; -0.37)	0.86 (0.66; 0.94)	3.62 (2.78; 4.38)	0.98 (0.74; 1.49)	0.48 (0.36; 0.72)	Marginal
VE/VCO ₂	0.10 (trivial)	0.37 (-0.69; 1.43)	0.80 (0.54; 0.92)	3.83 (2.56; 5.40)	1.52 (1.15; 2.30)	0.63 (0.48; 0.96)	Marginal
VD/VT	0.00 (trivial)	0.00 (0.00; 0.01)	0.82 (0.58; 0.83)	4.40 (2.44; 6.38)	0.01 (0.01; 0.01)	0.01 (0.00; 0.02)	Ok

Notes.

ES, effect size; ICC, intraclass correlation coefficient; CV, coefficient of variation; TE, typical error; SWC, smallest worthwhile change; CI, confidence intervals.

‘good’, indicating that the test is sufficiently sensitive to detect the smallest meaningful change.

Results from this study were considered in the context of previous studies aiming to develop and investigate the reliability statistics of field-based dancesport tests for measuring aerobic capacity (Wallman et al., 2003; Redding et al., 2009; Twitchett et al., 2011; Seifert et al., 2021; Wyon et al., 2023). In the study by Wallman et al. (2003), the API test showed ‘good’ test-retest reliability for aerobic output (ICC = 0.98; mean diff.

= $0.02 \pm 0.16 \text{ W}\cdot\text{kg}^{-1}$; CV = 3.87%), rate of perceived exertion (RPE; ICC = 0.94, mean diff. = $0.05 \pm 2.10 \text{ a.u.}$; CV = 6.74%) and VO_2max (ICC = 0.98; mean diff. = $0.41 \pm 2.13 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; CV = 4.63%). In another reliability study, the B-DAFT dancesport protocol produced an almost perfect correlation between the two trials ($r = 0.998$) with the 95% limits of agreement calculated from the Bland-Altman plots to be $\pm 6.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Twitchett et al., 2011). Redding et al. (2009) reported somewhat poorer agreement values for the H1DT, ranging from 0.80 between bouts of each trial and 0.82 between the four trials for maximal heart rate (HRmax), VO_2 and blood lactate. A 3-min stage SAFD test for collegiate dancers exhibited moderated to excellent reliability for time (ICC = 0.85), VO_2peak (ICC = 0.92), RER (ICC = 0.50), HR (ICC = 0.86), blood lactate (ICC = 0.52) and RPE (ICC = 0.80) with no significant differences between the two trials (Seifert et al., 2021). In current dancesport practice, the most widely used tool to assess aerobic capacity has been the DAFT (Wyon et al., 2023), a 4-min five stage test with a $5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ bandwidth within each stage. Although the authors failed to provide the ICCs for VO_2max and HRmax as the outcome variables of the telemetric gas analyzer (COSMED K4 b², Italy), the CV for VO_2max and HRmax ranged from 1.4 to 6.0% and 1.5 to 3.5% between stages, indicating adequate reliability (Wyon et al., 2023). Indeed, VO_2 is the most common functional parameter for assessing consumption in dancesport athletes (Tiemens et al., 2023). Thus, our findings indicated that the ICCs for absolute and relative VO_2 were 0.96 and 0.89, which is in line with the abovementioned evidence. However, we noted that the CV was <5%, which was somewhat lower than the data reported for the DAFT test. Although some studies have suggested that the guidelines for reliability statistics are ICC > 0.80, moderate CV of $\leq 10\%$, and small ES (<0.60) (Atkinson & Nevill, 1998; Hopkins, 2000), we additionally strengthened the inclusion criteria to insure the test is reliable and pragmatic in real-time settings. Thus, our newly developed BAT protocol appears to be a reliable measure for testing aerobic capacity and its components.

Data from this study also showed that the BAT protocol yielded appropriate sensitivity to detect meaningful changes following performance. Unfortunately, this is the first study to have calculated TE and SWC. When observing the findings in Table 3, 'ok' to 'good' usefulness was presented for speed, absolute VO_2 , RER, VE, VT, VO_2 and BF norms and VD/VT, while relative VO_2 , BF, VE/ VO_2 and VE/ VCO_2 were deemed 'marginally' useful, as the TE was larger than the SWC. Changes in relative VO_2 ($1.21 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), BF (1.77 bpm), VE/ VO_2 (0.48) and VE/ VCO_2 (0.63) should be interpreted with caution, as the TE surpassed the SWC for capturing individual changes. Nevertheless, a higher proportion of variables were rated as 'ok' or 'good', confirming the BAT protocol as a useful test for aerobic performance monitoring. Although this study aimed to examine the test-retest reliability and usefulness of the BAT protocol, it is not without limitations. Sensitivity analysis calculated from the G*Power indicated that the appropriate sample size to detect ICC > 0.69 between the two occasions was $n = 11$, but we cannot exclude the possibility of insufficient statistical power. Additionally, training experience in dance ranged from 6 to 20 years, increasing the heterogeneity at both individual and dancesport couple levels. Because of the small sample size, we were unable to examine the differences based on experience.

Although dancesport is considered a high-intensity intermittent exercise (*Koutedakis & Jamurtas, 2004; Rodrigues-Krause, Krause & Reischak-Oliveira, 2015*), dancesport athletes are regarded as a 'risky' group of individuals with low level of cardiorespiratory fitness (*Tiemens et al., 2023*). Evidence regarding the development of aerobic capacity has consistently shown that none of their energy systems have been overly developed (*Wyon, 2005*). Another problem may be attributed to different energy requirements during the rehearsal and performance period, where the performance period is often accompanied by higher aerobic energy demands and more intense figure routines. Therefore, an advantage of the BAT protocol is that it simulates classical movements from five dancesport disciplines and mimics competition conditions. The current findings have provided evidence of its reliability properties and offer guidelines for the detection of meaningful changes in ventilatory and metabolic parameters. The authors suggest that this test can be implemented within the dancesport training program in preparatory and competitive periods, as it provides important information about changes and usefulness of aerobic performance variables. In terms of its 'real' applicability during training and choreography-based stimuli and the associations with long-term cardiovascular adaptations, the findings of the BAT protocol could be useful in enhancing both ventilatory and metabolic parameters related to dancesport activities. From a physiological perspective, the newly established dancesport protocol adequately addresses the most important factors of aerobic capacity in dancesport athletes, including $\text{VO}_{2\text{max}}$. By following the BAT protocol, which consists of gradual increase of exercise intensity and duration every 30 s, positive changes in physiological abilities may be attributed to enhanced vascular tone and parasympathetic modulation of autonomic nervous system (*Tomlinson & Naemi, 2025*). These beneficial adaptations may contribute to faster recovery and less energy requirements for the same amount of activity, which leads to more sustainable sports performance during training or competition (*Tao et al., 2022*).

Although we obtained promising results demonstrating adequate reliability and usefulness of the BAT protocol, we cannot exclude a few potential limitations. Despite using calculator software with available input to calculate the appropriate sample size (for reference, please see the 'Study participants' section), a small sample of $n = 13$ might not be sensitive enough to capture the 'true' reliability and usefulness properties of the BAT protocol. This implies that the findings obtained in this sample may not be generalizable to other dancesport athletes from different disciplines and techniques. However, test-retest data indicated extremely high reliability and ability to detect meaningful TE and SWC. Nevertheless, this approach should be tested in other groups of dancesport athletes to confirm whether the BAT protocol yields satisfactory properties (*Despot & Plavec, 2025*).

CONCLUSION

In summary, the BAT protocol is a reliable and useful progressive test for measuring aerobic capacity in standard discipline dancesport athletes. The test is suitable for administering in large groups indoors and can be completed in a relatively short period of time of ≈ 12 – 15 min. The characteristics through five stages which linearly progress by seven BPM and the

duration of 30 s at each stage make this test easy to administer among dancesport couples while mimicking competition conditions. Moreover, by combining several dancesport disciplines (English waltz, Slow foxtrot, Tango, Viennese waltz, and Quickstep), coaches and their teams may be able to monitor and track ‘meaningful’ changes in response to training and/or detraining periods. It should be highlighted that 30-second intervals are capable of accurately capturing small ventilatory and metabolic differences derived from the portable MetaMax[®] 3B gas analyzer. From a practical perspective, the BAT protocol is able to detect changes as low as $0.15 \text{ L} \cdot \text{min}^{-1}$ or $1.21 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ for absolute and relative VO_2 , providing a useful basis for planning and programming the training process during preparatory and competitive periods.

ADDITIONAL INFORMATION AND DECLARATIONS

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Competing Interests

Davor Plavec is an Academic Editor for PeerJ. Tamara Despot is employed by Dance studio ‘Dancespot’ and Davor Plavec is employed by Facility for medical care ‘Prima Nova’.

Author Contributions

- Tamara Despot conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Davor Plavec conceived and designed the experiments, authored or reviewed drafts of the article, and approved the final draft.

Human Ethics

The following information was supplied relating to ethical approvals (*i.e.*, approving body and any reference numbers):

The Ethical Committee of the Faculty of Kinesiology approved the study on the 29th of April 2020 (ethical code number: 77/2020).

Data Availability

The following information was supplied regarding data availability:

The raw measurement is available in the [Supplementary File](#).

Supplemental Information

Supplemental information for this article can be found online at <http://dx.doi.org/10.7717/peerj.20556#supplemental-information>.

