Mireia Cano Izquierdo

Validade do Chester step test para predizer a potência aeróbica e prescrever atividade física em pessoas hipertensas

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Fisioterapia, realizada sob a orientação científica do Doutor Fernando Ribeiro, Professor Adjunto da Escola Superior de Saúde da Universidade de Aveiro

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“Don’t let anyone rob you of your imagination, your creativity, or your curiosity”

Mae Jemison
o júri

Presidente
Professora Doutora Alda Sofia Pires de Dias Marques
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Palavras chave

Resumo

Enquadramento: A hipertensão é uma condição que afeta mais de um bilhão de pessoas no mundo. Está diretamente relacionada com o desenvolvimento de eventos cardio-- e cerebrovasculares e/ou renais. O consumo máximo de oxigénio (VO₂max) é um dos maiores preditores de saúde. Os testes para avaliar a capacidade cardiorrespiratória são importantes para avaliar os programas de exercício e encorajar os indivíduos a adotar um estilo de vida ativo. A avaliação direta do VO₂max é um processo caro e demorado. O Chester Step test é um teste submáximo já validado em indivíduos saudáveis que, se provar a sua validade em adultos hipertensos, poderá ser usado para estimar o VO₂max no contexto da hipertensão.

Objetivos: Validar o Chester Step test para predizer o VO₂max em adultos hipertensos. O objetivo secundário foi estudar a influência de diferentes fórmulas para determinar a frequência cardíaca máxima prevista para a idade ao estimar o VO₂max pelo Chester Step test.

Métodos: Onze adultos hipertensos (36,4% mulheres) com idade média de 53,9 ± 7,4 anos participaram no estudo. Realizaram no mesmo dia o Chester Step test e um teste de exercício máximo em cicloergómetro no qual foram avaliados o VO₂, a frequência cardíaca e a pressão arterial.

Resultados: Foi encontrada uma correlação forte e positiva entre o VO₂max medido e o estimado, entre r=0.982 e r=0.986 (p<0.01), dependendo da fórmula usada para predizer a frequência cardíaca máxima. A melhor estimação foi obtida com o uso da fórmula Fox--Haskell (220--idade). O VO₂max estimado pelo Chester Step test usando a fórmula Fox--Haskell não foi significativamente diferente do medido no teste em cicloergómetro [dif média (95%IC): --0.319 (--1.248 – 0.610), p=0.462]; os limites de concordância foram de 3.03 a -2.4 ml·Kg⁻¹·min⁻¹.

Conclusão: Apesar de tender a sobrestimar o VO₂max real, o Chester Step test é uma ferramenta válida e promissora na avaliação de adultos hipertensos.
Background: Hypertension is a condition which affects more than a billion people worldwide. It is directly related with developing cardiovascular and renal events. Maximal oxygen uptake (VO$_{2max}$) has become one of the greatest predictors of health and fitness. Cardiorespiratory fitness tests are important to evaluate exercise programs and to encourage individuals to adopt an active lifestyle. The direct assessment of VO$_{2max}$ is an expensive and time-consuming procedure. The Chester Step test is a submaximal test already validated in healthy subjects, if proven valid could be used for estimation of VO$_{2max}$ in the context of hypertension.

Objectives: To validate the Chester Step test for estimating the VO$_{2max}$ in hypertensive adults. A secondary aim was to study the influence of different formulas for age predicted maximal heart rate when estimating VO2max by the Chester Step test.

Methods: Eleven adults with hypertension (36.4% females), mean age 53.9 ± 7.4 years participated in the study. They performed in the same day the Chester step test and a maximal cycloergometer test, in which VO$_2$, heart rate and blood pressure were assessed.

Results: A strong and positive correlation was found between the measured and the estimated VO$_{2max}$, ranging from \( r=0.982 \) to \( r=0.986 \) (\( p<0.01 \)) depending on which age--predicted formulas was used to predict the HR$_{max}$. The best prediction was obtained when Fox--Haskell formula (220--age) was used. No difference was observed for the Fox--Haskell formula [mean diff (95% CI): --0.319 (--1.248 – 0.610), \( p=0.462 \)]; the limits of agreement range from 3.03 to --2.4 ml·Kg$^{-1}$·min$^{-1}$.

Conclusions: Despite the fact that the Chester step test tends to overestimate VO$_{2max}$, the test is a valid and promising tool for assessing hypertensive adults.
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>CHAPTER 1 BACKGROUND</td>
<td>3</td>
</tr>
<tr>
<td>1.1 HYPERTENSION</td>
<td>3</td>
</tr>
<tr>
<td>1.1.2 EPIDEMIOLOGY</td>
<td>4</td>
</tr>
<tr>
<td>1.1.3 AETIOLOGY</td>
<td>5</td>
</tr>
<tr>
<td>1.1.4 DIAGNOSIS</td>
<td>5</td>
</tr>
<tr>
<td>1.1.5 TREATMENT</td>
<td>5</td>
</tr>
<tr>
<td>1.2 PHYSICAL ACTIVITY</td>
<td>6</td>
</tr>
<tr>
<td>1.2.1 PHYSIOLOGICAL ACUTE ANSWER TO PHYSICAL ACTIVITY</td>
<td>6</td>
</tr>
<tr>
<td>1.2.2 PHYSIOLOGICAL CHRONIC ANSWER TO PHYSICAL ACTIVITY</td>
<td>7</td>
</tr>
<tr>
<td>1.2.3 PHYSICAL ACTIVITY AND HYPERTENSION</td>
<td>8</td>
</tr>
<tr>
<td>1.3 ASSESSMENT OF AEROBIC FITNESS</td>
<td>9</td>
</tr>
<tr>
<td>CHAPTER 2 METHODS</td>
<td>11</td>
</tr>
<tr>
<td>2.1 PURPOSE</td>
<td>11</td>
</tr>
<tr>
<td>2.2 PARTICIPSANS</td>
<td>11</td>
</tr>
<tr>
<td>2.3 PROCEDURES</td>
<td>12</td>
</tr>
<tr>
<td>2.3.1 CHESTER STEP TEST</td>
<td>12</td>
</tr>
<tr>
<td>2.3.2 INCREMENTAL EXERCISE TEST</td>
<td>13</td>
</tr>
<tr>
<td>2.4 DATA TREATMENT AND STATISTICS</td>
<td>14</td>
</tr>
<tr>
<td>CHAPTER 3 RESULTS</td>
<td>17</td>
</tr>
<tr>
<td>3.1 CHARACTERISTICS OF THE PARTICIPANTS</td>
<td>17</td>
</tr>
<tr>
<td>3.1 RESULTS OF THE TESTS</td>
<td>19</td>
</tr>
<tr>
<td>3.2 ASSESSMENT OF VALIDITY</td>
<td>22</td>
</tr>
<tr>
<td>CHAPTER 4 DISCUSSION</td>
<td>27</td>
</tr>
<tr>
<td>4.1 LIMITATIONS OF THE STUDY</td>
<td>30</td>
</tr>
<tr>
<td>4.2 FUTURE LINES OF RESEARCH</td>
<td>30</td>
</tr>
<tr>
<td>CHAPTER 5 CONCLUSIONS</td>
<td>31</td>
</tr>
<tr>
<td>CHAPTER 6 REFERENCES</td>
<td>33</td>
</tr>
<tr>
<td>CHAPTER 7 ANNEX</td>
<td>39</td>
</tr>
<tr>
<td>7.1 ANNEX 1. PARTICIPANT’S QUESTIONNAIRE</td>
<td>39</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 1 – 2018 HT classification of the ESC
Table 2 – Characteristics of participants
Table 3 – Data characteristics of GXT
Table 4 – Data characteristics of CST
Table 5 – Pearson’s correlation coefficients
Table 6 – Bias 95% LoA between the differences of the estimated VO_{2max} and the measured VO_{2max}
LIST OF FIGURES

Figure 1 – RPE and HR at each stage of the CST
Figure 2 – Estimated vs measured VO_{2peak} expressed in ml*Kg^{-1}*min^{-1}
Figure 3. Bland and Altman plot of estimated vs measured VO_{2peak} expressed in ml*Kg^{-1}*min^{-1}
LIST OF ABBREVIATIONS

BMI – Body mass index  
BP – Blood pressure  
CST – Chester step test  
CV – Cardiovascular  
DBP – Diastolic blood pressure  
ESC – European society of cardiology  
GXT – Grade exercise test  
HR – Heart rate  
HR_{max} – Maximal heart rate  
HT – Hypertension  
LoA – Limits of agreement  
QoL – Quality of life  
RER – Respiratory exchange ratio  
RPM – revolutions per minute  
SBP – Systolic blood pressure  
SEE – Standard error of estimate  
VO_2 – Oxygen uptake  
VO_{2max} – Maximum oxygen uptake  
WHO – World Health Organization
Introduction

The prevalence of hypertension has increased exponentially over the last decades, affecting more than a billion people worldwide, ranging from 5.2 to 70.7% worldwide [1,2]. In Portugal, the prevalence of hypertension was estimated to be 42.2% [3]. It is one of the main factors for developing cardiovascular disease and/or a morbid renal event. However, hypertension neither has any characteristic symptom, nor a defined aetiology in 95% of the cases. For this reason, health organizations have named it “the silent killer” [1,4].

