Universidade do Estado do Rio de Janeiro
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Fase de verificação para confirmar o 'verdadeiro' $VO_{2máx}$ em adultos aparentemente saudáveis: análise meta-analítica dos critérios adotados

Rio de Janeiro
2020

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Dissertação apresentada, como requisito parcial para obtenção do título de Mestre, ao Programa de Pós-Graduação em Ciências do Exercício e do Esporte, da Universidade do Estado do Rio de Janeiro. Área de concentração: Aspectos Biopsicossociais do Exercício.

Orientador: Prof. Dr. Felipe Amorim da Cunha

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RESUMO

COSTA, Victor André Balbino. *Fase de verificação para confirmar o 'verdadeiro' $VO_{2máx}$ em adultos aparentemente saudáveis:* análise meta-analítica dos critérios adotados. 2020. 139 f. Dissertação (Mestrado em Ciências do Exercício e do Esporte) – Instituto de Educação Física e Desportos, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, 2020.

O teste cardiopulmonar de exercício (TCPE) é considerado método padrão-ouro para avaliação da potência aeróbia máxima expressa pelo consumo máximo de oxigênio ($VO_{2máx}$). O critério primário para confirmação do "*verdadeiro*" $VO_{2máx}$ é baseado na obtenção de um platô no VO_2 ao final do TCPE, ou em critérios secundários, como valores de pico para razão de troca respiratória, porcentagem da frequência cardíaca máxima predita pela idade ou concentrações de lactato sanguíneo pós-TCPE. No entanto, o platô no VO_2 frequentemente não é observado. Por outro lado, a adoção dos critérios secundários pode resultar na avaliação imprecisa do $VO_{2máx}$. Como procedimento alternativo para superar essas limitações, tem sido proposta a realização de uma sessão adicional de exercício após a fase incremental do TCPE, denominada "fase de verificação". Porém, dúvidas permanecem no tocante à validade e aplicação dessa abordagem como um procedimento necessário para medida do $VO_{2máx}$. O objetivo desta Dissertação de Mestrado foi investigar, por meio de meta-análise, a aplicação da fase de verificação como procedimento para confirmação do $VO_{2máx}$ obtido em TCPE em adultos aparentemente saudáveis. Adicionalmente, a influência de critérios adotados na fase de verificação sobre os tamanhos de efeito das diferenças *vs*. TCPE foram analisados. A revisão foi conduzida de acordo com as recomendações PRISMA, incluindo-se estudos em língua inglesa. As seguintes bases de dados foram utilizadas até 30 de janeiro de 2020: MEDLINE (viaPubMed), *Web of Science*, SPORTDiscus e *Cochrane* (via Wiley), combinando descritores a partir do *medical subjects heading* (MeSH). Adicionalmente, foi realizada busca manual nas referências de estudos publicados sobre o assunto. Meta-análises foram realizadas para determinar a diferença média entre os valores mais elevados de VO_2 e a frequência cardíaca nas fases incremental e de verificação. Análises de subgrupo foram usadas para avaliar possíveis fatores moderadores. O protocolo da revisão foi registrado na base *International Prospective Register of Systematic Reviews* (PROSPERO) e aprovado sob o número CRD42019123540. Após aplicação dos critérios de elegibilidade 78 estudos foram incluídos no estudo (amostra total de 1.634 participantes; faixa de idade 19-68 anos). Não houve diferença entre o $VO_{2máx}$ *vs*. VO_{2verif} [n = 52, diferença média = 0,02 (IC 95% = -0,01 a 0,06) L/min, P = 0,17]. Além disso, o VO_{2verif} não foi afetado por sexo, nível de aptidão cardiorrespiratória, modalidade de exercício, protocolo para TCPE bem como forma de realização da fase de verificação. Porém, a maior frequência cardíaca obtida na fase de verificação foi significativamente menor do que a obtida no TCPE [n = 36, diferença média = 2,7 (95% IC = 2,0 a 3,5) L/min, P < 0,00001]. Conclui-se que a fase de verificação é um procedimento robusto para confirmar o verdadeiro $VO_{2máx}$ em indivíduos aparentemente saudáveis. No entanto, a utilização da frequência cardíaca como critério suplementar à confirmação do $VO_{2máx}$ não pode ser atualmente recomendada, até que novas investigações estabeleçam procedimentos mais robustos.

Palavras-chave: Teste cardiopulmonar de exercício. Consumo de oxigênio. Critério, medida e avaliação. Platô. Aptidão cardiorrespiratória.

ABSTRACT

COSTA, Victor André Balbino. *Verification phase to confirm 'true' VO_{2max} in apparently healthy adults:* meta-analytical analysis of the criteria adopted. 2020. 139 f. Dissertação (Mestrado em Ciências do Exercício e do Esporte) – Instituto de Educação Física e Desportos, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, 2020.

The cardiopulmonary exercise test (CPET) is considered the gold standard method for assessing the maximum aerobic power expressed by the maximum oxygen consumption (VO_{2max}). The primary criterion for confirming the 'true' VO_{2max} is based on obtaining a VO_2 plateau at the end of the CPET, or on secondary criteria, such as peak values for respiratory exchange ratio, percentage of maximum heart rate predicted by age, or concentrations of blood lactate after CPET. However, the VO_2 plateau is often not observed. On the other hand, the adoption of secondary criteria may result in an inaccurate VO_{2max} assessment. As an alternative procedure to overcome these limitations, it has been proposed to conduct an additional exercise session after the incremental phase of the CPET, called the 'verification phase'. However, doubts remain regarding the validity and application of this approach as a necessary procedure for measuring VO_{2max}. The aim of this Master's Dissertation was to investigate, through meta-analysis, the application of the verification phase as a procedure for confirming the VO_{2max} obtained in CPET in healthy adults. Additionally, the influence of criteria adopted in the verification phase on the effect sizes of the differences *vs.* TCPE were analyzed. MEDLINE (accessed through PubMed), Web of Science, SPORTDiscus, and Cochrane (accessed through Wiley) were searched using a combination of medical subject heading (MeSH) descriptors in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Meta-analyses were performed to investigate the mean differences between the highest VO_2 and heart rate responses during a CPET and verification phase. Subgroup and meta-regression analyses were used to assess potential moderating factors. Seventy-eight studies met the eligibility criteria (total sample of 1,634 participants; age range 19-68 yr.). The highest VO_2 in the CPET and verification phase was similar [n = 52, mean difference = 0.02 (95% CI = -0.01 to 0.06) L/min, $P = 0.17$], and not affected by sex, cardiorespiratory fitness level, CPET modality, CPET protocol design, or how the verification phase is performed. The highest heart rate attained was significantly lower in the verification phase, however [n = 36, mean difference = 2.7 (95% CI = 2.0 to 3.5) bpm, $P < 0.00001$]. In conclusion, the verification phase seems a robust procedure for confirming true VO_{2max} among apparently healthy adults. Using maximal heart rate to help verify attainment of VO_{2max}, however, currently cannot be recommended until further research establishes more robust procedures.

Keywords: Exercise test. Oxygen consumption. Criteria. Measurement and evaluation. Plateau. Cardiorespiratory fitness.

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LISTA DE ABREVIATURAS E SIGLAS

ATP	adenosina trifosfato
a-vO_2	diferença arteriovenosa
BMI	*body mass index*
bpm	batimentos por minuto
CaO_2	conteúdo arterial máximo de O_2
CI	*confidence interval*
CPET	cardiopulmonar exercise test
CRF	*cardiorespiratory fitness level*
CSI	*continuous step-incremented*
$CT_{máx}$	carga de trabalho máxima
CV	coeficiente de variação
CYC	*cycling*
DisCSI	*discontinuous step-incremented*
DP	desvio-padrão
F	*female*
$FC_{máx}$	frequência cardíaca máxima
FC_{verif}	frequência cardíaca obtida na fase de verificação
HIIT	*high-intensity interval training*
IMC	índice de massa corporal
IPC	*ischemic preconditioning*
km/h	quilômetros por hora
La_{max}	*maximal blood lactate concentration*
L/min	litros por minuto
M	*male*
MeSH	*medical subjects headings*
min	minutos
$mL \cdot kg^{-1} \cdot min^{-1}$	$mililitros \cdot kilograma^{-1} \cdot minuto^{-1}$
mL/min	mililitros por minuto
mmHg	milímetros de mercúrio
mph	milhas por hora
N/A	*not applicable*
NS	*not stated*
PSE	percepção subjetiva de esforço
PROSPERO	*International Prospective Register of Systematic Reviews*
R	razão de troca gasosa e respiratória
RER_{max}	*maximal respiratory exchange ratio*
RPE	*rating of perceived exertion*
SD	*standard deviation*

SPV	*self-paced maximal oxygen uptake*
TCPE	teste cardiopulmonar de exercício
TR	*treadmill*
VCO_2	consumo de gás carbônico
VO_2	consumo de oxigênio
$VO_{2máx}$	consumo máximo de oxigênio
VO_{2pico}	consumo de oxigênio de pico
VO_{2verif}	consumo de oxigênio obtido na fase de verificação
VP	*verification phase*
WR	work rate

LISTA DE SÍMBOLOS

≥	Maior ou igual que
<	Menor que
=	Igual
%	Porcentagem
±	Mais ou menos
×	Multiplicação
N	Tamanho amostral
Δ	Delta (variação)
ºC	Graus Celsius

SUMÁRIO

INTRODUÇÃO

O consumo máximo de oxigênio ($VO_{2máx}$) representa um limite fisiológico da capacidade integrada dos sistemas respiratório, cardiovascular e neuromuscular de captar O_2 a nível alveolar, transportar e utilizar O_2 a nível tecidual para a ressíntese de adenosina trifosfato (ATP) durante um trabalho mais árduo possível (FLETCHER; ADES; KLIGFIELD; ARENA *et al.*, 2013; POOLE; JONES, 2017). A oferta central de O_2 depende do débito cardíaco máximo ($Q_{máx}$) e do conteúdo arterial máximo de O_2 (CaO_2), ao passo que a extração periférica de O_2 transportado, comumente expressa pela diferença arteriovenosa ($a\text{-}vO_2$), depende de uma cascata de eventos celulares e moleculares a nível da musculatura esquelética para difundir o CaO_2 para as mitocôndrias e promover a produção oxidativa de ATP (LEVINE, 2008). Ao combinarmos estes fatores, teremos a habilidade de fazer com que o sistema circulatório ofereça e extraia O_2, como expresso pela equação de Fick: $VO_{2máx}$ $Q_{máx}$ (volume sistólico × frequência cardíaca) × diferença $a\text{-}vO_2$ (BASSETT; HOWLEY, 2000).

O conceito de $VO_{2máx}$, a partir da existência de uma taxa finita de transporte máximo de O_2 do ambiente para as mitocôndrias para apoiar a produção oxidativa de ATP durante a realização do trabalho físico, começou com HILL, A. V. e LUPTON, H. (1923). Desde então, vem sendo amplamente utilizado nas ciências do exercício e do esporte como uma medida normativa da aptidão cardiorrespiratória (FRANKLIN, 2007; JONES, 2006; MOORE; BRINKER; STRAY-GUNDERSEN; MITCHELL, 1993; SMITH; MCNAUGHTON; MARSHALL, 1999; VANHEES; LEFEVRE; PHILIPPAERTS; MARTENS *et al.*, 2005; WASSERMAN, 1997). Além disso, é utilizado no diagnóstico e prognóstico de doença cardiovascular (MCMURRAY; AINSWORTH; HARRELL; GRIGGS *et al.*, 1998), consistindo em preditor independente de mortalidade por todas as causas (BLAIR; KOHL; BARLOW; PAFFENBARGER *et al.*, 1995; MYERS; PRAKASH; FROELICHER; DO *et al.*, 2002). Enfim, é amplamente utilizado para avaliar os efeitos do treinamento físico (ASTORINO; SCHUBERT; PALUMBO; STIRLING *et al.*, 2013; SCHARHAG-ROSENBERGER; MEYER; WALITZEK; KINDERMANN, 2009; WEATHERWAX, R.; HARRIS, N.; KILDING, A. E.; DALLECK, L., 2019), bem como prescrever a intensidade e volume das sessões de exercício (ACSM, 2018; DA CUNHA; FARINATTI PDE; MIDGLEY, 2011; GARBER; BLISSMER; DESCHENES; FRANKLIN *et al.*, 2011). Consequentemente, a obtenção de valores válidos e confiáveis de $VO_{2máx}$ é importante para comparar indivíduos ou grupos, no contexto das pesquisas observacionais e experimentais com diferentes delineamentos metodológicos.

Conceituado como padrão-ouro para mensuração do $VO_{2máx}$, o teste cardiopulmonar de exercício (TCPE) vem ganhando importância crescente como método capaz de aumentar a precisão, confiabilidade e objetividade da medida do $VO_{2máx}$ em diferentes populações (ALBOUAINI; EGRED; ALAHMAR; WRIGHT, 2007; HERDY; RITT; STEIN; ARAÚJO *et al.*, 2016; MEZZANI, 2017). No TCPE, obtém-se medida das variáveis de trocas gasosas e respiratórias por meio de calorimetria indireta, aferindo-se a produção de energia a partir dos equivalentes calóricos de VO_2 e da produção de gás carbônico (VCO_2). Admitindo-se que todo O_2 consumido é utilizado para oxidar os substratos energéticos e que todo CO_2 produzido é eliminado pela respiração, é possível calcular a quantidade total de energia produzida (SIMONSON; DEFRONZO, 1990). Assim, o $VO_{2máx}$ pode ser expresso em termos de volume absoluto de O_2 consumido por minuto (mL/min ou L/min) ou relativo à massa corporal ($mL \cdot kg^{-1} \cdot min^{-1}$), em condições denominadas de STPD (do inglês, *Standard Temperature Pressure and Dry*), ou seja, 0ºC de temperatura, pressão de 760 mmHg e ausência de vapor de água no ar.

Por outro lado, a adequação do TCPE para determinar um "*verdadeiro*" $VO_{2máx}$ por meio de protocolos de exercício até a exaustão (ex.: do tipo descontínuo/intermitente, escalonado, ou em rampa) está sob investigação há décadas. De fato, questões conceituais sobre o $VO_{2máx}$ ainda são fonte de debate e desacordo na literatura (BASSETT; HOWLEY, 1997; BERGH; EKBLOM; ASTRAND, 2000; NOAKES, 1998; 2008a; ROBERGS, 2001). Em particular, o estudo dos critérios para confirmação do "*verdadeiro*" $VO_{2máx}$ é um assunto desafiador e que tem recebido destaque nas últimas décadas (MIDGLEY; CARROLL, 2009; MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007).

Desde a década de 1920, por exemplo, o conceito de $VO_{2máx}$ tem sido associado ao desenvolvimento de um platô no VO_2 mediante o aumento da carga de trabalho e da demanda crescente de O_2 – de acordo com HILL e LUPTON (1922), "*ao correr ... o VO_2 pode atingir seu máximo e permanecer constante apenas porque não pode subir mais devido às limitações do sistema circulatório e respiratório*". Posteriormente, essa teoria foi apoiada por TAYLOR; BUSKIRK e HENSCHEL (1955), em estudo que revelou manutenção do VO_2 ($\Delta VO_2 < 150$ mL/min ou $\leq 2{,}1$ $mL \cdot kg^{-1} \cdot min^{-1}$) paralelo a aumento na inclinação da esteira em 108 de 115 indivíduos (uma taxa de sucesso de 94% para o conceito de platô do VO_2) que completaram um protocolo descontínuo para avaliação do $VO_{2máx}$. Como será discutido em sessão posterior, nem sempre um platô no VO_2 é identificado em todos os indivíduos testados. Portanto, vários critérios secundários foram propostos para validar o $VO_{2máx}$ a partir de concentrações elevadas de lactato sanguíneo nos minutos iniciais pós-TCPE, alcance de um

percentual da frequência cardíaca máxima ($FC_{máx}$) predita ajustada pela idade, elevada razão de troca gasosa e respiratória (R) e percepção subjetiva de esforço (PSE) (HOWLEY; BASSETT; WELCH, 1995; MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007). Porém, estudos prévios demonstraram que a adoção dos critérios secundários pode subestimar o "*verdadeiro*" $VO_{2máx}$ em até 30%-40% (MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; POOLE; WILKERSON; JONES, 2008). Não é difícil entender que esse erro teria consequências práticas importantes para os resultados das pesquisas, por exemplo, erro do tipo II (*ou seja*, manutenção incorreta da hipótese nula falsa) ou, na pior das hipóteses, erro do tipo I (*ou seja*, rejeitar incorretamente uma hipótese nula verdadeira) (POOLE; JONES, 2017).

Nesse contexto, emerge um procedimento alternativo para confirmação do "*verdadeiro*" $VO_{2máx}$, denominado fase de verificação ou validação (MIDGLEY; CARROLL, 2009). Em termos práticos, a fase de verificação consiste na realização de uma sessão adicional de exercício até a exaustão, com intensidade prescrita preferencialmente acima da carga máxima de trabalho atingida em protocolo incremental prévio, realizada após um período de recuperação (*ou seja*, pós-TCPE), culminando com uma comparação entre os valores de VO_{2pico} medidos nas duas fases (*ou seja*, protocolo incremental *vs.* fase de verificação) (THODEN, 1991). De forma geral, a fase de verificação baseia-se nas seguintes premissas (POOLE; JONES, 2017): a) protocolos incrementais podem falhar na obtenção de um "*verdadeiro*" $VO_{2máx}$; b) existe um limite superior para o VO_2 e esse valor só pode ser subestimado, mas não superestimado; c) durante um exercício de carga constante até o limite de tolerância no domínio pesado-severo da cinética de O_2, o VO_2 será projetado para o $VO_{2máx}$ dentro do tempo de fadiga muscular.