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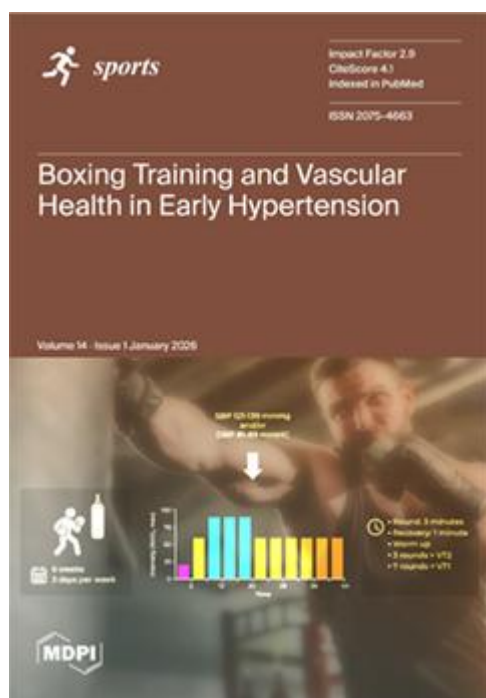
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15.2. Study 2

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Article

The Criterion Validity of a Newly Developed Ballroom Aerobic Test (BAT) Protocol Against Objective Methods

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Abstract

Although laboratory testing to assess aerobic capacity has been a ‘gold standard’ in sports science, its high costs and time-consuming protocols may not be feasible for monitoring and tracking progress in limited conditions. In dancesport athletes, several field-based aerobic tests have been proposed, but the majority of them have been developed for ballet or contemporary dancers at the individual level, while the data among dance couples engaging in standard dance styles is lacking. Therefore, the main purpose of this study was to validate a newly developed Ballroom Aerobic Test (BAT) protocol against objective methods. Twelve standard dancesport couples (age: 20.4 ± 3.9 years; height: 172.1 ± 8.7 cm; weight: 60.1 ± 9.4 kg) with 8.2 ± 3.4 years of training and competing experience participated in this study. Ventilatory and metabolic parameters were generated using the MetaMax[®] 3B portable gas analyzer (the BAT), while the KF1 (an increase in speed by $0.5 \text{ km} \cdot \text{h}^{-1}$ by every minute) and Bruce protocols were followed in laboratory-based settings on the running ergometer. Large to very large correlations were obtained between the BAT and KF1/Bruce protocols for the absolute maximal oxygen uptake ($\text{VO}_{2\text{max}}$; $r = 0.88$ and 0.87) and relative $\text{VO}_{2\text{max}}$ ($r = 0.88$ and 0.85), respiratory exchange ratio (RER; $r = 0.78$ and 0.76), expiratory ventilation (VE; $r = 0.86$ and 0.79), tidal volume (VT; $r = 0.75$; 95% CI = $0.57\text{--}0.87$; $p < 0.001$), ventilatory equivalent for O_2 (VE/VO_2 ; $r = 0.81$ and 0.80) and CO_2 (VE/VCO_2 ; $r = 0.78$ and 0.82), and dead space (VD/VT ; $r = 0.70$ and 0.74). The Bland–Altman plots indicated no systematic and proportional biases between the BAT and KF1 protocols (standard error of estimate; SEE = $\pm 3.36 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) and the BAT and Bruce protocols (SEE = $\pm 3.75 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). This study shows that the BAT exhibits satisfactory agreement properties against objective methods and is a valid dance protocol to accurately estimate aerobic capacity in dancesport athletes participating in standard dance styles.

Keywords: dance; field-based test; aerobic capacity; agreement; Bruce protocol; KF1 protocol; MetaMax[®] 3B portable gas analyzer



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1. Introduction

Dance has often been defined as a combination of art and sport, with some intermittent intensity elements which are performed at higher levels [1]. Regardless of the style of dance, the ability to withstand the training and competition schedules is a prerequisite, and these physiologic capabilities are essential. Evidence suggests that aerobic capacity plays a

significant role for success in dance [2]. Prioritizing the efficiency of the uptake, transport, and oxygen use efficiently is crucial for dance performance [3]. However, it has been noted that both semi-professional and professional dancers tend to have lower levels of maximal oxygen uptake (VO_2max) in comparison to other athletes [4]. The VO_2max in dancesport athletes is approximately 30% lower, in comparison to mono-structural and team sport athletes [1]. A further explanation for the VO_2max hypothesis in dance might relate to the limited capacity of dance to stimulate positive training adaptations. Research has shown that improvements in aerobic capacity are not linked to rehearsal activities but rather to the intensity and duration of physical performances [5]. During specific dance movements or training protocols, the level of VO_2max should ideally be maintained at a level between 70% and 80% of an individual's VO_2max , and the duration should exceed 20 min in order to effectively boost the aerobic capacity [1]. From a practical view, complex dance movements do not necessarily mean intensity but rather complexity. The shortcoming of dance is that there is no methodology for developing aerobic capacity and defined dance structures through which both intensity and duration are achieved. Thus, aerobic endurance is maintained or even increased through multiple repetitions of dance routines and choreography.

In the field of dance, assessing aerobic capacity using objective measures such as heart rate monitors and ergometers is crucial for tailoring training programs at an individual level [4]. Determining an individual's cardiovascular and respiratory capabilities is important for effectively managing the training load and focusing on achieving positive aerobic outcomes during the preparatory period. However, evaluating 'maximal' aerobic levels in dance presents challenges due to its non-competitive nature and the predetermined intensity by a choreographer [6]. Traditional objective methods for assessing aerobic performance, such as running- or cycling-based ergometers, are not well-suited for dance as they are costly, difficult to administer, and do not replicate the intricate movements involved in dance. Furthermore, dancers may experience biomechanical constraints during running or walking, stemming from limited dorsiflexion movements in the ankle and the highly developed turn out of the feet, leading to potential stress on the knee and hip joints [7]. When running, dancers often experience discomfort and pain in the shin area and uneven force distribution between tendons, ligaments, and muscles (especially in the calf area), leading to a higher risk of injuries or strain-related musculoskeletal problems [8]. To address these limitations, previous studies have endeavored to develop on-field aerobic tests specifically tailored for dance. A systematic review by Tiemens et al. [4] identified several common cardiorespiratory fitness test protocols in dance, including the Aerobic Power Index (API) [9], the Ballet-Specific Aerobic Fitness Test (B-DAFT) [10], the Dance Aerobic Fitness Test (DAFT) [11], the High-Intensity Dance Performance Fitness Test (HIDT) [12], and the Seifert Assessment of Functional Capacity for Dancers (SAFD) [13].

Although an effort has been made to adequately predict aerobic outcomes derived from objective methods from dance-specific testing protocols [9–13], most previous studies have correlated the VO_2max and maximal heart rate (HRmax) from a single device [10,11]. Also, the agreement between correlation coefficients for the VO_2max and associated factors ranged from -0.12 [13] to 0.91 [11], limiting the 'true' validity in dancesport athletes. Finally, the available tests have been primarily developed for ballet or contemporary dancers [10–13] at the individual level, while the validity properties in ballroom dance couples engaging in standard dance styles have yet to be investigated. Ballet and contemporary dancers have different training routines and movement patterns compared to the standard dance practitioners [14]. Also, ballet dancers have been shown to have an even lower accumulated fat mass %, which often goes below 10%, while ballroom style dancers tend to maintain their fat mass % between 10 and 20%, respectively [15]. Standard male and

female ballroom dancers tend to have higher average VO_2max values [15], compared to ballet or contemporary dancers [10,11]. This would imply that higher levels of the VO_2max and peak heart rate (HR_{peak}) are generally needed to maintain performance at a high level and to cope with training and competition demands [15]. From a sport-specific point of view, ballroom dancesport athletes who come from modern dance typically develop aerobic capacity and maximal performance at different rates, while athletes from other endurance activities tend to increase their aerobic capacities linearly throughout their career [15]. On the other hand, by comparing the maximal aerobic capacity of dancers to other endurance sport athletes, the average VO_2max is $48.0 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, while it ranges between 55.0 and $77.0 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ in swimmers, middle- and long-distance runners, rowers, and triathlon athletes [1]. Interestingly, the VO_2max in dancers is similar to sedentary behaviors ($\approx 44.0 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), highlighting that the endurance in dancesport athletes is only developed throughout dance routines, while the development-oriented endurance training has yet to be investigated [1]. Thus, aerobic capacities and field-based tests in these athletes cannot be generalized to other dance styles, due to different physiological profiles and training/performance regimes during the preparatory and competition periods [1,4]. By examining the regular training and performance by using a specific test to assess aerobic capacity, coaches and choreographers would be able to monitor and track both cardiovascular and respiratory demands of different standard dance styles and could adjust the training volume to tackle physiological enhancements.

Because of the shortcomings from previously developed and validated dance protocols, the primary purpose of this study was to develop and validate a newly established Ballroom Aerobic Test (BAT) protocol specifically designed for dance couples performing in various standard dance styles. A secondary purpose was to establish the typical error of measurement and Bland–Altman agreement between the protocols. Based on the available evidence, we hypothesized that the BAT protocol would yield large to very large criterion validity properties against treadmill-based methods (KF1 and Bruce protocols) for measuring aerobic capacity.

2. Materials and Methods

2.1. Experimental Approach

In this study, a within subject test–retest sub-study was utilized to examine the validity properties of the BAT in standard dancesport athletes. This study was part of a project entitled ‘Construction and validation of a test protocol to assess aerobic capacity in dancesport athletes from standard dance styles.’ The project was divided into four segments to examine (i) reliability and usefulness; (ii) validity; (iii) sensitivity; and (iv) pragmatic validity of the BAT. For the purpose of this study, two standard progressive treadmill tests (the KF1 and Bruce protocols) were assessed to determine aerobic capacity, followed by the BAT protocol one week later. The testing procedure was initiated during the preparatory period of dancesport athletes. Measurements were conducted by the same experienced researcher to avoid possible measurement errors. During testing, the participants wore their standard dance equipment (light T-shirt, tights, dance shoes). The air temperature conditions of indoor facility and laboratory were controlled to be between 22°C and 24°C with a humidity of $\approx 55\%$.

2.2. Study Participants

Through a public call between April 2025 and June 2025, a convenience sample of twenty-four standard dancesport athletes (12 dance couples; age: 20.4 ± 3.9 years; height: 172.1 ± 8.7 cm; weight: 60.1 ± 9.4 kg) with 8.2 ± 3.4 years of training and competing experience participated in the study. All participants were members of certified dance

clubs who competed at national and international levels. The inclusion criteria to enter the study were as follows: (i) being free from any kind of injury, acute or chronic illness, and disease, confirmed by a certified dance association doctor; (ii) age range between 16 and 35 years; and (iii) complete both measurements for validity properties of the BAT protocol. The exclusion criteria included having dance experience < 5 years, suffering from musculoskeletal or any other injury that precluded them from entering and completing the testing procedures, being without a training partner, which could not mimic conditions from competition, and not being able to complete the field- and laboratory-based protocols. The a priori power analysis calculated by the G*Power software ver. 3.1.9.7 [16] showed that by setting the input parameters of a two-tailed $\alpha < 0.05$, a minimum required correlation between the two methods at $r > 0.69$, and statistical power of $1 - \beta = 0.95$, the required total sample size was $n = 16$. Because of a possible drop-out rate, we enlarged the sample size by 50% to $n = 24$. Before the study began, all participants had signed a written informed consent form to participate in the study and to use data solely for scientific purposes. All procedures in this study were anonymous and in accordance with the Declaration of Helsinki [17]. The Ethical Committee of the Faculty of Kinesiology approved this study on 29 April 2020 (ethical code number: 77/2020).