Some trends show that approximately 90% of non-hypertensive people in the age between 55 and 65 years will develop hypertension by the age of 80 and almost 15% of the world deaths will be caused by it [2]. Due to these alarming numbers, the World Health Organization has prioritized the fight against hypertension in its agenda. The action plan foresees implementing physical activity jointly with the pharmacological treatment [1,2,5,6]. Therefore, it is necessary to provide health professionals valid tools to assess, monitor and prescribe physical activity and exercise.

Nowadays, there are several ways to assess cardiorespiratory fitness and monitor the effects of the exercise interventions on it. However, the most important and effective way of measuring cardiorespiratory fitness is measuring the maximal oxygen uptake (\(\text{VO}_{2\text{max}}\)) in a graded exercise test (GXT). The \(\text{VO}_{2\text{max}}\) is the maximum amount of oxygen that the body can absorb, transport and consume in a given time. It is a strong predictor of health and fitness, suggesting low values of it are associated with an increased risk of morbidity and mortality [7–9].

Direct assessment of the cardiorespiratory fitness is usually obtained from a GXT. Nonetheless, it is an expensive and time-consuming method that has to be supervised by a health professional [8]. The Chester Step Test is one of the many submaximal tests that can be used to predict the \(\text{VO}_{2\text{max}}\) and prescribe physical activity. Developed by Kevin Sykes for assessing the aerobic fitness by predicting the maximal aerobic power, the Chester Step Test is safe, simple, inexpensive and portable, due to the limited equipment needed [8,10]. Participants are thought to step up and down a step of a particular height (depending on the age and their fitness condition). The \(\text{VO}_{2\text{max}}\) prediction of this test is based on the linear relation between the heart rate and the \(\text{VO}_2\), since they both increase linearly until 80–85% of the \(\text{VO}_{2\text{max}}\) when the workload increases.
[11]. However, when tested in healthy subjects the Chester step test has shown an error from 5% to 15% in this prediction, probably due to a set of errors that do not all depend on the test itself [10]. Nevertheless, it has already been proved its reliability for detecting changes after a physical activity protocol [10].

Therefore, becomes clear that submaximal tests are needed in physical therapy context, where health professionals become a reference for giving recommendations to their patients. However, therapists suffer from lack of time and equipment. Submaximal tests turn into an excellent tool to work with and assess the aerobic fitness, prescribe physical activity and exercise training and monitoring the efficacy of some interventions in this group of people, where physical activity and exercise training are one of the first line treatments [5].

This study aimed to test the validity of the Chester step test to estimate the VO$_{2\text{max}}$ in hypertensive adults. A secondary aim was to assess the influence of different formulas used for predicting the age--predicted maximal heart rate when estimating VO$_{2\text{max}}$ by the Chester Step Test in hypertensive adults. None of these formulas had been evaluated in submaximal tests in hypertensive people before.

The current thesis is divided in five chapters: Chapter 1 Background, Chapter 2 Methods, Chapter 3 Results, Chapter 4 Discussion, Chapter 5 Conclusions, Chapter 6 References and Chapter 7 Annexes.
CHAPTER 1 Background

1.1 HYPERTENSION

The World Health Organization (WHO) defines arterial hypertension (HT) as “a condition in which the blood vessels have persistently raised pressure.” The standard blood pressure (BP) values for an adult are 120mmHg of systolic blood pressure (SBP) and 80mmHg of diastolic blood pressure (DBP). A higher or raised BP is considered when the SBP values are equal to or above 140mmHg and/or DBP values equal or above 90mmHg [12]. The classification of HT was set up by the European Society of Cardiology/European Society of Hypertension, the last upgrade is presented in table 1 [13].

Often people with HT do not experience symptoms at all, but in some cases, headache, shortness of breath, dizziness, chest pain, palpitation of the heart or nosebleeds occur. HT is the main risk factor for cardiovascular (CV) (stroke, heart failure, peripheral artery disease) and renal morbid events [1,4]. Metabolic risk factors are also higher with high values of BP [5]. A rise as small as 2mmHg on BP leads to a 10% higher probability for a stroke as death cause. However, as He et al. showed in 2003 in the UK [14], when the condition was well controlled, most of hypertensive patients could decrease the incidence of strokes by a 28--44% and ischemic heart disease by 20--35%.

<table>
<thead>
<tr>
<th>CATEGORY</th>
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<th>DBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal</td>
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</tr>
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<td>Normal</td>
<td>120-129</td>
<td>and/or</td>
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<tr>
<td>High normal</td>
<td>130-139</td>
<td>and/or</td>
</tr>
<tr>
<td>Grade 1 HT</td>
<td>140-159</td>
<td>and/or</td>
</tr>
<tr>
<td>Grade 2 HT</td>
<td>160-179</td>
<td>and/or</td>
</tr>
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<td>Grade 3 HT</td>
<td>&gt;180</td>
<td>and/or</td>
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<tr>
<td>Isolated systolic HT</td>
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1.1.2 EPIDEMIOLOGY

In the last years, the prevalence of HT has been estimated at over one billion people in the world [1,2], mostly due to the aging of the population. One of the most leading indicators of the magnitude of the problem is the prevalence of stroke mortality, which has been demonstrated to be the closest one [5]. Nowadays, trends point that HT will not decrease in the closed future and approximately 90% of the non--hypertensive people aged between 55 and 65 years will develop the condition by the age of 80--85 years and almost 15% of the world deaths will be caused by it [2].

Prevalence differs among the population according to age, sex, and ethnicity. Older people have higher probability to develop HT; becoming the SBP the most important CV risk factor beyond 50 years old. It has also been demonstrated that females have lower incidence than males, and black people have a 50% higher probability to develop HT due to some variation in the renin--angiotensin system. Although there is no correlation between economic status and the HT incidence, some lifestyle factors can enhance its incidence such as stress, diet, and lower levels of daily physical activity [2,4,15].

In Portugal it has been estimated a prevalence of 42.2%, which follows the global tendency of HT. It appears to be higher in the elders, in men, in nonsmokers and in those with lower education level. It was also positively associated with BMI, diabetes, dyslipidemia and previous CV events [3].

With these alarming numbers, WHO has pointed out HT as one of its priorities to decrease the mortality of the noncommunicable diseases, also known as chronic diseases, by 2% per year. In order to achieve this goal not only the WHO is bearing responsibility, but also the governments need to implement new global politics to reduce the risk of CV diseases with cost--effective actions at the community level [1,2,5]. These politics must include strict medical monitoring of HT among the community and measures towards the promotion of healthy diet, physical activity and curtail main pitfalls such as the consumption of tobacco. A highly important role has to be given to the politics done in schools to prevent misbehaviors among society at an early stage. Besides, primary prevention is starting to be most applied in the primary care settings. In this environment, the physicians know well the patients, and the trust between them creates a good atmosphere so that recommendations can be made. It has been showed that the greatest long--term action to prevent somehow this condition is the application of strategies early in life [6]. Only with these strategies, the governments could reduce the economic burden of HT, including expenses for hospitalization, pharmacological treatment or rehabilitation.
1.1.3 AETIOLOGY
Scientists consider the BP as a result of the interaction between genetic and environmental factors. Hence, 95% of HT cases do not have a determined aetiology and are known as essential HT [16]. Some factors that can lead to this condition are overweight, insulin resistance, alcohol, salt intake, sedentary lifestyle, stress, and some diets deficient in potassium and calcium [16]. Being aware of these risk factors allows preventive measures for prehypertensive people [2].

