INSTITUTO POLITÉCNICO DE BRAGANÇA
Escola Superior de Educação

StepTest4all: Improving the Prediction of Cardiovascular Capacity Assessment in Young Healthy Adults

Tatiana Peixoto Sampaio

Work project submitted to Escola Superior de Educação do Instituto Politécnico de Bragança for obtaining the degree of Master in Exercise and Health.

Supervisors:
José Augusto Afonso Bragada
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“If we knew what it was we were doing, it would not be called research, would it?”
Albert Einstein

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Abstract

Introduction: Cardiovascular capacity, expressed as maximal oxygen uptake (VO_{2max}), is a strong predictor of health and fitness and is considered a key measure of physiological function in the healthy adult population. **Objective:** The aims of this study were to conduct a comprehensive bibliometric review of the literature on step tests and investigate the influence of the physical activity level (PA_{level}) of participants in the StepTest4all (a validated protocol for the estimation of VO_{2max} in healthy young adults). **Methods:** The bibliometric review relied on the Web of Science Core Collection (WoS by Clarivate Analytics) database up until 2023 to ascertain publications featuring the search term "step-test" or "step test" within their titles or abstracts. Regarding the experimental study, the sample consisted of 69 participants, including 27 women (age 21.7 ± 3.6 years; body mass = 63.5 ± 14.8 kg; height = 1.64 ± 0.06 m; body mass index = 23.7 ± 5.3 kg/m2) and 42 men (aged 21.7 ± 3.4 years; body mass = 72.0 ± 7.3 kg; height = 1.77 ± 0.07 m; body mass index = 23.1 ± 2.1 kg/m2). The participants were assigned to one of the two groups: (i) the VO_{2max} prediction group and (ii) the prediction model validation group. **Results:** The identified clusters in the bibliometric review guide future research, suggesting possibilities for refining protocols, exploring health implications, optimizing tests for specific conditions like chronic obstructive pulmonary disease, and adapting step tests across diverse populations. Regarding the experimental study, the linear regression retained the following predictors of VO_{2max}: sex ($p < 0.001$), physical activity level ($p = 0.014$), and HRR_{60} ($p = 0.020$). The prediction equation (coefficient of determination (R^2) = 74.0%, standard error of estimate (SEE) = 4.78) was considered high and can be expressed as follows: $VO_{2max} = 17.105 + 0.260 \cdot (HRR_{60}) + 8.563 \cdot (sex) + 4.097 \cdot (PA_{level})$.

The validation process revealed a strong agreement with a high relationship between the VO_{2max} measured and estimated. **Conclusions:** The bibliometric review highlighted the broad participation of institutions in step test research. Retaining PA_{level} as a significant predictor allows us to better individualize the participants VO_{2max}.

Keywords: StepTest4all; cardiovascular capacity; validation; cardiovascular classification; health.

Resumo

Introdução: A capacidade cardiorespiratória, expressa como absorção máxima de oxigénio (*VO_{2max}*), é um forte preditor de saúde e aptidão física, e é considerada uma medida chave da função fisiológica na população adulta saudável. **Objetivo:** Os objectivos deste estudo foram realizar uma revisão bibliométrica abrangente da literatura sobre os *step tests* e investigar a influência do nível de atividade física ($AF_{nível}$) dos participantes no *StepTest4all* (protocolo validado para estimar o *VO_{2max}* em jovens adultos). **Métodos:** A revisão bibliométrica baseou-se na base de dados *Web of Science Core Collection (WoS by Clarivate Analytics)* até 2023 para determinar publicações com o termo de pesquisa *"step-test"* ou *"Step test"* nos títulos ou resumos. No que respeita ao estudo experimental, a amostra foi constituída por 69 participantes, incluindo 27 mulheres (idade 21,7 ± 3,6 anos; massa corporal = 63,5 ± 14,8 kg; estatura = 1,64 ± 0,06 m; índice de massa corporal = 23,7 ± 5,3 kg/m^2) e 42 homens (idade 21,7 ± 3,4 anos; massa corporal = 72,0 ± 7,3 kg; estatura = 1,77 ± 0.07 m; índice de massa corporal: 23,1 ± 2,1 kg/ m^2). Os participantes foram atribuídos a um dos dois grupos: (i) o grupo para estimar o VO_{2max} e (ii) o grupo de validação. **Resultados:** Os *clusters* identificados na revisão bibliométrica orientam investigação futura, sugerindo possibilidades para refinar protocolos, explorar implicações para a saúde, otimizar testes para condições específicas, como a doença pulmonar obstrutiva crónica, e adaptar *step tests* em diversas populações. Na regressão linear múltipla, permaneceram significativos os seguintes preditores de *VO_{2max}*: sexo ($p < 0,001$), nível de atividade física ($p = 0,014$), e HRR_{60} ($p = 0,020$). A equação preditiva (coeficiente de determinação (R^2) = 74,0%, erro padrão de estimativa (SEE) = 4,78) foi considerada elevada e pode ser expressa da seguinte forma: $VO_{2max} = 17.105 + 0.260 \cdot (HRR_{60}) + 8.563 \cdot (sexo) + 4.097 \cdot (AF_{nível})$.

O processo de validação revelou uma forte concordância com uma relação alta entre o VO_{2max} medido e estimado. **Conclusões:** A revisão bibliométrica destacou a ampla participação das diversas instituições. Manter o $AF_{nível}$ como um preditor significativo permite-nos individualizar melhor o VO_{2max} dos participantes.

Palavras-chave: StepTest4all; capacidade cardiorespiratória; validação; classificação cardiorrespiratória, saúde.

Acronyms

BMI – Body Mass Index

CI – Confidence Intervals

COPD – Chronic Obstructive Pulmonary Disease

CST – Chester Step Test

CVC – Cardiovascular Capacity

GXT – Graded Exercise Test

HHR – Heart Rate Recovery

HR – Heart Rate

HR_{max} – Maximal Heart Rate

HRR_{60} – Heart Rate Recovery of 60 seconds

ICC – Interclass Correlation Coefficient

IPAQ – International Physical Activity Questionnaire

METs – Metabolic Equivalents

PA – Physical Activity

PA_{level} – Physical Activity Level

UK – United Kingdom

USA – United States of America

VO_{2max} – Maximal Oxygen Uptake

WoS – Web of Science

Articles resulting from the content of the work project

Published articles: Sampaio, T., Morais, J. E., & Bragada, J. A. (2024). StepTest4all: Improving the Prediction of Cardiovascular Capacity Assessment in Young Adults. Journal of Functional Morphology and Kinesiology, 9(1), 30.

Submitted articles: Sampaio, T., Marinho, D. A., Bragada, J. A., Morais, J. E. (2024) Bibliometric Review of the Step Test: A Comprehensive Analysis of Research Trends and Evolution. European Journal of Applied Physiology.

Abstracts for Congresses: Sampaio, T., Morais, J. E., Bragada, J. P., Bragada, J. A. (2024) StepTest4all: A Feasible Protocol for Health Practitioners to Assess Cardiorespiratory Capacity. Annual International (Bio)Medical Students Meeting (AIMS Meeting).

1. Introduction

To provide oxygen to the working tissue during physical activity (PA), the respiratory, muscular, and circulatory systems must function together, resulting in cardiovascular capacity (CVC), a health-related aspect of physical fitness (1). Research about this topic indicates that several cardiovascular and metabolic risk factors, including those related to poor cardiovascular capacity, are linked to an elevated risk of morbidity and death in both men and women (2–4). Therefore, it may be argued that maintaining and evaluating CVC is essential to preventing aerobic capacity declines and reducing the health risks that accompany them.

The maximum amount of oxygen that can be utilised, regardless of how exercise intensity is increased, is entitled to maximal oxygen uptake (VO_{2max}) (5). This variable is typically expressed clinically in: (i) relative ($mL \cdot kg^{-1} \cdot min^{-1}$), (ii) in absolute ($mL \cdot min^{-1}$) terms or (iii) in MET (metabolic equivalents) by assuming that 1 MET equals to 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ (6). It gives parameters of CVC, cardiovascular health, and function and is the maximum rate at which oxygen may be absorbed and used by the body (5). It is the most widely used metric to show how training has affected aerobic capacity (7–9).

A graded exercise test (GXT) that requires exertion to volitional exhaustion is frequently used to directly assess VO_{2max}, with the subject's expired air being analysed (10). This protocol causes a great deal of physical stress and is expensive, time-consuming, and unsuitable for real-world environmental circumstances (10–12). Consequently, when time is limited, laboratory equipment is unavailable, or it can be considered dangerous to exercise at high intensities, submaximal exercise testing is frequently employed to predict VO_{2max} (13,14). Therefore, step tests are an affordable, easy-to-use, and environmentally friendly method of submaximal determining VO_{2max} (15). Step testing is an inexpensive protocol that can be used to predict CVC by assessing post exercise heart rate recovery (HRR) by stepping at a defined cadence and/or step height (6).