2.3. The BAT Protocol

To assess the level of aerobic capacity of dancesport athletes, we constructed a field-based BAT protocol. The protocol was standardized by 5 standard dance styles with the following order: (i) English waltz; (ii) slow fox; (iii) tango; (iv) Viennese waltz; and (v) quick step. Every dance style had multiple levels of dancing that were progressively linked, where the speed of dancing (tempo) was defined by individual beats per minute (bpm). The English waltz consisted of 6 levels, danced in 3/4 time in the range of 75–110 bpm. The slow fox included 5 levels, danced in 4/4 time in the range of 117–145 bpm. The tango had 5 levels, danced in 4/4 time in the range of 152–180 bpm. The Viennese waltz was carried out through 3 levels, danced in 3/4 time in the range of 187–201 bpm. Finally, the quick step consisted of 6 levels, danced in 4/4 time in the range of 208–243 bpm. At each level, dance couples had to perform standard dance figures for 30 s at a defined speed without the melody (Table 1), while the time was cumulatively summed from the beginning of the BAT protocol. The speed expressed in beats progressively increased throughout the protocol by 7 bpm. The initial speed of the dance protocol was set at 75 bpm. Participants danced to a pre-defined dance tempo and rhythm by following the metronome. The elements for each dance style were basic and easy to perform, with the freedom of dance couples to create their own choreography. The duration of the BAT protocol was cumulatively added up and each pair danced until exhaustion.

2.4. The MetaMax[®] 3B Outcomes

To examine the reliability properties of the BAT protocol, we used the MetaMax[®] 3B (CORTEX Biophysik GmbH, Leipzig, Germany), a reliable and valid portable breath-by-breath ventilatory and metabolic measurement system specifically designed for field- and laboratory-based testing [18]. The device was composed of two parts designed to be worn on the chest. By using an electrochemical cell and an infrared analyzer, the MetaMax[®] 3B was able to calculate O_2 and CO_2 concentrations based on standard metabolic equations [19]. Based on manufacturer's recommendations and previous studies [17], the system was turned on for at least 20 min and calibrated prior to the testing. The calibration process included adjusting the gas analyzers by using reference gas values of O_2 (14.97%), CO_2 (4.96%), and N_2 ($\pm 0.02\%$) and volume with a standardized 3 L syringe (5530 series, Hans Rudolph, Inc., Kansas City, MO, USA). The MetaMax[®] 3B software generated data

regarding absolute ($L \cdot \min^{-1}$) and relative $VO_{2\max}$ ($mL \cdot kg^{-1} \cdot \min^{-1}$) and associated variables including respiratory exchange ratio of CO_2 produced to O_2 consumed during metabolism (RER), expiratory ventilation as the total volume of air inhaled or exhaled per min ($VE; L \cdot \min^{-1}$), tidal volume as the volume inhaled or exhaled during a normal breath ($VT; L$), ventilatory equivalent for O_2 (VE/VO_2) and CO_2 (VE/VCO_2) as determinants of breathing efficiency, and dead space to tidal volume ratio (VD/VT), which indicated the air that failed to participate in O_2 and CO_2 exchange process during breathing.

Table 1. The BAT dance protocol for every dance style.

Dance Styles	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
<i>English waltz</i>						
Beats	75	82	89	96	103	110
Time	30 s	60 s	1.5 min	2 min	2.5 min	3 min
<i>Slow fox</i>						
Beats	117	124	131	138	145	
Time	3.5 min	4.0 min	4.5 min	5.0 min	5.5 min	
<i>Tango</i>						
Beats	152	159	166	173	180	
Time	6.0 min	6.5 min	7.0 min	7.5 min	8.0 min	
<i>Viennese waltz</i>						
Beats	187	194	201			
Time	8.5 min	9.0 min	9.5 min			
<i>Quick step</i>						
Beats	208	215	222	229	236	243
Time	10.0 min	10.5 min	11.0 min	11.5 min	12.0 min	12.5 min

Time = cumulative time from BAT start.

The testing procedure indicated that both male and female dancers (one dance couple) were simultaneously measured with the MetaMax[®] 3B in order to simulate conditions from competitions in real-life settings. Although the order of trial was fixed, where dance couples first had to be tested for the BAT protocol and 48h after with the KF1 and 72 h after the KF1 protocol with the Bruce protocol in laboratory conditions, the possibility of a learning effect was vastly diminished. Each dance couple was tested individually to other dance couples for both field-and laboratory-based protocols. Also, they were told to keep the dance protocols and procedures to themselves and not to unveil them to the next dance couple. The BAT protocol was performed in an environment specific to dance, regarding the floor and dance attire that needed to be worn, while the KF1 and Bruce protocols were examined in laboratory conditions.

2.5. The KF1 and Bruce Testing Protocols

$VO_{2\max}$ and associated ventilatory and metabolic parameters were assessed by a breath-by-breath pulmonary gas exchange system (Quark b², COSMED, Roma, Italy) during an incremental treadmill test (KF1 and Bruce). KF1 is a standard test for the assessment of aerobic and anaerobic energy capacity [20]. The starting speed of the KF1 was $3 \text{ km} \cdot \text{h}^{-1}$ at a slope of 1% (continuous) for a duration of 2 min, after which the speed increased by $0.5 \text{ km} \cdot \text{h}^{-1}$ at the end of the third min and after that every 30 s until volitional

exhaustion. During recovery after each test protocol, the subjects walked at $5 \text{ km} \cdot \text{h}^{-1}$ for 3 min.

In the Bruce protocol, the participants started exercising at a treadmill speed of $2.7 \text{ km} \cdot \text{h}^{-1}$ and an incline of 10% gradient for 3 min. Workloads (speed and inclination) were subsequently increased each 3 min period in a simultaneous way until volitional exhaustion was reached [21]. Both protocols generated equal cardiorespiratory data as the MetaMax[®] 3B, which were filtered and averaged on a 5 s basis.

2.6. Data Analysis

Shapiro–Wilk’s (S-W) test was used to assess data normality. Data were checked for the critical W values, Q-Q plot inspection and the homogeneity of the variance was confirmed using the Leven test. If a calculated W value was larger than tabulated W value, this denoted that we did not reject the null hypothesis. All variables included in further analysis came from a hypothetical normal distribution, so data were presented as means and standard deviations (SDs) with 95% confidence interval limits (95% CI). To examine whether there was a couple dependence present during the BAT protocol, we utilized a linear-mixed effects model (LMM) with random intercept for couples and showed that there was no dependence effect within each couple for VO_2max , as our primary outcome of the study ($F = 1.533$, $p = 0.244$). Differences between each protocol were examined with repeated measures analysis of variance (RM ANOVA). The magnitude of the change between the two measurements (the BAT protocol vs. KF1 and Bruce protocols) was examined with a standardized mean difference and the following effect sizes (ESs) proposed by Hopkins et al. [22]: trivial ($\text{ES} < 0.2$), small ($0.2 < \text{ES} < 0.5$), moderate ($0.5 < \text{ES} < 0.8$), large ($0.8 < \text{ES} < 1.6$), and very large ($\text{ES} > 1.6$). Degree of coherence between ventilatory and metabolic parameters of the BAT protocol vs. KF1 and Bruce protocols was assessed using Pearson’s product-moment correlation (r). Correlation values denoted association between variables and tests as small ($r = 0.1\text{--}0.3$), moderate ($r = 0.3\text{--}0.5$), large ($r = 0.5\text{--}0.7$), very large ($r = 0.7\text{--}0.9$), and almost perfect ($r = 0.9\text{--}1.0$) [23]. Since VO_2max is considered as one of the most important determinants of performance in dancesport athletes [1,4,5], a Bland–Altman plot was created to present a graphical visualization of the agreement between the BAT and KF1/Bruce protocols for relative VO_2max . In brief, the difference between the BAT and KF1 (BAT and Bruce) protocol was calculated on the y -axis, while the average of the two measurements was presented on the x -axis. To be able to determine the mean difference ideally close to (0) and the upper and lower limits of agreement ($\pm 1.96 \text{ SD}$), we created three horizontal lines. Based on data representation, we were able to (i) determine visual agreement between the two methods; (ii) identify possible bias where the mean difference was significantly different from 0; (iii) assess the presence of magnitude of random error; and (iv) establish the limits of agreement to confirm whether the differences between the two methods were clinically meaningful [24]. Finally, we calculated Lin’s concordance coefficient of correlation (ρ_c), an analysis which tests both precision and accuracy of bivariate pairs of observations relative to a ‘gold standard’ or another set of data. According to Altman [25], the cut-off points for ‘poor’ vs. ‘excellent’ agreement were <0.20 and >0.80 . In addition, a Passing–Bablok regression analysis was considered as a non-parametric technique for comparing the BAT with the KF1 and Bruce protocols to observe a potential error in both measurements [26]. All statistical analyses were performed in SPSS v27.0 software (IBM, Armonk, NY, USA), with an alpha level set a priori at $p < 0.05$ to denote statistical significance.

3. Results

3.1. Primary Outcomes

According to the objective termination criteria of an RER ≥ 1.10 , of the 24 participants, the proportion of the participants who reached this cut-off was 20.8% for the BAT protocol and 45.8% and 37.5% for the KF1 and Bruce protocols. Basic descriptive statistics of the study participants are presented in Table 2. No significant differences between the KF1 and BAT nor between the Bruce and BAT protocols were observed for the absolute VO_2max ($F_{1,3} = 0.206$; $p = 0.816$; $\eta^2_p = 0.02$) and relative VO_2max ($F_{1,3} = 1.502$; $p = 0.245$; $\eta^2_p = 0.12$), RER ($F_{1,3} = 2.272$; $p = 0.094$; $\eta^2_p = 0.24$), VE ($F_{1,3} = 1.956$; $p = 0.165$; $\eta^2_p = 0.15$), VT ($F_{1,3} = 2.833$; $p = 0.065$; $\eta^2_p = 0.31$), VE/ VO_2 ($F_{1,3} = 2.514$; $p = 0.104$; $\eta^2_p = 0.19$) and VE/ VCO_2 ($F_{1,3} = 2.737$; $p = 0.087$; $\eta^2_p = 0.20$), and VD/VT ($F_{1,3} = 2.878$; $p = 0.078$; $\eta^2_p = 0.21$). ESs showed trivial to small changes. Large to very large correlations were calculated between the KF1 and BAT protocols for absolute VO_2max ($r = 0.88$; 95% CI = 0.75–0.95; $p < 0.001$) and relative VO_2max ($r = 0.88$; 95% CI = 0.76–0.95; $p < 0.001$), RER ($r = 0.78$; 95% CI = 0.59–0.90; $p < 0.001$), VE ($r = 0.86$; 95% CI = 0.62–0.96; $p < 0.001$), VT ($r = 0.75$; 95% CI = 0.57–0.87; $p < 0.001$), VE/ VO_2 ($r = 0.81$; 95% CI = 0.55–0.91; $p < 0.001$) and VE/ VCO_2 ($r = 0.78$; 95% CI = 0.65–0.94; $p < 0.001$), and VD/VT ($r = 0.70$; 95% CI = 0.40–0.87; $p < 0.001$). Large to very large correlations were obtained between the Bruce and BAT protocols for absolute VO_2max ($r = 0.87$; 95% CI = 0.72–0.95; $p < 0.001$) and relative VO_2max ($r = 0.85$; 95% CI = 0.71–0.93; $p < 0.001$), RER ($r = 0.76$; 95% CI = 0.50–0.91; $p < 0.001$), VE ($r = 0.79$; 95% CI = 0.50–0.94; $p < 0.001$), VT ($r = 0.83$; 95% CI = 0.71–0.91; $p < 0.001$), VE/ VO_2 ($r = 0.80$; 95% CI = 0.64–0.92; $p < 0.001$) and VE/ VCO_2 ($r = 0.82$; 95% CI = 0.75–0.94; $p < 0.001$), and VD/VT ($r = 0.74$; 95% CI = 0.44–0.89; $p < 0.001$).