De acordo com ROSSITER; KOWALCHUK e WHIPP (2006), a falta de diferenças significativas nas respostas de VO_2 mensuradas na fase de verificação, tanto em 95% quanto em 105% da carga máxima de trabalho, em comparação com o $VO_{2máx}$ observado durante o protocolo incremental, foi um indicativo de que o procedimento de verificação não apenas corroborou a presença de um limite superior da resposta de VO_2, mas também indicou que os valores mais altos de VO_2 obtidos durante um protocolo incremental não eram diferentes daqueles observados durante a fase de verificação, confirmando, portanto, o "*verdadeiro*" $VO_{2máx}$. Em 2009, Midgley e Carroll (ref) publicaram um artigo de revisão -, sugerindo que estudos futuros se concentrassem na investigação dos protocolos adequados para fase de verificação em diferentes populações. Além disso, os autores destacaram a necessidade de se

estabelecer padronização adequada como critério de verificação para confirmar o "*verdadeiro*" $VO_{2máx}$.

Após 10 anos, é importante avaliar as descobertas científicas que se seguiram em relação à fase de verificação e se existem ou não questões que ainda requerem mais atenção. Por exemplo, existem recomendações claras sobre como a fase de verificação deve ser aplicada (ex.: intensidade, duração, tempo de recuperação entre as fases incremental e de verificação, e limiar de critério)? Com esse propósito e visando contextualizar o presente projeto de Dissertação de Mestrado, a próxima seção dedica-se a revisar a literatura sobre os critérios tradicionais e emergentes para medida do $VO_{2máx}$.

1 **REVISÃO DE LITERATURA**

1.1 **Aspectos históricos da avaliação do $VO_{2máx}$**

A avaliação das respostas fisiológicas dinâmicas humanas durante o exercício incremental tem sido uma tarefa em constante evolução há quase 200 anos. Entre os séculos XVIII e XIX, fisiologistas pioneiros como Antoine Lavoisier e Nathan Zuntz conduziram os primeiros experimentos científicos envolvendo estresse fisiológico induzido por sessões de exercício em condições de normóxia e hipóxia em seres humanos. Em 1918, Lambert descreveu o uso de uma série de testes de exercício com o intuito de examinar o impacto do exercício na pressão arterial e estabelecer um índice confiável de eficiência miocárdica (LAMBERT, 1918). No início do século XX, inspirado por Lambert e pelos trabalhos de Francis Benedict, Goran Liljestrand e August Krogh, o fisiologista britânico Archibald Vivian Hill conduziu uma série fundamental de experimentos que permanecem como a gênese da fisiologia do exercício (TIPTON, 2014).

Com o objetivo de investigar a relação entre intensidade e VO_2, HILL e LUPTON (1922) publicaram um artigo intitulado "*o consumo de oxigênio durante a corrida*" (em inglês, *the oxygen consumption during running*). Hill, descrito como "*bastante apto e acostumado a correr, mas nunca um corredor de primeira classe*", foi o voluntário do estudo. Usando bolsa de Douglas para coletar amostras de ar expiradas, analisadores de gás Haldane para determinar concentrações fracionadas O_2 e CO_2 e um gasômetro Tissot para medir volumes de ar durante um protocolo descontínuo (ex.: velocidades de 6,4 - 7,4 - 9,1 - 10 mph), executado em volta de uma pista ao ar livre com 92 ½ metros de circunferência, Hill e Lupton registraram valores de pico para o VO_2 e VCO_2 de 4,175 e 4,475 L/min, respectivamente. Contudo, os valores registrados indicaram que o VO_2 atingiu um pico de 4,175 L/min a 9,1 mph, seguido de uma queda para 4,055 L/min a 10 mph. Embora não tenha sido descrita por Hill como tal, isso era uma evidência clara de que um "*platô de VO_2*" havia sido alcançado (BASSETT, 2002).

Posteriormente, Hill e Lupton acompanharam o trabalho de 1922 com um conjunto de quatro artigos intitulados "*exercício muscular, ácido lático, suprimento e utilização de oxigênio*" (em inglês, *muscular exercise, lactic acid and the supply and utilisation of oxygen*). O primeiro apareceu no *Quarterly Journal of Medicine* (HILL, A. V.; LUPTON, H., 1923),

seguido por oito estudos publicados em três partes no *Proceedings of the Royal Society of London* (HILL; LONG; LUPTON, 1924a; b; c). Numa série de cinco a seis tentativas correndo em velocidades constantes de 181, 203, e 267 m/min, aqueles autores mediram o VO_2 em si mesmos e em outros corredores ao redor de uma trilha de grama de 85 m. Observou-se que, durante a corrida, a demanda de O_2 aumentava continuamente à medida em que a velocidade aumentava, alcançando um máximo além do qual nenhum esforço adicional seria capaz de impulsioná-lo, sugerindo, portanto, a existência de um "*teto*" ou limite superior na captação máxima de O_2 devido às limitações do sistema cardiorrespiratório.

Desde então, uma das questões mais duradouras decorrentes do trabalho de Hill e colaboradores é a distinção entre VO_2 "*máximo*" e "*pico*". O critério primário para o $VO_{2máx}$ é o desenvolvimento de um platô na relação entre VO_2 e taxa de trabalho, embora o platô dependa de muitas variáveis de protocolo. Indivíduos incapazes ou não dispostos a completar uma intensidade de exercício necessária para tal desenvolvimento são descritos como tendo atingido o VO_{2pico}. Em outras palavras, o VO_{2pico} é o maior valor obtido durante o TCPE e representa a tolerância ao exercício de um indivíduo, enquanto o $VO_{2máx}$ representa o maior valor fisiologicamente atingível (DAY; ROSSITER; COATS; SKASICK *et al.*, 2003). Logo, um $VO_{2máx}$ é sempre um pico, mas um VO_{2pico} nem sempre é máximo. A maioria dos primeiros participantes de Hill caiu na última categoria e a indefinição do platô tem sido um tema constante de pesquisa na fisiologia do exercício há décadas.

Há pouco mais de duas décadas, Noakes (1997 e 1998) apresentou um desafio sistemático ao conceito subjacente de $VO_{2máx}$, ao argumentar que este se baseia em uma interpretação incorreta dos dados originais de HILL, A. V. e LUPTON, H. (1923). Um dos argumentos centrais de Noakes contra o conceito de platô no VO_2 é que, nos primeiros estudos experimentais, os sujeitos não realizaram um estágio subsequente de exercício com maior exigência de O_2, para demonstração da validade do fenômeno (NOAKES, 1997; 1998). Uma vez que os argumentos de Noakes desafiaram um paradigma fundamental na fisiologia do exercício, é razoável que vários trabalhos tenham sido publicados, defendendo o conceito de $VO_{2máx}$ como sendo dependente do platô no VO_2 (BASSETT; HOWLEY, 1997; BASSETT; HOWLEY, 2000; BERGH; EKBLOM; ASTRAND, 2000). Contudo, estudos experimentais usando protocolos incrementais do tipo rampa, seguidos por sessão de exercício em intensidade "*supramáxima*" (ou fase de verificação), não observaram alteração no $VO_{2máx}$, apesar de realizar uma carga de trabalho acima daquela obtida no protocolo incremental (HAWKINS; RAVEN; SNELL; STRAY-GUNDERSEN *et al.*, 2007; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MIDGLEY; MCNAUGHTON;

CARROLL, 2006; 2007b; POOLE; WILKERSON; JONES, 2008; ROSSITER; KOWALCHUK; WHIPP, 2006). Esses estudos forneceram suporte importante ao conceito "*clássico*" de $VO_{2máx}$.

1.2 **Critérios tradicionais para confirmação do $VO_{2máx}$**

Apesar de o conceito de $VO_{2máx}$ existir há quase 100 anos, ainda não há diretrizes padronizadas para confirmar a presença do $VO_{2máx}$. Por outro lado, influenciado pelos estudos clássicos de HILL, A. e LUPTON, H. (1923) e TAYLOR; BUSKIRK e HENSCHEL (1955), o platô no VO_2 assumiu papel de destaque na literatura como critério primário para confirmar a obtenção do $VO_{2máx}$, sendo este definido como um pequeno ou nenhum aumento do VO_2 em resposta a um aumento na taxa de trabalho para demonstrar que a taxa de transporte e utilização de O_2 atingiu seu limite.

Em 1955, Taylor *et al*. (ref) descreveu uma abordagem cuidadosa e sistemática para estabelecer uma definição operacional para avaliação do $VO_{2máx}$ em seus procedimentos. Os sujeitos foram submetidos a uma série de 3 a 5 visitas ao laboratório para execução de um protocolo de teste descontínuo para confirmação do $VO_{2máx}$. Na primeira visita, após uma familiarização com os equipamentos e procedimentos, os sujeitos concluíram uma versão do *Harvard Fitness Test* para estimar a inclinação necessária da esteira para um determinado $VO_{2máx}$. Na visita seguinte, foi realizado um aquecimento com velocidade de 3,5 mph e inclinação de 10% (a duração variou de 10 a 60 min). Após um breve período de recuperação (≥ 5 min), percorria-se 3 min a 7 m/h numa inclinação previamente selecionada. A coleta de ar expirado era feita a partir de 1 min 45seg até 2 min 45seg. Esse procedimento foi repetido na visita seguinte, porém com uma inclinação superior da esteira de 2,5%. Os testes continuaram até que os dois últimos valores de VO_2, medidos em dias diferentes (representando duas notas diferentes), diferissem em menos de 150 mL/min ou 2,1 $mL \cdot kg^{-1} \cdot min^{-1}$. Nesse sentido, TAYLOR; BUSKIRK e HENSCHEL (1955) observaram que o aumento médio no VO_2 de 299,3 ± 86,5 mL/min (ou 4,2 ± 1,1 $mL \cdot kg^{-1} \cdot min^{-1}$) para uma mudança de inclinação entre os estágios de 2,5% a 7 m/h foi menor do que 2 desvios-padrões (DP) do aumento esperado para o VO_2 no estágio seguinte (*ou seja*, < 150 mL/min ou ≤ 2,1 $mL \cdot kg^{-1} \cdot min^{-1}$, considerando uma massa corporal média de 72 kg). De fato, aqueles autores demonstraram que apenas 7 dos 115 homens testados deixaram de exibir uma estabilização no

VO_2 entre cargas consecutivas para confirmação do "*verdadeiro*" $VO_{2máx}$. Logo, o estudo de TAYLOR; BUSKIRK e HENSCHEL (1955) tornou-se o primeiro a propor um limiar de critério para determinar a incidência de platô no VO_2.

Posteriormente, alguns estudos propuseram outros limiares de critério (ou ponto de corte) como, por exemplo: ΔVO_2 < 54 mL/min (MITCHELL; SPROULE; CHAPMAN, 1958), < 80 mL/min (ASTRAND, 1960), < 100 mL/min (ISSEKUTZ; RODAHL, 1961), e < 50 mL/min (CUMMING; FRIESEN, 1967). Porém, duas observações podem ser feitas sobre a variabilidade na definição de um limiar de critério para o platô de VO_2: a) alguns valores de corte podem ser muito generosos (ex.: 2,1 $mL \cdot kg^{-1} \cdot min^{-1}$), resultando na subestimação do "*verdadeiro*" $VO_{2máx}$; b) outros valores de corte são tão pequenos (ex.: < 50-60 mL/min), que vão além da capacidade de medir uma diferença real no VO_2 (HOWLEY; BASSETT; WELCH, 1995).

Outro aspecto importante, que deve ser levado em consideração para a identificação de um platô no VO_2, é a variação interindividual para qualquer aumento específico na intensidade do exercício durante o TCPE. Por exemplo, o critério ideal para analisar a presença do platô deveria basear-se no declive individual da relação entre intensidade do exercício *vs*. ΔVO_2 (MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007). Porém, os critérios adotados entre as décadas de 1950 e 1990 assumiram um ponto de corte para analisar a diferença entre o VO_2 medido em duas cargas consecutivas (ou estágios) na fase final do TCPE, inviabilizando a identificação de uma curva descendente na resposta do VO_2 e a confirmação do platô.

Mais recentemente, como uma alternativa para protocolos incrementais do tipo rampa, foi proposto o uso de modelos matemáticos para verificar a ocorrência do platô no VO_2, como a análise de regressão por meio do método dos mínimos quadrados na fase linear da resposta de VO_2 ao TCPE (descartando, portanto, os primeiros 4 min e os últimos 3 min). Esse ajuste linear é, então extrapolado, para o final do TCPE e a presença (ou tendência) do platô de VO_2 é determinada pela diferença entre a resposta real de VO_2 no ponto de fadiga e o ajuste linear extrapolado (DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; ROSSITER; KOWALCHUK; WHIPP, 2006).

No que diz respeito à presença do platô de VO_2, estudos prévios têm relatado uma variação drástica de 0% a 100% (ASTORINO; WILLEY; KINNAHAN; LARSSON *et al.*, 2005; DUNCAN; HOWLEY; JOHNSON, 1997; FROELICHER; BRAMMELL; DAVIS; NOGUERA *et al.*, 1974; MYERS; WALSH; BUCHANAN; FROELICHER, 1989; POOLE; WILKERSON; JONES, 2008; ROSSITER; KOWALCHUK; WHIPP, 2006). Essa

inconsistência tem sido atribuída a diferenças no critério para detecção do platô de VO_2 (HOWLEY; BASSETT; WELCH, 1995; MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007; TAYLOR; BUSKIRK; HENSCHEL, 1955), características da população investigada (CUMMING; FRIESEN, 1967; EDVARDSEN; HEM; ANDERSSEN, 2014; SIDNEY; SHEPHARD, 1977), frequência de amostragem do analisador metabólico para análise do VO_2 (ASTORINO, 2009; ASTORINO; WILLEY; KINNAHAN; LARSSON *et al.*, 2005; MYERS; WALSH; SULLIVAN; FROELICHER, 1990), modalidade de exercício (GORDON; MEHTER; GERNIGON; CADDY *et al.*, 2012), aquecimento prévio ao TCPE (GORDON; SCHAITEL; PENNEFATHER; GERNIGON *et al.*, 2012), e tipo de protocolo para TCPE (DUNCAN; HOWLEY; JOHNSON, 1997; FROELICHER; BRAMMELL; DAVIS; NOGUERA *et al.*, 1974; MCARDLE; KATCH; PECHAR, 1973; STAMFORD, 1976). A falta de motivação e esforço também pode explicar a ausência do platô no VO_2, uma vez que um nível relativamente alto de anaerobiose e desconforto são necessários para atingi-lo (WYNDHAM; STRYDOM; MARITZ; MORRISON *et al.*, 1959).

Cabe destacar que, até a década de 1970, a maioria dos estudos aplicava protocolos de teste descontínuo, caracterizados por uma série de estágios prolongados realizados com carga constante de trabalho, para atingir um estado quase estável ou sustentável de VO_2. Esses estágios eram intercalados com períodos de recuperação (as vezes um dia) e aumento progressivo da carga de trabalho nos estágios subsequentes, até que uma intensidade crítica (ou exaustão) fosse atingida, favorecendo, portanto, a ocorrência de platô no VO_2, apesar do aumento na demanda de energia (ASTRAND, 1960; GLASSFORD; BAYCROFT; SEDGWICK; MACNAB, 1965; TAYLOR; BUSKIRK; HENSCHEL, 1955). No entanto, em parte porque esses procedimentos eram trabalhosos, demorados e, como tal, inadequados para avaliações clínicas, havia interesse em desenvolver testes mais curtos do tipo contínuo (MCARDLE; KATCH; PECHAR, 1973).

A partir das décadas de 1980 e 1990, o advento de analisadores de gases metabólicos que respondiam rapidamente à variação das trocas gasosas permitiu medi-las respiração-a-respiração (ver MACFARLANE, 2017 para uma revisão). Além disso, com o avanço tecnológico na produção de ergômetros controlados por *softwares*, pesquisadores começaram a se afastar de protocolos demorados. Nesse contexto, os estudos de WHIPP; DAVIS; TORRES e WASSERMAN (1981), DAVIS; WHIPP; LAMARRA; HUNTSMAN *et al.* (1982), BUCHFUHRER; HANSEN; ROBINSON; SUE *et al.* (1983) e MYERS; BUCHANAN; WALSH; KRAEMER *et al.* (1991) foram fundamentais para popularizar o uso de protocolos incrementais do tipo rampa, caracterizados por um aumento progressivo e

constante da carga de trabalho ao longo de 8 a 12 min, até a exaustão voluntária máxima (ou limite da tolerância individual). Trata-se de protocolos individualizados, que promovem uma boa adaptação ao trabalho por meio de incrementos de carga lentos e progressivos (ver MYERS; BELLIN, 2000; SILVA; MONTEIRO; FARINATTI, 2011 para uma revisão).

Se, por um lado, a economia de tempo é amplamente favorável, alguns estudos têm questionado a precisão de protocolos do tipo rampa para a confirmação do "*verdadeiro*" $VO_{2máx}$, já que um platô no VO_2 nem sempre (ou raramente) é discernível em função de uma resposta acelerada do VO_2 ao se aproximar da fadiga muscular no final do TCPE (DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MYERS; WALSH; SULLIVAN; FROELICHER, 1990; POOLE; WILKERSON; JONES, 2008; ROSSITER; KOWALCHUK; WHIPP, 2006). Nos casos em que um platô no VO_2 não é alcançado como evidência definitiva do $VO_{2máx}$, os pesquisadores, geralmente, decidem pela utilização dos chamados critérios secundários [ex.: concentração de lactato sanguíneo pós-TCPE, percentual atingido da $FC_{máx}$ predita pela idade, R (razão entre VCO_2 e VO_2) e PSE] para garantir a confiabilidade e a validade da medida do $VO_{2máx}$ (HOWLEY; BASSETT; WELCH, 1995; MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007).

Em 2008, Poole *et al*. (ref) examinaram a validade dos critérios secundários com base em valores amplamente adotados na literatura [ex.: R de 1,10 e 1,15; FC correspondente a 5% ou ± 10 bpm da $FC_{máx}$ predita para a idade; concentração de lactato sanguíneo ≥ 8 mmol/L]. Um total de 8 homens aparentemente saudáveis (27 ± 4 anos) realizaram TCPE em cicloergômetro com protocolo em rampa. A principal descoberta foi que os critérios secundários foram satisfeitos em intensidades de exercícios que produziram valores de VO_2 muito abaixo do $VO_{2máx}$ eventualmente atingido no TCPE (até 73% do $VO_{2máx}$). Esses critérios são, portanto, limitados devido à falta de especificidade na identificação de indivíduos que não se exercitaram no limite de tolerância.