Bridging the gap between laboratory-based assessments and real-world scenarios, these step tests carry practical implications that extend beyond research laboratories. The step tests offer practical implications by serving as accurate indicators of an individual's regular physical activity level and overall cardiorespiratory fitness (16). Additionally, they present a straightforward and easily accessible means of fitness assessment, eliminating the need for specialised equipment or expert supervision (17). Whether utilised in home-based fitness monitoring (18), clinical evaluations (19), or research studies involving diverse populations (20), step tests have transcended their simplicity to become indispensable tools for health and exercise practitioners.

Literature about step tests includes systematic reviews in various populations (16,21,22). For instance, the systematic review of Bennet et al. (16), conducted in 2016, aimed to assess the validity and reliability of submaximal step-test protocols as methods to estimate VO_{2max} in healthy adults (18–65 years) against a validated measure of VO_{2max}. The authors highlighted the significant correlation between VO_{2max} and overall health, emphasising its relevance in health assessments for both the general adult population and rehabilitation settings (16). This correlation forms the basis for safe and effective health monitoring. Proactive testing and maintenance of cardiovascular capacity are viewed as potential safeguards against declines in overall health. Notably, the step test emerged as a user-friendly and ecologically valid approach for submaximal cardiovascular assessment across diverse settings, thereby enhancing its practicality in health evaluations (16).

Furthermore, unlike systematic reviews that focus on the clinical effectiveness of the step test, a bibliometric review offers a suitable perspective by systematically analysing publication trends, key contributors, and emerging clusters in the step test literature (23). Applying a bibliometric review to this topic (i.e., step test) will provide valuable insights into the historical development and current state of step test research up to 2023.

Notwithstanding, literature reports that step tests present advantages and disadvantages. Some of the disadvantages are the pre-established durations, efforts exceeding recommended levels for certain demographics, and inadequate fixed step heights for specific individuals (24). For example, the Harvard Step Test (25) and the YMCA Step test (26) are commonly used, but their fixed protocols may not accommodate the individual's various physical abilities and characteristics. Furthermore, the Queen's College Step Test (27) is limited by a defined duration, potentially posing challenges for participants with different levels of fitness. Thus, Bragada et al. (17) introduced the StepTest4all, a cardiovascular assessment protocol that involves participants in a continuous progressive test on a stable step ranging from 15 to 40 cm, alternating between ascending, and descending with a cadence increase of 2.5 cycles per minute and an expected duration of 10 minutes. The StepTest4all is distinguished for being adaptable, suitable for people with different physical abilities, with a personalised step height and adjustable difficulty to help participants easily reach the target effort level (80% of HR_{max}) in a short period of 4 to 10 minutes. This study retained a significant relationship between VO_{2max}, sex, and HRR_{60} (17). However, the authors noted that the lack of a variable related to the amount of the PA of participants could be a limitation (17). Thus, it would be interesting to confirm, with a larger sample, whether it is possible to improve the prediction of VO_{2max} from StepTest4all with the inclusion of the PA variable in the prediction formula.

1.1. Work Project Description/Objectives

This work project involved two distinct phases: a comprehensive bibliometric review of step test literature, and a subsequent phase focused on improving the accuracy of predicting VO_{2max} by using the StepTest4all by investigating the influence of the PA_{level}.

The first phase began with a bibliometric review of the literature concerning step tests for predicting VO_{2max}. Spanning studies published up to the year 2023, this review examined various parameters such as step height, duration, cadence, and recovery periods. Additionally, the first phase sought to analyse historical trends in step test protocols, identify key contributors and research institutions in the field of step test methodology for VO_{2max} prediction, and determine emerging trends and advancements in step test protocols for VO_{2max} prediction through analysis of keywords and publication outputs.

Therefore, the objective of this phase was:

- to conduct a comprehensive bibliometric review of the literature on step tests to identify common methodologies and limitations in predicting VO_{2max}.

More specifically, it aimed to:

- analyse historical trends in step test protocols;
- to identify key contributors and research institutions in the field of step test methodology for VO_{2max} prediction;
- to determine emerging trends and advancements in step test protocols for VO_{2max} prediction through analysis of keywords and publication outputs.

The second phase focused on improving the accuracy of predicting VO_{2max} by using the StepTest4all and investigating the influence of the PA_{level}. According to the literature, it is known that step tests have advantages and disadvantages associated with them, as previously mentioned. Therefore, StepTest4all was designed to satisfy some of these disadvantages. However, the authors noted that the lack of a variable related to the amount of the physical activity of participants could be a limitation (17). Therefore, this phase aims to diminish these limitations.

Thus, the main objective of this phase was:

- To enhance the prediction accuracy of VO_{2max} using StepTest4all.

The specific objective was:

- to investigate the influence of the PA_{level} of participants in the StepTest4all (a validated protocol for the estimation of VO_{2max} in adults).

2. Work Project Development

2.1. Bibliometric Review

The phase encompasses an review of the existing literature on step tests utilised for predicting VO_{2max}. This comprehensive analysis encompasses historical trends in step test protocols, the identification of key contributors and research institutions in the field, and the identification of emerging trends and advancements through keyword analysis and examination of publication outputs. This thorough examination of the literature serves as the foundation for identifying common methodologies and limitations, thereby informing the subsequent protocol enhancement phase aimed at reinforcing the accuracy of VO_{2max} prediction through step tests.

2.1.1. Methods

2.1.1.1. Source of Data and Search Strategy

The Web of Science (WoS) is a collection of legitimate worldwide citation databases covering all regions and more than 250 subjects (Clarivate, 2021). The WoS list provides comprehensive details on definitions, scope remarks, and the most significant impact factor score of certain journals chosen by index (Clarivate, 2021). It has been widely employed in previous bibliometric studies in various fields (28–31). Therefore, the literature review relied on the use of the Web of Science Core Collection (WoS by Clarivate Analytics) database.

The period of the search was until 2023 (access date: September 19, 2023). The search term used in WoS was “step-test” or “step test” in the title and in the abstract. Using this search technique, the WoS database yielded all publications published that contained the word “step test” in the title or in the abstract. Any disagreements related to the selection criteria were discussed and resolved with the assistance of an external referee with expertise in a similar research field.

2.1.1.2. Inclusion Criteria and Exclusion Criteria

The following inclusion criteria were applied: (1) articles written in Englis; (2) focused on the step test as a primary topic or assessment method, specifically for evaluating cardiovascular capacity.

The exclusion criteria comprised that did not meet the following specifications: (1) written in languages other than English; (2) lacked a primary focus on the step test as a topic or assessment method; and (3) document types such as meeting abstracts and letters.

2.1.1.3. Screening Process

Two authors independently reviewed the titles and summaries of the identified articles. In cases of doubt as to the eligibility of an article, the full text was collected. Two independent authors reviewed the articles in the integral and evaluated the eligibility requirements. Two authors independently evaluated each article in two phases of sorting: the title, the summary, and, subsequently, the full text of the article. Conflicts over eligibility have been resolved through dialogue and, if necessary, with the assistance of a third author.

Through the search on the Web of Science, 2610 records were found. 1568 were excluded after evaluating the title and abstract. Subsequently, the 1042 remaining studies were assessed by reading the relevant sections. We excluded 814 studies that did not meet the inclusion criteria. Finally, a total of 228 articles met the defined criteria and were included in the review. Figure 1 depicts the identification, screening, and inclusion of the articles from the database for the review.

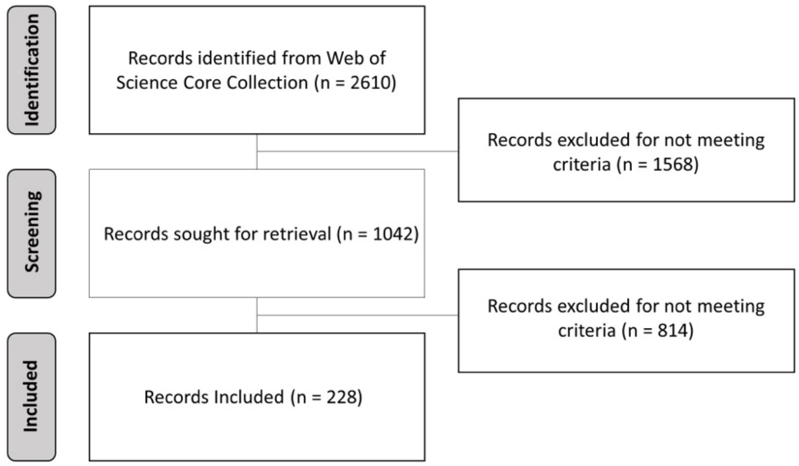

Figure 1 - Flowchart of the bibliometric review.

2.1.1.4. Analytical Methods and Tools

Bibliometric data extraction and analysis were performed using dedicated bibliometric software. The VOSviewer, a Java-based metrology tool developed by Van Eck and Waltman, specializes in co-occurrence network clustering and density analysis (23). Through its cooperative network visualisations, distinct clusters are visually represented by different colours, while lines between nodes denote collaborative relationships. Notably, in the average publication year graph, colours correspond to different years, aiding in temporal analysis. Additionally, in density visualisations, the colour spectrum, particularly the red hue, indicates the varying density levels, with redder shades indicating higher density areas (23).

The first category involves evaluating individuals (mainly authors, institutions, journals, and countries) using bibliographic data. The second category, scientific mapping, is a spatial visual representation of bibliometric networks that focuses at the relationships between disciplines, fields, specialties, individual articles, and authors. Thus, the VOSviewer software was employed to analyze the previous categories resulted in a detailed overview of the step test literature and its development.