1.1.4 DIAGNOSIS
Commonly, HT is asymptomatic, so that, the early diagnosis and identification of CV risk factors are essential to obviate fatal consequences. BP higher than 140/90 mmHg (SBP/DBP) defines the first stage of HT. However, many guidelines suggest that multiple measurements of BP are needed before giving a final diagnosis [17]. Since BP can be prone to fluctuations throughout the day due to hourly habits, such as caffeine consumption, stress, emotional condition, sudden changes in the diet or measuring the BP right after doing vigorous exercise [18–20]. BP measurements can be taken in clinical settings by doctors and self--monitoring can be used as an additional tool by the patient [17].

1.1.5 TREATMENT
Decreasing BP values is indispensable to reduce CV risk. Physicians are the responsible to determine the pharmacological treatment depending on the grade of HT [21]. Nevertheless, there is not a full consensus between all the clinicians when one should start the drug treatment. In this sense, some clinicians recommend to initiate it even if the patient has no other associated risk factors, others only when the patient with stage 1 HT presents risk factors, whereas others recommend starting with a period of changes in lifestyle and behavior programs.

Non--pharmacological treatment includes changes in lifestyle among hypertensive individuals, including in diet and physical activity habits. WHO recommends 3--5 times per week of moderate physical activity, such as a combined program of walking and aerobic or endurance training [5,17,21]. Therefore, this implies that all health professionals have to be aware of the recommendations and have the necessary tools to promote physical activity among these individuals. Primary prevention is starting to be applied by routine in the primary care settings. In this environment, the doctors know well the patients, and the relationship between them
creates a good atmosphere so that recommendations can be made. It has been demonstrated that the greatest long-term action to prevent somehow this condition is the application of strategies early in life [6,22–24].

1.2 PHYSICAL ACTIVITY

1.2.1 PHYSIOLOGICAL ACUTE ANSWER TO PHYSICAL ACTIVITY

Few situations in life achieve stress levels as high as when exercise is performed. It is one of the states where most of the body systems participate. The CV system is one of the main responsible for the adjustments that occurs during exercise. As regards the acute answer of physical activity results in an increase of $O_2$ and metabolic demands for the muscular tissue, so there will be an increase in metabolic detritus. All CV changes will be focus on satisfying the demands of the body, having three main objectives: ensure blood supply in active muscles, dissipate the heat generated by the active muscles and maintain the blood supply to the brain and the heart [11].

In normal conditions, the body responds to this first requirement with a boost of sympathetic activity to the heart and systemic blood vessels and a decrease of vagal outflow; this will result in a higher cardiac output. Cardiac output is the product of HR and systolic volume; however, HR is the main responsible for this increase. Normally, the cardiac output at rest value is around 5 l/min, and during maximal exercise can achieve 20 to 40 l/min depending on the conditions of each subject [11].

When the intensity of the exercise starts to increase, HR increases linearly with workload and VO$_2$, until the subject is getting closer to the total exhaustion and HR experiments a stabilization [11].

In the other hand, the systolic volume makes the heart works with more efficiency, and determines cardiorespiratory fitness (CRF). Studies show that systolic volume increases linearly until intensities of exercise around 40--60%, after this point it stabilizes and sometimes could even experiment a small decrease [11,25].

One direct effect of cardiac output increase is the rise in SBP, which will increase until a stabilization point. DBP remains constant during physical activity. However, this answer cannot be applied to the strength exercises. High intramuscular pressure during resistance exercise exceeds the BP and temporarily disrupt the blood flow, so that both SBP and DBP increase [20,26–28].
Another key point is the blood redistribution around the body during exercise. Sympathetic nervous system is responsible for redirecting blood to the areas with higher demands. This is evidenced because at rest only between 15--20% of the cardiac output goes to the muscles. But during intense exercise these percentage can be placed above 80%. This is achieved due to a sympathetic stimulation that will lead to a reduction in blood flow to the kidneys, liver, stomach and intestines. At the same time that this is happening, metabolic detritus concentration increases inside the active muscles, causing an increase in acidity, in carbon dioxide (CO$_2$) and in the temperature of the tissue [11,25]. Any abnormality in this answer is used for the prognostic stratification of HT; a SBP which does not raise could mean a sign of ischemia, on the other side a disproportionate answer may be a factor for future treatment decisions [26].

After some minutes or hours, BP will return to the previous values before the physical activity or even lower; an effect called postexercise hypotension. The evidence shows that this reduction appears in both healthy and hypertensive people and can last up to 6 to 8 hours. It is assumed that the inhibition of sympathetic system and central baroreflex network play a significant role in this effect [29,30].

1.2.2 PHYSIOLOGICAL CHRONIC ANSWER TO PHYSICAL ACTIVITY

Benefits in body after performing regular physical activity are irrefutable and not only in reducing CV risk factor. Exercise is defined in the literature as a “polypill” with multi-systemic benefits, few side--effects and low cost, although the magnitude of the gain depends on the characteristics of the training (intensity, duration, frequency, type of exercise) [11,25]. In this section only the effects of aerobic exercise in the CV system will be described.

Commonly, the first changes can be observed after some weeks of training, and the increase in stroke volume seems to be responsible for the improvement of cardiac output [28,31]. Long--term benefits also include hypertrophy of the heart which will suppose a greater force in each beat; studies have shown a strong correlation between left ventricular mass and VO$_{2\text{max}}$ [25]. Consequently, the BP at rest and in submaximal exercise will decrease [32]. HR at rest will significantly decrease after a training program, and it is attributed to an increase in parasympathetic activity in the heart. In the same way submaximal HR will also decrease due to the improved efficiency of the heart, which will need less effort for performing the same level of activity.

The improvements observed in blood flow can be explain by 4 reasons: greater capillarization of the trained muscles, greater opening of the capillaries of the muscles, a more efficient redistribution of blood flow and an increase in blood volume.
On the other hand, VO$_{2\text{max}}$ will also enhance after a training program, although the improvements will be conditioned by age [31]. Another important factor is the increased in plasma volume, a factor that will enhance the systolic volume that will directly affect the VO$_{2\text{max}}$.

1.2.3 PHYSICAL ACTIVITY AND HYPERTENSION

Physical activity is defined as "any movement of the body which increases the energy consumption above the resting levels" [33].

As mentioned above it is one of the first line treatments to improve the quality of life (QoL) of hypertensive people. It also seems to show benefits in the prevention of this condition [5]; however, the most extensive studies conclude that this effect only appears at certain doses of physical activity [33].

The effectiveness of physical activity in the reduction of BP has been observed in several studies; it results in a decrease of both SBP and DBP, and improvements in the aerobic condition and central and peripheral hemodynamic factors [5,7,34–38].

Systematic reviews [22,39,40] settle that all types of exercise training (aerobic, resistance, aerobic + resistance, and even isometric) decrease BP in HT. Two of them suggests that isometric exercise has the potential to lead to the most significant reduction in the SBP. However, all of these types of training will involve the CRF, which integrates circulatory, respiratory and muscular systems, the main target point for reducing the risk of morbidity and mortality in the CV diseases, including, of course, HT [8].

Regarding the characteristics of the training, most studies show a decrease in BP when hypertensive people exercise between 3 and 5 days a week in sessions of at least 30 minutes up to 1 hour. The studies have also shown that the greatest hypotensive effect is achieved when hypertensive people train between 40% and 70% of VO$_{2\text{max}}$ [25,40,41]. For many years, hypertensive patients were thought to control their diet strictly and either the amount and type of exercise. In the last years, interventions promoting the self--management of BP has proven be important in the control of blood pressure, allowing the subjects to control their progress and limits [38,41]. Indeed, the self--management has become an excellent tool for the patients, not only for the adherence to the protocols but also for checking their improvements. The introduction of new technologies has been increasing offering the possibility to daily check symptoms, treatment adherence and/or the physical activity performance [41].