Table 2. Basic descriptive statistics, mean difference (diff.), and ES between the BAT protocol against the KF1 and Bruce protocols.

Study Variables	KF1	Bruce	BAT	Absolute Diff. (95% CI)		Relative Diff. (%)		ES	
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	KF1–BAT	Bruce–BAT	KF1–BAT	Bruce–BAT	KF1–BAT	Bruce–BAT
Absolute VO_2 ($\text{L} \cdot \text{min}^{-1}$)	3.05 $\pm$ 0.74	3.05 $\pm$ 0.75	3.00 $\pm$ 0.65	−0.05 (−0.19–0.10)	−0.05 (−0.20–0.11)	1.64%	1.64%	0.07 (trivial)	0.07 (trivial)
Relative VO_2 ($\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	50.92 $\pm$ 7.47	49.98 $\pm$ 7.55	50.21 $\pm$ 5.96	−0.71 (−2.24–0.83)	0.23 (−1.47–1.93)	1.39%	0.46%	0.11 (trivial)	0.03 (trivial)
RER	1.09 $\pm$ 0.05	1.08 $\pm$ 0.04	1.07 $\pm$ 0.06	−0.02 (−0.03–0.02)	−0.01 (−0.02–0.02)	1.83%	0.93%	0.36 (small)	0.20 (small)
VE ($\text{L} \cdot \text{min}^{-1}$)	110.21 $\pm$ 28.43	110.43 $\pm$ 28.75	104.20 $\pm$ 26.37	−6.01 (−12.22–0.20)	−6.23 (−13.83–1.37)	5.45%	5.64%	0.22 (small)	0.23 (small)
VT (L)	1.93 $\pm$ 0.42	1.98 $\pm$ 0.54	1.77 $\pm$ 0.36	−0.16 (−0.28–0.04)	−0.22 (−0.54–0.28)	8.29%	11.11%	0.41 (small)	0.46 (small)
VE/ VO_2	33.65 $\pm$ 3.82	33.85 $\pm$ 3.46	32.93 $\pm$ 2.93	−0.71 (−1.67–0.24)	−0.91 (−1.78–0.04)	2.11%	2.69%	0.21 (small)	0.29 (small)
VE/ VCO_2	30.90 $\pm$ 3.83	30.16 $\pm$ 2.67	31.04 $\pm$ 3.51	0.14 (−0.89–1.17)	0.88 (−0.03–1.73)	0.45%	2.92%	0.04 (trivial)	0.28 (small)
VD/VT	0.15 $\pm$ 0.03	0.14 $\pm$ 0.03	0.15 $\pm$ 0.02	0.003 (−0.005–0.01)	0.009 (−0.001–0.02)	2.00%	6.43%	0.01 (trivial)	0.39 (small)

Lin's analysis indicated an excellent concordance between the KF1 and BAT protocols for the absolute VO_2max ($\rho_c = 0.93$; 95% CI = 0.84–0.97) and relative VO_2max ($\rho_c = 0.92$; 95% CI = 0.82–0.97), RER ($\rho_c = 0.86$; 95% CI = 0.68–0.94), VE ($\rho_c = 0.92$; 95% CI = 0.82–0.97), VT ($\rho_c = 0.85$; 95% CI = 0.66–0.94), VE/ VO_2 ($\rho_c = 0.88$; 95% CI = 0.71–0.95) and VE/ VCO_2 ($\rho_c = 0.88$; 95% CI = 0.71–0.95), and VD/VT ($\rho_c = 0.81$; 95% CI = 0.57–0.92). Similarly, the data showed an excellent concordance between the Bruce and BAT protocols for the absolute VO_2max ($\rho_c = 0.93$; 95% CI = 0.83–0.97) and relative VO_2max ($\rho_c = 0.90$; 95% CI = 0.78–0.96), RER ($\rho_c = 0.83$; 95% CI = 0.62–0.93), VE ($\rho_c = 0.88$; 95% CI = 0.73–0.95), VT

($\rho_c = 0.87$; 95% CI = 0.70–0.94), VE/VO_2 ($\rho_c = 0.89$; 95% CI = 0.73–0.95) and VE/VCO_2 ($\rho_c = 0.88$; 95% CI = 0.73–0.95), and VD/VT ($\rho_c = 0.84$; 95% CI = 0.63–0.93).

3.2. Secondary Outcomes

Figure 1 shows the Bland–Altman scatterplot of the VO_{2max} agreement between the BAT and KF1 protocols. The mean difference between the two methods yielded a value of -0.71 , indicating no measurement bias ($p > 0.05$). Although a negative linear trend was observed, a linear regression analysis showed no potential proportional bias ($\beta = -0.24$; 95% CI -0.46 – 0.02 ; $p = 0.066$), with a standard error for the estimate (SEE) of $3.36 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. The linear regression equation to predict the relative VO_{2max} from the KF1 protocol was as follows: $VO_{2max_{KF1}} (\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) = -4.305 + (1.100 \cdot VO_{2max_{BAT}})$ ($R^2 = 0.77$; $p < 0.001$). The slope coefficient between the BAT and KF1 protocols was $b = 1.625$ with a 95% CI (0.90, 2.25), while the intercept coefficient was $a = -18.43$ with a 95% confidence interval (-64.65 , 42.13). According to Passing and Bablok [26], if one was included in the CI for the slope and zero was included for the intercept, the BAT procedure yielded similar measurements to the KF1 procedure.

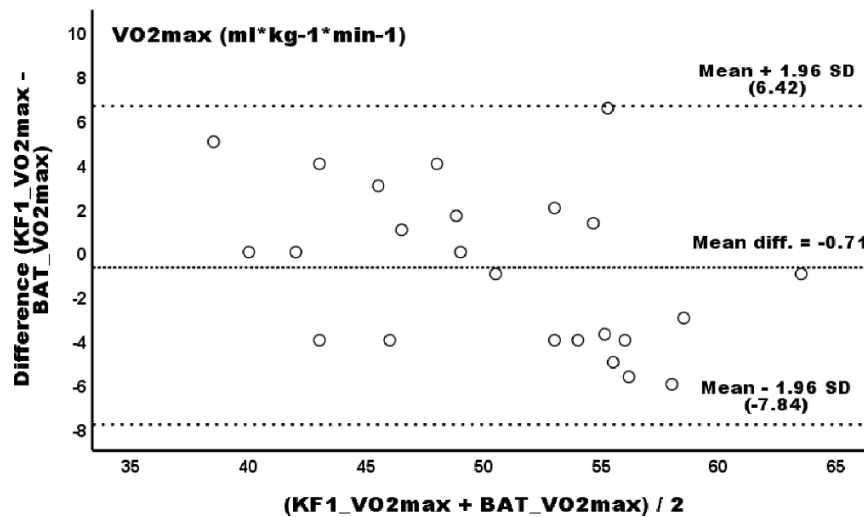


Figure 1. Bland–Altman plot of differences between the BAT and KF1 protocols (y-axis) and the average of the two measurements (x-axis) for relative VO_{2max} .

The Bland–Altman scatterplot of the VO_{2max} agreement between the BAT and Bruce protocols is presented in Figure 2. The mean difference between the two methods yielded a value of 0.23 , indicating no measurement bias ($p > 0.05$). Similarly to the BAT–KF1, a negative linear trend between the BAT and Bruce protocols was observed; however, no potential proportional bias was shown ($\beta = -0.26$; 95% CI -0.51 – 0.15 ; $p = 0.087$). The generated SEE of the VO_{2max} was $3.75 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Similarly to the KF1 protocol, the linear regression equation to predict the relative VO_{2max} from the Bruce protocol was as follows: $VO_{2max_{BRUCE}} (\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) = -3.996 + (1.075 \cdot VO_{2max_{BAT}})$ ($R^2 = 0.72$; $p < 0.001$). The slope coefficient between the BAT and KF1 protocols was $b = 1.10$ with a 95% CI (0.80, 1.30), while the intercept coefficient was $a = -1.05$ with a 95% confidence interval (-10.17 , 9.90), indicating that the BAT protocol yielded similar measurements to the Bruce protocol.

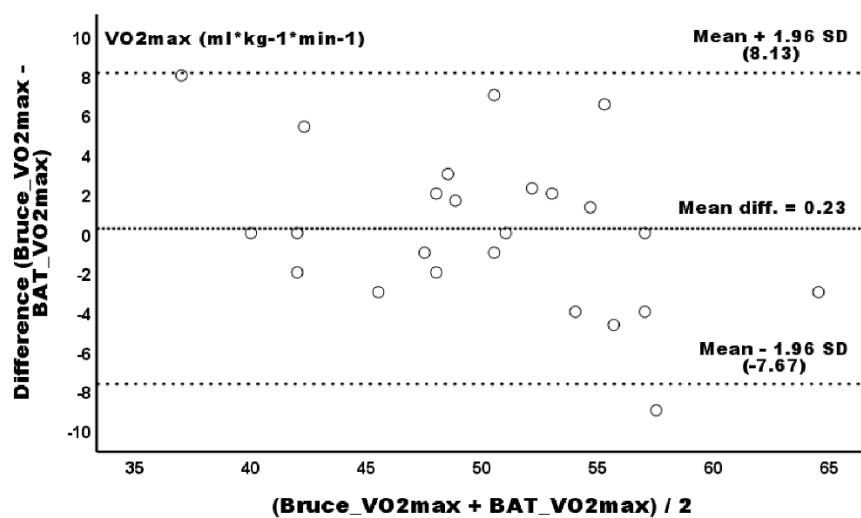


Figure 2. Bland–Altman plot of differences between the BAT and Bruce protocols (*y*-axis) and the average of the two measurements (*x*-axis) for relative VO_2max .