2.1.2. Results

2.1.2.1. Analysis of Publication Outputs

Between 1946 (the year of the first publication with a step test) and 2023, the WoS database contained a total of 248 papers related to the step tests. Figure 2 illustrates the publication output regarding step test research from 1946 to 2023. The annual publications showed a tendency to increase over the years, from one publication in 1946 to fourteen in 2022. Notably, the greatest number of articles was published in 2020 and 2021, both years with 14 papers per year. Also, 2021 emerges as having the most extensive publications and the greatest number of citations (14 publications and 243 citations).

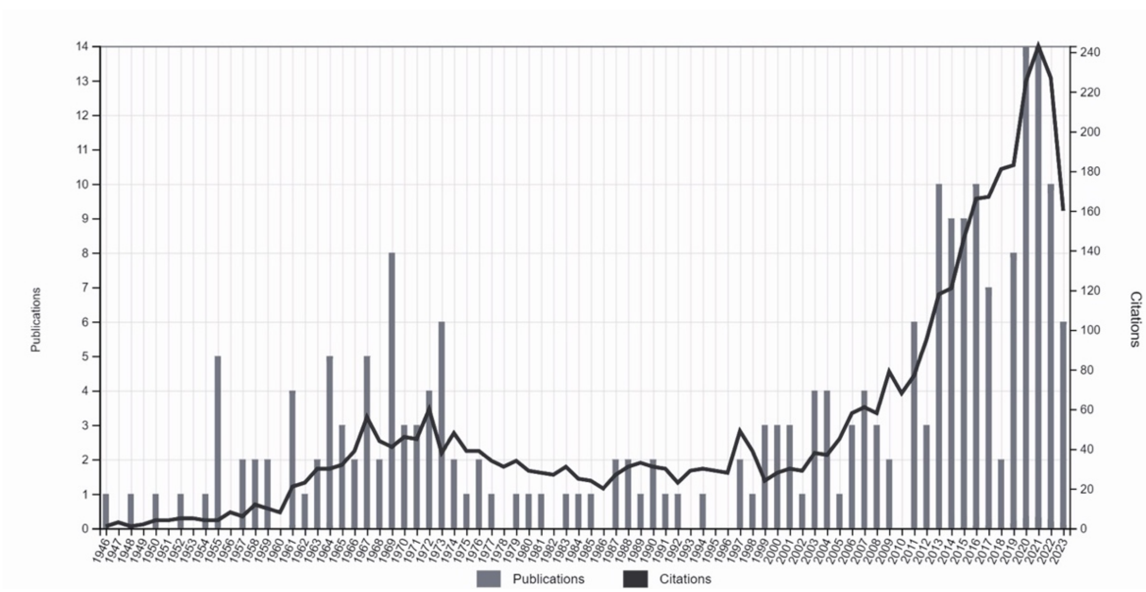

Figure 2 - Annual number of publications and citations per year.

Publications related to the step test exhibit a segmented evolution into four distinct stages, according to publication numbers: the initial phase (1946 – 1969), the second stage (1969 – 2011), the third stage (2011 –2021), and the fourth stage (2021 – 2023). The step test gained interest until 2011 due to pivotal scientific advancements. However, there was a decline in publication numbers until that year. Subsequently, in 2013, the number of publications surpassed 10 for the first time. From then on, the volume of literature steadily increased, reaching a consistent upward trajectory and breaking the 14-mark for the first time in 2020. Over the last two years, however, there has been a decline in the number of publications.

2.1.2.2. Analysis of Countries and Institutions

According to the correspondence authors' country, a total of 31 countries and regions contributed to cardiovascular assessment with the step test. In the period 1946 – 1973, only three countries (the United States of America, Japan, and Canada) contributed to the step test outputs, while during 2013–2023, researchers from twenty-seven countries were devoted to such research. The top ten countries and regions were: Brazil was the most contributive country (n = 44 publications), accounting for 19% of the total publications, followed by the United States of America (USA, n = 40), England (n = 13), Australia (n = 10), Japan (n = 10), Canada (n = 9), Portugal (n = 8), India (n = 6), Scotland (n = 6), and Belgium (n = 5) (Figure 3).

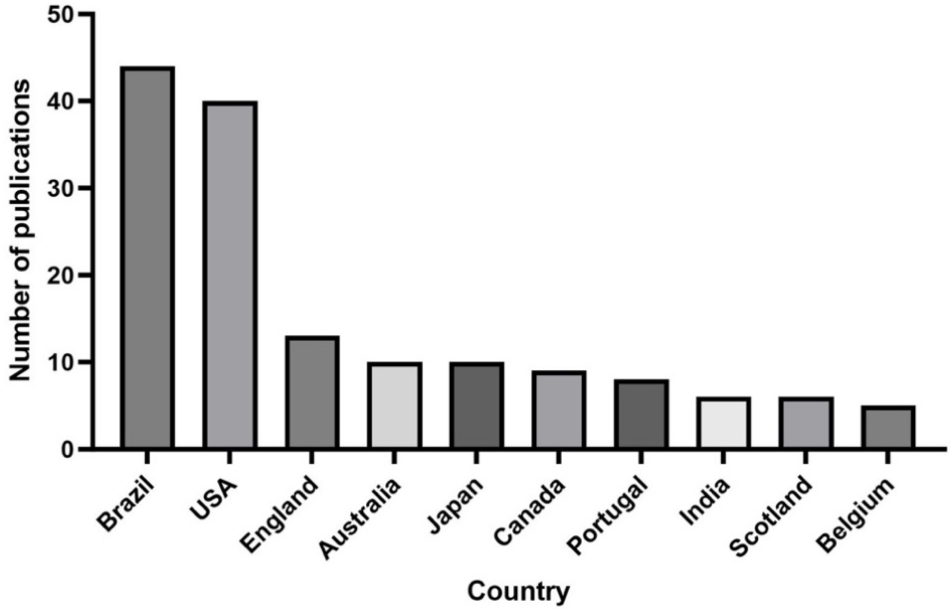

Figure 3 - Top 10 productive countries on the Step Test.

Figure 4 depicts the co-authorship analysis by country and provides a visualisation of collaborative networks in step test research over time. By overlaying the timeline onto the co-authorship network, this figure illustrates the evolution of collaborative patterns among countries across different periods. The varying thickness of the lines and the positioning of nodes signify the strength and changes in international collaborations over time.

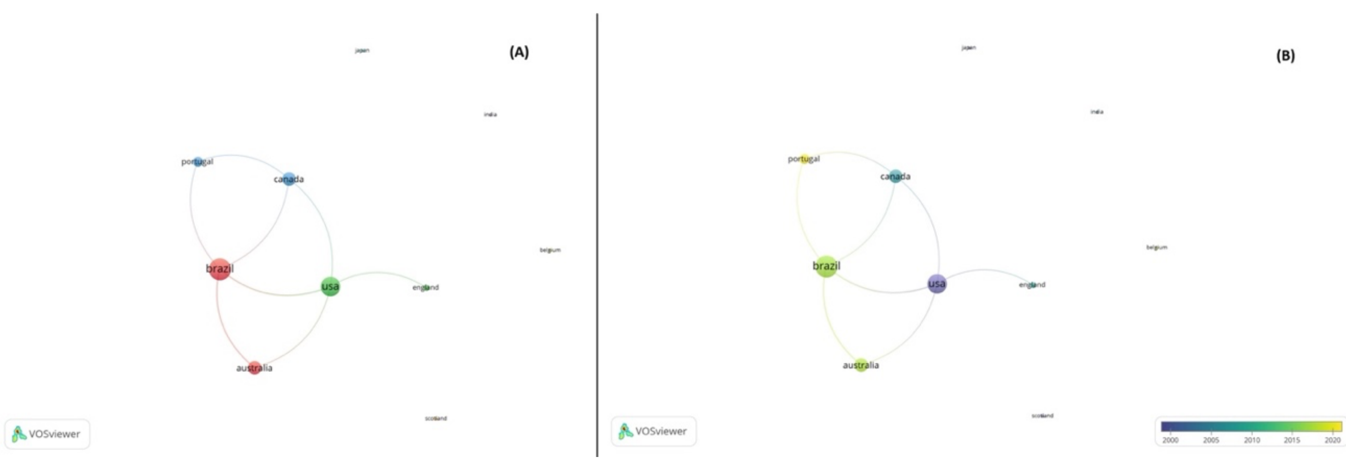

Figure 4 - The cooperation network visualization map of institutions based on VOSviewer (Panel (A)); The cooperation network visualization map of institutions based on VOSviewer with the timeline (Panel (B)).

A total of 1,849 institutions participated in the research regarding the step test as a tool for cardiovascular assessment between 1946 and 2023. The top ten institutions were: University of Alabama System, Universidade Nove de Julho, Universidade Federal de São Carlos, Universidade do Estado do Rio de Janeiro, Universidade Federal de São Paulo (UNIFESP), Bangor University, Monash University, University of Dundee, City University of New York, and Icahn School of Medicine at Mount Sinai. The top ten institutions contributing to step test research are shown in Table 1.