The awareness of the importance of CRF increases the need for low cost, simple, valid, reliable, and safe methods to assessed it. In this line, numerous tests and formulas have been created to predict VO$_{2\text{max}}$, aiming to have an indicator to individualize the training prescription and monitor the benefits of the interventions [26].
1.3 ASSESSMENT OF AEROBIC FITNESS

Generally, the assessment of CRF is fulfilled in a clinical setting and supervised by health professionals. This assessment usually includes the collection of some data such as: the HR, the VO$_{2\text{max}}$, the BP (both SBP and DBP) and the ratings of perceived exertion (RPE). The VO$_{2\text{max}}$ is the highest rate at which oxygen can be taken in and utilised by the body in a given time. It is the most effective way to measure the aerobic capacity and is one of the main indicators of health [7–9]. One of the largest cohort studies [24] ever made showed that CRF is inversely associated with all--cause mortality.

The HR$_{\text{max}}$ is the highest HR that can be attained by an individual in strenuous activity. The measurement of these two values can be directly obtained from a GXT. However, this protocol is expensive, time--consuming, commonly not used in real--world setting and could lead the subject to high physical stress [8]. Hence, some submaximal tests have been created for easily predict the VO$_{2\text{max}}$ and the HR$_{\text{max}}$ in an inexpensively, simple and portable way. The main difference between them is the obtaining of the values. While in GXT the VO$_{2\text{max}}$ and the HR$_{\text{max}}$ are obtained directly; in the submaximal tests these values are obtained from the prediction of submaximal ones [42].

Several submaximal step--test protocols are available and validated. They differ in the frequency of the step, test duration and number of test stages [8,43]. The Chester Step Test (CST) is one of many tests that could be used to determine VO$_{2\text{max}}$ and prescribe physical activity. It was developed by Kevin Sykes for assessing aerobic fitness by predicting the maximal aerobic power [10]. One of the main advantages is the reduced equipment needed to perform it: a step, a HR monitor, the audio with the cassette tape and the RPE scale. Moreover, it is really adaptable to any aerobic condition of the people, letting chose the step weight which is better related to age and physical activity history. For predicting the values of VO$_{2\text{max}}$ it is also needed to take for granted a linear relation between mechanical load, VO$_{2}$ and HR obtained during the test; besides assuming that the HR$_{\text{max}}$ can be optimally predicted through the age--predicted formulas. When validated, the CST has shown an error from 5% to 15% for predicting VO$_{2\text{max}}$, which means values ranging from -9ml·kg$^{-1}$·min$^{-1}$ to 5.5ml·kg$^{-1}$·min$^{-1}$ [10,44]. One study [10] tried to reveal the reason of this error, trying to figure out which of the parameters was responsible for it. They concluded that errors in age--predicted formula and the estimation of VO$_{2}$ at each stage of the CST could lead to big errors in the final VO$_{2\text{max}}$ prediction.

In the other hand, the reliability for detecting changes has been better probed. Thus, this level of error could be acceptable just as a reliable measurement tool for health promotion, but not for taking important decisions [10].
Predicting $HR_{\text{max}}$ could be necessary to estimate $VO_{2\text{max}}$. There are several formulas describe in the literature and use for this purpose. The most common one is the Fox--Haskell formula $(220-\text{age})$ [45]; this formula has been widely used in research since 1971 when it was develop by Fox. However, this formula has historically reported some errors and may underestimate $HR_{\text{max}}$ [46,47]. However, there are also other formulas that can be used, such as the Tanaka formula $(208-0.7*\text{age})$ [47] and the Nes formula $(211-0.64*\text{age})$ [47,48].
CHAPTER 2  METHODS

2.1 PURPOSE

The purpose of this study was to examine the validity of the CST for estimating the VO$_{2\text{max}}$ in hypertensive and adults. A secondary aim was to check the influence of different formulas used for predicting the age--predicted HR$_{\text{max}}$ when estimating VO$_{2\text{max}}$ by the CST.

2.2 PARTICIPANTS

The present study included 11 subjects, diagnosed with essential arterial HT according to the recommendations of the ESC and the European Society of Hypertension [5]. The inclusion criteria were: age between 40 and 70 years old; SBP $\geq$ 140 mmHg, DBP $\geq$ 90 mmHg, or being medicated for HT. Patients with secondary HT, insulin--treated diabetes, unstable angina pectoris, pregnant women, or any other contraindication or medical condition that could limit participation in exercise (e.g. peripheral arterial occlusive disease and musculoskeletal disorder) were excluded. Participants were recruited in the HT clinic (consultation) of the Cardiology Department, Hospital Infante D.Pedro – Centro Hospitalar do Baixo Vouga, Aveiro. The hospital ethics committee approved the study (N/Ref. 24--01--2018). Participants provided written informed consent, and all procedures were conducted according to the Declaration of Helsinki.

Power calculation was previously computed using the software G*Power version 3.1 (University Düsseldorf, Germany). Based on Cohen’s values, a correlation of 0.5 or higher represents a strong correlation. For the current power calculation, a correlation of 0.8 was used to represent a strong correlation. Assuming a Type 1 and Type 2 error of 5% and 20%, respectively, this resulted in a sample size of 10 participants. In order to accommodate a 10%, dropout rate, and missing data, the estimated sample size was of 12 participants.
2.3 PROCEDURES

Participants visited the laboratory at the School of Health Sciences, University of Aveiro, for testing on one occasion. For practical reasons the CST was performed on the same day of the GXT. Participants performed first the CST, and then, the GXT was executed, leaving at least 15 minutes of rest, and being sure the basal HR was achieved again. Participants were instructed to avoid performing strenuous exercise 24 hours before testing and not to consume any food, caffeine, alcohol, or tobacco in the 3 hours before being assessed.

First, data on demographics, disease-related characteristics, medication and level of physical activity of the participants was gathered (annex 1). On the visit, height and weight measurements were attained using a standard wall-mounted stadiometer and scale (Seca 285, Seca, Birmingham, United Kingdom). Body mass index (BMI) was calculated from the ratio of weight (Kg) to squared height (m$^2$). Participants rested 5 minutes in a seated position before the assessment of HR and BP, which were measured using a digital automatic BP monitor (M6, Omron Healthcare Co, Kyoto, Japan). Participants sat down, resting their right arm on a table, so brachial artery was levelled with the heart. Two measurements were then obtained at intervals of 1 minute, and the average was recorded. If there was more than 5mmHg of difference, one more reading was obtained for averaging [49,50]. The evaluation room was kept quiet, and speaking was not allowed during BP measurements. A 12-lead ECG was performed at rest to clear participants to the exercise tests. Participants were not allowed to have knowledge of their HR to avoid bias. They were instructed in the use of RPE, of CST and in the GXT. All participants were informed about the procedures before starting with it and sign the informed consent.

2.3.1 CHESTER STEP TEST

The CST is a safe and practical submaximal test designed to assess aerobic fitness [44]. The test has 5 stages, each of 2 minutes’ duration. The step cadence is set with a cassette tape, which starts at 15 steps/min and increases by 5 steps/min every 2 minutes: stage 1 (15 steps/min), stage 2 (20 steps/min), stage 3 (25 steps/min), stage 4 (30 steps/min), stage 5 (35 steps/min). The test stops when 80% of the age-estimated HR$_{max}$ is exceeded or a value above 14 on Borg’s scale is reached. A minimum of 2 exercise HR (completing at least the first 2 stages of the Chester step test) is required. From the point that the regression line crosses the HR$_{max}$ prediction, a perpendicular line is drawn down to the graph’s X-axis, which gives an estimated VO$_{2max}$ (ranging from 10–
76ml·kg⁻¹·min⁻¹). In this study, the outcome evaluator who derived the \( \text{VO}_{2\text{max}} \) in the CST was blinded to the purpose of the study.

This test is based on two assumptions. The first one is the linear relationship between HR and \( \text{VO}_{2\text{max}} \). These values increase simultaneously and linearly with the increasing of workload, this behaviour last until the 80--85% of the \( \text{VO}_{2\text{max}} \). The other one is that \( \text{HR}_{\text{max}} \) is age--dependent, and the estimation of it will differ depending on the age--predicted formula used.

In this protocol \( \text{HR}_{\text{max}} \) was calculated with three different formulas Fox--Haskell formula \((220--\text{age})\), Tanaka formula \((220--0.7*\text{age})\) and Nes formula \((220--0.64*\text{age})\). Besides the Fox--Haskell formula was used for estimating the \( \text{HR}_{\text{max}} \) and then to determine the 80% of age--predicted \( \text{HR}_{\text{max}} \) (the end point of the CST).

Each subject underwent a step--test training prior the test to determine if he or she was able to keep up the cadence set by the metronome. All participants performed the CST using the movement techniques described in the CST manual and instructions on the cassette tape.