4. Discussion

The main purpose of this study was to develop and examine the criterion validity and Bland–Altman agreement of the BAT protocol against the KF1 and Bruce laboratory protocols in dancesport athletes performing in standard dance styles. Findings suggest that the ventilatory and metabolic parameters derived from the MetaMax[®] 3B portable gas analyzer during the BAT protocol correlate as large to very large with the KF1 and Bruce aerobic outcomes. The level of agreement calculated from the Bland–Altman plots for the relative VO_2max shows no systematic nor proportional biases between the two methods with the SEE of $3.36 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (KF1) and $3.75 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (Bruce).

To the best of the authors' knowledge, this is the first study examining the development and validity of a progressive test to assess aerobic capacity in standard dancesport athletes. Our results should be interpreted in light of previous studies. To date, several progressive field-based tests to assess the level of aerobic capacity in dance have been proposed and validated against more objective methods. For example, a study by Wallmann et al. [9] showed that the API submaximal exercise fitness test correlated well with the VO_2max ($r = 0.89$ and 0.90), with a technical error of measurement (TEM) of a power output = $0.07 \text{ W} \cdot \text{kg}^{-1}$ and $\text{VO}_2\text{max} = 0.71 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Another dance protocol designed for ballet dancers indicated that the mean squared root (s_w^2) for the test was 5.01, with a SEE of $6.20 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ [10]. One of the most common fitness protocols to examine aerobic capacity is the DAFT, a five-stage 4 min progressive test [10]. In a study by Wyon et al. [11], data generated from the portable telemetric gas analyzer (Cosmed K4 b2, Italy) indicated that the HRmax and VO_2max correlated very strongly for the test ($r = 0.91$; SEE = $5.60 \text{ b} \cdot \text{min}^{-1}$). Similar observations were noted for the HIDT dance protocol, where five participants ($n = 5$) undertook both the treadmill and dance tests to estimate the VO_2max [12]. During the treadmill protocol, the mean VO_2max was $46.40 \pm 3.60 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, and during the HIDT, the VO_2max value was $51.00 \pm 6.60 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. A pairwise comparison between the treadmill and dance protocols showed no significant differences in VO_2max ($p = 0.100$) [12]. The same study also showed that the mean % of the HRmax was significantly lower in the HIDT

compared to the treadmill test (97.50 vs. 101.00%, $p = 0.020$), while the validity of blood lactate values were high (HIDT = $6.10 \pm 1.90 \text{ mmol} \cdot \text{L}^{-1}$ vs. treadmill = $6.30 \pm 1.70 \text{ mmol} \cdot \text{L}^{-1}$, $p = 0.860$) [12]. The most recent SAFD test to evaluate the functional capacity of collegiate dancers revealed large to very large correlations with the peak treadmill test for the relative VO_2max ($r = 0.78$), HRmax ($r = 0.85$), blood lactate ($r = 0.72$), and rate of perceived exertion (RPE; $r = 0.84$), while trivial to moderate correlations were found for time ($r = 0.60$) and the RER ($r = -0.12$) [13].

Although the existing progressive dance protocols to assess aerobic capacity exhibited satisfactory validity properties against objective measures [9–13], our newly developed BAT protocol yielded high agreements with the treadmill test following two protocols (KF1 and Bruce). The incremental difference and the novelty between our and other dance protocols lies in the fact that it is specifically designed for dance couples who engage in standard dance styles. This is very important, because both individuals need to cope with each other during the rehearsal/training or competition. This would suggest that their aerobic capacity needs to be at equal level in order to keep up with the partner. Despite the fact that the VO_2max tends to be low in dancesport athletes, compared to other athletes [4–6], the intention of the BAT protocol is to enhance the aerobic system and to physiologically prepare for stress during training and/or performance. Dance movements in standard dance styles are often characterized by sway components and the interplay between rises and falls, which are considered key elements for preserving or increasing functional performance in competitive dancesport athletes [27]. Moreover, the complexity of figures and faster pace during training and competition in standard dance styles is not comparable to ballet or contemporary dance styles, where the movements are often performed in static conditions, emphasizing esthetic rather than functional components of dance. Therefore, the BAT protocol can serve as an avenue for screening and tracking aerobic capacity within the narrow niche of standard style dance athletes.

The practical application of the BAT protocol is reflected in the development of a completely new model for measuring aerobic capacity and an algorithm for estimating the VO_2max in standard dances under the conditions of the sport-specific activity. This enables a realistic assessment of physical and energy loads specific to the activity, in comparison with the existing tests for assessing aerobic capacity. Since standard dance styles have been often categorized as high-intensity physical activities that need aerobic and anaerobic energy systems to perform [28], the newly established dance protocol would be able to increase aerobic capacity and to optimize dance training. Indeed, correct and timely diagnostic procedures for measuring and/or assessing energy capacities in dance are needed to achieve primary goals and positive trends towards sports success [1,4].

This study is not without limitations. First, a cross-sectional design prevents us from confirming a causal relationship between field- and laboratory-based testing protocols for assessing aerobic capacity. Second, we did not include the HRmax nor blood lactate parameters as indicators of aerobic and anaerobic capacities, limiting our findings to data generated from the MetaMax® 3B and treadmill devices. Previous studies have shown a strong relationship between HRmax and VO_2max [10,11] and adequate sensitivity in HRmax and blood lactate changes following the dance protocol [13]. Third, a relatively small sample size might have underpowered the validity properties of the BAT protocol. Although we performed a sample size calculation (for more information, please see the ‘Study Participants’ section), we cannot exclude the lack of statistical power. Fourth, we failed to examine the rate of perceived exertion (RPE) and collect blood samples for lactate concentrations following the BAT, KF1, and Bruce protocols. These physiological measures have been constantly used as potential markers for determining fatigue and should be considered in further research in dancesport athletes. Fifth, the BAT protocol was measured

with the MetaMax® 3B, while the treadmill tests used COSMED Quark b². The difference in devices could introduce systematic errors independent of the protocol. Finally, the BAT protocol was not cross-validated in other athletes from different dance styles (ballet, contemporary, or Latin American), limiting its applicability. Nevertheless, the authors suggest that the BAT protocol is a valid training and performance tool for measuring aerobic capacity and associated factors in dancesport athletes from standard dance styles.

5. Conclusions

In summary, this study shows that the BAT protocol has a strong to excellent criterion validity against the KF1 and Bruce protocols. Also, the Bland–Altman analysis indicated that the SEE for the KF1 and Bruce protocols against the BAT protocol was $3.36 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and $3.75 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. The advantage of the BAT protocol is that it simulates classical movements from five dance styles and mimics competition conditions. The current findings have provided evidence of its validity properties and potential guidelines for monitoring and tracking ventilatory and metabolic parameter changes under different training conditions. The authors suggest that this test can be implemented within the dance training program in preparatory and competitive periods, as it gives important and valid information about the agreement between field and laboratory aerobic performance variables among standard dancesport athletes.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki, and the Ethical Committee of the Faculty of Kinesiology approved this study on 29 April 2020 (ethical code number: 77/2020).

Informed Consent Statement: Written informed consent was obtained from all subjects involved in this study.

Data Availability Statement: The data that support the findings of this study are available upon reasonable request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Conflicts of Interest: Author Tamara Despot is professionally engaged through her own company, Dancespot d.o.o. The company served solely as the legal entity through which the author conducts her professional activities and has no financial, commercial, or other interests that could be considered a potential conflict of interest in relation to the present study. Author Davor Plavec is employed at Polyclinic Prima Nova. The institution had no financial, commercial, or other involvement that could be construed as a potential conflict of interest in relation to the present study.

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15.3. Study 3

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The Ballroom Aerobic Test for estimating cardiorespiratory fitness in standard style dancesport athletes: diagnostic accuracy against laboratory measures

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Purpose: The main purpose of the study was to investigate the sensitivity properties of a newly developed Ballroom Aerobic Test (BAT) protocol for cardiorespiratory fitness against objective methods.

Methods: Twenty-four young dancesport couple athletes who competed at international level were recruited (age 20.40 ± 3.90 years; stature 172.10 ± 8.70 cm; body mass 60.10 ± 9.40 kg; 50.00% women). Physiological parameters from the field-based BAT protocol were evaluated using the MetaMax® 3B portable gas analyzer, while objective data were generated on the running ergometer following the KF1 and Bruce protocols. The area under the curve (AUC), sensitivity, specificity, false positive (FP), false negative (FN), positive likelihood ratio (PLR) and negative likelihood ratio (NLR) were calculated.

Results: The AUC for the BAT against the KF1 and Bruce protocols yielded satisfactory values of $> .75$, with the largest agreements for absolute ($AUC = .92$; 95% CI $.82 - 1.00$ and $.94$; 95% CI $.90 - 1.00$) and relative maximal oxygen uptake ($\dot{V}O_{2max}$; $AUC = .94$; 95% CI $.90 - 1.00$ and $.95$; 95% CI $.86 - 1.00$). Other ventilatory and metabolic parameters yielded somewhat lower AUC values ($.65 \leq AUC \leq .93$). Sensitivity and specificity analyses exhibited acceptable agreement percentages between the BAT and KF1/Bruce protocols, ranging from 66.70% to 95.10% for sensitivity and 60.00% to 100.00% for specificity. The largest PLRs were shown for relative $\dot{V}O_{2max}$ in both KF1 (10.31) and Bruce (11.05) protocols.

Conclusions: This study shows that the BAT protocol may be considered as a good diagnostic tool for evaluating ventilatory and metabolic parameters of standard style dancesport athletes.

Keywords: Diagnostic testing; Dance; Physiological parameters; Sensitivity; Specificity.