Table 1 - Top ten institutions contributing to step test research.

Rank	Institution	Number of Articles	Country
1	University of Alabama System	16	USA
2	Universidade Nove de Julho	14	Brazil
3	Universidade Federal de São Carlos	11	Brazil
4	Universidade do Estado do Rio de Janeiro	6	Brazil
5	Universidade Federal de São Paulo	6	Brazil
6	Bangor University	5	UK
7	Monash University	5	Australia
8	University of Dundee	5	UK
9	City University of New York	4	USA
10	Icahn School of Medicine at Mount Sinai	4	USA

Note: USA: United States of America; UK: United Kingdom.

2.1.2.3. Analysis of authors

Since 1946, 761 researchers have contributed to advancing research in this topic. The use of visualisation maps can provide valuable insights into potential collaborators, aiding researchers in establishing productive partnerships. By employing a threshold of four documents per author, the figure below allows the visualisation of nine distinct clusters. As shown in the illustration, the research landscape in this domain has not yet merged into a tightly knit network; instead, it represents a diverse range of authors with some smaller authors. Noteworthy is the presence of a 12-member team actively participating in small-scale cooperation, as highlighted in Figure 5.

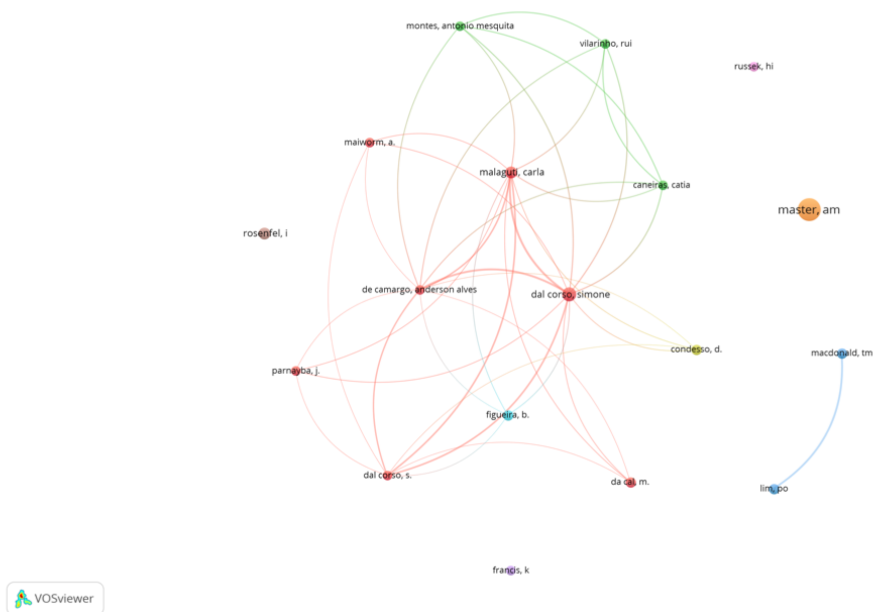

Figure 5 - The cooperation network visualization map of authors based on VOSviewer.

2.1.2.4. Analysis of keywords

Co-occurrence clustering of keywords can help identify emerging trends and patterns in the evolution of the topic as well as research hotspots in the field of study. It may demonstrate the field's research frontier and the internal organisation of an academic field. Figures 6 and 7 depict the co-occurrence keyword analysis. By employing a threshold of a minimum of five times of occurrence per keyword, it allows the visualisation of distinct clusters. The larger the dot represents, the more occurrences and more representativeness of the hotspots in the field, and the nodes are connected to represent the strength of association, and the more lines represent, the more occurrences of two keywords in the same article. The different colours represent different clusters, i.e., topics of research, and the time of appearance is represented from blue to yellow.

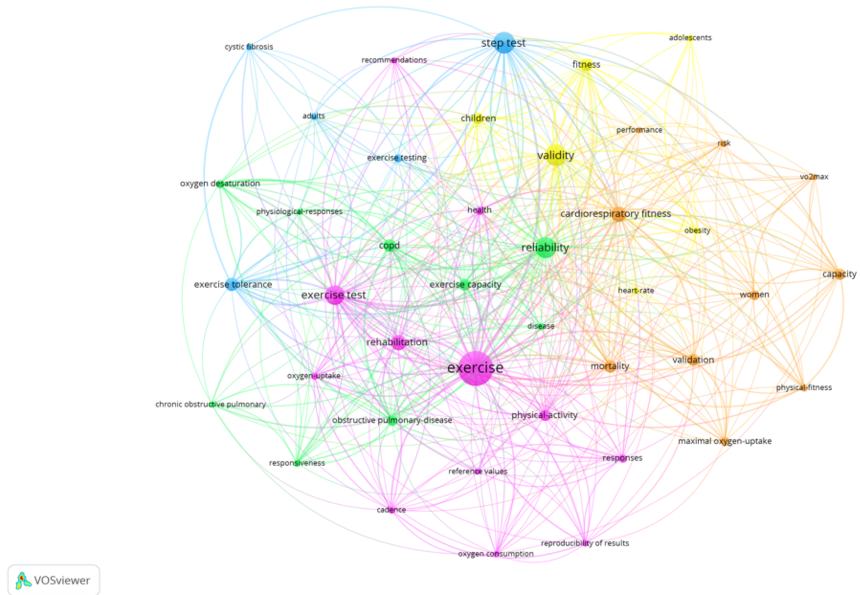

Figure 6 - Keywords clustering map based on VOSviewer.

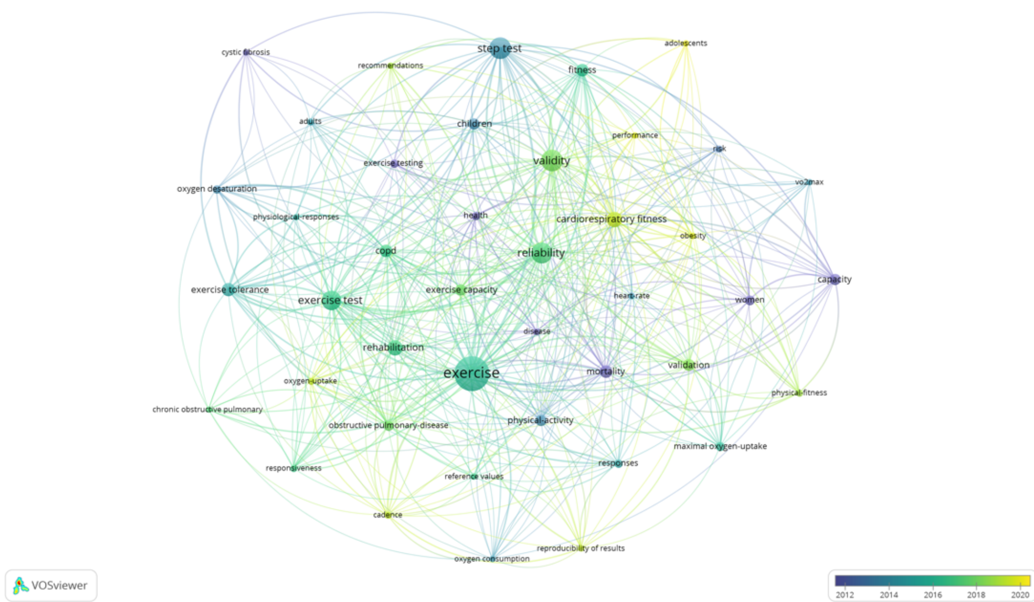

Figure 7 - Keywords clustering map with the timeline based on VOSviewer.

2.1.3. Step test protocols

Step tests serve as valuable tools for evaluating cardiovascular capacity, utilising VO_{2max} as a key metric (16). Some protocols provide a qualitative classification based directly on VO_{2max} values, such as those outlined by the American College of Sports Medicine (ACSM) (32).

Others offer a qualitative classification using heart rate dynamics (17,33). In some step test protocols, qualitative classification based on heart rate recovery (HRR) dynamics is stratified according to the quantity of beats per minute (bpm) recovered within one minute after completing the protocol (27,34). Scientific evidence supports the association between HRR and cardiovascular disease prognosis, highlighting the importance of routine HRR recording in clinical practice (35,36).

The step test serves as a valuable tool in assessing cardiovascular capacity by estimating VO_{2max}, providing insights into an individual's aerobic fitness level (16). Additionally, the step test allows for the evaluation of autonomic nervous system activity, particularly through the assessment of heart rate dynamics such as heart rate recovery (HRR) (37). Research has shown that a delayed decrease in heart rate during the first minute after exercise is associated with increased mortality risk, independent of workload or the presence of myocardial perfusion defects (5,38,39). Furthermore, higher levels of aerobic fitness have been linked to beneficial effects on autonomic control of post-exercise heart rate, highlighting the importance of cardiovascular fitness in maintaining healthy autonomic nervous system function (40). Therefore, integrating HRR assessment into step test protocols can provide valuable information for risk assessment and prognosis of cardiovascular disease, supporting its routine use in clinical practice (35,36).

In this evolutionary context, several specific step test protocols have emerged over time, each characterised by distinct features such as cadence, step height, and duration of the test, among other relevant parameters. Table 2 presents the most commonly used protocols, offering a detailed and comparative view of their characteristics.