Outro aspecto que merece destaque diz respeito à elevada variabilidade inter e intraindividual dos critérios secundários para confirmação do "*verdadeiro*" $VO_{2máx}$. DUNCAN; HOWLEY e JOHNSON (1997) relataram uma concentração máxima de lactato sanguíneo pós-TCPE (protocolo descontínuo) de 14,3 ± 2,7 mmol/L, indicando que a maioria dos indivíduos provavelmente teria atingido o limite de 8 mmol/L se interrompessem o teste ao atingir seu limite de tolerância. Ora, diferenças interindividuais elevadas podem significar que alguns sujeitos não satisfizeram um critério específico, mesmo quando um esforço máximo é atingido. Essa limitação pode ser mais pronunciada para o critério de $FC_{máx}$, uma

vez que o intervalo de confiança de 95% para a $FC_{máx}$ prevista pela idade pode ser de até 45 bpm (LONDEREE; MOESCHBERGER, 1984). Não obstante, a capacidade de satisfazer critérios secundários também pode ser específica do indivíduo. Sabe-se, por exemplo, que indivíduos treinados em *endurance* têm uma menor capacidade de metabolismo anaeróbio do que aqueles treinados em *sprint* (MEDBO; SEJERSTED, 1985), o que limitaria *per se* as chances de satisfazer os critérios relacionados ao R (MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007).

Em 1995, HOWLEY; BASSETT e WELCH (1995) fizeram um levantamento dos critérios tradicionais adotados para medida do $VO_{2máx}$ em estudos experimentais publicados na revista *Medicine & Science in Sports & Exercise* (MSSE) entre outubro de 1993 e maio de 1994. Dos 29 estudos analisados, 22 (76%) relataram um ou mais critérios para confirmação do "*verdadeiro*" $VO_{2máx}$. Já entre outubro de 2005 e maio de 2006, MIDGLEY; MCNAUGHTON; POLMAN e MARCHANT (2007) replicaram este levantamento no MSSE, incluindo, porém, outros três periódicos científicos proeminentes na área das ciências do exercício e do esporte, a saber: *European Journal of Applied Physiology* (EJAP), *International Journal of Sports Medicine* (IJSM) e *Journal of Applied Physiology* (JAP). A Tabela 1 apresenta os critérios tradicionais para confirmação do $VO_{2máx}$ adotados por estudos publicados no MSSE, EJAP, IJSM e JAP entre 1993-94 *vs*. 2004-05. Como pode ser observado, apenas 17 (44%) dos 39 estudos publicados no MSSE entre 2004-05 fez uso de algum critério para obtenção do "*verdadeiro*" $VO_{2máx}$ – ou seja, uma queda de 32% em relação à pesquisa original feita com dados publicados entre 1993-1994. Considerando os quatro periódicos (MSSE, EJAP, IJSM e JAP), apenas 79 (38%) dos 207 estudos adotaram um ou mais critérios para a medida do $VO_{2máx}$. De acordo com MIDGLEY; MCNAUGHTON; POLMAN e MARCHANT (2007), críticas direcionadas aos critérios tradicionais para confirmação do "*verdadeiro*" $VO_{2máx}$ (DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; DUNCAN; HOWLEY; JOHNSON, 1997; ROSSITER; KOWALCHUK; WHIPP, 2006) podem ser a causa dessa aparente redução no seu uso.

Diante do exposto, o conjunto de critérios tradicionais para a confirmação do $VO_{2máx}$, especialmente na era dos protocolos incrementais do tipo rampa, tornou-se um tópico controverso (HOWLEY; BASSETT; WELCH, 1995; MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007). Recentemente, POOLE e JONES (2017) declararam que o "VO_{2pico}" não seria mais aceitável e que os resultados validados de $VO_{2máx}$, derivados de uma *fase de verificação* pós-TCPE deveriam ser apresentados em todos os estudos futuros. Um ponto importante levantado por Poole e Jones é que, embora o protocolo em rampa possa

produzir uma resposta de $VO_{2máx}$ altamente reprodutível em atletas acostumados a se esforçar até a exaustão, esse pode não ser o caso de populações não-atléticas.

Tabela 1- Critérios tradicionais para confirmação do $VO_{2máx}$ adotados por estudos publicados em quatro periódicos científicos proeminentes nas ciências do exercício e do esporte.

Critérios Tradicionais	**Limiar de Critério**	**HOWLEY; BASSETT e WELCH** MSSE 1993-1994	**MIDGLEY; MCNAUGHTON; POLMAN e MARCHANT (2007)** MSSE 2005-2006	EJAP - IJSM - JAP - MSSE 2005-2006
Nenhum declarado		7	22	128
Consumo de oxigênio	Não especificado	3	7	28
	Platô absoluto*	1	0	2
	≤ 2.1 mL·kg^{-1}·min^{-1}	4	1	10
	≤ 280 mL/min	1	0	0
	≤ 200 mL/min	0	1	2
	≤ 150 mL/min	3	1	14
	≤ 100 mL/min	0	0	5
Concentração de lactato sanguíneo	Menor que predito	1	0	0
	≥ 10 mmol/L	0	0	3
	≥ 8 mmol/L	1	1	6
Razão de troca gasosa e respiratória	$\geq 1,20$	0	0	1
	$\geq 1,15$	0	0	9
	$\geq 1,13$	1	0	0
	$\geq 1,12$	0	0	1
	$\geq 1,10$	7	13	55
	$\geq 1,08$	0	0	1
	$\geq 1,05$	2	0	3
	$\geq 1,05$	4	1	5

Tabela 1- Critérios tradicionais para confirmação do $VO_{2máx}$ adotados por estudos publicados em quatro periódicos científicos proeminentes na nas ciências do exercício e do esporte (*con*tinuação).

Frequência cardíaca	Platô absoluto*	1	1	4
	± 15 bpm FCMPI	1	0	0
	± 10 bpm FCMPI	0	1	16
	± 5 bpm FCMPI	3	3	3
	≥ 100% FCMPI	2	1	13
	≥ 95% FCMPI	0	1	8
	≥ 90% FCMPI	3	1	11
	≥ 85% FCMPI	0	1	3
	1 DP da FCMPI	0	0	1
	Próximo da FCMPI	0	0	1
Percepção subjetiva de esforço	≥ 19 (escala 6-20)	?	1	1
	≥ 18 (escala 6-20)	?	2	5
	≥ 17 (escala 6-20)	?	0	1
Exaustão subjetiva		?	1	9
Diminuição da frequência de pedalagem		?	3	14

FCMPI: frequência cardíaca máxima prevista pela idade; DP: desvio-padrão; MSSE: *Medicine & Science in Sports & Exercise*; EJAP: *European Journal of Applied Physiology*; IJSM: *International Journal of Sports Medicine*; JAP: *Journal of Applied Physiology*. *: nenhum aumento em resposta ao incremento na carga de trabalho. ?: Não pesquisado por HOWLEY; BASSETT e WELCH (1995).

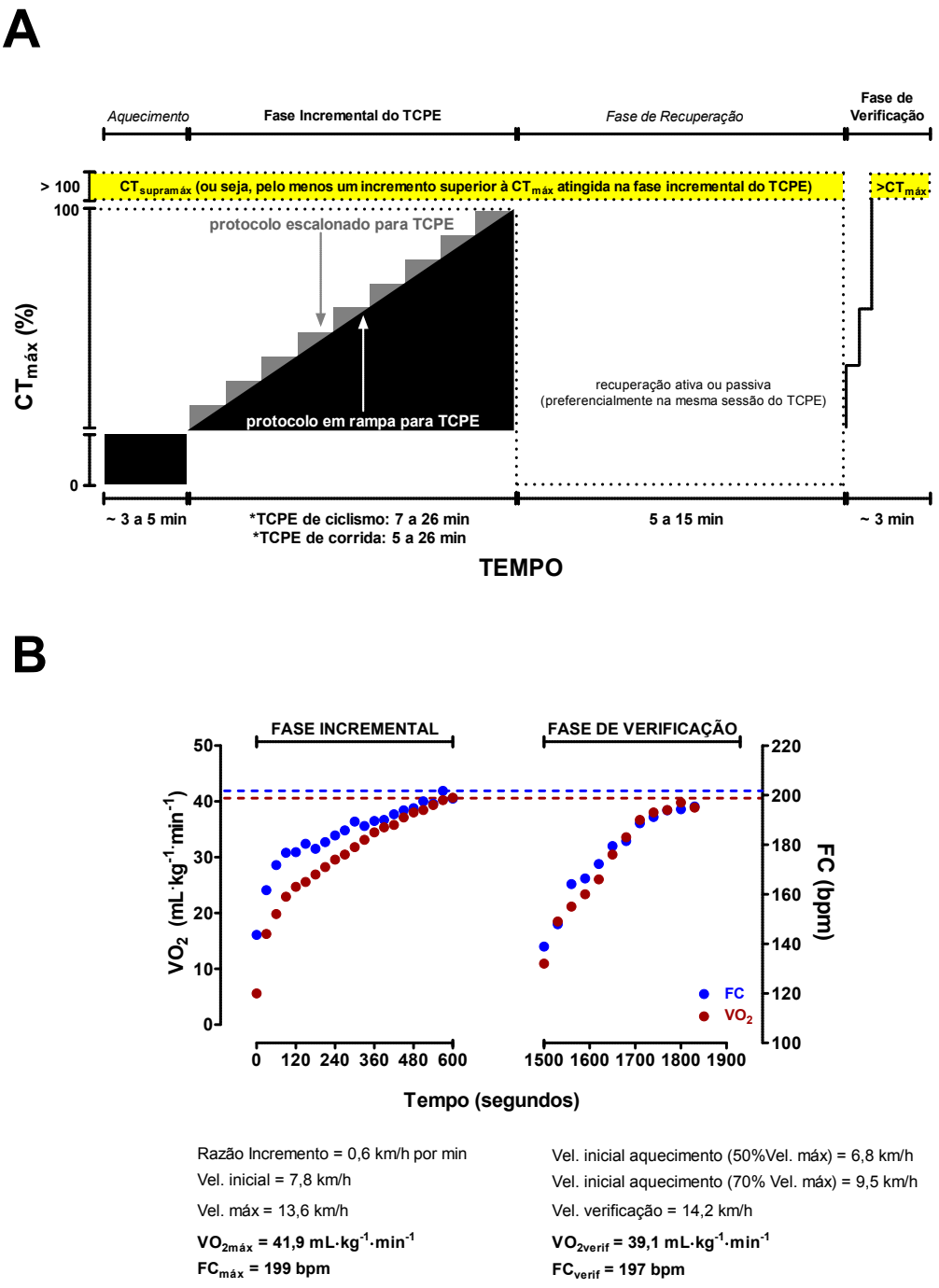
Fonte: Adaptado de HOWLEY; BASSETT e WELCH (1995) e MIDGLEY; MCNAUGHTON; POLMAN e MARCHANT (2007)

1.3 **Fase de verificação para confirmação do $VO_{2máx}$**

Sabe-se que obtenção do "*verdadeiro*" $VO_{2máx}$ requer que o TCPE seja realizado até o limite de tolerância individual ao esforço com vistas à obtenção de um platô no VO_2 (WAGNER, 2000). Surge um problema na identificação dos indivíduos que terminam o TCPE prematuramente e, portanto, podem não ter exibido um "*verdadeiro*" $VO_{2máx}$. De acordo com TAYLOR; BUSKIRK e HENSCHEL (1955), *"(...) o procedimento mais seguro é insistir na prova da obtenção do $VO_{2máx}$ em todos os casos*".

Diante desse contexto, foi proposto um procedimento alternativo denominado "*fase de verificação*" para confirmação do "*verdadeiro*" $VO_{2máx}$. De forma geral, a fase de verificação é caracterizada por uma sessão de exercício com carga de trabalho constante e intensidade preferencialmente acima da fase incremental do TCPE [*ou seja*, um estágio ou uma razão de incremento acima da carga de trabalho máxima ($CT_{máx}$) atingida na fase incremental], realizada após um breve período de recuperação depois da finalização do teste inicial – o $VO_{2máx}$ pode ser confirmado mediante comparação feita entre os valores alcançados para o VO_2 ou FC nas fases incremental e de verificação. Como desfecho primário, espera-se que o maior valor obtido na fase de verificação (VO_{2verif}) seja similar ao valor atingido na fase incremental ($VO_{2máx}$), conforme exemplificado na Figura 1A-B (KEILLER; GORDON, 2018; MIDGLEY; CARROLL, 2009; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009). Na ocorrência de um aumento significativo do VO_2 entre as fases incremental e de verificação (ex.: $VO_{2máx} > VO_{2verif}$), o investigador deve considerar que o protocolo de teste incremental foi inadequado para promover o "*verdadeiro*" $VO_{2máx}$ (MIDGLEY; MCNAUGHTON; CARROLL, 2006). Conceitualmente, a fase de verificação assemelha-se à identificação de um platô de VO_2 durante um protocolo de teste descontínuo para confirmação do $VO_{2máx}$, mas com a notável vantagem de exigir apenas uma única visita ao laboratório (MIDGLEY; CARROLL, 2009).

Figura 1- (**A**) Ilustração de um protocolo incremental para teste cardiopulmonar de exercício (TCPE) seguido de uma fase de verificação de múltiplos estágios na mesma sessão do TCPE. (**B**) Respostas de consumo de oxigênio e frequência cardíaca durante a fases incremental do TCPE e a fase de verificação em um voluntário do sexo masculino.



Legenda: TCPE – teste cardiopulmonar de exercício; CT – carga de trabalho; VO_2 – consumo de oxigênio; FC – frequência cardíaca.

Nota: O protocolo consiste em aquecimento de 3-5 min seguido de incrementos até a exaustão. Após um período de 5-10 min de recuperação, um esforço em uma carga de trabalho (CT) superior à $CT_{máx}$ atingida no TCPE é realizada, precedida por um estágio de 2 min a 50% e 1 min a 70% $CT_{máx}$ (MIDGLEY; CARROLL, 2009).

Fonte: Elaborada pelo autor.

Embora sua origem não seja clara, a fase de verificação para validação do $VO_{2máx}$ remonta ao capítulo de livro publicado nas diretrizes da Associação Canadense de Ciências do Esporte para testes fisiológicos. Os autores, originalmente, denominaram o procedimento de "*fase exaustiva*" (THODEN, 1982) e depois adotaram a terminologia "*fase de verificação*" (THODEN, 1991). Em 1982, Thoden *et al*. (ref) recomendaram que, após 15 min de recuperação da fase incremental, um exercício constante, com uma carga de trabalho equivalente à última etapa concluída na fase incremental, fosse realizado até o limite de tolerância. Se a fase de verificação durasse mais de 6 min, eles recomendariam que, após o novo TCPE, o indivíduo fosse obrigado a realizar uma fase de verificação em um estágio superior àquele aplicado no último estágio da fase incremental. Em diretrizes atualizadas, THODEN (1991) sugeriu uma recuperação entre 5 e 15 min, a fim de obter uma FC de 100 bpm, com a fase de verificação inicialmente realizada em carga de trabalho equivalente a um estágio acima do último concluído na etapa incremental do TCPE. Se a duração da fase incremental do TCPE for inferior a 8 min, a fase de verificação deve ser realizada na mesma carga de trabalho concluída na fase incremental do TCPE.

O primeiro estudo científico que adotou a fase de verificação parece ter sido o de NIEMELA; PALATSI; LINNALUOTO e TAKKUNEN (1980). Os autores submeteram 16 homens saudáveis (idade: 29,3 ± 6,5 anos) a um protocolo incremental do tipo rampa em cicloergômetro ($VO_{2máx}$: 39,7 ± 7,3 $mL \cdot kg^{-1} \cdot min^{-1}$). Uma semana depois, aplicaram a sessão de verificação, compreendendo uma ou duas cargas de trabalho submáximas seguidas de esforço com carga de trabalho acima daquela obtida no protocolo incremental ($VO_{2máx}$: 40,7 ± 6,8 $mL \cdot kg^{-1} \cdot min^{-1}$). Porém, o primeiro estudo que incorporou a fase de verificação no mesmo dia do protocolo incremental como parte do seu método para confirmação do $VO_{2máx}$ foi o de MORGAN; BALDINI; MARTIN e KOHRT (1989), em um grupo de 10 corredores treinados e homogêneos para aptidão cardiorrespiratória (idade: 27,3 ± 3,6 anos; tempo de treinamento: 9,2 ± 4,7 anos; $VO_{2máx}$: 64,8 ± 2,1 $mL \cdot kg^{-1} \cdot min^{-1}$). Nesse estudo, o procedimento de verificação consistiu em recuperação de 10 min após a fase incremental, seguida de um período de aquecimento de 2 min e 2 min de corrida com um incremento maior que o último estágio concluído na fase incremental do TCPE. Duas características distinguíveis do procedimento utilizado por MORGAN; BALDINI; MARTIN e KOHRT (1989) foram que a fase de verificação não foi continuada até o limite de tolerância e foi aplicada apenas quando um platô no VO_2 não foi discernível na fase incremental ($\Delta VO_2 \leq 2,1$ $mL \cdot kg^{-1} \cdot min^{-1}$ entre as duas últimas cargas de trabalho).

Se a fase de verificação deve ser realizada quando um platô de VO_2 na fase incremental é evidente, é motivo de debate, já que não executar a fase de verificação, deve-se reconhecer, economiza tempo e não coloca o sujeito sob estresse adicional. Por outro lado, deve-se notar que o mesmo sujeito que realiza um TCPE duas vezes pode mostrar um platô no VO_2 em apenas um deles (HOWLEY, 2007; MIDGLEY; MCNAUGHTON; CARROLL, 2006; MISQUITA; DAVIS; DOBROVOLNY; RYAN *et al.*, 2001). Em termos práticos, a inconsistência do platô no VO_2 reforçaria o uso da fase de verificação como procedimento necessário para confirmar que um "*verdadeiro*" $VO_{2máx}$ foi alcançado. Por exemplo, após aplicarem um protocolo em rampa para avaliar o $VO_{2máx}$ em 71 indivíduos, DAY; ROSSITER; COATS; SKASICK *et al.* (2003) observaram que apenas 12 (17%) indivíduos demonstraram um platô no VO_2. Em dia subsequente ao protocolo em rampa, 38 dos 71 indivíduos concluíram um protocolo para fase de verificação com carga constante de ~ 90% da potência máxima atingida na rampa. O $VO_{2máx}$ alcançado na fase de verificação não foi diferente daquele medido durante o protocolo em rampa. O ponto central deste manuscrito foi que, embora um platô não tenha sido observado na grande maioria dos casos no protocolo em rampa, o $VO_{2máx}$ não foi diferente daquele obtido na fase de verificação.