Introduction

Dance is often seen as a vigorous form of exercise that demands higher levels of muscular and cardiorespiratory capacities.¹ Being able to handle the rigors of training and competition in dance is essential, underscoring the importance of physiological capabilities.² Research indicates that having a strong aerobic capacity is vital for success in dance. It's crucial for dancers to be efficient in how they take in, transport, and use oxygen to enhance their performance.³ Interestingly, studies show that both semi-professional and professional dancers typically have lower maximal oxygen uptake ($\dot{V}O_{2max}$) compared to athletes from other sports. In fact, dancers in competitive dance sports exhibit a $\dot{V}O_{2max}$ that is about 30% lower than that of athletes involved in mono-structural and team sports.⁴ One possible reason for this lower $\dot{V}O_{2max}$ in dancers may be linked to the limited ability of dance training to induce significant training adaptations. Findings suggest that improvements in aerobic capacity are more related to the intensity and duration of physical performance rather than rehearsal activities. This approach is key to effectively boosting their aerobic performance. From a practical view, complex dance movements do not necessarily mean intensity, but rather

complexity. The shortcoming of dance is a lack of standardized or sport-specific protocols integrated into routine training and defined dance structures through which both intensity and duration are achieved. Thus, aerobic endurance is maintained or even increased through multiple repetitions of dance routines and choreography.⁵

In the realm of dance, it is essential to evaluate aerobic capacity using objective tools like heart rate monitors and ergometers to customize training programs for each individual.⁶ Assessing an athlete's cardiovascular and respiratory abilities is vital for effectively regulating the training load and aiming for beneficial aerobic results during the preparatory phase. Nonetheless, measuring 'maximal' aerobic levels in dance is challenging due to its non-competitive aspects and the predetermined intensity set by the choreographer. Conventional objective techniques for measuring aerobic performance, such as running- or cycling-based ergometers, are not ideal for dance because they are expensive, complicated to implement, and fail to mimic the complex movements required in dance.^{7,8} In a complex, aesthetic, and skill-based discipline (like dance or parkour), where traditional testing is inadequate, reinforcing the need for ecologically valid tests is warranted.^{8,9} To address these

limitations, previous studies have endeavored to develop on-field aerobic tests specifically tailored for dance. A systematic review by Tiemens et al.⁴ identified several common cardiorespiratory fitness test protocols in dance, including the Aerobic Power Index (API),¹⁰ the Ballet-specific Aerobic Fitness Test (B-DAFT),¹¹ the Dance Aerobic Fitness Test (DAFT),¹² the High-Intensity Dance Performance Fitness Test (HIDT),¹³ and the Seifert Assessment of Functional Capacity for Dancers (SAFD).¹⁴ Despite attempts to accurately forecast aerobic results based on objective methods from dance-specific testing protocols,¹⁰⁻¹⁴ the majority of earlier studies have linked $\dot{V}O_{2\max}$ and maximal heart rate ($HR_{\max}$) using a single device.^{13,14} Ultimately, the tests that are available have mostly been created for ballet or contemporary dancers¹²⁻¹⁵ on a personal basis, whereas the diagnostic aspects in ballroom dance pairs participating in standard dance styles have not been explored. Ballet and contemporary dancers follow distinct training regimens and movement styles in contrast to traditional dance performers.¹⁶ From a biomechanical point of view, ballroom dancers tend to have higher knee extension torque movements, accompanied by greater hip external and internal rotations, and hip extension, opposed to more traditional dance disciplines.^{16,17} Also, studies have shown that ballroom dancers, being more competitive and sport-related, in comparison to ballet and contemporary dancers, have more hamstring muscle length and dynamic balance, indicating higher levels of physical fitness.¹⁷ Lower mobility in the pelvis region found in ballet dancers might indicate more intra-articular lesions, followed by discomfort and pain more frequently.¹⁷ The biomechanical problem in the lumbo-sacral region may also indicate a complex association with altered gait biomechanics, specifically kinematics and kinetics of the dance movements. Greater dynamic balance in ballroom dancesport athletes leads to a lower risk of sport-related lower limb injury rate. Moreover, ballet dancers exhibit an even lower percentage of accumulated fat mass, often falling below 10%, whereas ballroom dancers typically keep their fat mass percentage between 10 and 20%, respectively.¹⁷ From a physiological point of view, typical male and female ballroom dancers generally exhibit higher average $\dot{V}O_{2\max}$ values¹⁶ when compared to ballet or contemporary dancers.¹⁰⁻¹⁴ This suggests that elevated $\dot{V}O_{2\max}$ and peak heart rate (HR_{peak}) are usually required to sustain high-level performance and meet the challenges of training and competition demands.¹⁷ From a discipline-specific perspective, ballroom dancesport competitors originating from modern dance usually enhance their aerobic capacity and peak performance at varying rates, whereas those from other endurance sports generally see a gradual increase in their aerobic abilities throughout their careers.¹⁷ Conversely, when examining the maximal aerobic capacity of dancers relative to other endurance sport athletes, the mean $\dot{V}O_{2\max}$ is recorded at 48.0 ml·kg⁻¹·min⁻¹, whereas it varies from 55.0 to 77.0 ml·kg⁻¹·min⁻¹ among swimmers, middle- and long-distance runners, rowers, and triathletes.¹ Notably, the $\dot{V}O_{2\max}$ in dancers aligns with sedentary activities ($\approx$ 44.0 ml·kg⁻¹·min⁻¹), emphasizing that the endurance of dancesport athletes is cultivated solely during dance performances, while endurance training designed for improvement remains unexplored.¹ Consequently, aerobic capacities and field tests in these dancers cannot be applied to other dance forms, as a result of varied physiological profiles and training/competition routines throughout the preparatory and competitive phases.^{1,4} Through the analysis of consistent training and performance with a designated test to evaluate aerobic capacity, coaches and choreographers can oversee and record the cardiovascular and respiratory requirements of various standard dance styles and can modify training volume

to address physiological improvements. Therefore, the main purpose of the study was to examine the sensitivity properties of a newly developed Ballroom Aerobic Test (BAT) protocol for cardiorespiratory fitness against objective methods. We hypothesized that the BAT protocol would yield satisfactory sensitivity and specificity values in comparison to laboratory-based aerobic capacity tests.

Materials and methods

Experimental approach

This observational sub-study, conducted within subjects, aimed to assess the diagnostic characteristics of the BAT in standard dancesport athletes. The research was a component of a project titled 'Development and validation of a testing protocol to evaluate aerobic capacity in dancesport competitors from standard dance styles.' The project was split into four segments to investigate: i) reliability and utility; ii) validity; iii) diagnostic accuracy; and iv) practical validity of the BAT. Portions of the text have been published recently regarding the validity properties of the BAT protocol, where we used continuous data to evaluate correlations and Bland-Altman analyses between the BAT against the KF1/ Bruce protocols. Of note, the standard error of estimate (SEE) for relative $\dot{V}O_{2\max}$ was 3.36 ml·kg⁻¹·min⁻¹ (KF1) and 3.75 ml·kg⁻¹·min⁻¹ (Bruce).¹⁸ In this study, two standard progressive treadmill tests (the KF1 and Bruce protocols) were evaluated to measure aerobic capacity, with the BAT protocol conducted one week later. The testing process commenced during the training phase of dancesport competitors. Assessments were carried out by the same skilled researcher to prevent potential measurement inaccuracies. During the tests, the participants donned their usual dance gear (light T-shirt, tights, dance shoes). The indoor facility and laboratory's air temperature was maintained between 22°C and 24°C, with a humidity level of approximately 55%

Study participants

Twenty-four standard dancesport athletes (12 dance couples; age 20.4±3.9 years; stature 172.1±8.7 cm; body mass 60.1±9.4 kg) with 8.2±3.4 years of training and competing experience participated in the study. All participants were members of certified dance clubs who competed at national and international level. The inclusion criteria to enter the study were: i) being free from any kind of injury, acute or chronic illness and disease confirmed by a certified dance association doctor; ii) age range between 16 and 35 years; and iii) complete both measurements for validity properties of the BAT protocol. The *a-priori* power analysis calculated by the G*Power software ver. 3.1.9.7¹⁹ showed that by setting the input parameters of a two-tailed $P < .05$, a minimum required correlation between the two methods at $R > .69$, and statistical power of $1-\beta = .95$, the required total sample size was $n=16$. Because of a possible drop-out rate, we enlarged the sample size by 50% to $n=24$. Before the study began, all participants had signed a written informed consent to participate in the study and to use data solely for scientific purposes. All procedures in the study were anonymous and in accordance with the Declaration of Helsinki.²⁰

The BAT protocol

To assess the level of aerobic capacity of dance sport athletes, we constructed a field-based BAT protocol. The protocol was standardized by 5 standard dance styles with the following order: i) English waltz; ii) Slow fox; iii) Tango; iv) Viennese waltz; and v) Quick step. Every dance style had multiple level of dancing that were progressively linked, where the speed of dancing (tempo) was defined by individual beats per minute

(b·pm⁻¹), and by beat (bars per minute – BPM) denoting rhythm. The English waltz consisted of 6 levels, danced in 3/4 time in the range of 25–37 BPM or 75–110 BPM. The Slow fox included 5 levels, danced in 4/4 time in the range of 29–36 BPM or 117–145 BPM. The Tango had 5 levels, danced in 4/4 time in the range of 38–45 BPM or 152–180 bpm. The Viennese waltz was carried out through 3 levels, danced in 3/4 time in the range of 62–67 BPM or 187–201 BPM. Finally, the Quick step consisted of 6 levels, danced in 4/4 time in the range of 52–60 BPM or 208–243 BPM. At each level, dance couples had to perform standard dance figures for 30 sec at a defined speed without the melody (Table 1). The speed expressed in beats progressively

increased throughout the protocol by 7 BPM. The initial speed of the dance protocol was set at 75 BPM. Participants danced on a pre-defined dance tempo and rhythm by following the metronome. The elements for each dance style were basic and easy to perform, with the freedom of dance couples to create their own choreography. The duration of the BAT protocol was cumulatively added up and each pair danced until exhaustion.

The MetaMax® 3B outcomes

To examine the reliability properties of the BAT protocol, we used the MetaMax® 3B (CORTEX Biophysik GmbH, Leipzig, Germany), a reliable and valid portable breath-by-breath ventilatory and metabolic measurement system specifically

Table 1. The BAT dance protocol for every dance style.

Dance styles	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
<i>English waltz</i>						
Beats (bpm ⁻¹)	75	82	89	96	103	110
Time (min)	0.5	1.0	1.5	2.0	2.5	3.0
<i>Slow fox</i>						
Beats (bpm ⁻¹)	117	124	131	138	145	
Time (min)	3.5	4.0	4.5	5.0	5.5	
<i>Tango</i>						
Beats (bpm ⁻¹)	152	159	166	173	180	
Time (min)	6.0	6.5	7.0	7.5	8.0	
<i>Viennese waltz</i>						
Beats (bpm ⁻¹)	187	194	201			
Time (min)	8.5	9.0	9.5			
<i>Quick step</i>						
Beats (bpm ⁻¹)	208	215	222	229	236	243
Time (min)	10.0	10.5	11.0	11.5	12.0	12.5

Note: Ballroom Aerobic Test (BAT).

designed for field- and laboratory-based testing.²¹ The device was composed of two parts designed to be worn on the chest. By using an electrochemical cell and an infrared analyzer, the MetaMax® 3B was able to calculate O₂ and CO₂ concentrations based on standard metabolic equations.²² Based on manufacturer's recommendations and previous studies,²¹ the system was turned on for at least 20 min and calibrated prior to the testing. The calibration process included adjusting the gas analyzers by using reference gas values of O₂ (14.97%), CO₂ (4.96%) and N₂ (± 0.02%) and volume with a standardized 3-L syringe (5530 series, Hans Rudolph, Inc., MO, USA). The MetaMax® 3B software generated data regarding absolute (l·min⁻¹) and relative VO_{2max} (ml·kg⁻¹·min⁻¹) and associated variables including respiratory exchange ratio of CO₂ produced to O₂ consumed during metabolism (RER), expiratory ventilation as the total volume of air inhaled or exhaled per min (VE; l·min⁻¹), tidal volume as the volume inhaled or exhaled during a normal breath (VT; L), ventilatory equivalent for O₂ (VE/VO₂) and CO₂ (VE/VCO₂) as determinants of breathing efficiency, and dead space to tidal volume ratio (VD/VT), which indicated the air that failed to participate in O₂ and CO₂ exchange process during breathing.