The estimated oxygen cost (\( \text{VO}_2 \) in ml·Kg⁻¹·min⁻¹) for each stage of the CST was taken from version three of the CST resource manual. The source of these \( \text{VO}_2 \) estimations is not reported within the manual, but they agree to within 1.5 ml·Kg⁻¹·min⁻¹ of the estimation calculation for stepping outlined by the American College of Sports Medicine.

In either case, estimated \( \text{VO}_2 \) is a function of the step height (m) and stepping rate (steps/min). Based on the CST manual recommendations for age and activity history, a 0.15 m step was chosen for this group of participants; the estimated \( \text{VO}_2 \) values for CST stages I through V were 11, 14, 18, 21 and 25 ml·Kg⁻¹·min⁻¹, respectively.

### 2.3.2 INCREMENTAL EXERCISE TEST

The GXT allows a direct measurement of \( \text{VO}_{2\text{max}} \). Typically, \( \text{VO}_{2\text{max}} \) tests can be performed on a treadmill or cycle ergometer. For this study, a maximal cycle test was chosen to determine maximal oxygen consumption rather than a treadmill protocol for several reasons. Firstly, cycle ergometer and step tests have been shown to yield similar \( \text{VO}_{2\text{max}} \) results, with both methods tending to result in lower \( \text{VO}_{2\text{max}} \) values when compared to treadmill tests [51]. Secondly, maximal cycling tests in older and inactive adults increase safety by allowing smaller gradations in work and a higher quality ECG. Different values were measured during the cyclo ergometer test until volitional exhaustion with continuous monitorization by a 12--lead ECG. The participant was instructed to keep a cadence of 60 revolutions per minute (rpm) until volitional exhaustion. The first 2 min of the test involved pedalling at 50 watts. Every two minutes,
resistance augmented in increments of 25 watts, until volitional exhaustion. HR, BP and RPE were measured at the end of every two-minute stage [52]. Pulmonary gas exchange analysis was performed throughout the test (Cardiovit CS--200 Ergo--Spiro, Schiller, Baar, Switzerland). Measurement of VO$_2$, CO$_2$ production, minute ventilation, and respiratory exchange ratio (RER) were collected breath--by--breath. Peak VO$_2$ was defined as the highest VO$_2$ achieved by the participant during the test. Values for VO$_2$ were indexed to body weight. HR was monitored during the test and averaged every 20s. Peak HR was considered the highest mean 20s value achieved during the test. BP was measured with a mercury sphygmomanometer at rest, during the last 45s of each stage of exercise, and in the last 15s of exercise near the end of the test. Peak SBP and DBP were recorded as the highest value achieved during the test. Outcome measures obtained during the cycling test to volitional exhaustion included VO$_2$ peak, peak HR, RER, and ratings of perceived exertion (RPE). The test was accepted to be limited by the cardiorespiratory system when the participants no longer could maintain the targeted 60rpm along with at least two of the following criteria: a RER>1.10, RPE exceeded 16 out of 20 according to the Borg's RPE scale and a HR$_{\text{max}}$ exceeding 90% of the estimated age--predicted HR$_{\text{max}}$ (220--age) [45]. Before each test session the pulmonary gas exchange system was calibrated for respiratory gases and air flow using standardized gases and a 3 litters calibration syringe, respectively.

2.4 DATA TREATMENT AND STATISTICS

A database was generated in Microsoft Excel for been analyzed using SPSS 22 for Windows (SPSS Inc, Chicago, IL, USA) where statistical significance for all tests was set up at $p \leq 0.05$. Qualitative data are described using frequencies and percentages. Descriptive quantitative data are described using the mean, median and standard deviation (SD). The Shapiro-Wilk test and analysis of histograms were used to assess the normality of the data ($p \leq 0.05$).

Pearson’s correlation was used to calculate the strength and the direction of the association among the measurement of the VO$_2$peak during the exercise test and VO$_2$max estimated by the CST with the three different formulas. The results were interpreted according to Cohen’s values ranging from 0 to 1 point [53]. Thereby, from 0.50 to 1 it was considered a strong association between the values 0.30--0.49 a moderate association and from 0.10--0.29 the association was actually small. However, another test was needed to check the agreement of the data since the Pearson's correlation was just informing about how much associate were the values and not which was the agreement between them. Hence, the agreement between the VO$_2$max predicted by the
CST and the actual \( \text{VO}_{2\text{max}} \) from the GXT was assessed using the bias ±95% limits of agreement (LoA). Paired t-tests were used to test differences between measured VO\(_2\) and the VO\(_2\) estimated from the CST. A Bland and Altman plot [54] was used to visualize graphically the agreement. Upper and lower LoA closed to 0 meant similar results were detected. Thus, the limits established the range where approximately the 95% of the cases were expected to be found.
CHAPTER 3 RESULTS

3.1 CHARACTERISTICS OF THE PARTICIPANTS

Eleven subjects formed the sample, 7 males (63.63%) and 4 women (36.36%) diagnosed with arterial HT. The average age was 53.91 ± 7.38 years and the BMI 28.36 ± 5.01 Kg/m², indicating the sample was overweight.

Regarding the healthy habits, it was observed that the sample tended to follow unhealthy habits; 63.6% of the sample had either present or history of tobacco, even that in the present the percentage of smokers represents only 36.36%. The participants were not participating in exercise or recreational sport. Most of them reported not to perform at least 30 minutes of moderate physical activity per day in any day of the week (45.45%).

All the participants were taken HTA drugs. However, the three most used drugs were the angiotensin--converting enzyme (ACE) inhibitors (36.36%), calcium channels blockers (CCB) (36.36%) and the diuretics (36.36%). Just two patients (18.18%) were under lipid--lowering drugs and two were treated with antiplatelet. The characteristics of the participants are summarized in Table 2.
<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>53.91±7.38</td>
<td>55.00</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>81.78±16.19</td>
<td>77.50</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.70±0.08</td>
<td>1.68</td>
</tr>
<tr>
<td>BMI (Kg/m²)</td>
<td>28.36±5.01</td>
<td>27.97</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
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<td></td>
</tr>
<tr>
<td>Female</td>
<td>4</td>
<td>36.36</td>
</tr>
<tr>
<td>Male</td>
<td>7</td>
<td>63.63</td>
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<tr>
<td>Tobacco habits</td>
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<td></td>
</tr>
<tr>
<td>Yes</td>
<td>7</td>
<td>63.63</td>
</tr>
<tr>
<td>No</td>
<td>4</td>
<td>36.36</td>
</tr>
<tr>
<td>Tobacco history</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>4</td>
<td>36.36</td>
</tr>
<tr>
<td>Past</td>
<td>3</td>
<td>27.27</td>
</tr>
<tr>
<td>Nowadays</td>
<td>4</td>
<td>36.36</td>
</tr>
<tr>
<td>Alcohol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>3</td>
<td>27.27</td>
</tr>
<tr>
<td>Daily</td>
<td>4</td>
<td>36.36</td>
</tr>
<tr>
<td>1-3 times/week</td>
<td>3</td>
<td>27.27</td>
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<tr>
<td>1-3 times/month</td>
<td>1</td>
<td>9.09</td>
</tr>
<tr>
<td>Physical activity (30 min of moderate per day)</td>
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<td></td>
</tr>
<tr>
<td>No</td>
<td>5</td>
<td>45.45</td>
</tr>
<tr>
<td>1-2 times/week</td>
<td>2</td>
<td>18.18</td>
</tr>
<tr>
<td>≥3 times/week</td>
<td>4</td>
<td>36.36</td>
</tr>
<tr>
<td>Medication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACE inhibitors</td>
<td>4</td>
<td>36.36</td>
</tr>
<tr>
<td>CCB</td>
<td>4</td>
<td>36.36</td>
</tr>
<tr>
<td>ARBs</td>
<td>3</td>
<td>27.27</td>
</tr>
<tr>
<td>Antiplatelet</td>
<td>2</td>
<td>18.18</td>
</tr>
<tr>
<td>Diuretics</td>
<td>4</td>
<td>36.36</td>
</tr>
<tr>
<td>Lipid-lowering drugs</td>
<td>2</td>
<td>18.18</td>
</tr>
<tr>
<td>Beta-blockers</td>
<td>1</td>
<td>9.09</td>
</tr>
</tbody>
</table>