Table 2 - Most utilized Step Test protocols.

Year	Protocol Name	Step height (cm)	Stepping Cadence (steps/min)	Duration (min)	HR measurement
1954 (41)	Astrand-Rhyming Step Test	Young male = 40 Male = 27 Female = 33	22.5	5	Between 15 and 30 seconds after the test
1943 (25)	Harvard Step Test	50.8	30	5	1 to 1.5 min, 2 to 2.5 min, 3 to 3.5 after the test
1947 (*)	Progressive Pulse Ratio Step Test	Male = 43.1 Female =35.6	Incremented (12/18/24/30)	5	After 10 seconds
1965 (*)	Kasch Step Test	30.8	24	3	1 to 2 min after the test
1969 (42)	OSU Step Test	Incremented (38.1/38.1/50.8)	24, 30, 30	Maximum of 15	NE
1971 (*)	Skubic & Hodgkin Step Test	45.7	24	3	1 to 1.5 after the test
1972 (27)	Queens' College Step Test	41.3	22	3	15 seconds at the 6^{th}-20^{th} seconds after the test
1973 (*)	F-EMU Step Test	35.6/35.6/43.1/50.8	Incremented (24/30/30/30)	Maximum of 17	NE
1991 (43)	Height-Adjusted Step Test	According with the knee angle produced when the feet is flat on the step	Incremented (22/26/30)	3	15 seconds at the 6^{th}-20^{th} seconds after the test
2014 (*)	Individualized Protocol	According with the participant's height (cm)	According with the PFA questionnaire score	8	1 min
2022 (44)	StepTest4all	Adjustable (15 to 40 cm)	Started at 15 and incremented 2.5 per minute	4 to 10	1 min after the test

Note: OSU: The Ohio State University Step Test, CHFT: Canadian Home Fitness Test; PFA: Perceived Funtional Ability Questionnaire, *Information retrived from (37).

Figure 8 shows an infogram of the StepTest4all specificities as well as the advantages and disadvantages of the StepTest4all protocol compared to others.

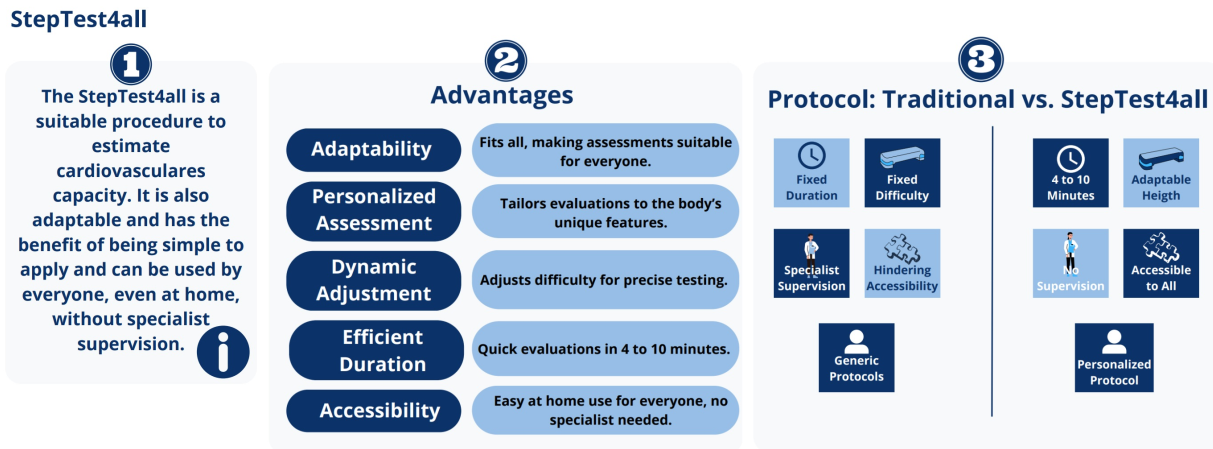

Figure 8 - StepTest4all infogram (retrieved from Sampaio et al. (45)).

2.2. Improvement of the VO_{2max} prediction formula

The phase includes the improvement of the accuracy of predicting VO_{2max} by using the StepTest4all by investigating the influence of the PA_{level}.

2.2.1. Methods

2.2.1.1. Participants

The sample consisted of 69 participants, including 27 women (age 21.7 ± 3.6 years; body mass = 63.5 ± 14.8 kg; height = 1.64 ± 0.06 m; BMI = 23.7 ± 5.3 kg/m^2) and 42 men (age 21.7 ± 3.4 years; body mass = 72.0 ± 7.3 kg; height = 1.77 ± 0.07 m; body mass index = 23.1 ± 2.1 kg/m^2). Those with physical limitations that prevented them from ascending or descending the step or those with medical conditions that prevented them from performing moderate physical exertion were not included in the sample recruitment. All participants signed an informed consent form. All protocols were in accordance with the Declaration of Helsinki regarding human research, and the research design was approved by the Polytechnic Ethics Board.

The groups were randomised and consisted of the following: (i) the VO_{2max} prediction equation group and (ii) the prediction model validation group. The characteristics of the participants are shown in Table 3.

Table 3 - Characteristics of the participants.

	Equation Group			Validation Group		
	Mean ± 1 SD			Mean ± 1 SD		
	Women (n = 17)	Men (n = 13)	Total	Women (n = 10)	Men (n = 29)	Total
Age [years]	20.8 ± 2.3	21.6 ± 2.8	21.7 ± 2.4	23.1 ± 4.8	21.7 ± 3.6	22.1 ± 3.9
Body mass [kg]	57.0 ± 6.8	71.6 ± 7.0	68.7 ± 11.5	74.6 ± 18.2	72.2 ± 7.6	71.8 ± 11.0
Height [m]	1.61 ± 0.04	1.77 ± 0.07	1.72 ± 0.09	1.68 ± 0.07	1.77 ± 0.07	1.74 ± 0.08
BMI [kg/m^2]	22.0 ± 3.1	22.8 ± 1.6	23.3 ± 3.7	26.7 ± 6.9	23.2 ± 2.3	24.1 ± 4.2
HRR_{60} [bpm]	36 ± 9	36 ± 11	36 ± 10	37 ± 10	38 ± 11	38 ± 11
VO_{2max} [mL·kg^{-1}·min^{-1}]	32.86 ± 4.95	45.03 ± 8.19	39.83 ± 9.38	32.95 ± 9.20	43.97 ± 8.19	41.14 ± 9.65
HRR_{rest} [bpm]	83 ± 11	67 ± 11	76 ± 13	78 ± 12	69 ± 11	71 ± 12
VO_{2rest} [mL·kg^{-1}·min^{-1}]	3.53 ± 0.56	3.97 ± 0.67	3.73 ± 0.64	3.17 ± 0.92	3.44 ± 0.61	3.37 ± 0.70

Note: Total—both sexes summed together.

2.2.1.2. Physical Activity Level

The International Physical Activity Questionnaire, in its short form, was used to assess physical activity. This was carried out in accordance with the official IPAQ classification procedure (46), which divides people into three levels of physical activity and is consistent with the categorization shown in several studies (47–49). These values are determined by multiplying the total PA completed during the week by a weighted approximation and then multiplying the result by the duration (minutes), frequency (per week), and MET (MET-min/week) (47).

The official IPAQ scoring system classifies individuals into three PA_{levels}:

Low Level: Participants whose energy expenditure does not reach PA_{level} or meet the criteria for levels moderate or high.

Moderate Level: (a) Three or more days of vigorous physical activity for at least 20 min per day; or (b) five or more days of moderate, vigorous, or walking for at least 30 min per day; or (c) five or more days of PA per week (moderate, vigorous, walking, or the sum of PA) for at least 600 MET-min/week.

High Level: At least (a) three days of vigorous physical activity accumulating 1500 MET-min/week, or (b) at least seven days of physical activity that includes walking, moderate and vigorous intensity activities accumulating a minimum of 3000 MET-min/week.

The distinction between moderate and vigorous physical activity is not very strict. Usually the evaluation is based on the compendium of physical activity (50). Another possible way is through the scales of subjective perception of effort. In these cases the subject self evaluates the effort, attributing a classification that corresponds to a certain level, which can also be qualitative (i.e. rest, light, moderate, vigorous and very vigorous). Another possible way is to use the NetHR to assess and prescribe intensity levels. According to bragada et al. (51) the values NetHR per MET increment is 9.1 bpm. Knowing the resting HR it is possible to determine the intensity of exercise by measuring the NetHR during the training session. With this amplitude (between rest HR and NET HR) associated with exercise divided by 9, it is possible to determine the increase in METs associated with a training session. In this way, taking into account the classification of the ACSM (light intensity PA is described as 2.0–2.9 METs, moderate as 3.0–5.9 METs, and vigorous as ≥ 6.0 METs), it is possible to determine the MET associated with a given training session (6).

Table 4 shows the PA_{levels} of the participants categorised based on the IPAQ scores. The scores were decoded into low (Level 1), moderate (Level 2), and high (Level 3).

Table 4 - Physical activity levels (PA_{levels}) of the participants.