The KF1 and Bruce testing protocols

VO_{2max} and metabolic parameters were assessed by a breath-by-breath pulmonary gas exchange system (Quark b², COSMED, Italy) during an incremental treadmill tests (KF1 and Bruce).

KF1 is a standard test for the assessment of aerobic and anaerobic energy capacity.²³ The starting speed of the KF1 was 3 km·h⁻¹ at a slope of 1% (continuous) for a duration of 2 min, after which the speed increased by 0.5 km·h⁻¹ at the end of the third min and after that every 30 sec until volitional exhaustion. During recovery after each test protocol, the subjects walked at 5 km·h⁻¹ for 3 min. In the Bruce protocol, the participants started exercising at a treadmill speed of 2.7 km·h⁻¹ and an incline of 10% gradient for 3 min. Workloads (speed and inclination) were subsequently increased each 3-minute period in a simultaneous way until volitional exhaustion was reached.²³ Both protocols generated equal cardiorespiratory data as the MetaMax® 3B, which were filtered and averaged on a 5-second basis.

Statistical analysis

Diagnostic accuracy of outcome measures derived from the BAT protocol against the KF1 and Bruce protocols included sensitivity, specificity, false positive (FP) and false negative (FN) values, and the level of positive likelihood ratio (PLR) and negative likelihood ratio (NLR). The outcome was every variable derived from the KF1 and Bruce protocols categorized as 'low' (below the 50th percentile) and 'high' (above the 50th percentile) according to the median value. Such approach has been previously used for soccer players and general population to determine the level of physical fitness.^{24,25} Based on the two groups for each variable, we cross-tabulated the values from the MetaMax® 3B portable

device and calculated the abovementioned statistical procedures. Sensitivity represented the proportion of individuals with the 'true' positive test, while specificity denoted those with the 'true' negative test. Sensitivity and specificity equations were as follows: sensitivity = (true positives)/(true positives + FN) and specificity = (true negatives)/(true negatives + FP). Individuals categorized in the 'high' group for the KF1 and Bruce protocols, but 'low' for the BAT protocol and *vice versa* represented FP and FN. Likelihood ratios determined the utility of the BAT protocol. PLR was calculated as sensitivity/(1-specificity), while NLR was calculated as (1-sensitivity)/specificity. To examine the discriminatory ability of the ventilatory and metabolic outcomes derived from the MetaMax® 3B portable device to predict the same variables from the KF1 and Bruce protocols, we used receiver operating characteristics (ROC) curves quantified by the area under the curve (AUC). ROC curves analyses were designed to test the discriminatory power. The AUC represented the diagnostic power of a test classified as small (AUC= .55 – .62), moderate (AUC= .63 – .71) and large (AUC> .71). Two-sided values of P were used, and significance was set at P<.05. All the analyses were calculated in Statistical Packages for Social Sciences v.23 (SPSS, Chicago, IL, United States).

Results

Before the examination of diagnostic accuracy of the BAT protocol against the KF1 and Bruce protocols, we determined if a couple dependence was present during the testing procedures, by utilizing a linear-mixed effects model (LMM) with random intercept for couples. Data showed no dependence effect within each couple for $\dot{V}O_{2max}$, as our primary outcome of the study ($F=1.533$, $P=.244$). As previously stated,¹⁸ the proportion of the

participants who reached the cut-off of $RER \geq 1.10$ was 20.8% for the BAT protocol and 45.8% and 37.5% for the KF1 and Bruce protocols. Ventilatory and metabolic parameters obtained from the MetaMax® 3B portable device yielded great diagnostic properties in terms of sensitivity and specificity (Table 2). The AUCs exhibited were the largest for the absolute and relative $\dot{V}O_{2max}$, followed by VE and VT. The lowest AUCs were presented for VE/ $\dot{V}O_2$ and VE/ $\dot{V}CO_2$. Nevertheless, all AUCs were mostly categorized as 'large'.

Table 3 shows the sensitivity, specificity, FP and FN, and PLR and NLR properties of the ventilatory and metabolic parameters from the BAT protocol against the KF1 and Bruce protocols. Similar to AUCs, the largest sensitivity and specificity properties were generated for the absolute and relative $\dot{V}O_{2max}$. Again, VE/ $\dot{V}O_2$ and VE/ $\dot{V}CO_2$ exhibited somewhat lower diagnostic properties. However, all parameters showed PLR greater than 1, indicating that the participants categorized in either 'low' or 'high' categories of the BAT protocol were more likely to be categorized in the same category of the KF1 and BAT protocols. The lowest PLRs were obtained for the VE/ $\dot{V}CO_2$ in the KF1 protocol (1.68) and VD/VT for the Bruce protocol (1.92). The BAT protocol yielded large to very large correlations with the KF1 and Bruce protocols for both absolute ($R=.88$ and $.87$) and relative $\dot{V}O_{2max}$ ($R=.88$ and $.85$), RER ($R=.78$ and $.76$), VE ($R=.86$ and $.79$), VT ($R=.75$ and $.83$), VE/ $\dot{V}O_2$ ($R=.81$ and $.80$) and VE/ $\dot{V}CO_2$ ($R=.78$ and $.82$), and VD/VT ($R=.70$ and $.74$).

The linear regression equation to predict the relative $\dot{V}O_{2max}$ from the KF1 protocol was as follows: $\dot{V}O_{2max-KF1} (ml \cdot kg^{-1} \cdot min^{-1}) = -4.305 + (1.100 \cdot \dot{V}O_{2max-BAT})$ ($R^2=.77$). The slope coefficient between the BAT and KF1 protocols was $\beta=1.625$ with a 95% CI (.90, 2.25), while the intercept coefficient was $a=-18.43$ with a 95% confidence interval (-64.65, 42.13), indicating no

Table 2. Classification of the study participants based on the median values of the KF1 protocol against the BAT protocol.

Study variables	Protocol	AUC (95% CI)	Std. error	Significance
$\dot{V}O_{2max}$ -absolute ($l \cdot min^{-1}$)	KF1	.92 (.82 – 1.00)	.053	$P<.001$
	Bruce	.93 (.83 – 1.00)	.050	$P<.001$
$\dot{V}O_{2max}$ -relative ($ml \cdot kg^{-1} \cdot min^{-1}$)	KF1	.94 (.90 – 1.00)	.021	$P<.001$
	Bruce	.95 (.86 – 1.00)	.047	$P<.001$
RER	KF1	.81 (.63 – .99)	.091	$P=.010$
	Bruce	.85 (.69 – 1.00)	.080	$P=.004$
$\dot{V}E$ ($l \cdot min^{-1}$)	KF1	.87 (.70 – 1.00)	.086	$P=.002$
	Bruce	.86 (.69 – 1.00)	.087	$P=.003$
$\dot{V}T$ (l)	KF1	.85 (.70 – 1.00)	.078	$P=.003$
	Bruce	.93 (.83 – 1.00)	.054	$P<.001$
BF (bpm^{-1})	KF1	.84 (.69 – 1.00)	.080	$P=.004$
	Bruce	.88 (.74 – 1.00)	.069	$P=.002$
$\dot{V}E/\dot{V}O_2$	KF1	.84 (.68 – 1.00)	.083	$P=.005$
	Bruce	.76 (.56 – 0.96)	.103	$P=.033$
$\dot{V}E/\dot{V}CO_2$	KF1	.65 (.43 – .87)	.114	$P=.214$
	Bruce	.80 (.60 – 1.00)	.102	$P=.012$
$\dot{V}D/VT$	KF1	.76 (.57 – .96)	.099	$P=.030$
	Bruce	.82 (.66 – .99)	.084	$P=.014$

Note: Ballroom Aerobic Test (BAT).

Table 3. Sensitivity, specificity, FP and FN of the BAT protocol against the KF1 and Bruce protocols.

BAT protocol	Protocol	Sensitivity (%)	Specificity (%)	FP (%)	FN (%)	PLR	NLR
$\dot{V}O_{2max}$ (l·min ⁻¹)	KF1	83.30	75.00	16.70	25.00	3.33	0.22
	Bruce	91.70	75.00	8.30	25.00	3.67	0.11
$\dot{V}O_{2max}$ (ml·kg ⁻¹ ·min ⁻¹)	KF1	95.90	90.70	4.10	9.30	10.31	0.05
	Bruce	91.70	91.70	8.30	8.30	11.05	0.09
RER	KF1	76.90	72.70	23.10	27.30	2.82	0.32
	Bruce	76.90	81.80	23.10	18.20	4.23	0.28
$\dot{V}E$ (l·min ⁻¹)	KF1	80.00	100.00	20.00	0.00	4.00	0.00
	Bruce	83.30	83.30	16.70	16.70	4.99	0.20
$\dot{V}T$ (l)	KF1	76.90	81.80	23.10	18.20	4.23	0.28
	Bruce	84.60	90.90	15.40	9.10	9.30	0.93
BF (bpm ⁻¹)	KF1	80.00	71.40	20.00	28.60	2.80	0.28
	Bruce	73.30	88.90	26.70	11.10	6.60	0.30
$\dot{V}E/\dot{V}O_2$	KF1	81.80	76.90	18.20	23.10	3.54	0.24
	Bruce	73.30	88.90	26.70	11.10	6.60	0.30
$\dot{V}E/\dot{V}CO_2$	KF1	66.70	60.00	33.30	40.00	1.68	0.56
	Bruce	81.80	76.90	18.20	23.10	3.54	0.24
$\dot{V}D/VT$	KF1	70.60	85.70	29.40	14.30	4.94	0.34
	Bruce	82.40	57.10	17.60	42.90	1.92	0.31

Note: Ballroom Aerobic Test (BAT), The area under the curve (AUC), sensitivity, specificity, false positive (FP), false negative (FN), positive likelihood ratio (PLR) and negative likelihood ratio (NLR).

proportional bias. Similarly, the linear regression equation to predict the relative $\dot{V}O_{2max}$ from the Bruce protocol was as follows: $\dot{V}O_{2max-BAT} \text{ (ml·kg}^{-1}\text{·min}^{-1}\text{)} = -3.996 + (1.075 \cdot \dot{V}O_{2max-Bruce})$ ($R^2 = .72$). The slope coefficient between the BAT and KF1 protocols was $\beta = 1.10$ with a 95% CI (.80, 1.30), while the intercept coefficient was $\alpha = -1.05$ with a 95% confidence interval (-10.17, 9.90).