No estudo de HAWKINS; RAVEN; SNELL; STRAY-GUNDERSEN *et al.* (2007), a questão do platô é revisitada, usando 52 corredores de distância bem treinados. Neste estudo cuidadosamente realizado, usando técnicas clássicas de medição (ex.: bolsa de Douglas para coletar amostras de ar expiradas, espectrômetro de massa para determinar concentrações fracionadas O_2 e CO_2 e um gasômetro Tissot), os investigadores mostraram de forma convincente que o $VO_{2máx}$ alcançado em um TCPE de corrida não era diferente daquele alcançado em um protocolo de verificação em dia subsequente com carga de trabalho 30% acima do máximo obtido na fase incremental. Por exemplo, não houve diferença significativa entre os valores médios de $VO_{2máx}$ obtidos nas fases incremental e de verificação (63,3 ± 6,3 *vs*. 62,9 ± 6,2 $mL \cdot kg^{-1} \cdot min^{-1}$, respectivamente).

Por outro lado, a temática ainda se faz obscura em decorrência de uma ausência de padronização (ou consenso) de como a fase de verificação deve ser aplicada. Como previamente mencionado, o platô de VO_2 é influenciado por diversos fatores – porém, dúvidas permanecem no tocante a influência do sexo, nível de aptidão cardiorrespiratória, modalidade de exercício, características do protocolo incremental para TCPE, características do protocolo para fase de verificação (*ou seja*, intensidade, duração, intervalo de recuperação entre TCPE *vs*. fase de verificação, tipo de recuperação passiva *vs*. ativa), processamento dos dados obtidos pelos analisadores metabólicos, e limiar de critério (ex.: diferença entre $VO_{2máx}$ *vs*.

VO_{2verif}) sobre a robustez do procedimento de verificação para confirmação do "*verdadeiro*" $VO_{2máx}$.

Logo, a presente revisão sistemática busca identificar os aspectos metodológicos usados com maior frequência para delineamento do protocolo de verificação, fornecendo orientações sobre como a fase de verificação deve ser aplicada em adultos aparentemente saudáveis (ex.: intensidade, duração, intervalo de recuperação entre as fases incremental e de verificação, frequência de saída de dados do analisador metabólico e critério de verificação), bem como meta-analisar os dados de VO_2 e FC obtidos nas fases incremental e de verificação para confirmar o procedimento de verificação como critério válido para uma medição confiável do $VO_{2máx}$. A FC foi utilizada como critério suplementar para a confirmação do $VO_{2máx}$ uma vez que foi o único critério adicional adotado, porém com valores de corte diferentes dos estipulados pelo critério tradicional da própria FC. Nesse sentido, análises agrupadas a partir do sexo, nível de aptidão cardiorrespiratória, modalidade de exercício (cicloergômetro e esteira), tipo de protocolo para teste incremental (ex.: descontínuo, contínuo escalonado e rampa), intensidade do protocolo de verificação (ex.: $CT_{submáx}$, $CT_{máx}$ e $CT_{supramáx}$), tipo de recuperação entre as fases (ex.: passiva e ativa), protocolo de verificação realizado no mesmo dia do TCPE ou em um dia diferente e adoção do limiar de critério para verificação (ex.: sim e não) são importantes para identificar possíveis moderadores das respostas de VO_2 e FC nas fases incremental e de verificação do TCPE.

2. OBJETIVOS

2.1 Geral

O objetivo da presente Dissertação de Mestrado foi investigar de forma sistematizada estudos que adotaram a fase de verificação como procedimento para confirmação do $VO_{2máx}$ em adultos aparentemente saudáveis, e aplicar o modelo meta-analítico para verificar a consistência entre as respostas de VO_2 e FC obtidas no protocolo incremental para TCPE e na fase de verificação. Adicionalmente, a influência de critérios adotados na fase de verificação sobre os tamanhos de efeito das diferenças entre $VO_{2máx}$ *vs*. VO_{2verif} e $FC_{máx}$ *vs*. FC_{verif} foram analisados.

2.2 Específicos

Para atender o objetivo geral, foram delineados os seguintes objetivos específicos:

a) Identificar e selecionar as pesquisas que adotaram a fase de verificação como procedimento metodológico para determinação do $VO_{2máx}$ em adultos aparentemente saudáveis, sumarizando os principais aspectos metodológicos relacionados à sua aplicação.
b) Meta-analisar os dados de VO_2 obtidos no TCPE ($VO_{2máx}$) e na fase de verificação (VO_{2verif}) para identificar possíveis moderadores dessa relação.
c) Meta-analisar os dados de FC no TCPE ($FC_{máx}$) e na fase de verificação (FC_{verif}) para identificar possíveis moderadores dessa relação.

3. ORGANIZAÇÃO DO ESTUDO

A presente Dissertação de Mestrado foi organizada sob a forma de estudo independente (artigo de revisão), apresentado de forma a guardar coerência e coesão com o objetivo central. O estudo procurou incluir em seu escopo uma introdução, esclarecendo as razões específicas de sua condução, e a descrição detalhada dos métodos utilizados, bem como a apresentação e discussão dos resultados obtidos.

4. MÉTODOS

4.1 Critérios de elegibilidade e fontes de pesquisa

Essa revisão sistemática foi conduzida de acordo com os principais itens estabelecidos pelas recomendações PRISMA (MOHER; SHAMSEER; CLARKE; GHERSI *et al.*, 2015). O protocolo da revisão foi registrado na base *International Prospective Register of Systematic Reviews* (PROSPERO) e aprovado sob o número CRD42019123540.

As seguintes bases de dados foram utilizadas para a revisão da literatura (desde seu início até 30 de janeiro de 2020): MEDLINE (via PubMed), *Web of Science*, SPORTDiscus e *Cochrane* (via Wiley), combinando descritores a partir do *medical subjects heading* (MeSH). A estratégia de busca foi baseada na pergunta de pesquisa "*PICO*" *(P=patients or population; I=intervention; C=comparison; O=outcome)* (AKOBENG, 2005). Adicionalmente, foi realizada uma busca manual nas referências de estudos já publicados sobre o assunto em adultos aparentemente saudáveis. Foram levados em conta artigos completos publicados em periódicos e artigos submetidos aceitos. As palavras-chave foram: "*maximal oxygen uptake*", "*verification phase*" e "*healthy volunteers*" e seus sinônimos, conforme a seguir:

POPULATION: *("Healthy Volunteers" [Mesh] OR "Healthy Volunteers" OR "Healthy Volunteer" OR "Healthy" OR "Healthy Participants" OR "Healthy Participant" OR "Healthy Subjects" OR "Healthy Subject" OR "Human Volunteers" OR "Human Volunteer" OR "Normal Volunteers" OR "Normal Volunteer" OR "Healthy Individuals" OR "Healthy Individual" OR "Runner" OR "Corredores" OR "Ativos subjects" OR "Athlete" OR "Atletas" OR "Athletics" OR "Participant" OR "Participants" OR "Ativos participant" OR "Ativos participants" OR "Recreational-treinados" OR "Men" OR "Women" OR "Adult" OR "Adultos" OR "Young"); combined with* ***INTERVENTION:*** *("Exercise test" [Mesh] OR "Exercise test" OR "Exercise tests" OR "Test, Exercise" OR "Tests, Exercise" OR "Bicle Ergometry Test" OR "Bicle Ergometry Tests" OR "Test, Bicle Ergometry" OR "Fitness Testing" OR "Testing, Fitness" OR "Step Test" OR "Step Tests" OR "Test, Step" OR "Step exercise test" OR "Stress Test" OR "Stress Tests" OR "Test, Stress" OR "Treadmill Test" OR "Test, Treadmill" OR "Treadmill Tests" OR "Physical Fitness Testing" OR "Cardiopulmonary Exercise Test" OR "Cardiopulmonary Exercise Tests" OR*

"Exercise Test, Cardiopulmonary" OR "Test, Cardiopulmonary Exercise" OR "incremental test" OR "incremental tests" OR "incremental exercise" OR "Graded Exercise Test" OR "Graded Exercise Tests" OR "Graded Exercise Testing" OR "Graded-Exercise test" OR "GXT" OR "Graded maximal exercise tests" OR "Graded maximal exercise test" OR "Maximal oxygen uptake test" OR "Maximal oxygen uptake tests" OR "maximal oxygen uptake" OR "maximal oxygen consumption" OR "maximum oxygen consumption" OR "maximal oxygen" OR "VO2" OR "VO2 uptake" OR "VO2 consumption" OR "VO2max" OR "VO2 max" OR "VO2MAX" OR "VO2 peak" OR "VO2peak" OR "peak oxygen uptake" OR "VO2 platô") ***AND*** *("Verification" OR "Verification bout" OR "Verification phase" OR "Verification criteria" OR "Verification Stage" OR "Verification testing" OR "Verification test" OR "Supramaximal verification" OR "linear phase" OR "supramaximal test" OR "supramaximal testing" OR "GXT-verification" OR "Maximal verification oxygen uptake" OR "exhaustive square-wave run" OR "Higher power output" OR "Speeds above VO2max").*

Os termos foram adaptados para uso em outras bases de dados. A pesquisa foi realizada de maneira padronizada por dois pesquisadores independentes (VABC e TP). Somente estudos em inglês foram elegíveis para inclusão, caso satisfizessem três critérios: (1) participantes aparentemente saudáveis (homens ou mulheres com idade ≥ 18 anos), (2) mensuração do $VO_{2máx}$ por calorimetria indireta, e (3) TCPE realizado em cicloergômetro ou esteira. Foram excluídos estudos exibindo as seguintes características: (1) uso de suplementos ou medicamentos que pudessem ter efeito sobre a massa corporal, perfil metabólico ou desempenho individual, (2) adoção de protocolos submáximos para confirmar o "*verdadeiro*" $VO_{2máx}$ através da fase de verificação (ou seja, sem atingir a exaustão voluntária máxima) e (3) TCPE realizado em pista. Em relação à meta-análise, também foi considerado como critério de exclusão a ausência dos valores médios ± DP para o $VO_{2máx}$ em L/min nas fases incremental e de verificação, ou mesmo a ausência do valor médio ± DP para massa corporal em kg, necessário para converter o VO_2 em $mL \cdot kg^{-1} \cdot min^{-1}$ para unidade absoluta L/min.

4.2 **Seleção dos estudos**

Potenciais estudos foram analisados para inclusão a partir de três métodos: (1) somente por título; (2) título e resumo e (3) texto integral. Além disso, foi conduzida uma busca manual na lista de referências de todos os artigos elegíveis. Dois investigadores pesquisaram e selecionaram independentemente os artigos incluídos, resolvendo por consenso os casos de discordância. O coeficiente de concordância Kappa (COHEN, 1960) obtido pelos pesquisadores após a leitura de títulos e resumos foi considerado forte ($\kappa = 0{,}811$; $P < 0{,}05$).

4.3 **Extração e gerenciamento dos dados**

Dois revisores independentes extraíram os dados utilizando formato padronizado. As seguintes informações foram sumarizadas: (1) características dos participantes [tamanho amostral, sexo, idade, índice de massa corporal (IMC), aptidão cardiorrespiratória]; (2) tipo de intervenção (modalidade de exercício, protocolo para TCPE, critérios tradicionais para confirmação do "*verdadeiro*" $VO_{2máx}$, limiar de critério para fase de verificação, e duração das fases incremental e de verificação) e (3) desfechos (valores médios ± DP para o $VO_{2máx}$ em L/min e FC nas fases incremental e de verificação). Assim como na triagem de seleção, discordâncias foram solucionadas por consenso. Quando dados quantitativos não eram relatados, os autores dos estudos foram contatados para fornecê-los.

4.4 **Avaliação da qualidade metodológica**

O risco de viés de todos os estudos elegíveis não foi aplicado devido às características da presente revisão, uma vez que não havia grupo de comparação para geração da sequência de randomização e ocultação da alocação de tratamento. Em outras palavras, cada indivíduo correspondia ao seu próprio controle, uma vez que a comparação foi feita entre testes (*ou seja*, fase incremental *vs*. fase de verificação). Além disso, vale ressaltar a ausência de cegamento em voluntários e avaliadores que aplicaram os testes, já que todos os protocolos de exercício foram realizados em uma ordem fixa (*ou seja*, fase incremental e fase de verificação, respectivamente). Por se tratar de uma variável numérica, o cegamento dos resultados pelo avaliador não gerou uma interpretação diferente para os valores de $VO_{2máx}$

obtidos em ambas as intervenções. Além disso, em decorrência da característica transversal do estudo, com um único resultado de interesse, não houve mortalidade experimental.

4.5 **Análise dos dados**

Os dados foram inseridos, analisados e projetados em gráfico do tipo Forest Plot com o auxílio do software *Review Manager*, versão 5.3 (RevMan 5; *Cochrane Collaboration*, Oxford, Reino Unido). O desfecho primário foi a diferença média [intervalos de confiança (IC) de 95%]entre os valores mais elevados de VO_2 (L/min) e FC (bpm) obtidos nas fases incremental e de verificação (ex.: $VO_{2máx} - VO_{2verif}$ / $FC_{máx} - FC_{verif}$). As estimativas do efeito combinado foram expressas como a diferença da média padronizada (DMP) entre os grupos. Os cálculos foram realizados por meio de modelos de efeitos aleatórios. Com o método da DMP, a estimativa do efeito agrupado representa uma média ponderada de todas as comparações de grupo de estudos incluídos, atribuindo maior e menor peso na meta-análise para os estudos com maior e menor tamanhos amostrais, respectivamente. A heterogeneidade estatística entre os estudos foi avaliada usando-se o teste Q de Cochran e o teste de inconsistência I^2, que mede quanto da diferença entre os estudos é devida à heterogeneidade. Foram considerados como tendo baixa heterogeneidade os tamanhos de efeito com um valor $I^2 \leqslant 50\%$. O nível de significância foi fixado em $P < 0{,}10$.

As análises de subgrupos foram definidas a priori para investigar diferenças hipotéticas na magnitude dos efeitos do tratamento entre os ensaios (*ou seja*, $VO_{2máx}$ *vs*. VO_{2verif} e $HR_{máx}$ *vs*. HR_{verif}), a saber: (a) estudos agrupados mediante características do protocolo para fase de verificação – *i*) intensidade (carga de trabalho submáxima *vs*. supramáxima), *ii*) recuperação entre as fases (ativa *vs*. passiva), *iii*) protocolo de verificação realizado no mesmo dia do TCPE e em um dia diferente, e *iv*) adoção do limiar de critério (sim *vs*. não); (b) estudos agrupados de acordo com as características de subgrupos específicos – *i*) sexo (masculino e feminino), *ii*) nível de aptidão cardiorrespiratória (baixo: <40 $mL \cdot kg^{-1} \cdot min^{-1}$; moderado: 40-50 $mL \cdot kg^{-1} \cdot min^{-1}$; alto: >50 $mL \cdot kg^{-1} \cdot min^{-1}$) (ASTORINO; MCMILLAN; EDMUNDS; SANCHEZ, 2015), *iii*) modalidade de exercício (ciclismo e corrida), e *iv*) protocolo para TCPE (descontínuo, escalonado e rampa).

5. ARTIGO: 'VERIFICATION PHASE' FOR CONFIRMING 'TRUE' MAXIMAL OXYGEN UPTAKE IN APPARENTLY HEALTHY ADULTS: SYSTEMATIC REVIEW, META-ANALYSIS, AND RECOMMENDATIONS FOR BEST PRACTICE[1]

5.1 **Abstract**

Background: The 'verification phase' has emerged as an alternative procedure to traditional maximal oxygen uptake (VO_{2max}) criteria for confirming whether a 'true' VO_{2max} has been attained during a cardiopulmonary exercise test (CPET). **Objective:** Compare the highest VO_2 and heart rate responses attained in different verification phase procedures with their preceding CPET for confirming 'true' VO_{2max}. **Methods:** MEDLINE (accessed through PubMed), Web of Science, SPORTDiscus, and Cochrane (accessed through Wiley) were searched for trials including apparently healthy adults; VO_{2max} determination by indirect calorimetry; CPET on cycle ergometer or treadmill. Meta-analyses incorporated random-effects assumptions. Subgroup analyses were used to test the moderator effects of sex, cardiorespiratory fitness, exercise modality, CPET and verification phase protocols. **Results:** Seventy-eight studies were included in the analysis (total sample of 1,634 participants; 452 women, age 19-68 yr.; VO_{2max}, 47.2±12.0 $mL \cdot kg^{-1} \cdot min^{-1}$). The highest VO_2 in the CPET and verification phase was similar [n = 52, mean difference = 0.02 (95% CI = -0.01 to 0.06) L/min, $P = 0.17$], and not affected by any of the potential moderator factors. The highest heart rate attained was significantly lower in the verification phase [n = 36, mean difference = 2.7 (95% CI = 2.0 to 3.5) bpm, $P < 0.00001$]. Greater heart rates (~3 bpm) were observed in CPETS applied to males ($P < 0.001$), with moderate- to high cardiorespiratory fitness ($P < 0.05$), and using discontinuous step-incremented, continuous step-incremented, and ramp-incremented protocols ($P < 0.005$). **Conclusions:** The verification phase seems a robust procedure for confirming true VO_{2max} during CPET. Unlike VO_2 responses, heart rate cannot be currently recommended to help verify VO_{2max}. However, the great concordance between the highest VO_2 achieved in CPET and verification phase puts into question its application in all testing circumstances. **PROSPERO Registration ID:** CRD42019123540.