SD = Standard deviation, BMI = body mass index, ACE = angiotensin converting enzyme, CCB = calcium channels blockers, ARBs = angiotensin II receptor blocker
3.1 RESULTS OF THE TESTS

As regards the characteristics of the GXT (table 3), the participants achieved 151.27 ± 15.34 watts while performing it. The HR increased 68.09 bpm in comparison with the base value of 83.18 ± 9.9 at the beginning of the test, to a HR\textsubscript{max} measured of 151.27 ± 15.34 bpm. Most of the participants, but one, completed at least 6 minutes in the GXT, being the duration of the test 7.55± 3.53min. The VO\textsubscript{2peak} obtained in the GXT was 24.53 ± 8.10 ml·Kg\textsuperscript{-1}·min\textsuperscript{-1}, no differences were observed in the peak VO\textsubscript{2} between males and females (p=0.129). The achieved peak VO\textsubscript{2} represents 94.64% of the predicted VO\textsubscript{2max} (94.64 ± 21.36 ml·Kg\textsuperscript{-1}·min\textsuperscript{-1}) for this group of participants.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mean (SD)</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR at rest (bpm)</td>
<td>83.18 ± 9.9</td>
<td>89.00</td>
</tr>
<tr>
<td>HR\textsubscript{max} (bpm)</td>
<td>151.27 ± 15.34</td>
<td>152.00</td>
</tr>
<tr>
<td>SBP at rest (mmHg)</td>
<td>132.45 ± 13.91</td>
<td>128.00</td>
</tr>
<tr>
<td>DBP at rest (mmHg)</td>
<td>87.73 ± 4.36</td>
<td>87.00</td>
</tr>
<tr>
<td>SBP at peak exercise (mmHg)</td>
<td>186.55 ± 19.31</td>
<td>190.00</td>
</tr>
<tr>
<td>DBP at peak exercise (mmHg)</td>
<td>91.27 ± 14.97</td>
<td>90.00</td>
</tr>
<tr>
<td>Duration of the test (min)</td>
<td>7.55 ± 3.53</td>
<td>6.00</td>
</tr>
<tr>
<td>Maximal workload (Watt)</td>
<td>151.27 ± 15.34</td>
<td>152.00</td>
</tr>
<tr>
<td>RER at measured VO\textsubscript{2peak}</td>
<td>1.13 ± 0.09</td>
<td>1.10</td>
</tr>
<tr>
<td>VO\textsubscript{2} peak percentage (%)</td>
<td>94.64 ± 21.36</td>
<td>87.00</td>
</tr>
<tr>
<td>Measured VO\textsubscript{2peak} (ml·Kg\textsuperscript{-1}·min\textsuperscript{-1})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total group</td>
<td>24.53 ± 8.10</td>
<td>21.91</td>
</tr>
<tr>
<td>Females</td>
<td>18.80 ± 3.10</td>
<td>18.10</td>
</tr>
<tr>
<td>Males</td>
<td>27.80 ± 8.37</td>
<td>27.56</td>
</tr>
</tbody>
</table>

Measured VO\textsubscript{2peak} = maximal oxygen uptake at peak exercise, RER = respiratory ratio exchange, HR = heart rate, bpm = beats per minute, BP = blood pressure, RPE = ratings of perceived exertion
The results of the CST are summarized in Table 4. The test was fully finished just by one participant, 4 of the participants (36.36%) complete two stages, 1 participant (9.09%) complete three stages, and the remaining 5 participants (45.45%) completed four stages of the CST. The recommendations from the CST resource manual suggested all the values of HR are valid to estimate the VO$_{2\text{max}}$ and more accurate when two stages at least were completed. In this study the average of completed staged was 3.37 ± 1.10. When the mean HR at the final stage of each participant was 133.45 ± 14.77 bpm. The 133.45 bpm obtained in the CST represents 88.21% of the HR$_{\text{max}}$ achieved in the GXT.

All age--predicted formulas estimated higher HR$_{\text{max}}$ values than the real ones. The Fox--Haskell formula (220--age) resulted to be the closest one with an overestimation of 14.83 bpm. In the other hand, Nes formula (220--0.64*age) had the highest HR$_{\text{max}}$ overestimation with 25.22 bpm.

Likewise, all age--predicted also overestimated the real value of the VO$_{2\text{max}}$, ranging from 0.31 ml·Kg$^{-1}$·min$^{-1}$ to 2.05 ml·Kg$^{-1}$·min$^{-1}$. The formulas showed a small SEE ranging from 1.33 ml·Kg$^{-1}$·min$^{-1}$ to 1.58 ml·Kg$^{-1}$·min$^{-1}$. However, the SD of all formulas were high and all bigger than 7.64 ml·Kg$^{-1}$·min$^{-1}$. 
<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR stage 1 (n=11) (bpm)</td>
<td>97.91 ± 10.02</td>
<td>96.00</td>
</tr>
<tr>
<td>HR stage 2 (n=11) (bpm)</td>
<td>113.36 ± 13.83</td>
<td>114.00</td>
</tr>
<tr>
<td>HR stage 3 (n=7) (bpm)</td>
<td>122.57 ± 19.92</td>
<td>117.00</td>
</tr>
<tr>
<td>HR stage 4 (n=6) (bpm)</td>
<td>133.33 ± 17.35</td>
<td>140.00</td>
</tr>
<tr>
<td>HR stage 5 (n=1) (bpm)</td>
<td>122</td>
<td>122.00</td>
</tr>
<tr>
<td>HR at finishing stage (bpm)</td>
<td>133.45 ± 14.77</td>
<td>133.00</td>
</tr>
<tr>
<td>RPE at finishing stage (Borg’s scale)</td>
<td>12.36 ± 2.01</td>
<td>13.00</td>
</tr>
<tr>
<td>Completed stages</td>
<td>3.37 ± 1.10</td>
<td>4.00</td>
</tr>
</tbody>
</table>

**Age-predicted formulas (bpm)**

<table>
<thead>
<tr>
<th>Formula</th>
<th>Mean ± SD</th>
<th>SEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age-predicted $HR_{max}$ Fox-Haskell</td>
<td>166.10 ± 7.38</td>
<td>5.94</td>
</tr>
<tr>
<td>Age-predicted $HR_{max}$ Tanaka</td>
<td>170.26 ± 5.16</td>
<td>4.16</td>
</tr>
<tr>
<td>Age-predicted $HR_{max}$ Nes</td>
<td>176.49 ± 4.72</td>
<td>3.80</td>
</tr>
<tr>
<td>Age-predicted $HR_{max}$ mean value</td>
<td>170.95 ± 5.76</td>
<td>4.64</td>
</tr>
</tbody>
</table>

**Predicted $VO_{2max}$ (ml·Kg⁻¹·min⁻¹)**

<table>
<thead>
<tr>
<th>Formula</th>
<th>Mean ± SD</th>
<th>SEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fox-Haskell formula</td>
<td>24.84 ± 7.64</td>
<td>1.33</td>
</tr>
<tr>
<td>Tanaka formula</td>
<td>25.59 ± 7.84</td>
<td>1.55</td>
</tr>
<tr>
<td>Nes formula</td>
<td>26.58 ± 8.13</td>
<td>1.58</td>
</tr>
<tr>
<td>Mean value of the 3 formulas</td>
<td>25.67 ± 7.87</td>
<td>1.46</td>
</tr>
</tbody>
</table>

HR=heart rate, RPE = ratings of perceived exertion, SEE = standard error of estimate.
Figure 1 (Graphs A and B) summarize the values of RPE and HR from stages 1 to 4. Both graphs showed a linear relationship between the HR, the RPE and the increase of the load; reaching an HR of 133.45 ± 14.77 bpm and 12.36 ± 2.01 points in the Borg scale in the last valid step.

3.2 ASSESSMENT OF VALIDITY

All Pearson’s correlation coefficients showed a positive and strong relationship between the measured and the estimated VO₂. The values range between $r=0.982$ and $r=0.986$ (Table 5), being the strongest correlation the estimation done by the Fox–Haskell formula (220–age) and the lowest the one by the Nes formula (211–0.64*age). Calculating the VO₂ from the average of the three formulas did not increase the correlation in comparison to the Fox–Haskell formula.