	Equation Group		Validation Group	
	Women (n = 17)	Men (n = 13)	Women (n = 10)	Men (n = 29)
PA_{level}				
1	8	0	7	3
2	6	7	2	17
3	3	6	1	9

Note: PA_{level}: physical activity level.

2.2.1.3. Data Collection

An electronic scale (Seca 884, Hamburg, Germany) and a digital stadiometer (Seca 242, Hamburg, Germany) were used to measure anthropometric characteristics. A stationary breath-by-breath electronic metabolic device (Cortex, Model MetaLyzer 3B, Leipzig, Germany) was used to monitor HR and VO_2. A heart rate transmitter (Polar Electro Oy, Kempele, Finland) is part of the device. The device was calibrated with standard gases prior to each test. The standard error for oxygen and carbon dioxide sensors is 0.1%, according to the manufacturer's handbook.

Each participant's VO_2 and HR were continuously monitored as they performed the activities in the following order: rest, StepTest4all protocol, and recovery. The HR and VO_2 values obtained were used for further analysis: resting values (average of the last minute of rest), values obtained during StepTest4all (average of the last 5 s of each intensity level), and recovery phase (average of the last 5 s of the first minute of recovery). Resting HR and resting VO_2 were continuously measured while sitting in a quiet, dimly lit room for ten minutes. The participants were not allowed to nap. The last-minute values were used for data analysis. In the recovery phase, although HR values were recorded after the first two minutes, only the value from the first minute was considered. The one-minute recovery period was chosen because it has higher reproducibility (52).

2.2.1.4. StepTest4all Protocol

Each participant completed a continuous progressive test that involved stepping up and down on a steady step. After the step-up phase, the participant stood vertically, supported by both legs, and the opposite leg also stepped up to the platform. This was followed by the step-down phase. The step-down phase ended when the participant returned to the starting point, where he or she stood vertically again, supported by both legs. It began with the same leg as the previous phase.

Using data on each participant's CVC, step height was determined for each participant. The variables selected were sex, age, physical fitness, height, body mass index, and smoking status. Each variable was assigned a numerical value as follows: (i) sex (women = 0.5; men = 1), (ii) age (senior = 0, adult = 0.5, young = 1), (iii) physical fitness (insufficiently active = 0, moderately active = 0.5, vigorously active = 1), (iv) body mass index (BMI < 25 = 0.5, BMI < 30 = 0, BMI ≥ 30 = - 0.5), and (v) smoking status (smoker = 0, nonsmoker = 0.5). From these data, the step height was calculated using the formula Step height (cm) = $4 \times Sum\ of\ the\ Variables + 15$, and it could range from 15 to 40 cm as proposed by Bragada et al. (44). These ponderation factors were only used to calculate the step's height.

This formula is the result of many tests conducted on individuals with varying physical abilities and characteristics. Although the step height is important, it can vary somewhat because the precise adjustment is done by increasing of the cadence of the ascent and descent phases controlled by the metronome.

In the current study, a fast pace resulted in an intensity that reached 80% of the estimated maximum heart rate (HR_{max}) in 5 to 10 minutes. This occurs even in subjects with good physical fitness and tall stature. A height of 40 to 45 cm has been used previously in other protocols, such as the Harvard step (33).

Depending on the metronome control, the test began at a rate of 15 cycles per minute. In each cycle, the participant walked up and down the step so that the cycle ended at the same time the second leg reached the ground. The cadence was increased by 2.5 cycles per minute. The test should take no more than ten minutes. Anyone can perform the very slow ascent and descent at the lower limit of 15 cycles per minute, which also serves as a warm-up. A high cadence of 37.5 cycles per minute is achieved only by subjects with high physical capacities. A visual representation of the StepTest4all is shown in Figure 9.

Figure 9 - Visual representation of StepTest4all (retrieved from Sampaio et al. (45)).

The test ended when one of the following criteria was met: (i) when the HR reached 80% of HR_{max}, (ii) when the subject felt uncomfortable with the exertion, or (iii) when the subject was unable to complete the exercise at the correct cadence. In this case, all participants met the first criterion, i.e., they reached 80% of HR_{max}. The participants were instructed to stand for two minutes after the completion of the test. While standing, participants were asked not to talk, grab, or hold onto anything. Instead, they were encouraged to relax and recover as much as possible. The step height and rhythm increments, together with the intensity threshold of the test (80% of HR_{max}), allowed for the effective assessment of CVC in a manageable length of time (5 to 10 min) on a wide range of subjects. HR was continuously collected during the recovery period using the Garmin Fenix 6 and its HR belt (Garmin International, Inc., Olathe, KS, USA).

HR_{max} and VO_{2max} were estimated as follows. HR_{max} was estimated using the formula presented in figure 10.

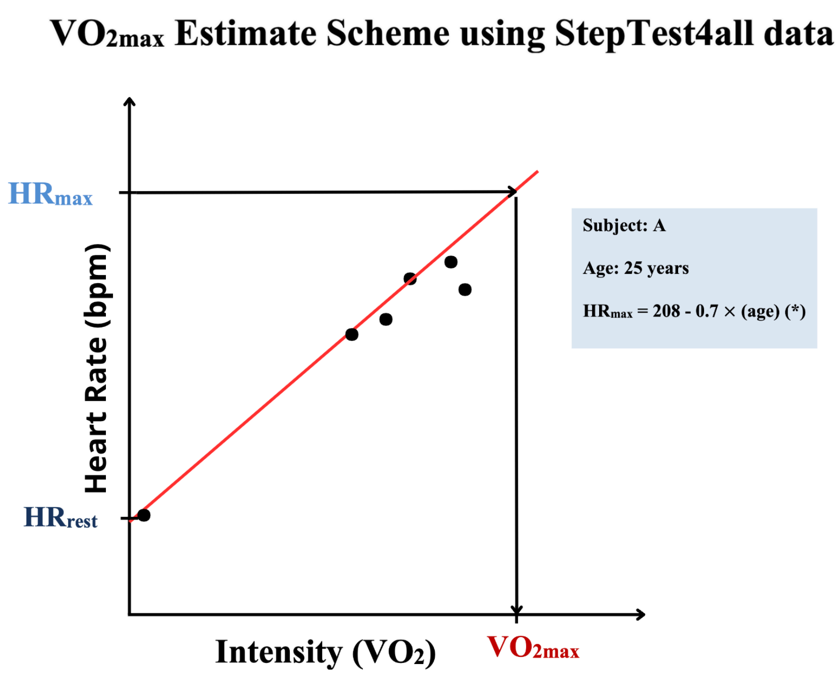

Figure 10 - VO_{2max} estimate scheme using StepTest4all data. * Information retrieved from (53).

Specifically, by determining the value of VO_2 corresponding to HR_{max}, VO_{2max} was estimated using the individual equation of the regression line corresponding to HR–VO_2 obtained from the resting data and during three or more steps of StepTest4all (54). This value was assumed as VO_{2max}. The range of individual linear regressions (R^2) was 0.97 to 0.99, indicating an almost perfect relationship. This is a standard and appropriate method for estimating VO_{2max} in participants who may find it inconvenient to perform a maximal test to exhaustion.

Submaximal testing has been shown to be an adequate method for estimating VO_{2max} from the HR–VO_2 relationship (55,56). In a systematic review, Evans and colleagues (57) reported non-significant discrepancies between the measured and predicted VO_{2max} in 28 equations. HR (N = 19) was the most used variable in the predictive equations. A submaximal treadmill-based protocol was also reviewed by Bennett and colleagues (58). The authors found that estimating VO_{2max} from the projection of HR_{max} provided a more accurate result.

2.2.1.5. Statistical Analysis

First, normality and homoscedasticity were assessed using the Kolmogorov–Smirnov and Levene tests, respectively. The means of the descriptive data were computed together with one standard deviation (1 SD). Stepwise regression (backward elimination) was used to predict VO_{2max} based on the following independent variables, i.e., sex, body mass, height, BMI, PA_{level}, and HRR_{60}. Only significant predictors were retained ($p < 0.05$) in the final model. The qualitative interpretation of the relationship was outlined as: (i) very weak, if $R^2 < 0.04$; (ii) weak, if $0.04 \leq R^2 < 0.16$; (iii) moderate, if $0.16 \leq R^2 < 0.49$; (iv) high, if $0.49 \leq R^2 < 0.8$; and (v) very high, if $0.81 \leq R^2 < 1.0$ (59).

The validation procedure between measured and predicted VO_{2max} was based on the following: (i) a comparison of the mean data, (ii) intraclass correlation coefficient (ICC), and (iii) Bland–Altman analysis. The paired sample t-test ($p < 0.05$) was used to compare the mean data between the estimated and measured VO_{2max}. The effect size index used was Cohen's d, along with the mean difference and 95% confidence intervals (CI). Cohen's d was considered to be (i) trivial (<0.20), (ii) small (0.20–0.59), (iii) moderate (0.6–1.19), (iv) large (1.2–1.99), and

(v) very large (≥2.0) (60). The two-way mixed model with an "absolute agreement" definition was used for the ICC (61). The qualitative interpretation was performed as follows: (i) poor, if ICC < 0.5; (ii) moderate, if 0.5 ≤ ICC < 0.75; (iii) good, if 0.75 ≤ ICC < 0.90; and (iv), excellent, if ICC > 0.90 (62). Bland-Altman plots showing the mean and difference between the measured and predicted VO_{2max} were analysed (63). For a strong agreement, at least 80% of the plots must be within the ±1.96 standard deviation of the difference (95% CI).