Keywords: exercise test; incremental test; CPX, indirect calorimetry; cardiorespiratory fitness; ergometer.

5.2 **Introduction**

[1]Autores: Victor A. B. Costa, Adrian W. Midgley, Sean Carroll, Todd A. Astorino, Tainah de Paula, Paulo Farinatti, e Felipe A. Cunha. Submetido *ao Sports Medicine*.

Maximal oxygen uptake (VO_{2max}) represents the upper physiological limit to the integrated capacity of the respiratory, cardiovascular and neuromuscular systems to uptake oxygen and transport it to peripheral tissues, and for the peripheral tissues to utilize the oxygen for adenosine triphosphate (ATP) resynthesis during strenuous exercise involving a large muscle mass and continued to volitional exhaustion (FLETCHER; ADES; KLIGFIELD; ARENA *et al.*, 2013; POOLE; JONES, 2017). The VO_{2max} is widely regarded as the gold standard measure of cardiorespiratory fitness and is typically determined using a cardiopulmonary exercise test (CPET) in clinical, applied physiology, and sport and exercise science settings (DI PRAMPERO, 2003; FLETCHER; ADES; KLIGFIELD; ARENA *et al.*, 2013; FRANKLIN, 2007; GARBER; BLISSMER; DESCHENES; FRANKLIN *et al.*, 2011; VANHEES; LEFEVRE; PHILIPPAERTS; MARTENS *et al.*, 2005). The VO_{2max} is often used to diagnose cardiovascular disease (MCMURRAY; AINSWORTH; HARRELL; GRIGGS *et al.*, 1998), predict all-cause mortality (BLAIR; KOHL; BARLOW; PAFFENBARGER *et al.*, 1995; MYERS; PRAKASH; FROELICHER; DO *et al.*, 2002; STRASSER; BURTSCHER, 2018), develop exercise prescriptions (ACSM, 2018; DA CUNHA; FARINATTI PDE; MIDGLEY, 2011; GARBER; BLISSMER; DESCHENES; FRANKLIN *et al.*, 2011), and evaluate the efficacy of exercise programmes (ASTORINO; SCHUBERT; PALUMBO; STIRLING *et al.*, 2013; SCHARHAG-ROSENBERGER; MEYER; WALITZEK; KINDERMANN, 2009; WEATHERWAX, R.; HARRIS, N.; KILDING, A. E.; DALLECK, L., 2019). Consequently, the validity of VO_{2max} values obtained during CPETs has widespread importance in clinical, sporting, and research-related contexts.

The use of indirect calorimetry for the determination of VO_{2max} during exercise testing to volitional exhaustion on a treadmill or cycle ergometer has become common during the past few decades (ALBOUAINI; EGRED; ALAHMAR; WRIGHT, 2007; HERDY; RITT; STEIN; ARAÚJO *et al.*, 2016; MEZZANI, 2017). This has largely been attributed to the development of fast responding metabolic gas analyzers allowing the time-efficient acquisition of real-time, breath-by-breath, respiratory gas data during CPET (see MACFARLANE, 2017 for a review). These technological advances have contributed to a transition from the original time-consuming discontinuous step-incremented CPET protocols used for the determination of VO_{2max}. The value of more time-efficient continuous ramp or pseudo-ramp protocols for determining VO_{2max} and other submaximal physiological variables has been increasingly applied (BUCHFUHRER; HANSEN; ROBINSON; SUE *et al.*, 1983; DAVIS; WHIPP; LAMARRA; HUNTSMAN *et al.*, 1982; MYERS; BUCHANAN; WALSH;

KRAEMER *et al.*, 1991; WHIPP; DAVIS; TORRES; WASSERMAN, 1981). Despite the considerable progress in the efficiency by which CPET can be conducted and evaluated, there is still much to be learned about the limitations to VO_{2max} (BASSETT; HOWLEY, 1997; BERGH; EKBLOM; ASTRAND, 2000; MIDGLEY; CARROLL, 2009; MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007; NOAKES, 1998; POOLE; JONES, 2017). One particularly problematic aspect has been the confirmation that a participant has elicited a valid or 'true' VO_{2max}. For example, a true VO_{2max} may not be achieved due to an inappropriate test protocol or poor participant motivation and lack of effort (MIDGLEY; MARCHANT; LEVY, 2018).

The concept of a VO_{2max} originated almost 100 years ago with the seminal works of Hill and colleagues (HILL, A.; LUPTON, H., 1923; HILL; LONG; LUPTON, 1924a), who proposed the existence of an individual upper limit or 'ceiling' of VO_2 during maximal exercise, beyond which no further increase in VO_2 occurs despite increasing work rate and higher metabolic demand. The primary criterion for confirming that a true VO_{2max} has been elicited has historically been based on the occurrence of a VO_2 plateau, commonly defined as a small or no increase in VO_2 despite a continued increase in work rate (TAYLOR; BUSKIRK; HENSCHEL, 1955). The landmark study of Taylor et al. (1955) was the first to use a formal VO_2 plateau criterion, which was defined as an increase in VO_2 of less than 150 L/min (or $\leq$ 2.1 $mL \cdot kg^{-1} \cdot min^{-1}$) in response to a specific discontinuous step-incremented protocol performed over 3-5 laboratory visits. The plateau criterion of Taylor et al. (1955) was defined as an increase in VO_2 that was less than 50% of the expected increase for a step-incremented increase in work rate. Subsequent studies have often used the Taylor et al. criterion or alternative thresholds to confirm the attainment of a VO_2 plateau, such as $\Delta VO_2 <$ 54 mL/min (MITCHELL; SPROULE; CHAPMAN, 1958), < 80 mL/min (ASTRAND, 1960), < 100 mL/min (ISSEKUTZ; RODAHL, 1961), or < 50 mL/min (CUMMING; FRIESEN, 1967). Since the widespread adoption of continuous short-duration and ramp-based CPET protocols, several studies have reported low incidences of the VO_2 plateau (DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MYERS; WALSH; SULLIVAN; FROELICHER, 1990; POOLE; WILKERSON; JONES, 2008; ROSSITER; KOWALCHUK; WHIPP, 2006). The variability in VO_2 plateau incidence has been attributed to differences in the criteria used for detecting the VO_2 plateau (HOWLEY; BASSETT; WELCH, 1995; MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007), VO_2 sampling intervals (ASTORINO, 2009; ASTORINO; WILLEY; KINNAHAN; LARSSON *et al.*, 2005; MYERS; WALSH;

SULLIVAN; FROELICHER, 1990), exercise modality (GORDON; MEHTER; GERNIGON; CADDY *et al.*, 2012), type of CPET protocol (DUNCAN; HOWLEY; JOHNSON, 1997; FROELICHER; BRAMMELL; DAVIS; NOGUERA *et al.*, 1974; MCARDLE; KATCH; PECHAR, 1973; STAMFORD, 1976), and various participant characteristics (CUMMING; FRIESEN, 1967; EDVARDSEN; HEM; ANDERSSEN, 2014; SIDNEY; SHEPHARD, 1977). Since the incidence of a VO_2 plateau is often low, secondary criteria have become commonly used to evaluate whether a true VO_{2max} was attained. Secondary VO_{2ma} criteria are typically based upon achievement of threshold values for the respiratory exchange ratio (RER), percentage of age-predicted maximal heart rate, post-exercise blood lactate concentration, and ratings of perceived exertion (RPE) (HOWLEY; BASSETT; WELCH, 1995; MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007). Secondary VO_{2max} criteria have been criticized by numerous investigators; however, due to the individual variability in maximal physiological responses for these variables and lack of specificity in identifying individuals who did not continue the CPET to their limit of exercise tolerance (DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; HOWLEY; BASSETT; WELCH, 1995; MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007; POOLE; JONES, 2017; POOLE; WILKERSON; JONES, 2008; ROSSITER; KOWALCHUK; WHIPP, 2006). Notably, some individuals can satisfy some of the secondary criteria thresholds long before the highest VO_2 value observed in the CPET has been attained (POOLE; WILKERSON; JONES, 2008). For example, the maximal RER criterion can be satisfied at VO_2 values 27%-39% lower than the highest VO_2 value achieved in the CPET (MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; POOLE; WILKERSON; JONES, 2008). In addition, an important issue with secondary VO_{2max} criteria is that they are often dependent on exercise modality, test protocol, and participant characteristics (2007).

A review by Midgley et al. (2007) suggested a new set of standardized VO_{2max} criteria should be developed that are independent of exercise modality, test protocol, and participant characteristics, so they can be universally applied. In 2009, MIDGLEY e CARROLL (2009) provided an early narrative review of an evolving test procedure that showed promise for developing more standardized VO_{2max} criteria, the so-called 'verification phase'. The verification phase consists of an appended 'supramaximal' square wave bout (or similar multistage exercise bout), performed until the limit of exercise tolerance. This procedure has most commonly been applied after a short recovery period from a single continuous CPET. Others have applied the supramaximal phase after a longer recovery period or within the next 24-48 hours (DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; HAWKINS; RAVEN;

SNELL; STRAY-GUNDERSEN *et al.*, 2007; POOLE; WILKERSON; JONES, 2008). The verification phase is based on the premise that when the highest VO_2 values in the CPET and verification phase are consistent with each other (typically within 2-3% in accordance with the test-retest reliability of VO_{2max}), this provides substantial empirical support that a true VO_{2max} has been elicited. Verification of maximal heart rate also has been proposed for providing further evidence that a true VO_{2max} has likely been attained (MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009). The justification is that it would be improbable to elicit almost identical highest heart rates in the CPET and verification phase if a submaximal effort had been given (MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007). Evidencing that a maximal effort has likely been given during the CPET suggests that the participant likely elicited a true VO_{2max} and is the basis for the use of traditional secondary VO_{2max} criteria. According to MIDGLEY e CARROLL (2009), a continuous CPET followed by an appended supramaximal verification phase is conceptually similar to the discontinuous tests most commonly used from the 1920s to the 1970s, but with the notable advantage of requiring only a single visit to the laboratory. Poole and Jones (POOLE; JONES, 2017) recently stated that the VO_{2peak}, a term often used to express the highest value attained during a CPET in the absence of a VO_2 plateau, is no longer acceptable. They further suggest that a supramaximal verification phase should be undertaken in all future studies to confirm that true VO_{2max} values have been obtained. An important issue, however, is the current lack of knowledge regarding the most appropriate verification phase procedure with respect to intensity, duration, the length of recovery from the preceding CPET, and VO_2 sampling interval. Moreover, evidence is even more limited regarding the identification of a suitable verification criterion threshold.

A narrative review published in 2017 updated recommendations on the design of the verification phase within the context of research and applied settings (SCHAUN, 2017). Although the review has progressed our understanding of the verification phase, it did not include a systematic review and meta-analysis to comprehensively summarize the evidence for improving our understanding of the strengths and weaknesses of the substantial number of different verification procedures that have been utilized. Important questions remain as to whether there is sufficient evidence that the verification phase procedure is a valid alternative to verify the attainment of VO_{2max}. Additionally, there remains uncertainty regarding the most appropriate verification protocol. Thus, the aim of the present study was to systematically review and provide a meta-analysis on the validity and application of the verification phase as an emerging procedure for confirming true VO_{2max} in apparently healthy adults.

5.3 **Methods**

Eligibility Criteria and Research Sources

The systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was registered with PROSPERO (CRD42019123540). The main questions addressed by the present study were: Is there evidence that the verification phase procedure is a valid alternative to confirm the attainment of the 'true' VO_{2max}? Secondly, what is the most appropriate protocol for applying the verification phase in apparently healthy adults?

MEDLINE (by PubMed), Web of Science, SPORTDiscus, and Cochrane (by Wiley) were searched for peer-reviewed literature using a combination of medical subject heading (MeSH) descriptors, with a time frame that spanned the inception of each database until the search date (January 30th, 2020). The search strategy was developed based on the PICO method [i.e. *P*articipants: humans of any health condition; *I*nterventions: any intervention involving exercise; *C*omparisons: incremental CPET and an appended square-wave or multistage verification phase; and *O*utcome: VO_{2max} confirmation]. The keywords "maximal oxygen uptake", "verification phase" and "healthy volunteers" were used in combination with medical subject heading (MeSH) descriptors, as follows: **POPULATION:** ("Healthy Volunteers" [Mesh] OR "Healthy Volunteers" OR "Healthy Volunteer" OR "Healthy" OR "Healthy Participants" OR "Healthy Participant" OR "Healthy Subjects" OR "Healthy Subject" OR "Human Volunteers" OR "Human Volunteer" OR "Normal Volunteers" OR "Normal Volunteer" OR "Healthy Individuals" OR "Healthy Individual" OR "Runner" OR "Runners" OR "Active subjects" OR "Athlete" OR "Athletes" OR "Athletics" OR "Participant" OR "Participants" OR "Active participant" OR "Active participants" OR "Recreational-trained" OR "Men" OR "Women" OR "Adult" OR "Adults" OR "Young"); combined with **INTERVENTION:** ("Exercise test" [Mesh] OR "Exercise test" OR "Exercise tests" OR "Test, Exercise" OR "Tests, Exercise" OR "Bicycle Ergometry Test" OR "Bicycle Ergometry Tests" OR "Test, Bicycle Ergometry" OR "Fitness Testing" OR "Testing, Fitness" OR "Step Test" OR "Step Tests" OR "Test, Step" OR "Step exercise test" OR "Stress Test" OR "Stress Tests" OR "Test, Stress" OR "Treadmill Test" OR "Test, Treadmill" OR "Treadmill Tests" OR "Physical Fitness Testing" OR "Cardiopulmonary Exercise Test" OR "Cardiopulmonary Exercise Tests" OR "Exercise Test, Cardiopulmonary"

OR “Test, Cardiopulmonary Exercise” OR “incremental test” OR “incremental tests” OR “incremental exercise” OR "Graded Exercise Test" OR "Graded Exercise Tests" OR "Graded Exercise Testing” OR “Graded-Exercise test” OR “GXT” OR “Graded maximal exercise tests” OR “Graded maximal exercise test” OR “Maximal oxygen uptake test” OR “Maximal oxygen uptake tests” OR “maximal oxygen uptake” OR “maximal oxygen consumption” OR “maximum oxygen consumption” OR “maximal oxygen” OR “VO2” OR “VO2 uptake” OR “VO_2 consumption” OR “VO2max” OR “VO2 max” OR “VO2MAX” OR “VO2 peak” OR “VO2peak” OR “peak oxygen uptake” OR “VO2 plateau”) **AND** (“Verification" OR “Verification bout" OR “Verification phase” OR “Verification criteria” OR “Verification Stage” OR “Verification testing” OR “Verification test” OR “Supramaximal verification” OR "linear phase" OR “supramaximal test” OR “supramaximal testing” OR “GXT-verification” OR “Maximal verification oxygen uptake” OR “exhaustive square-wave run” OR “Higher power output” OR “Speeds above VO2max”).

The terms were adapted for use with other bibliographic databases. Reference lists and citations of eligible articles were also hand searched for additional relevant studies. The search was performed in a standardized manner by two independent researchers (VABC and TP). Only English language studies were eligible for inclusion and only if they satisfied three *a priori* criteria: (1) involved apparently healthy participants that were ≥18 years of age; (2) determined VO_{2max} using expired gas analysis indirect calorimetry; and (3) the CPET was carried out on a cycle ergometer or treadmill. Studies were excluded if they involved: (1) participants who had taken dietary supplements or drugs that could affect body mass, metabolic profile, or exercise performance; (2) the use of non-maximal test protocols; and (3) included tests performed on a running track.

Study Selection

Potential studies were screened for inclusion using three methods: (1) title only; (2) title and abstract; and (3) full-text review. Two investigators independently searched and selected articles, and coauthors subsequently confirmed articles to be included in the analysis. Disagreements were resolved by consensus. Agreement between investigators with respect to inclusion and/or exclusion of potential trials was ratified in 252 randomly selected abstracts by means of Cohen’s kappa ($\kappa = 0.811$, $P < 0.05$). In the final review, we provided a table of characteristics of included studies and another table of excluded studies, with reasons for their exclusion.

Data extraction and management

Two independent reviewers extracted data using a standardized form. The following data were summarized: (1) characteristics of trial participants [total sample number, sex, age, body mass index (BMI), and cardiorespiratory fitness]; (2) type of intervention (CPET and verification phase duration, exercise modality, and exercise protocol used); and (3) outcome measures [mean ± standard deviation (SD) values for VO_{2max}, maximal heart rate, and protocol duration during the CPET and verification phase). Disagreements were resolved by consensus. When the relevant quantitative data were not reported, authors were contacted to request the data.

Quality assessment

The risk of bias for all eligible studies was not assessed because it does not apply to the characteristics of the present review. For example, randomization sequence generation and treatment allocation concealment were not applied, since there were no comparison groups and each individual acted as their own control. It is also noteworthy to mention the absence of blinding in both participants undergoing testing and evaluators who applied the CPET and verification phases, because procedurally all exercise protocols were performed in a fixed order (i.e. CPET followed by the verification phase). Given that VO_{2max} is the evaluation of a numerical variable, the blinding of the evaluator does not generate a different interpretation of the VO_{2max} values obtained in a CPET and verification phase. Finally, the assessment of incomplete outcome data (sample loss) and selective reporting (selective reporting of outcomes) also does not apply, because it is a cross-sectional study with a single outcome of interest.

Data presentation

All meta-analyses were performed using Review Manager (RevMan) software version 5.3. (Copenhagen, The Nordic Cochrane Centre, The Cochrane Collaboration, 2014). Data are presented as the mean ± SD unless otherwise stated. The primary outcome was the mean difference (95% confidence interval, CI) between the CPET and verification phase for the highest absolute VO_2 (L/min). The mean difference in the highest heart rate (bpm) attained

was used as a secondary outcome. Given that absolute VO_2 and heart rate values are continuous data, the weighted mean difference (WMD) method was used for combining study effect size estimates. With the WMD method, the pooled effect estimate represents a weighted mean of all included study group comparisons. The weighting assigned to each individual study group (i.e. the comparison of the CPET and verification phase results) in the analysis is inversely proportional to the variance of the absolute VO_2 (L/min). This method typically assigns more weight in the meta-analysis to studies with larger sample sizes and less weight to those with a smaller sample. The WMDs were calculated using random-effects models given the study group differences in CPET modalities and protocols, types of recovery, and verification phase protocols.