<table>
<thead>
<tr>
<th>VO₂ ml·Kg⁻¹·min⁻¹</th>
<th>Mean (SD)</th>
<th>r-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured VO₂peak</td>
<td>24.53 (8.10)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Estimated VO₂max by Fox-Haskell formula</td>
<td>24.85 (7.65)</td>
<td>0.986</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Estimated VO₂max by Tanaka formula</td>
<td>25.60 (7.84)</td>
<td>0.982</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Estimated VO₂max by Nes formula</td>
<td>26.58 (8.14)</td>
<td>0.983</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Estimated VO₂max by the average of the 3 formulas</td>
<td>25.67 (7.87)</td>
<td>0.984</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
In the Figure 2 (graphs C--F) overestimations can be observed in most of the values. In relation to the Fox--Haskell formula, the figure suggested it was better to predict low values of VO$_{2\text{max}}$, while the Tanaka predicted better the higher values. The Nes formula overestimated both values equally.
The paired t--test revealed a significant difference between the measure VO$_{2\text{peak}}$ and the VO$_{2\text{max}}$ derived from the CST when using the Tanaka formula [mean diff (95% CI): --1.065 (--2.087 -- --0.042), p=0.043], the Nes formula [mean diff (95% CI): --2.056 (--3.063 -- --1.478), p=0.001], and the mean of the 3 formulas [mean diff (95% CI): --1.145 (--2.107 -- --0.184), p=0.024]. No differences were observed for the Fox--Haskell formula [mean diff (95% CI): --0.319 (--1.248 -- 0.610), p=0.462].

The 95% LoA are displayed in Table 6. Fox--Haskell formula range from 3.03 to --2.4 ml·Kg$^{-1}$·min$^{-1}$. The other formulas obtained a 95% LoA of: Tanaka formula from 4.05 to --1.914 ml·Kg$^{-1}$·min$^{-1}$; Nes formula from 5.00 to --0.88 ml·Kg$^{-1}$·min$^{-1}$; and the average of the three formulas from 3.95 to --1.66 ml·Kg$^{-1}$·min$^{-1}$.

<table>
<thead>
<tr>
<th>TABLE 6. BIAS +95% LoA BETWEEN THE DIFFERENCES AND THE MEANS OF THE ESTIMATED VO$<em>{2\text{max}}$ AND THE MEASURED VO$</em>{2\text{peak}}$</th>
<th>95% LoA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upper limit (% of difference)</td>
</tr>
<tr>
<td>Measured – estimated by Fox-Haskell</td>
<td>3.03 (13.62%)</td>
</tr>
<tr>
<td>Measured – estimated by Tanaka</td>
<td>4.05 (20.82%)</td>
</tr>
<tr>
<td>Measured – estimated by Nes</td>
<td>5.00 (28.72%)</td>
</tr>
<tr>
<td>Measured – estimated by average 3 formulas</td>
<td>3.95 (20.75%)</td>
</tr>
</tbody>
</table>
In Bland and Altman plots (Figure 3) it can be observed the distribution of the results and the representation of the 95% LoA. The graphics showed an independent distribution between the differences of estimated VO$_{2\text{max}}$ and the measured VO$_{2\text{peak}}$ levels.

FIGURE 3. BLAND AND ALTMAN PLOTS OF ESTIMATED VO$_{2\text{max}}$ VS MEASURED VO$_{2\text{peak}}$ EXPRESSED IN ML·KG$^{-1}$·MIN$^{-1}$
Mean = red line
Mean + 2SD = discontinue red lines
CHAPTER 4  DISCUSSION

This is the first study to assess the validity of the CST for estimating VO\textsubscript{2max} in hypertensive people. The results of this study indicate a good estimation of VO\textsubscript{2max} made by the CST, becoming this test a valid instrument to estimate VO\textsubscript{2max} in this population. Nowadays hypertensive people represent a large percentage of our older adult population, and most of the times their CRF level is not assessed in clinical settings. Submaximal step test provides a safe and straightforward way to evaluate it.

Nonetheless, there are more than 10 step tests protocols described in the literature, making difficult the validation of each one due to the lack of strong evidence and how to compare the results when there are few studies.

The findings of the present study become more relevant in hypertensive patients, where CV risk is higher than the average and VO\textsubscript{2max} is a substantial predictor value for mortality. A systematic review with meta-analysis indicates that a value below 28 ml·Kg\textsuperscript{-1}·min\textsuperscript{-1} means low CRF level which increases the mortality risk [55]. In our study, the VO\textsubscript{2max} average of the patients was 24.53 ± 8.10, a relatively low value, insomuch as they already have a CV disease. When studied by sex, VO\textsubscript{2max} peak obtained in the GXT tended to be lower for the women 18.80 ± 3.10 ml·Kg\textsuperscript{-1}·min\textsuperscript{-1} versus 27.80 ± 8.37 ml·Kg\textsuperscript{-1}·min\textsuperscript{-1} in men; however, it was not statistically different. This tendency in our study probably could be confirm with a bigger sample size, since systematic reviews point out that women have lower VO\textsubscript{2max} than the men [56].

Nowadays hypertensive people represent a large percentage of our older adult population, and most of the times their CRF level is not assessed in clinical settings. First of all, VO\textsubscript{2max} prediction of the submaximal test is based on the assumption that the relationship between VO\textsubscript{2max} and HR is linear with increase of the load. Studies showed a strong correlation between them (r=0.991, p<0.001), and also a significant relationship between the RPE and the VO\textsubscript{2max} (r=-0.904, p<0.05) [57]. Figures A and B show this behaviour of RPE and HR, even though a small exponential line could be seen. This tendency is also observed in other studies. Buckley et al. [58] in their study with healthy people, proposed that the exponential line could be caused by the error of the VO\textsubscript{2max} estimated by the CST protocol and the real one in stage 1.

A general assumption is that HR is age-dependent, and in order to estimate VO\textsubscript{2max} one needs to predict the HR\textsubscript{max}. There are many formulas, and there is none that does not
present errors. The Fox--Haskell formula has reported errors when studied it up to 20bpm, underestimating with increasing age, but making good predictions for the young adults [47,48,59]. The Tanaka formula was tested with a group of healthy, unmedicated and nonsmoking adults; however, this formula also underestimates the HR$_{\text{max}}$ in the elders up to 20 bpm [47]. The Nes formula [48] was also tested by the first time in healthy, unmedicated and nonsmoking subjects and they found no influences of gender, physical activity status or BMI, however a SEE of 10.8bpm could be expected. In our study all formulas tended to overestimate instead of underestimates. Fox--Haskell formula was the one which overestimated the less with 14.83 bpm, although the SEE reached 5.94 bpm. In the other hand, the Nes formula was the one which overestimated the most with 25.22 bpm and a SEE of 3.8; finally, the Tanaka formula overestimate the HR$_{\text{max}}$ by 18.99 with a SEE of 4.16.

In our study, the CST tended to overestimate more than underestimate the real values, even though there was a really robust correlation ($r=0.986--0.982$), depending on the formula used for estimating the HR$_{\text{max}}$. There is only another study in the literature where the authors estimated the VO$_{2}\text{max}$ from a submaximal step test in people with CV risk factors [60]. In this case, they estimated the peak oxygen consumption by the Astrand/Van Dobeln equations, the Milligam equation and one proposed by Sharkey. They used the Tecumseh sub--maximal test, a 3 minutes step test with a 20cm step. They obtained a strong correlation $r=0.80$ with the Astrand/Van Dobeln formula. However, the two other estimation methods were poorly correlated with the actual value.