2.2.2. Results

In the linear regression, the following predictors of VO_{2max} remained significant: sex ($p < 0.001$), PA_{level} ($p = 0.014$), and HRR_{60} ($p = 0.020$). Age, body mass, height, and BMI were not significant in this model. The prediction equation ($R^2 = 74.0\%$, SEE = 4.78) was high and can be expressed as follows (equation (1)):

$$VO_{2max} = 17.105 + 0.260 \times (HRR_{60}) + 8.563 \times (sex) + 4.097 \times (PA_{level}) \quad (1)$$

In which VO_{2max} is the maximum oxygen uptake ($mL \cdot kg^{-1} \cdot min^{-1}$), HRR_{60} is the heart rate recovery (beats per minute) for one minute immediately after the end of the step test, sex is zero for women and 1 for men, and PA_{level} is level 1 (low), level 2 (moderate), and level 3 (high).

Table 5 shows the comparison between measured and estimated VO_{2max}. The results showed nonsignificant differences with a trivial effect size.

Table 5 - Paired samples t-test comparison between measured and estimated VO_{2max} in the validation group. The effect size index (Cohen's d) is also shown.

Measured VO_{2max} [mL·kg^{-1}·min^{-1}]	**Estimated VO_{2max} [mL·kg^{-1}·min^{-1}]**			
Mean ± 1 SD	**Mean ± 1 SD**	**Mean Difference (95%CI)**	***t*-Test (*p* Value)**	**d [Descriptor]**
41.14 ± 9.65	41.48 ± 6.94	-0.345 (-2.767 to 2.076)	-0.289 (0.774)	0.04 [trivial]

Note: VO_{2max}: maximal oxygen uptake.

The ICC between measured and predicted VO_{2max} showed good agreement between the measurements (ICC = 0.759, $p < 0.001$). Figure 11 shows the Bland–Altman plots. This analysis also met the agreement criteria, with more than 80% of the plots within the 95% CI.

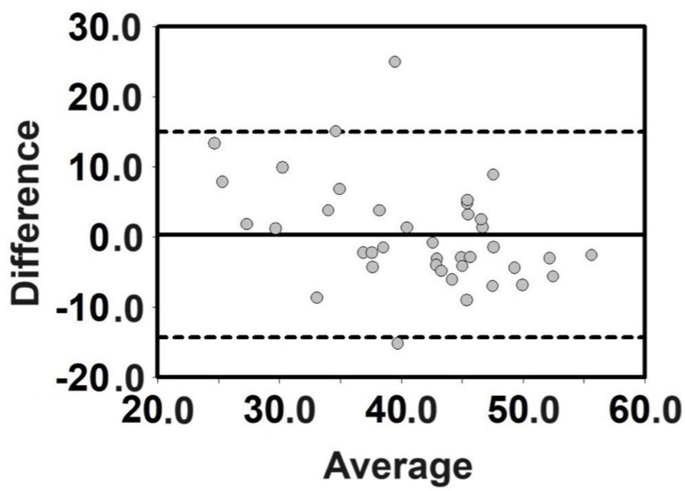

Figure 11 - Bland–Altman plots of the measured and predicted VO_{2max}. The y-axes refer to the difference between the measured and predicted VO_{2max} [mL·kg^{-1}·min^{-1}]. The x-axes refer to the average between the measured and predicted VO_{2max} [mL·kg^{-1}·min^{-1}].

3. Discussion and Conclusions

3.1.1. Discussion of the bibliometric review

The exploration of research main points within step test studies, utilizing co-occurrence keyword analysis, has revealed distinctive clusters, indicating emerging trends that significantly guide the ongoing research in cardiovascular assessment. This comprehensive analysis serves as a crucial tool for pinpointing emerging research and to guide forthcoming investigations, thereby developing comprehension of the critical themes influencing step test research.

Throughout the bibliometric analysis of step test literature, five clusters have emerged, each delineated as proposed: (1) Health and Exercise Guidelines; (2) Cardiovascular Fitness and Mortality Risk; (3) Chronic Obstructive Pulmonary Disease (COPD) and Respiratory Response; (4) Paediatric Exercise and Fitness; and (5) Adult Populations and Specific Conditions.

Within the cluster related to health and exercise guidelines (cluster 1), the convergence of keywords such as cadence, exercise, exercise test, health, and oxygen uptake signifies a substantial emphasis on standardizing protocols, establishing reference values, and formulating guidelines for conducting step tests. The inclusion of terms like rehabilitation and reproducibility of results underscores ongoing endeavours to refine and enhance the reliability of step test outcomes. Protocols, such as the StepTest4all proposed by Bragada et al. (17), involved participants in a continuous progressive test on a stable step, alternating between ascending and descending. Step height was individually determined based on factors like sex, age, physical fitness, height, body mass index (BMI), and smoking status. The formula, derived from diverse tests, considered factors influencing cardiovascular capacity. Protocols like StepTest4all proposed by Bragada et al. (17) contribute to a broader applicability in health and exercise contexts, allowing a reliable framework to evaluate CVC and overall health.

In the second cluster, cardiovascular fitness and mortality risk, keywords such as capacity, cardiorespiratory fitness, maximal oxygen uptake, and mortality. This highlights a distinct emphasis on elucidating the cardiovascular implications of step test scores. Heart rate seems to be an important parameter from a clinical point of view. This parameter can be obtained from most step tests (i.e. StepTest4all) (44).

Research within this cluster likely searches into the intricate relationship between step test outcomes and broader health considerations, particularly mortality risk (38). The presence of terms such as validation and VO_{2max} underscores a meticulous analysis of the validity of step test measures in assessing cardiovascular capacity.

Moving on to the third cluster, chronic obstructive pulmonary disease and respiratory response, keywords like chronic obstructive pulmonary disease, exercise capacity, and physiological response indicate a specialized focus on respiratory aspects and the application of the step test within COPD populations. For instance, the Chester step test has been identified as highly reproducible in patients with COPD, as demonstrated by de Camargo et al. (64), further emphasizing the relevance and effectiveness of the step test in this specific context. The exploration of oxygen desaturation, reliability, and responsiveness within this cluster reflects a targeted effort to comprehend and enhance the utility of step tests in assessing respiratory health. The Chester step test was conducted using a 20 cm tall, handle-free single-step device. This test comprises five stages, each lasting 2 minutes, with a total test duration of 10 minutes. The step cadence, initially set at 15 steps/min, increases by 5 steps/min every 2 minutes across the stages: 15 steps/min in stage 1, 20 steps/min in stage 2, 25 steps/min in stage 3, 30 steps/min in stage 4, and 35 steps/min in stage 5 (64).

In the fourth cluster, paediatric exercise and fitness, the inclusion of keywords like adolescents, children, fitness, and obesity underscores a interest in applying step tests among younger populations. The emphasis on these keywords suggests ongoing efforts to refine and validate step test protocols specifically adapted for assessing fitness and health in children and adolescents. For instance, the Chester step test has been proven to be versatile, as indicated by Maggio et al. (65), who demonstrated its ability to assess cardiorespiratory fitness in children in clinical settings, highlighting its applicability across diverse paediatric populations.

Finally, in the fifth cluster, adult populations and specific conditions, keywords such as adults, cystic fibrosis, exercise testing, and exercise tolerance indicate research specifically focused on unique health conditions within the adult population. The inclusion of cystic fibrosis signals a specialised focus on applying the step test to populations struggling with distinct health challenges. This cluster likely navigates the adaptability and efficacy of step tests in diverse adult populations. Notably, the study by Holland et al. (66) reveals that desaturation during the 3-minute Step Test is associated with long-term pulmonary deterioration and more hospital days in adults with cystic fibrosis. Holland et al. (66) suggested that the 3-minute step test may be a useful screening tool for patients with moderate to severe cystic fibrosis lung disease, highlighting its potential as a valuable measure for identifying individuals who require increased intervention and monitoring.

3.2. Discussion of the improvement of the VO_{2max} prediction formula

The aim of this study was to investigate the influence of the PA_{level} of participants in the StepTest4all (a validated protocol for estimating VO_{2max} in adults). The study retained the PA_{level} as a significant predictor of VO_{2max} simultaneously with the previous predictors (sex, HRR_{60}) of the young adult population. In addition, these results showed that the magnitude of the HR decrease that occurs immediately after exercise is a useful indicator of CVC. This suggests that StepTest4all can be used to assess CVC for individualised, longitudinal monitoring of cardiovascular fitness. Regular use of StepTest4all facilitates the tracking of cardiovascular fitness progression over time. However, comparing VO_{2max} results between different populations should be carried out with caution. The same VO_{2max} value may indicate different physical capabilities for different demographic variables, including age and sex. Therefore, individual VO_{2max} values should be compared with benchmark tables available in the literature to verify compliance with the proposed standards (6).