Heterogeneity of net study group changes in VO_{2max} (L/min) and maximal heart rate (bpm) was examined using the Q statistic. Cochran's Q statistic is computed by summing the squared deviations of each trial's estimate from the overall meta-analytic estimate and weighting each trial's contribution in the same manner as in the meta-analysis. *P*-values are obtained by comparing the statistic with a χ^2 distribution with k-1 degrees of freedom (where k is the number of trials). A *P*-value of < 0.10 was adopted since the Q statistic tends to suffer from low differential power. The formal Q statistic was used in conjunction with the methods for assessing heterogeneity. The I^2 statistic measures the extent of inconsistency among the trials' results, interpreted approximately as the proportion of total variation in trial estimates that is due to heterogeneity rather than sampling error. Effect sizes with a corresponding I^2 value of $\leqslant 50\%$ were considered to have low heterogeneity. Subgroup analyses were defined *a priori* to investigate the magnitude of differences between CPETs and verification phases due to variations in sex, cardiorespiratory fitness level, exercise modality, CPET protocol design, or how the verification phase was performed.

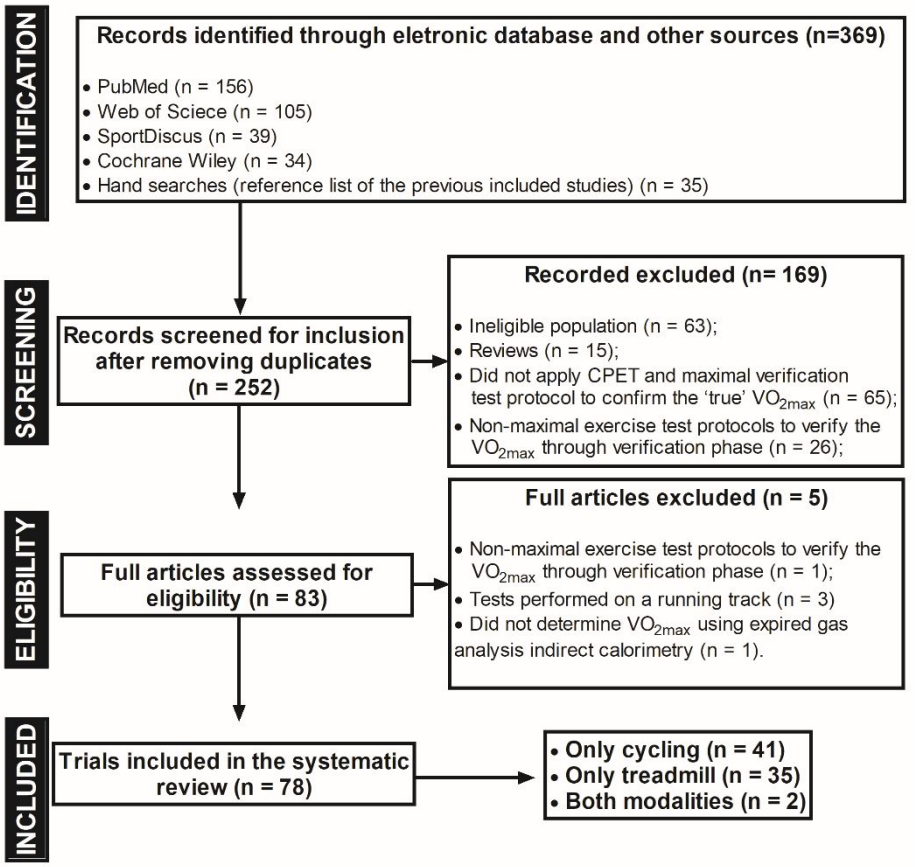
Forest plots were constructed to display values at the 95% confidence level. Effect sizes were calculated by subtracting the highest values for VO_2 (L/min) and heart rate (bpm) observed in the CPET from the verification phase values, on the basis of grouping studies with selected verification phase characteristics for intensity (i.e. submaximal *vs*. supramaximal work rate) and type of recovery between the CPET and verification phase (i.e. active *vs*. passive). The studies also were classified according to whether a criterion threshold for VO_{2max} was used for the verification phase (i.e. yes *vs*. no) and whether the verification phase was performed in the same testing session as the CPET or on a different day. Stratified analyses also were conducted according to particular subgroups such as sex (i.e. male and female), cardiorespiratory fitness level using the cut-points proposed by Astorino et al.

(ASTORINO; MCMILLAN; EDMUNDS; SANCHEZ, 2015) (i.e. low: < 40 mL·kg^{-1}·min^{-1}; moderate: 40-50 mL·kg^{-1}·min^{-1}; high: > 50 mL·kg^{-1}·min^{-1}), exercise test modality (i.e. cycling and running), and CPET protocol design (i.e. discontinuous step-incremented, continuous step-incremented, and ramp protocols).

5.4 **Results**

The literature search identified 369 potential articles, with 334 obtained from electronic database searches and 35 from the wider inspection of reference lists and electronic citations of these articles. All potential articles were initially screened by reading the study title and abstract. A total of 78 studies published between 1980 and 2020 met the eligibility criteria and were included in the systematic review. Figure 1 summarizes the screening and selection process.

Figure 1- Flowchart of the systematic review and meta-analysis according to the PRISMA guidelines.



Subtitles: CPET: cardiopulmonary exercise test; VO_{2max}: maximal oxygen uptake.

Participants

The total number of participants recruited across all eligible studies was 1,634 (1,052 men, 452 women, and the sex of 130 participants was not specified). Included studies had a median (interquartile range, IQR) sample size of 12 participants (9). The age was between 19 and 68 yr., all apparently healthy, and with a physical activity status ranging from sedentary to highly trained endurance athletes. Thirty-six primary studies included only men, two included only women, 39 included both men and women, and one study did not specify the sex of the participants (see Table 1). On average, participants had a body mass index within the normal range [mean ± SD (range): BMI, 24.4 ± 2.5 (19.4-32.0) kg/m^2] and a moderate level of cardiorespiratory fitness (VO_{2max} normalized to body mass) [mean ± SD (range): VO_{2max}, 47.2 ± 12.0 (23.9-68.6) $mL \cdot kg^{-1} \cdot min^{-1}$] according to the cut-off points proposed by Astorino et al. (ASTORINO; MCMILLAN; EDMUNDS; SANCHEZ, 2015).

Table 1. Sample characteristics of the reviewed studies (N= 78).

Study	**Year**	Population			**mean values**		
			Sex M/F	N	Age years	BMI kg/m^2	VO_{2max} $mL \cdot kg^{-1} \cdot min^{-1}$
NIEMELA; PALATSI; LINNALUOTO e TAKKUNEN (1980)	1980	healthy adults	M	16	25-35	23.3	42.5
STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.* (1992)	1992	healthy adults	M/F	33/18	30.6	NS	49.2
DAY; ROSSITER; COATS; SKASICK *et al.* (2003)	2003	healthy adults	M	38	19-61	NS	NS
WINGO; LAFRENZ; GANIO; EDWARDS *et al.* (2005)	2005	healthy adults	M	9	25	22.4	61.2
MIDGLEY; MCNAUGHTON e CARROLL (2006)	2006	middle- and long-distance runners	M	16	38.7	23.0	57.1
ROSSITER; KOWALCHUK e WHIPP (2006)	2006	healthy adults	M	7	26	25.1	51.5
FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.* (2007)	2007	physically active non-athletes (cycling)	M	16	31.5	24.0	51.7
			F	4	28	21.6	
		competitive runners (treadmill running)	M	12	21.6	22.9	56.3
			F	8	21	20.5	

HAWKINS; RAVEN; SNELL; STRAY-GUNDERSEN *et al.* (2007)	2007	distance runners	M/F	36/16	NS	NS	63.3
MIDGLEY; MCNAUGHTON e CARROLL (2007b)	2007	distance runners	M	9	38.2	24.6	55.0
POOLE; WILKERSON e JONES (2008)	2008	healthy adults	M	8	27	NS	50.8
Table 1 (*cont.*).							
ASTORINO; WHITE e DALLECK (2009)	2009	Sedentary	M/F	6/9	22.4	24.5	32.7
		Sedentary	M/F	1/8	21.8	22.9	42.1
MCKAY; PATERSON e KOWALCHUK (2009)	2009	healthy adults	M	12	25	NS	44.5
MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.* (2009)	2009	runners	M	10	39.3	23.6	53.6
		Cyclists		10	36.0	23.2	57.7
ASTORINO e WHITE (2010)	2010	physically active	M	13	23.5	24.3	43.8
			F	17	22.9	22.0	40.7
MURIAS; KOWALCHUK e PATERSON (2010a)	2010	older adults	F	6	69	27.0	23.9
		younger adults	F	8	25	23.8	41.2
MURIAS; KOWALCHUK e PATERSON (2010b)	2010	older adults	M	8	68	26.0	28.3
		younger adults	M	8	23	25.2	48
ALEXANDER e MIER (2011)	2011	soccer athletes	M/F	5/6	21.3	22.7	57.7
BISI; STAGNI e GNUDI (2011)	2011	healthy adults	M	11	23.5	22.6	35.0
JOHNSON; SEXTON; PLACEK; MURRAY *et al.* (2011)	2011	recreationally trained runners and cyclists	M/F	6/5	22	24.1	46.9
KIRKEBERG; DALLECK; KAMPHOFF e PETTITT (2011)	2011	recreational-trained men	M	12	29	27.5	49.2
SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.* (2011)	2011	healthy adults	M/F	20/20	24	23.0	50.0
VOGIATZIS; LOUVARIS; HABAZETTL; ATHANASOPOULOS *et al.* (2011)	2011	Cyclists	M	11	38	22.1	62.0
BELTRAMI; FROYD; MAUGER; METCALFE *et al.* (2012)	2012	runners or cross-country skiers	M/F	23/3	29	23.5	61.3
DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.* (2012)	2012	healthy adults	M/F	9/9	59.7	27.8	27.7
DOGRA; SPENCER e PATERSON (2012)	2012	older adults (trained)	F	7	62.7	23.4	37.8
		older adults (untrained)	F	10	68.8	26.1	24.1

GOODALL; GONZALEZ-ALONSO; ALI; ROSS *et al.* (2012)	2012	Cyclists	M	9	28.1	23.1	61.1
MIER; ALEXANDER e MAGEEAN (2012)	2012	college athletes	M/F	8/27	20	23.5	55.5
CHIDNOK; DIMENNA; BAILEY; BURNLEY *et al.* (2013)	2013	active adults	M	7	20	24.8	57.7
Table 1 (*cont.*).							
CLARK; MURRAY e PETTITT (2013)	2013	adults of various fitness levels	M/F	3/12	22	22.0	NS
MAUGER; METCALFE; TAYLOR e CASTLE (2013)	2013	well-trained runners	M	14	22.7	23.4	64.4
SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.* (2013)	2013	recreationally trained	M/F	6/7	29	23.9	50.1
WILLIAMS; PATERSON e KOWALCHUK (2013)	2013	healthy adults	M	8	27	NS	43.0
		healthy adults	M	5	23	NS	48.0
YEH; LAW e LIM (2013)	2013	healthy adults	M/F	14/1	23.3	21.9	48.9
MANN; WEBSTER; LAMBERTS e LAMBERT (2014)	2014	Runners	M	20	30	24.2	60.2
			F	12	28	21.7	51.9
NALCAKAN (2014)	2014	healthy adults	M	15	21.7	25.0	40.3
NOLAN; BEAVEN e DALLECK (2014)	2014	active adults	M/F	6/6	23	22.7	57.5
STRAUB; MIDGLEY; ZAVORSKY e HILLMAN (2014)	2014	trained cyclists	M	12	33	24.8	56.5
			F	4	38	22.1	
ASTORINO; MCMILLAN; EDMUNDS e SANCHEZ (2015)	2015	low CRF	M/F	5/5	25.7	22.7	36.2
		moderate CRF	M/F	5/5	26.3	24.1	46.4
		high CRF	M/F	9/1	26	23.7	57.9
COLAKOGLU; OZKAYA; BALCI e YAPICIOGLU (2015)	2015	Athletes	M	9	24.2	23.0	59.7
ELLIOTT; SKOWNO; PRABHU; NOAKES *et al.* (2015)	2015	Cyclists	M	8	40.5	25.2	53.7
FAULKNER; MAUGER; WOOLLEY e LAMBRICK (2015)	2015	recreationally trained	M	13	25.5	24.5	63.9
HOGG; HOPKER e MAUGER (2015)	2015	highly trained	M	14	28	23.2	68.6
MANN; PLATT; LAMBERTS e LAMBERT (2015)	2015	Runners	M	8	36	24.1	57.9
			F	2	32	24.9	49.9
SCHEADLER e DEVOR (2015)	2015	experienced runners	NS	13	25	22.5	64.9

COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A. e YAPICIOGLU, B. (2016)	2016	well-trained athletes	M	9	23.6	23.1	60.2
COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS e YAPICIOGLU, BULENT (2016)	2016	Athletes	M	9	23.6	23.1	60.2
Table 1 (*cont.*).							
HANSON; SCHEADLER; LEE; NEUENFELDT *et al.* (2016)	2016	recreationally trained	M/F	8/5	24	24.7	56.2
JAMNICK; BY; PETTITT e PETTITT (2016)	2016	active adults	M	31	29	25.2	48.6
			F	26	27	23.4	39.8
TAYLOR; SEEGMILLER e VELLA (2016)	2016	runners and triathlon athletes	M	11	28.5	22.6	63.7
			F	8	26.3	21.8	52.3
WEATHERWAX; RICHARDSON; BELTZ; NOLAN *et al.* (2016)	2016	elite endurance-trained	M	18	21.9	19.8	62.8
			F	6	20.2	19.4	51.7
WILHELM; GONZALEZ-ALONSO; PARRIS e RAKOBOWCHUK (2016)	2016	healthy adults	M	9	25	25.1	41.0
MCGAWLEY (2017)	2017	recreational runners	M/F	5/5	32	NS	59.8
SABINO-CARVALHO; LOPES; OBEID-FREITAS; FERREIRA *et al.* (2017)	2017	Runners	M	14	22.3	21.2	67.0
			F	4	24	20.4	60.1
ASTORINO e DEREVERE (2018)	2018	recreationally trained	M/F	19/11	26	NS	47.2
			M/F	41/38	23.3	NS	40.5
ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.* (2018)	2018	active adults (HIIT-Baseline)	M/F	3/11	27	22	38.0
		active adults (HIIT - Week 3)					40.4
		active adults (Control - Baseline)	M/F	8/6	23	24	40.2
		active adults (Control - Week 3)					40.5
BELTZ; AMORIM; GIBSON; JANOT *et al.* (2018)	2018	recreationally trained	M	16	23.6	26.6	47.4
DICKS; JOE; HACKNEY e PETTITT (2018)	2018	Firefighters	M	30	34.5	28.7	41.0
JAMNICK; BOTELLA; PYNE e BISHOP (2018)	2018	trained cyclists	M	17	36.2	24.1	62.1
KEILLER e GORDON (2018)	2018	recreationally trained	M/F	9/2	22.4	24.4	51.6
KRAMER; DU RANDT; WATSON e PETTITT (2018)	2018	soccer athletes	M	15	23.1	23.0	50.5
MURIAS; POGLIAGHI e PATERSON (2018)	2018	younger adults	M	30	25	24.9	49.4
		older adults		31	68	25.8	33.0

STROM; PETTITT; KRYNSKI; JAMNICK *et al.* (2018)	2018	healthy adults	M/F	21/29	30.3	24.0	47.3
TUCKER; SAWYER; JARRETT; BHAMMAR *et al.* (2018)	2018	nonexercise-trained young	M	17	27	25.6	41.6
WEATHERWAX; HARRIS; KILDING e DALLECK (2018)	2018	sedentary adults	M	5	53.6	32.0	32.3
			F	11	52.2	29.4	24.8

Table 1 (*cont.*).

ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.* (2019)	2019	active adults	M/F	14	27	22.5	38.0
DEXHEIMER; SCHROEDER; SAWYER; PETTITT *et al.* (2019)	2019	active adults	M	12	29	31.4	50.6
			F	5	25.6	24.4	43.7
DUCROCQ; HUREAU; MESTE e BLAIN (2019)	2019	recreationally trained	M/F	9/4	21.2	22.5	56.0
FREEBERG; BAUGHMAN; VICKEY; SULLIVAN *et al.* (2019)	2019	healthy adults	M/F	17/13	21.7	23.7	49.9
JAMES; TENLLADO VALLEJO; KANTEBEEN e FARRA (2019)	2019	squash players	M/F	6/2	20.3	22.1	48.8
KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.* (2019)	2019	Athletes	M	10	27.5	23.1	61.1
			F	7	28.4	22.5	54.3
KNAIER; NIEMEYER; WAGNER; INFANGER *et al.* (2019)	2019	high cardiorespiratory fitness	M	8	27.4	22.8	62.8
			F	5	27.6	22.7	55.2
NIEMEYER; LEITHAEUSER e BENEKE (2019)	2019	physically active	M	24	26.2	24.2	49.8
POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.* (2019)	2019	recreationally trained cyclists	M	19	23	25.3	48.0
RIBOLI; RAMPICHINI; CE; LIMONTA *et al.* (2019)	2019	soccer athletes	M	16	22.5	22.4	59.2
WEATHERWAX, R.; HARRIS, N.; KILDING, A. E. e DALLECK, L. (2019)	2019	sedentary adults (standardized - baseline)	M/F	4/16	51.2	29.6	24.3
		sedentary adults (standardized - week 4)	M/F	4/16	51.2	29.7	25.0
		sedentary adults (standardized - week 8)	M/F	4/16	51.2	29.6	26.3
		sedentary adults (standardized - week 12)	M/F	4/16	51.2	29.6	26.3
		sedentary adults (individualized - baseline)	M/F	5/14	44.9	27.2	29.5
		sedentary adults (individualized - week 4)	M/F	5/14	44.9	27.2	31.1
		sedentary adults (individualized - week 8)	M/F	5/14	44.9	27.1	31.3
		sedentary adults (individualized - week 12)	M/F	5/14	44.9	27.0	32.8
WEATHERWAX, R. M.; HARRIS, N. K.; KILDING,	2019	sedentary adults (control - baseline)	M/F	2/6	45.6	25.5	28.4
		sedentary adults (control - week 12)				25.5	27.7

A. E. e DALLECK, L. C. (2019)		sedentary adults (standardized - baseline)	M/F	4/16	51.2	29.6	24.3
		sedentary adults (standardized - week 12)				29.6	26.0
		sedentary adults (individualized - baseline)	M/F	5/14	44.9	27.1	29.5
		sedentary adults (individualized - week 12)				26.8	32.8
DEL GIUDICE; BONAFIGLIA; ISLAM; PREOBRAZENSKI *et al.* (2020)	2020	healthy adults	M	14	21.5	22.8	60.2
NIEMEYER; BERGMANN e BENEKE (2020)	2020	recreationally trained	M	46	25.6	24.0	50.8

BMI = body mass index; *CRF* = cardiorespiratory fitness level; *F* = female; *HIIT* = high-intensity interval training; *M* = male; *NS* = not stated; VO_{2max} = maximal oxygen uptake.