Discussion

The main purpose of the study was to develop and examine the diagnostic accuracy of the BAT protocol against the KF1 and Bruce laboratory protocols in dancesport athletes performing in standard dance styles. Findings suggest that the ventilatory and metabolic parameters derived from the MetaMax® 3B portable gas analyzer during the BAT protocol yield large to very large sensitivity and specificity properties with the KF1 and Bruce aerobic outcomes. The level of AUC indicates satisfactory discriminative power between 'low' vs. 'high' groups in each parameter with high PLRs and low NLRs.

As far as the author is aware, this is the initial research investigating the creation and reliability of a progressive exam to evaluate aerobic capacity in standard dancesport competitors. Our findings ought to be understood in the context of earlier research. So far, multiple advanced field tests to evaluate aerobic capacity in dance have been suggested and confirmed through more objective methods. A study conducted by Wallmann et al.⁹ demonstrated that the API submaximal exercise fitness test had a strong correlation with $\dot{V}O_{2max}$ ($R = .89$ and $.90$), along with a technical error of measurement (TEM) of power output = $.07 \text{ W·kg}^{-1}$ and $\dot{V}O_{2max} = .71 \text{ ml·kg}^{-1}\text{·min}^{-1}$. A different dance protocol

aimed at ballet dancers showed that the mean squared root (sw2) for the test was 5.01, and the SEE was $6.20 \text{ ml·kg}^{-1}\text{·min}^{-1}$.¹⁰ A frequently used fitness protocol to assess aerobic capacity is the DAFT, a 5-stage progressive test lasting 4 minutes.¹¹ A study conducted by Wyon et al.¹¹ showed that data from the portable telemetric gas analyzer (Cosmed K4 b2, Italy) demonstrated a very strong correlation between HRmax and $\dot{V}O_{2max}$ for the test ($R = .91$; $SEE = 5.60 \text{ b·min}^{-1}$). Comparable findings were observed for the H1DT dance protocol, with five individuals ($n=5$) participating in both the treadmill and dance assessments to evaluate $\dot{V}O_{2max}$.¹¹ In the treadmill protocol, the average $\dot{V}O_{2max}$ recorded was $46.40 \pm 3.60 \text{ ml·kg}^{-1}\text{·min}^{-1}$, while in the H1DT, the $\dot{V}O_{2max}$ value reached $51.00 \pm 6.60 \text{ ml·kg}^{-1}\text{·min}^{-1}$. A comparison between the treadmill and dance protocols indicated no notable differences in $\dot{V}O_{2max}$.¹² The identical research indicated that the average %HR_{max} was notably less in the H1DT when compared to the treadmill assessment (97.50 vs. 101.00 %), while the accuracy of blood lactate measurements was elevated (H1DT = $6.10 \pm 1.90 \text{ mmol·L}^{-1}$ vs. treadmill = $6.30 \pm 1.70 \text{ mmol·L}^{-1}$).¹² The latest SAFD assessment measuring the functional ability of collegiate dancers showed substantial to very substantial correlations with the peak treadmill evaluation for relative $\dot{V}O_{2max}$ ($R = .78$), HR_{max} ($R = .85$), blood lactate ($R = .72$), and rate of perceived exertion (RPE; $R = .84$), whereas trivial to moderate correlations were observed for time ($R = .60$) and RER ($R = -.12$).¹³

Despite the current progressive dance protocols for evaluating aerobic capacity showing acceptable validity compared to objective measures,⁹⁻¹³ our recently created BAT protocol demonstrated strong correlations with the treadmill test after two protocols (KF1 and Bruce). The unique aspect and distinction of

our dance protocols compared to others is that they are tailored specifically for dance couples practicing standard dance styles. This is crucial, as both people must support one another during practice or competition. This implies that comparable fitness levels may be beneficial for performance. Although $\dot{V}O_{2\max}$ is generally lower in dancesport athletes in comparison to other athletes,⁴⁻⁶ the aim of the BAT protocol is to improve the aerobic system and to physiologically prepare them for stress during training and/or competition.

Standard dance styles frequently feature movements defined by sway elements and the interaction of rises and falls, regarded as crucial factors for maintaining or enhancing functional performance in competitive dancesport competitors.²⁶ Additionally, the intricate figures and quicker tempo during training and competition in standard dance styles cannot be compared to ballet or contemporary dance styles, where movements are frequently executed in static settings, focusing more on aesthetics than on the functional aspects of dance. Consequently, the BAT protocol can act as a method for assessing and monitoring aerobic capacity within the limited group of standard style dance competitors.

This research has its limitations. Initially, a cross-sectional design inhibits our ability to validate causal relationships between field- and laboratory-based testing methods for evaluating aerobic capacity. Second, we omitted $HR_{\max}$ and blood lactate measures as indicators of aerobic and anaerobic abilities, restricting our results to data obtained from the MetaMax® 3B and treadmill equipment. Earlier research has demonstrated a significant connection between $HR_{\max}$ and $\dot{V}O_{2\max}$ ^{10,11} and sufficient sensitivity in $HR_{\max}$ and blood lactate variations after the dance protocol.^{27,28} The reasons for not considering these measures were the lack of time and devices for collecting and analyzing blood sampling. Third, a relatively limited sample size may have weakened the validity characteristics of the BAT protocol. Even though we conducted a sample size calculation (for additional details, refer to the 'Study participants' section), we cannot rule out the possibility of inadequate statistical power. Fourth, statistical analyses indicated that objectively measured ventilatory and metabolic parameters were split by a median into two groups (low vs. high), which could have led to a lack of statistical power and hypothetical significance. Thus, we re-calculated the continuous data and presented with the coefficients of correlation between the BAT and KF1/Bruce protocols and a set of regression equations to estimate predicted $\dot{V}O_{2\max}$. Also, previous studies have used the same approach to define the participants with low vs. high physical fitness levels, based on cardiorespiratory data.^{24,25} Ultimately, the BAT protocol was not cross validated in athletes from various dance styles (ballet, contemporary, or Latin-American), which constrains its applicability. The authors indicate that the BAT protocol serves as a legitimate training and performance instrument for assessing aerobic capacity and related factors in dancesport athletes engaged in standard dance styles. Finally, while the tempo was controlled, this freedom introduced potential variability in movement economy and energy expenditure between couples, which could influence the results.

Practical Applications

The practical use of the BAT protocol is shown in creating a brand-new model to assess aerobic capacity and an algorithm for estimating $\dot{V}O_{2\max}$ in competitive standard dances within sport-specific activity conditions. This allows for an accurate evaluation of physical and energy demands related to the

activity, in contrast to current tests for measuring aerobic capacity. Given that conventional dance styles are frequently identified as high-intensity physical activities requiring both aerobic and anaerobic energy systems for execution, the newly introduced dance protocol could enhance aerobic capacity and improve dance training. Accurate and promptly executed diagnostic methods for evaluating and/or measuring energy capacities in dance are essential to reach primary objectives and foster positive trends toward athletic success.^{1,4} On the other hand, data from the BAT protocol could be used in both clinical and coaching environment to test specific aerobic capacity related to dancesport performance. Health-related professionals and strength and conditioning coaches should include the BAT protocol to evaluate, monitor and track cardiorespiratory fitness and to adjust training and choreography regimes for maximal performance output and persistence of high ventilatory and metabolic parameters for future health. However, given the nature of the study, future research should consider establishing the minimal detectable change (MDC), which is critical for coaches to determine if an observed change in performance is a true improvement or simply measurement error.²⁹ This would improve practical ability of the test and denote whether changes in performance occur intentionally or by chance.

Conclusions

In conclusion, this research demonstrates that the BAT protocol exhibits excellent diagnostic accuracy properties when compared to the KF1 and Bruce protocols. The benefit of the BAT protocol lies in its ability to replicate classical movements from five dance styles while imitating competition environments. The present results have demonstrated sensitivity and specificity characteristics and possible recommendations for overseeing and observing changes in ventilatory and metabolic parameters across various training conditions. The authors propose that this assessment can be incorporated into the dance training regimen during preparatory and competitive phases, as it provides crucial and reliable insights into the correlation between field and laboratory aerobic performance metrics among standard dancesport competitors. As mentioned in the 'Practical application' section, MDC should be the next critical step for validating the BAT protocol for practical use. Since it tests the smallest change that is unlikely to be due to the measurement error, evaluating the MDC may be helpful for targeting a 'real' change. This can help coaches in planning the target ventilatory and metabolic outcomes to reach high confidence levels and to adjust the training program for enhancing aerobic capacity.

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Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Ethical Committee approval

The Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Zagreb, Croatia; approved the study on the 29th of April 2020 (ethical code number: 77/2020).

Topic

Sport science

Conflicts of interest

The authors have no conflicts of interest to declare.

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Author-s contribution

Conceptualization, T.D.; methodology, T.D.; software, T.D.; validation, T.D.; formal analysis, T.D.; investigation, T.D.; resources, T.D. and D.P.; data curation, T.D.; writing—original draft preparation, T.D., J.R. and D.P.; writing—review and editing, T.D., J.R. and D.P.; visualization, T.D.; supervision, D.P.; project administration, T.D. All authors have read and agreed to the published version of the manuscript.

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16. BIOGRAPHY OF THE AUTHOR AND LIST OF WORKS

Tamara Despot (born 4 October 1980 in Zagreb, Croatia) is a kinesiologist and strength and conditioning specialist. She graduated from the Faculty of Kinesiology, University of Zagreb, where she also enrolled in a doctoral programme in kinesiology. Since 2015 she has been a lecturer at the Faculty of Kinesiology in Zagreb in the fields of physical preparation of athletes and dance. From 2002 to 2020 she worked as a strength and conditioning coach at GNK Dinamo Zagreb, and from 2020 to 2024 as a conditioning coach of the Croatian National Folk Dance Ensemble LADO. Since 2025 she has been employed as a teacher at the Student Dormitory Novi Zagreb while continuing her professional work in sports conditioning and dance science. Her doctoral research focuses on the development and validation of a sport-specific aerobic fitness test for dancesport athletes.

The list of publicly published works is as follows:

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