From a clinical point of view, an attenuated HRR, defined as an insufficient decrease in HR immediately after exercise, indicates decreased parasympathetic nervous system activity (67,68). The decrease in HR during recovery is mostly caused by the reactivation of the parasympathetic nervous system, which occurs primarily in the initial phase of recovery (69). Measurement of the post-exercise HR decline also provides an indication of neural system function (70). Research has shown that a small drop in heart rate in the minutes following the end of exercise is associated with a higher risk of cardiovascular problems (71) and may even be the cause of early mortality (38). Conversely, a faster decline in HR after exercise is correlated with improved cardiovascular capacity (52). A study also found that sedentary, healthy individuals can improve heart rate recovery (HRR_{60} and HRR_{120}) by engaging in moderate-intensity exercise (72).

Adabag and Pierpont's (73) findings on the recovery of heart rate during exercise are consistent with the current study and emphasise that in recent years, assessments have been used more frequently to evaluate risk and functional autonomic state in both healthy individuals and those with a variety of disorders. HRR is usually calculated as the difference between the higher value obtained at the end of the exercise testing and the heart rate one to two minutes after stopping exercise (HRR_{60} and HRR_{120}, respectively). Other measures, including HRR_{180}, HRR_{240}, and HRR_{300}, have also been provided. Short-term reproducibility is demonstrated by these results, and validation has been established for HRR_{60} and HRR_{120}. For example, HRR values of 12–13 bpm in 1 minute are referred to as threshold levels in a review by Adabag et al. (73). However, due to the wide variety of tests used and the level of demand, care must be taken when setting cut-off values (between normal and abnormal). It is known that healthy athletes can recover 60 bpm or more in one minute, which is the ideal recovery number. Therefore, values between 12 and 60 bpm can be used to measure the magnitude and quaility of recovery. More studies are needed to establish precise threshold values between healthy individuals and individuals with diseases. Increasingly higher values indicate very good cardiovascular capacity and good autonomic nervous system function; values close to 12 bpm may indicate a higher risk of cardiovascular disease or parasympathetic nervous system dysfunction (73,74). The average HRR_{60} value found in the participants of the present study was 37 ± 11 bpm. This value is well above the minimum values mentioned earlier. In addition, a study by Carnethon et al. (75) found that participants who self-reported a high level of physical activity had a significantly higher HRR (but in this case measured after 2 minutes of exercise cessation) than participants in the lowest group (corresponding to the lowest level of physical activity). Thus, physical activity was associated with a faster HRR in a treadmill exercise test. Therefore, the participants in the current study seem to be consistent with their age group and active lifestyle (75).

The range of HRR variation (19 to 63 bpm of recovery over one minute) commonly found in these individuals was divided, and four categories were developed to provide a qualitative description of cardiovascular capacity in this population group (young adults). The cardiovascular capacity categorization, the reference VO_{2max} values for the participants in the present study aged between 18 and 29 years, and the values of comparable categories proposed by McArdle et al. (76) are shown in Table 4. This finding may indicate that there is no difference between the VO_{2max} values calculated by Equation 1 and other estimates. Using the StepTest4all, it has been observed that values below 25 are typically associated with a sedentary lifestyle and the presence of additional risk factors such as obesity and smoking, while values above 55 are typically found in individuals who lead a healthy lifestyle and engage in high levels of daily physical activity. Table 6 shows the VO_{2max} values predicted by equation (1) (from our study) and the values proposed by McArdle et al. (76) for similar categories. Similar values can also be found in the company of a world-renowned body composition assessment company (Tanita: https://tanita.eu/blog/could-improving-your-vo2-max-be-the-secret-of-success) (77).

Table 6 - Cardiovascular capacity classification based on HRR_{60} and corresponding HRR cut-off values.

CVC Classification	HRR_{60}	Men		Women	
		VO_{2max}	McArdle et al., 2003 (76)	VO_{2max}	McArdle et al., 2003 (76)
Poor	< 25	< 40	< 36.5	< 28	< 29
Moderate	25 – 39	42 – 44.2	36.5 – 42.4	28 – 32.2	29 – 32
Good	40 – 54	44.3 – 49	42.5 – 46.4	32.3 – 36.9	33 – 36
Excellent	≥ 55	≥ 49	≥ 46.5	≥ 37	≥ 37

The contribution of physical activity as a predictor of VO_{2max} is consistent with previous research, such as the study conducted by Dyrstad et al. (78). The aim of this study was to investigate how different levels of self-reported and objectively measured physical activity, including sedentary time, correlated with variations in VO_{2max}. This study included a sample of 759 participants (366 women and 393 men) with a mean age of 48.5 years (SD of 14.4) who completed the cardiopulmonary exercise test 5–8 months after completing the IPAQ questionnaire. The article by Dyrstad et al. (78) examines the relationship between physical activity and CVC, both of which are inversely associated with disease and all-cause mortality. Their results indicate that individuals classified as highly active by the IPAQ had a higher CVC than those who reported low levels of physical activity. In addition, meeting the PA recommendation of 150 minutes per week of daily moderate-intensity PA was associated with higher CVC. The study highlights the variation in CVC and underscores the central role of PA in maintaining good health and reducing the risk of disease and mortality. Indeed, our results showed that the PA_{level} was retained as a significant predictor of VO_{2max}. In comparison to the study of Bragada et al. (17), our modeling allowed us to increase the prediction output (R^2 from 63% to 74%). This reinforces the importance of PA_{level} in the assessment of CVC.

Because of its unique characteristics, the StepTest4all demonstrates adaptability to individuals with different physical abilities and varying somatic characteristics. While this is not the first step test to incorporate multiple characteristics in determining step height, this protocol refines this approach. This refined calculation allows for a primary adjustment that prevents the test from becoming too challenging or too easy. Further precision is achieved through careful control of the pace and its incremental adjustments throughout the test to ensure that the desired intensity of effort associated with 80% of HR_{max} (the upper limit) is achieved within an appropriate time frame of 5 to 10 minutes for all participants. This updated protocol builds on the foundation laid by Bragada et al. (17), contributing advancements to the methodology and enhancing its effectiveness in assessing CVC among individuals with varying physical characteristics.

In the current study, age was excluded as a predictor of VO_{2max} via stepwise regression modeling. This exclusion was influenced by the homogeneity of the sample, which consisted predominantly of young adults. It is plausible that in studies with a more diverse age range, age could become an important factor in the predictive equation for VO_{2max}. Expanding the age spectrum in future investigations may shed light on the potential impact of age on the predictive accuracy of the model.

In addition to this, the use of step tests, coupled with the above-mentioned advantages, remains favorable due to their simplicity, minimal space requirements, and ability to be performed by individuals at home. As demonstrated on the StepTest4all Facebook page (https://www.facebook.com/StepTest4all) (79), the accessibility of the protocol enhances its practicality and convenience, making it an attractive option for widespread participation in cardiovascular capacity assessments.

3.3. Practical Implications

The practical implications of the use StepTest4all protocol are several and underscore its versatility and accessibility in assessing cardiovascular capacity. The practical implications are the following:

- Allows for application across individuals with diverse levels of physical ability and somatic characteristics, rendering it inclusive and widely applicable;
- Its feasibility for implementation in a home setting, devoid of specialised equipment and supervision;
- The protocol's user-friendly design facilitates a straightforward and efficient assessment of cardiovascular capacity by using the simplified formula:

$$VO_{2max} = 17 + 0.3 \times (HRR_{60}) + 8.6 \times (sex) + 4.1 \times (PA_{level}) .$$

Overall, the StepTest4all protocol's practical implications emphasise its utility as a versatile, accessible, and efficient tool for assessing cardiovascular capacity in various populations and settings.

3.4. Limitations

The limitations of the present study are the following:

- The research was conducted with young adults only. Therefore, further studies with a broader demographic representation are needed to generalise the findings to different age groups.

- It is important to note that both VO_{2max} and HR_{max} values were estimated rather than directly measured. The HR_{max} from the previous formula. The VO_{2max} was estimated from regression equation (VO_2-HR), determinating the value of the VO_{2max} associated to HR_{max}. It is important to emphasise that this estimation method is consistent with standard procedures commonly used in non-athletic participants or special populations where it is not advisable to submit individuals to maximal tests to exhaustion.

- The reliability of the test was not measured in this particular sample. Thus, further studies could address this issue.

Despite these limitations, the findings of this study provide a foundation for future research efforts aimed at addressing these limitations and expanding the applicability of the StepTest4all protocol.

3.5. Conclusions

The bibliometric review of the step test literature revealed a dynamic landscape characterised by a gradual increase in publications until 2021, indicating a sustained interest in cardiovascular capacity assessment. Despite a recent decline in the past two years, the multidisciplinary nature of step test studies is evident. A total of 1,849 institutions participated in the research regarding the step test as a tool for cardiovascular capacity assessment between 1946 and 2023. This broad exploration underscores the relevance of step tests in diverse areas, reflecting their adaptability and applicability across occupational and clinical settings.

The StepTest4all was shown to be a suitable method for estimating cardiovascular capacity, expressed as VO_{2max}, in young adults. The validation procedure showed a high degree of agreement between measured and estimated VO_{2max}. Retaining PA_{level} as a significant predictor allows us to better individualise the participants' VO_{2max}. This method is easy to use and accessible to everyone, so it can be used at home without the need for specialised supervision.

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