Note: Whenever possible, authors were contacted to provide unavailable data.

Characteristics of studies regarding the CPET and verification phase protocols to evaluate VO_{2max}

Table 2 summarizes the characteristics of the CPET and verification phase protocols of the 78 studies included in this systematic review. Forty-one studies (53%) performed the CPET on cycle ergometer (ASTORINO; WHITE; DALLECK, 2009; ASTORINO; DEREVERE, 2018; ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2018; ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2019; ASTORINO; MCMILLAN; EDMUNDS; SANCHEZ, 2015; ASTORINO; WHITE, 2010; BISI; STAGNI; GNUDI, 2011; CHIDNOK; DIMENNA; BAILEY; BURNLEY *et al.*, 2013; CLARK; MURRAY; PETTITT, 2013; COLAKOGLU; OZKAYA; BALCI; YAPICIOGLU, 2015; COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A.; YAPICIOGLU, B., 2016; COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS; YAPICIOGLU, BULENT, 2016; DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.*, 2012; DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; DOGRA; SPENCER; PATERSON, 2012; ELLIOTT; SKOWNO; PRABHU; NOAKES *et al.*, 2015; GOODALL; GONZALEZ-ALONSO; ALI; ROSS *et al.*, 2012; JAMNICK; BOTELLA; PYNE; BISHOP, 2018; JAMNICK; BY; PETTITT; PETTITT, 2016; JOHNSON; SEXTON; PLACEK; MURRAY *et al.*, 2011; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; MCKAY; PATERSON; KOWALCHUK, 2009; MURIAS; KOWALCHUK; PATERSON, 2010a; b; MURIAS; POGLIAGHI; PATERSON, 2018; NALCAKAN, 2014; NIEMELA; PALATSI; LINNALUOTO; TAKKUNEN, 1980; NIEMEYER; BERGMANN; BENEKE, 2020;

NIEMEYER; LEITHAEUSER; BENEKE, 2019; POOLE; WILKERSON; JONES, 2008; POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.*, 2019; ROSSITER; KOWALCHUK; WHIPP, 2006; SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.*, 2013; STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.*, 1992; STRAUB; MIDGLEY; ZAVORSKY; HILLMAN, 2014; TUCKER; SAWYER; JARRETT; BHAMMAR *et al.*, 2018; VOGIATZIS; LOUVARIS; HABAZETTL; ATHANASOPOULOS *et al.*, 2011; WILHELM; GONZALEZ-ALONSO; PARRIS; RAKOBOWCHUK, 2016; WILLIAMS; PATERSON; KOWALCHUK, 2013; WINGO; LAFRENZ; GANIO; EDWARDS *et al.*, 2005), 35 (45%) on treadmill (ALEXANDER; MIER, 2011; BELTRAMI; FROYD; MAUGER; METCALFE *et al.*, 2012; BELTZ; AMORIM; GIBSON; JANOT *et al.*, 2018; DEL GIUDICE; BONAFIGLIA; ISLAM; PREOBRAZENSKI *et al.*, 2020; DEXHEIMER; SCHROEDER; SAWYER; PETTITT *et al.*, 2019; DICKS; JOE; HACKNEY; PETTITT, 2018; DUCROCQ; HUREAU; MESTE; BLAIN, 2019; FAULKNER; MAUGER; WOOLLEY; LAMBRICK, 2015; FREEBERG; BAUGHMAN; VICKEY; SULLIVAN *et al.*, 2019; HANSON; SCHEADLER; LEE; NEUENFELDT *et al.*, 2016; HAWKINS; RAVEN; SNELL; STRAY-GUNDERSEN *et al.*, 2007; HOGG; HOPKER; MAUGER, 2015; JAMES; TENLLADO VALLEJO; KANTEBEEN; FARRA, 2019; KEILLER; GORDON, 2018; KIRKEBERG; DALLECK; KAMPHOFF; PETTITT, 2011; KRAMER; DU RANDT; WATSON; PETTITT, 2018; MANN; PLATT; LAMBERTS; LAMBERT, 2015; MANN; WEBSTER; LAMBERTS; LAMBERT, 2014; MAUGER; METCALFE; TAYLOR; CASTLE, 2013; MCGAWLEY, 2017; MIDGLEY; MCNAUGHTON; CARROLL, 2006; 2007b; MIER; ALEXANDER; MAGEEAN, 2012; NOLAN; BEAVEN; DALLECK, 2014; RIBOLI; RAMPICHINI; CE; LIMONTA *et al.*, 2019; SABINO-CARVALHO; LOPES; OBEID-FREITAS; FERREIRA *et al.*, 2017; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011; SCHEADLER; DEVOR, 2015; STROM; PETTITT; KRYNSKI; JAMNICK *et al.*, 2018; TAYLOR; SEEGMILLER; VELLA, 2016; WEATHERWAX, R.; HARRIS, N.; KILDING, A. E.; DALLECK, L., 2019; WEATHERWAX; HARRIS; KILDING; DALLECK, 2018; WEATHERWAX, R. M.; HARRIS, N. K.; KILDING, A. E.; DALLECK, L. C., 2019; WEATHERWAX; RICHARDSON; BELTZ; NOLAN *et al.*, 2016; YEH; LAW; LIM, 2013), and two studies (2%) used both modalities (FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.*, 2007; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009). Seventy-one studies (91%) used continuous step-incremented or ramp/pseudo-ramp CPET protocols (ASTORINO; WHITE; DALLECK, 2009; ASTORINO; DEREVERE, 2018; ASTORINO;

DEREVERE; ANDERSON; KELLOGG *et al.*, 2018; ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2019; ASTORINO; MCMILLAN; EDMUNDS; SANCHEZ, 2015; ASTORINO; WHITE, 2010; BELTRAMI; FROYD; MAUGER; METCALFE *et al.*, 2012; BISI; STAGNI; GNUDI, 2011; CHIDNOK; DIMENNA; BAILEY; BURNLEY *et al.*, 2013; CLARK; MURRAY; PETTITT, 2013; COLAKOGLU; OZKAYA; BALCI; YAPICIOGLU, 2015; COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A.; YAPICIOGLU, B., 2016; COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS; YAPICIOGLU, BULENT, 2016; DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.*, 2012; DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; DEL GIUDICE; BONAFIGLIA; ISLAM; PREOBRAZENSKI *et al.*, 2020; DEXHEIMER; SCHROEDER; SAWYER; PETTITT *et al.*, 2019; DICKS; JOE; HACKNEY; PETTITT, 2018; DOGRA; SPENCER; PATERSON, 2012; DUCROCQ; HUREAU; MESTE; BLAIN, 2019; ELLIOTT; SKOWNO; PRABHU; NOAKES *et al.*, 2015; FAULKNER; MAUGER; WOOLLEY; LAMBRICK, 2015; FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.*, 2007; FREEBERG; BAUGHMAN; VICKEY; SULLIVAN *et al.*, 2019; GOODALL; GONZALEZ-ALONSO; ALI; ROSS *et al.*, 2012; HANSON; SCHEADLER; LEE; NEUENFELDT *et al.*, 2016; HAWKINS; RAVEN; SNELL; STRAY-GUNDERSEN *et al.*, 2007; JAMES; TENLLADO VALLEJO; KANTEBEEN; FARRA, 2019; JAMNICK; BOTELLA; PYNE; BISHOP, 2018; JAMNICK; BY; PETTITT; PETTITT, 2016; JOHNSON; SEXTON; PLACEK; MURRAY *et al.*, 2011; KEILLER; GORDON, 2018; KIRKEBERG; DALLECK; KAMPHOFF; PETTITT, 2011; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; KRAMER; DU RANDT; WATSON; PETTITT, 2018; MANN; PLATT; LAMBERTS; LAMBERT, 2015; MANN; WEBSTER; LAMBERTS; LAMBERT, 2014; MAUGER; METCALFE; TAYLOR; CASTLE, 2013; MCGAWLEY, 2017; MCKAY; PATERSON; KOWALCHUK, 2009; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MIDGLEY; MCNAUGHTON; CARROLL, 2006; MIER; ALEXANDER; MAGEEAN, 2012; MURIAS; KOWALCHUK; PATERSON, 2010a; b; MURIAS; POGLIAGHI; PATERSON, 2018; NALCAKAN, 2014; NIEMELA; PALATSI; LINNALUOTO; TAKKUNEN, 1980; NIEMEYER; BERGMANN; BENEKE, 2020; NIEMEYER; LEITHAEUSER; BENEKE, 2019; NOLAN; BEAVEN; DALLECK, 2014; POOLE; WILKERSON; JONES, 2008; POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.*, 2019; RIBOLI; RAMPICHINI; CE; LIMONTA *et al.*, 2019; ROSSITER; KOWALCHUK; WHIPP, 2006; SCHEADLER; DEVOR, 2015; SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.*, 2013; STACHENFELD; ESKENAZI; GLEIM;

COPLAN *et al.*, 1992; STRAUB; MIDGLEY; ZAVORSKY; HILLMAN, 2014; STROM; PETTITT; KRYNSKI; JAMNICK *et al.*, 2018; TAYLOR; SEEGMILLER; VELLA, 2016; TUCKER; SAWYER; JARRETT; BHAMMAR *et al.*, 2018; VOGIATZIS; LOUVARIS; HABAZETTL; ATHANASOPOULOS *et al.*, 2011; WEATHERWAX, R.; HARRIS, N.; KILDING, A. E.; DALLECK, L., 2019; WEATHERWAX; HARRIS; KILDING; DALLECK, 2018; WEATHERWAX, R. M.; HARRIS, N. K.; KILDING, A. E.; DALLECK, L. C., 2019; WILHELM; GONZALEZ-ALONSO; PARRIS; RAKOBOWCHUK, 2016; WILLIAMS; PATERSON; KOWALCHUK, 2013; WINGO; LAFRENZ; GANIO; EDWARDS *et al.*, 2005; YEH; LAW; LIM, 2013). Two studies (2%) applied self-paced protocols (BELTZ; AMORIM; GIBSON; JANOT *et al.*, 2018; HOGG; HOPKER; MAUGER, 2015), five (6%) used discontinuous step-incremented protocols (ALEXANDER; MIER, 2011; MIDGLEY; MCNAUGHTON; CARROLL, 2007b; SABINO-CARVALHO; LOPES; OBEID-FREITAS; FERREIRA *et al.*, 2017; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011; WEATHERWAX; RICHARDSON; BELTZ; NOLAN *et al.*, 2016), and another two studies (2%) used both discontinuous and continuous step-incremented protocols (ALEXANDER; MIER, 2011; MIDGLEY; MCNAUGHTON; CARROLL, 2007b). Thirty-one (40%) of the 78 studies included in the review adopted traditional criteria to establish VO_{2max} (ALEXANDER; MIER, 2011; BELTRAMI; FROYD; MAUGER; METCALFE *et al.*, 2012; BISI; STAGNI; GNUDI, 2011; COLAKOGLU; OZKAYA; BALCI; YAPICIOGLU, 2015; COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A.; YAPICIOGLU, B., 2016; COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS; YAPICIOGLU, BULENT, 2016; FAULKNER; MAUGER; WOOLLEY; LAMBRICK, 2015; FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.*, 2007; HANSON; SCHEADLER; LEE; NEUENFELDT *et al.*, 2016; HOGG; HOPKER; MAUGER, 2015; JAMES; TENLLADO VALLEJO; KANTEBEEN; FARRA, 2019; KEILLER; GORDON, 2018; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; MAUGER; METCALFE; TAYLOR; CASTLE, 2013; MCGAWLEY, 2017; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MIDGLEY; MCNAUGHTON; CARROLL, 2006; MIER; ALEXANDER; MAGEEAN, 2012; NALCAKAN, 2014; NIEMELA; PALATSI; LINNALUOTO; TAKKUNEN, 1980; NIEMEYER; BERGMANN; BENEKE, 2020; NIEMEYER; LEITHAEUSER; BENEKE, 2019; POOLE; WILKERSON; JONES, 2008; POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.*, 2019; RIBOLI; RAMPICHINI; CE; LIMONTA *et al.*, 2019; ROSSITER; KOWALCHUK; WHIPP, 2006; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL;

MAYER *et al.*, 2011; SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.*, 2013; STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.*, 1992; WINGO; LAFRENZ; GANIO; EDWARDS *et al.*, 2005). Of these, 28 used the VO_2 plateau (ALEXANDER; MIER, 2011; BELTRAMI; FROYD; MAUGER; METCALFE *et al.*, 2012; BISI; STAGNI; GNUDI, 2011; COLAKOGLU; OZKAYA; BALCI; YAPICIOGLU, 2015; COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A.; YAPICIOGLU, B., 2016; COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS; YAPICIOGLU, BULENT, 2016; FAULKNER; MAUGER; WOOLLEY; LAMBRICK, 2015; FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.*, 2007; HANSON; SCHEADLER; LEE; NEUENFELDT *et al.*, 2016; HOGG; HOPKER; MAUGER, 2015; JAMES; TENLLADO VALLEJO; KANTEBEEN; FARRA, 2019; KEILLER; GORDON, 2018; MAUGER; METCALFE; TAYLOR; CASTLE, 2013; MCGAWLEY, 2017; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MIDGLEY; MCNAUGHTON; CARROLL, 2006; MIER; ALEXANDER; MAGEEAN, 2012; NALCAKAN, 2014; NIEMELA; PALATSI; LINNALUOTO; TAKKUNEN, 1980; NIEMEYER; BERGMANN; BENEKE, 2020; NIEMEYER; LEITHAEUSER; BENEKE, 2019; POOLE; WILKERSON; JONES, 2008; RIBOLI; RAMPICHINI; CE; LIMONTA *et al.*, 2019; ROSSITER; KOWALCHUK; WHIPP, 2006; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011; SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.*, 2013; STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.*, 1992; WINGO; LAFRENZ; GANIO; EDWARDS *et al.*, 2005), 20 used the heart rate plateau or age-predicted maximal heart rate (BISI; STAGNI; GNUDI, 2011; COLAKOGLU; OZKAYA; BALCI; YAPICIOGLU, 2015; COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A.; YAPICIOGLU, B., 2016; COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS; YAPICIOGLU, BULENT, 2016; FAULKNER; MAUGER; WOOLLEY; LAMBRICK, 2015; HOGG; HOPKER; MAUGER, 2015; KEILLER; GORDON, 2018; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; MAUGER; METCALFE; TAYLOR; CASTLE, 2013; MCGAWLEY, 2017; MIDGLEY; MCNAUGHTON; CARROLL, 2006; MIER; ALEXANDER; MAGEEAN, 2012; NALCAKAN, 2014; NIEMELA; PALATSI; LINNALUOTO; TAKKUNEN, 1980; POOLE; WILKERSON; JONES, 2008; POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.*, 2019; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011; STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.*, 1992; WINGO; LAFRENZ; GANIO; EDWARDS *et al.*, 2005), 17 (55%) used the RER (BISI; STAGNI; GNUDI, 2011;

COLAKOGLU; OZKAYA; BALCI; YAPICIOGLU, 2015; COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A.; YAPICIOGLU, B., 2016; COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS; YAPICIOGLU, BULENT, 2016; FAULKNER; MAUGER; WOOLLEY; LAMBRICK, 2015; HANSON; SCHEADLER; LEE; NEUENFELDT *et al.*, 2016; HOGG; HOPKER; MAUGER, 2015; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; MAUGER; METCALFE; TAYLOR; CASTLE, 2013; MCGAWLEY, 2017; MIDGLEY; MCNAUGHTON; CARROLL, 2006; MIER; ALEXANDER; MAGEEAN, 2012; NALCAKAN, 2014; POOLE; WILKERSON; JONES, 2008; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011; STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.*, 1992), and 8 used the post-CPET blood lactate concentration (FAULKNER; MAUGER; WOOLLEY; LAMBRICK, 2015; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; MAUGER; METCALFE; TAYLOR; CASTLE, 2013; MCGAWLEY, 2017; POOLE; WILKERSON; JONES, 2008; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011; STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.*, 1992).