A systematic review in 2015 [8] which included 11 studies assessing different protocols of submaximal step test summarized correlations between 0.64--0.95, of which, the best ones belonged to the CST protocols and the personalized step test. However, for the rest of the protocols, the review concluded that they had in average moderate evidence to estimate the VO$_{2}\text{max}$ in healthy adults. Guo et al. [61] using the Ruffier squat test also in a healthy population found a correlation of 0.80, here the participants were taught to perform 30 squats in 45 seconds. Other studies which used submaximal test but for other pathologies also found a strong correlation coefficient. Cooney JK et al. [62] used the Siconolfi step test, a 25.4cm step for 3 minutes in rheumatoid arthritis patients and they obtained a correlation of $r=0.79$. Nordgren et al. [42] also evaluated two submaximal test in people with rheumatoid arthritis. When assessing the Fox--walk test and the Astrand cycle test a moderate correlation was obtained, $r=0.52$ and $r=0.68$ respectively. Interestingly, most of these coefficients were higher when the VO$_{2}\text{max}$ was measured by L/min, however, this measure does not contemplate the influence of the weight of each subject. It is essential to take this variable into account as it can completely change the result.
Our results indicate that the CST have in general a strong correlation when estimating the VO$_{2\text{max}}$. However, a strong correlation does not mean a good agreement between the methods. This agreement was used to know whether the estimation method was obtaining a value close and similar to the real one. The paired T--Test revealed there was a statistical difference between measured and estimated values when Nes and Tanaka formula were used (p=0.001, p=0.043, respectively). In the other hand, Fox--Haskell formula prediction had no statistical difference compared to the real VO$_{2\text{max}}$ (p=0.462). The 95% LoA for the estimated VO$_{2\text{max}}$ appearing in the graphics showed a wide range of values, oscillating from -2.4 to 5 ml·Kg$^{-1}$·min$^{-1}$. These values seem to be small; however, an overestimation of 5 ml·Kg$^{-1}$·min$^{-1}$ in a person could suppose a 28.72% VO$_2$ more of the real value. The study in percentages of the 95%LoA range from --8.49% to 28.72%, corresponding to the estimation made when the Fox--Haskell formula and the Nes formula were used, respectively. All formulas had a bigger tendency to overestimate.

Two studies which assessed the CST with the Fox--Haskell formula [10,44] found a bias of -0.8±3.7ml·Kg$^{-1}$·min$^{-1}$, meaning an error of the estimation between 11--17%. Values very similar to those were obtained in the current study. The study done in rheumatoid arthritis patients using Siconolfi step protocol presented a 95% LoA of ±5.7 ml·Kg$^{-1}$·min$^{-1}$, a bit superior compared with the other studies. Alike, the SEE was 2.6ml·Kg$^{-1}$·min$^{-1}$, the double than we found (1.33 ml·Kg$^{-1}$·min$^{-1}$) in the prediction of VO$_{2\text{max}}$ made by the Fox--Haskell formula. The results of rheumatoid arthritis patients in the study completed by Nordgren et al. drew attention [42] since they obtained a 95% LoA ranging from --3.4ml·Kg$^{-1}$·min$^{-1}$ to 25.4 ml·Kg$^{-1}$·min$^{-1}$. While the small overestimation of most studies could be explained by accumulated errors in the age--predicted formula and/or in the realization of the test, the case of Nordgren et al. cannot be compared with them.

Summarizing, a very strong correlation was found between the predicted VO$_{2\text{max}}$ made by the CST and the real value, however, it is important to take into account the small sample size. The Fox--Haskell formula seems to be the best age--predicted formula to use with this population, since the other results were statistically different from the actual VO$_{2\text{max}}$. The bias with the real VO$_{2\text{peak}}$ could be not significant when prescribing physical activity, but the presence of errors can make the CST not a tool when vital decisions should be taking, at least with the current evidence. All health professionals who can work with this tool must be aware of these limitations.
4.1 LIMITATIONS OF THE STUDY

The present study has some limitations that should be acknowledged. First, the present results should be interpreted cautiously given the small sample size; even though, the existing validation studies of submaximal tests had similar sample sizes. Second, our study enrolled mainly male, thus a stratified analysis by gender was not possible. Third, the lack of time and availability of participants to take part in multiple day assessments was also a limitation, so it was needed to take all measurements on the same day. Hence, the final results could be influenced by the accumulated fatigue of the participants from one test to the other; even there was a prudential time to rest. Actual errors on the age--predicted formulas described in the evidence could also lead to problems when validating CST as a tool for predicting the actual VO$_{2\text{max}}$, and not only for monitoring the physical activity.

As regards to the CST, in this study we used the proposed estimation of VO$_{2\text{max}}$ by the CST manual for the 0.15m step. However, this estimation is based in healthy subjects and have not been tested yet in hypertensive people, so that could also lead to an error in the VO$_{2\text{max}}$ estimated for each participant.

4.2 FUTURE LINES OF RESEARCH

This study is the first step for validating the CST as a test to assess CRF and prescribe physical activity and exercise for hypertensive people. However, more studies are needed, since this one is based in a small sample. From here it will also be needed to study how to apply the programs to the community and see how to reach the highest adherence to it. Although the aim of this study was not this one, we could observe that just explaining the patients the importance, for example, of the VO$_{2\text{max}}$ value which is an indicator of health, they were more predisposed to start somehow to do some exercise. Therefore, could be interesting to make an educational intervention before starting to prescribe exercise if it is not supervised.

The reliability of this test will also have to be analyzed, especially the inter--rater and the test--retest reliability to test out the degree of agreement of the values when working with this population.

Other areas of further research include, how to minimize the errors of the age--predicted formulas; evaluating the validity and reliability of the CST in hypertensive participants with other characteristics or other associated conditions; test if the estimated VO$_{2\text{max}}$ recommended by the CST is valid for this population.
CHAPTER 5  CONCLUSIONS

In an increasingly sedentary society, it is crucial that health professionals have at their disposal easy and useful tools to assess CRF. In recent years, the interest in VO\textsubscript{2max} has increased for its potential to be one of the best indicators and predictors of health. Commonly it is assessed from a maximal test; however, it is expensive, time--consuming and needs an experimented professional for interpreting the results. The submaximal test appears to be a solution for health professionals when taking essential decisions is not needed. On the other hand, the relationship between HT and an increase of CV risk has been adequately demonstrated and, physical activity has been tested successfully as a complement to reduce this risk, almost entirely without secondary effects. The assessment of CRF (VO\textsubscript{2max}) is needed when prescribing exercise and/or monitoring the process and success of the intervention.

In conclusion, the results of this study seems to show CST as a good tool for predicting VO\textsubscript{2max} in hypertensive people and subsequently be used to prescribe physical activity taking into account its limitations. Based on our results, the Fox--Haskell formula is preferable for predicting the HR\textsubscript{max}, when using the CST.

We recommend further research with this test since the results show an exciting and easy tool for predicting the VO\textsubscript{2max} in hypertensive people, accessible to the vast majority of health professionals.


46. Londeree BR, Moeschberger ML. Effect of Age and Other Factors on Maximal Heart


CHAPTER 7  ANNEX

7.1 ANNEX 1. PARTICIPANT’S QUESTIONNAIRE

Assinale apenas uma resposta para cada item

1. Idade ______ anos

2. Sexo:
   - [ ] Femenino
   - [ ] Masculino

3. Peso: ______ Kg   Altura:__________ (m)   IMC ________ (Kg/m²)

4. Estado civil:
   - [ ] Solteiro (a)
   - [ ] Casado (a)
   - [ ] Viúvo (a)
   - [ ] Divorciado (a)
   - [ ] União de facto

5. Qual é o seu grau de escolaridade:

6. Hábitos tabágicos:
   a) Atualmente tem hábitos tabágicos?   SIM / NÃO
      Se respondeu SIM passe para a alínea d)
   b) Ao longo da sua vida, teve hábitos tabágicos?   SIM / NÃO
      Se respondeu NÃO passe para a alínea c)
   c) Há quantos anos deixou de fumar? ________ anos
   d) Durante quantos anos fumou/fuma? ________ anos
   e) Em média, quantos cigarros fuma/fumou por dia? ______

7. Bebidas alcoólicas:
   a) Consome bebidas alcoólicas:   SIM / NÃO
      Se respondeu não passe para a alínea b)
b) Com que frequência bebe bebidas alcoólicas?

☐ Diariamente  ☐ 1--3 vezes por semana  ☐ 1--3 vezes por mês

c) Quando consome bebidas alcoólicas, em média, quantas bebidas bebe?

☐ 1--2  ☐ 3--4  ☐ 5 ou mais

8. Antecedentes familiares:

________________________________________________________________________________
________________________________________________________________________________

9. História clínica

a) Antecedentes pessoais:

________________________________________________________________________________

b) Medicação crónica:

________________________________________________________________________________

10. Tem diabetes II?  SIM / NÃO

a) Se sim, usa insulina? ___________

11. Tem alguma limitação para a prática de exercício físico?  SIM / NÃO

Se sim, qual?

________________________________________________________________________________

Pratca exercício físico regularmente?  SIM / NÃO

Se sim, quantas vezes por semana: _______

Durante quanto tempo_______________ (minutos)