In terms of processing respiratory VO_2 data at volitional exhaustion, the most common approach was based on time averages. Thirty-eight studies (49%) reported 5- to 30-s (or 3 x 10-s) averages (ALEXANDER; MIER, 2011; ASTORINO; WHITE; DALLECK, 2009; ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2018; ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2019; ASTORINO; WHITE, 2010; CLARK; MURRAY; PETTITT, 2013; COLAKOGLU; OZKAYA; BALCI; YAPICIOGLU, 2015; COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A.; YAPICIOGLU, B., 2016; COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS; YAPICIOGLU, BULENT, 2016; DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; DEL GIUDICE; BONAFIGLIA; ISLAM; PREOBRAZENSKI *et al.*, 2020; DICKS; JOE; HACKNEY; PETTITT, 2018; FAULKNER; MAUGER; WOOLLEY; LAMBRICK, 2015; FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.*, 2007; GOODALL; GONZALEZ-ALONSO; ALI; ROSS *et al.*, 2012; HOGG; HOPKER; MAUGER, 2015; JAMES; TENLLADO VALLEJO; KANTEBEEN; FARRA, 2019; JAMNICK; BOTELLA; PYNE; BISHOP, 2018; JAMNICK; BY; PETTITT; PETTITT, 2016; KIRKEBERG; DALLECK; KAMPHOFF; PETTITT, 2011; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; MAUGER; METCALFE; TAYLOR; CASTLE, 2013;

MCGAWLEY, 2017; MCKAY; PATERSON; KOWALCHUK, 2009; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MIDGLEY; MCNAUGHTON; CARROLL, 2006; 2007b; MURIAS; POGLIAGHI; PATERSON, 2018; NIEMEYER; BERGMANN; BENEKE, 2020; NIEMEYER; LEITHAEUSER; BENEKE, 2019; ROSSITER; KOWALCHUK; WHIPP, 2006; SABINO-CARVALHO; LOPES; OBEID-FREITAS; FERREIRA *et al.*, 2017; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011; SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.*, 2013; STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.*, 1992; STRAUB; MIDGLEY; ZAVORSKY; HILLMAN, 2014; STROM; PETTITT; KRYNSKI; JAMNICK *et al.*, 2018), whereas 29 (37%) used fixed intervals of 15- to 30-s (or 2 × 15-s) (ASTORINO; DEREVERE, 2018; ASTORINO; MCMILLAN; EDMUNDS; SANCHEZ, 2015; BELTRAMI; FROYD; MAUGER; METCALFE *et al.*, 2012; BELTZ; AMORIM; GIBSON; JANOT *et al.*, 2018; DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.*, 2012; DEXHEIMER; SCHROEDER; SAWYER; PETTITT *et al.*, 2019; DOGRA; SPENCER; PATERSON, 2012; FREEBERG; BAUGHMAN; VICKEY; SULLIVAN *et al.*, 2019; JOHNSON; SEXTON; PLACEK; MURRAY *et al.*, 2011; KEILLER; GORDON, 2018; KRAMER; DU RANDT; WATSON; PETTITT, 2018; MANN; PLATT; LAMBERTS; LAMBERT, 2015; MANN; WEBSTER; LAMBERTS; LAMBERT, 2014; MIER; ALEXANDER; MAGEEAN, 2012; MURIAS; KOWALCHUK; PATERSON, 2010a; b; NALCAKAN, 2014; NOLAN; BEAVEN; DALLECK, 2014; POOLE; WILKERSON; JONES, 2008; POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.*, 2019; RIBOLI; RAMPICHINI; CE; LIMONTA *et al.*, 2019; SCHEADLER; DEVOR, 2015; TUCKER; SAWYER; JARRETT; BHAMMAR *et al.*, 2018; WEATHERWAX, R.; HARRIS, N.; KILDING, A. E.; DALLECK, L., 2019; WEATHERWAX; HARRIS; KILDING; DALLECK, 2018; WEATHERWAX, R. M.; HARRIS, N. K.; KILDING, A. E.; DALLECK, L. C., 2019; WEATHERWAX; RICHARDSON; BELTZ; NOLAN *et al.*, 2016; WILLIAMS; PATERSON; KOWALCHUK, 2013; WINGO; LAFRENZ; GANIO; EDWARDS *et al.*, 2005), both averaged and fixed times (1%) (ASTORINO; WHITE; DALLECK, 2009), 15-breath average (2%) (HANSON; SCHEADLER; LEE; NEUENFELDT *et al.*, 2016; TAYLOR; SEEGMILLER; VELLA, 2016), 10-25-s moving average (2%) (BISI; STAGNI; GNUDI, 2011; WILHELM; GONZALEZ-ALONSO; PARRIS; RAKOBOWCHUK, 2016), 10-s epochs (1%) (ELLIOTT; SKOWNO; PRABHU; NOAKES *et al.*, 2015), 30-s rolling mean (1%) (CHIDNOK; DIMENNA; BAILEY; BURNLEY *et al.*, 2013), or Douglas bag collection (1%) (HAWKINS; RAVEN; SNELL; STRAY-GUNDERSEN *et al.*, 2007). Four

studies did not detail which VO_2 data processing method was applied (DUCROCQ; HUREAU; MESTE; BLAIN, 2019; NIEMELA; PALATSI; LINNALUOTO; TAKKUNEN, 1980; VOGIATZIS; LOUVARIS; HABAZETTL; ATHANASOPOULOS *et al.*, 2011; YEH; LAW; LIM, 2013).

Regarding the verification phase procedure, 34 studies (45%) used a short-term active recovery (e.g. pedaling at light-intensity, walking at a slow pace, or stretching) of 1 min (FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.*, 2007), 3 (CLARK; MURRAY; PETTITT, 2013; DICKS; JOE; HACKNEY; PETTITT, 2018; FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.*, 2007; JAMNICK; BY; PETTITT; PETTITT, 2016; JOHNSON; SEXTON; PLACEK; MURRAY *et al.*, 2011; KIRKEBERG; DALLECK; KAMPHOFF; PETTITT, 2011; KRAMER; DU RANDT; WATSON; PETTITT, 2018; STROM; PETTITT; KRYNSKI; JAMNICK *et al.*, 2018), 5 (JAMES; TENLLADO VALLEJO; KANTEBEEN; FARRA, 2019; MCKAY; PATERSON; KOWALCHUK, 2009; MURIAS; KOWALCHUK; PATERSON, 2010a; b; MURIAS; POGLIAGHI; PATERSON, 2018; ROSSITER; KOWALCHUK; WHIPP, 2006; WILLIAMS; PATERSON; KOWALCHUK, 2013), 6 (BISI; STAGNI; GNUDI, 2011), 8 min (ASTORINO; DEREVERE, 2018; ASTORINO; MCMILLAN; EDMUNDS; SANCHEZ, 2015), 10 min (ALEXANDER; MIER, 2011; ASTORINO; DEREVERE, 2018; ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2018; ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2019; ASTORINO; WHITE, 2010; DEXHEIMER; SCHROEDER; SAWYER; PETTITT *et al.*, 2019; FREEBERG; BAUGHMAN; VICKEY; SULLIVAN *et al.*, 2019; HANSON; SCHEADLER; LEE; NEUENFELDT *et al.*, 2016; HOGG; HOPKER; MAUGER, 2015; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; MAUGER; METCALFE; TAYLOR; CASTLE, 2013; MIDGLEY; MCNAUGHTON; CARROLL, 2006; MIER; ALEXANDER; MAGEEAN, 2012; NIEMEYER; LEITHAEUSER; BENEKE, 2019), or 5-10 min (TUCKER; SAWYER; JARRETT; BHAMMAR *et al.*, 2018), while 26 studies (33%) employed passive recovery of 5 min (DUCROCQ; HUREAU; MESTE; BLAIN, 2019; JAMNICK; BOTELLA; PYNE; BISHOP, 2018; MIDGLEY; MCNAUGHTON; CARROLL, 2007b; WILHELM; GONZALEZ-ALONSO; PARRIS; RAKOBOWCHUK, 2016), 6 (KEILLER; GORDON, 2018), 9 (MCGAWLEY, 2017), 10 min (DEL GIUDICE; BONAFIGLIA; ISLAM; PREOBRAZENSKI *et al.*, 2020; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011; STRAUB; MIDGLEY; ZAVORSKY;

HILLMAN, 2014; YEH; LAW; LIM, 2013), 15 (FAULKNER; MAUGER; WOOLLEY; LAMBRICK, 2015; POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.*, 2019), 20 min (BELTZ; AMORIM; GIBSON; JANOT *et al.*, 2018; NOLAN; BEAVEN; DALLECK, 2014; VOGIATZIS; LOUVARIS; HABAZETTL; ATHANASOPOULOS *et al.*, 2011; WEATHERWAX, R.; HARRIS, N.; KILDING, A. E.; DALLECK, L., 2019; WEATHERWAX; HARRIS; KILDING; DALLECK, 2018; WEATHERWAX, R. M.; HARRIS, N. K.; KILDING, A. E.; DALLECK, L. C., 2019; WEATHERWAX; RICHARDSON; BELTZ; NOLAN *et al.*, 2016; WINGO; LAFRENZ; GANIO; EDWARDS *et al.*, 2005), 60 min (DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.*, 2012; NOLAN; BEAVEN; DALLECK, 2014), or 60-90 min (ASTORINO; WHITE; DALLECK, 2009; ELLIOTT; SKOWNO; PRABHU; NOAKES *et al.*, 2015). One study (1%) employed a combination of passive and active recovery (e.g. 3-min passive followed by 7-min active) (SABINO-CARVALHO; LOPES; OBEID-FREITAS; FERREIRA *et al.*, 2017) and another (1%) used a self-paced approach (BELTRAMI; FROYD; MAUGER; METCALFE *et al.*, 2012). Two studies (2%) employed short-term recovery (e.g. 8-10 min) without stating whether it was active or passive (MANN; PLATT; LAMBERTS; LAMBERT, 2015; MANN; WEBSTER; LAMBERTS; LAMBERT, 2014). Fifteen studies (19%) carried out the verification phase on a different day to the CPET (19.7%) (ASTORINO; WHITE; DALLECK, 2009; CHIDNOK; DIMENNA; BAILEY; BURNLEY *et al.*, 2013; COLAKOGLU; OZKAYA; BALCI; YAPICIOGLU, 2015; COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A.; YAPICIOGLU, B., 2016; COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS; YAPICIOGLU, BULENT, 2016; DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; DOGRA; SPENCER; PATERSON, 2012; HAWKINS; RAVEN; SNELL; STRAY-GUNDERSEN *et al.*, 2007; NALCAKAN, 2014; NIEMELA; PALATSI; LINNALUOTO; TAKKUNEN, 1980; NIEMEYER; BERGMANN; BENEKE, 2020; POOLE; WILKERSON; JONES, 2008; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011; SCHEADLER; DEVOR, 2015; STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.*, 1992).

Fifty-eight studies (74%) used square-wave verification phase protocols (ASTORINO; WHITE; DALLECK, 2009; ASTORINO; DEREVERE, 2018; ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2018; ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2019; ASTORINO; WHITE, 2010; BISI; STAGNI; GNUDI, 2011; CLARK; MURRAY; PETTITT, 2013; COLAKOGLU; OZKAYA; BALCI; YAPICIOGLU, 2015; COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A.; YAPICIOGLU, B., 2016;

COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS; YAPICIOGLU, BULENT, 2016; DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; DEL GIUDICE; BONAFIGLIA; ISLAM; PREOBRAZENSKI *et al.*, 2020; DEXHEIMER; SCHROEDER; SAWYER; PETTITT *et al.*, 2019; DICKS; JOE; HACKNEY; PETTITT, 2018; DOGRA; SPENCER; PATERSON, 2012; DUCROCQ; HUREAU; MESTE; BLAIN, 2019; ELLIOTT; SKOWNO; PRABHU; NOAKES *et al.*, 2015; FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.*, 2007; FREEBERG; BAUGHMAN; VICKEY; SULLIVAN *et al.*, 2019; GOODALL; GONZALEZ-ALONSO; ALI; ROSS *et al.*, 2012; HANSON; SCHEADLER; LEE; NEUENFELDT *et al.*, 2016; HAWKINS; RAVEN; SNELL; STRAY-GUNDERSEN *et al.*, 2007; JAMES; TENLLADO VALLEJO; KANTEBEEN; FARRA, 2019; JAMNICK; BOTELLA; PYNE; BISHOP, 2018; JAMNICK; BY; PETTITT; PETTITT, 2016; JOHNSON; SEXTON; PLACEK; MURRAY *et al.*, 2011; KIRKEBERG; DALLECK; KAMPHOFF; PETTITT, 2011; KRAMER; DU RANDT; WATSON; PETTITT, 2018; MANN; PLATT; LAMBERTS; LAMBERT, 2015; MANN; WEBSTER; LAMBERTS; LAMBERT, 2014; MAUGER; METCALFE; TAYLOR; CASTLE, 2013; MCGAWLEY, 2017; MCKAY; PATERSON; KOWALCHUK, 2009; MIDGLEY; MCNAUGHTON; CARROLL, 2006; 2007b; MURIAS; KOWALCHUK; PATERSON, 2010a; b; MURIAS; POGLIAGHI; PATERSON, 2018; NALCAKAN, 2014; NIEMEYER; BERGMANN; BENEKE, 2020; NIEMEYER; LEITHAEUSER; BENEKE, 2019; NOLAN; BEAVEN; DALLECK, 2014; POOLE; WILKERSON; JONES, 2008; RIBOLI; RAMPICHINI; CE; LIMONTA *et al.*, 2019; ROSSITER; KOWALCHUK; WHIPP, 2006; SCHEADLER; DEVOR, 2015; SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.*, 2013; STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.*, 1992; STROM; PETTITT; KRYNSKI; JAMNICK *et al.*, 2018; TUCKER; SAWYER; JARRETT; BHAMMAR *et al.*, 2018; VOGIATZIS; LOUVARIS; HABAZETTL; ATHANASOPOULOS *et al.*, 2011; WEATHERWAX, R.; HARRIS, N.; KILDING, A. E.; DALLECK, L., 2019; WEATHERWAX; HARRIS; KILDING; DALLECK, 2018; WEATHERWAX, R. M.; HARRIS, N. K.; KILDING, A. E.; DALLECK, L. C., 2019; WILHELM; GONZALEZ-ALONSO; PARRIS; RAKOBOWCHUK, 2016; WILLIAMS; PATERSON; KOWALCHUK, 2013; WINGO; LAFRENZ; GANIO; EDWARDS *et al.*, 2005; YEH; LAW; LIM, 2013), while 20 studies (26%) used multistage verification protocols characterized by an initial warm-up stage (ALEXANDER; MIER, 2011; ASTORINO; MCMILLAN; EDMUNDS; SANCHEZ, 2015; BELTRAMI; FROYD; MAUGER; METCALFE *et al.*, 2012; BELTZ; AMORIM; GIBSON; JANOT *et al.*, 2018; CHIDNOK; DIMENNA; BAILEY; BURNLEY *et*

al., 2013; DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.*, 2012; FAULKNER; MAUGER; WOOLLEY; LAMBRICK, 2015; HOGG; HOPKER; MAUGER, 2015; KEILLER; GORDON, 2018; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MIER; ALEXANDER; MAGEEAN, 2012; NIEMELA; PALATSI; LINNALUOTO; TAKKUNEN, 1980; POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.*, 2019; SABINO-CARVALHO; LOPES; OBEID-FREITAS; FERREIRA *et al.*, 2017; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011; STRAUB; MIDGLEY; ZAVORSKY; HILLMAN, 2014; TAYLOR; SEEGMILLER; VELLA, 2016; WEATHERWAX; RICHARDSON; BELTZ; NOLAN *et al.*, 2016). Overall, 52 studies (i.e. 67%) adopted supramaximal intensities based upon the maximal work rate achieved during the CPET (e.g. one treadmill or cycle ergometer work rate stage higher than that completed in the CPET, or 105% to 130% of the highest CPET work rate) (ALEXANDER; MIER, 2011; ASTORINO; DEREVERE, 2018; ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2018; ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2019; ASTORINO; MCMILLAN; EDMUNDS; SANCHEZ, 2015; ASTORINO; WHITE, 2010; BELTRAMI; FROYD; MAUGER; METCALFE *et al.*, 2012; BELTZ; AMORIM; GIBSON; JANOT *et al.*, 2018; BISI; STAGNI; GNUDI, 2011; DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.*, 2012; DEL GIUDICE; BONAFIGLIA; ISLAM; PREOBRAZENSKI *et al.*, 2020; DEXHEIMER; SCHROEDER; SAWYER; PETTITT *et al.*, 2019; DUCROCQ; HUREAU; MESTE; BLAIN, 2019; ELLIOTT; SKOWNO; PRABHU; NOAKES *et al.*, 2015; FAULKNER; MAUGER; WOOLLEY; LAMBRICK, 2015; FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.*, 2007; FREEBERG; BAUGHMAN; VICKEY; SULLIVAN *et al.*, 2019; HANSON; SCHEADLER; LEE; NEUENFELDT *et al.*, 2016; HAWKINS; RAVEN; SNELL; STRAY-GUNDERSEN *et al.*, 2007; HOGG; HOPKER; MAUGER, 2015; JAMES; TENLLADO VALLEJO; KANTEBEEN; FARRA, 2019; KEILLER; GORDON, 2018; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; MANN; PLATT; LAMBERTS; LAMBERT, 2015; MANN; WEBSTER; LAMBERTS; LAMBERT, 2014; MAUGER; METCALFE; TAYLOR; CASTLE, 2013; MCGAWLEY, 2017; MCKAY; PATERSON; KOWALCHUK, 2009; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MIDGLEY; MCNAUGHTON; CARROLL, 2006; 2007b; MIER; ALEXANDER; MAGEEAN, 2012; NOLAN; BEAVEN; DALLECK, 2014; POOLE; WILKERSON; JONES, 2008; SABINO-CARVALHO; LOPES;

OBEID-FREITAS; FERREIRA *et al.*, 2017; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011; SCHEADLER; DEVOR, 2015; STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.*, 1992; STRAUB; MIDGLEY; ZAVORSKY; HILLMAN, 2014; TAYLOR; SEEGMILLER; VELLA, 2016; VOGIATZIS; LOUVARIS; HABAZETTL; ATHANASOPOULOS *et al.*, 2011; WEATHERWAX, R.; HARRIS, N.; KILDING, A. E.; DALLECK, L., 2019; WEATHERWAX; HARRIS; KILDING; DALLECK, 2018; WEATHERWAX, R. M.; HARRIS, N. K.; KILDING, A. E.; DALLECK, L. C., 2019; WEATHERWAX; RICHARDSON; BELTZ; NOLAN *et al.*, 2016; WILHELM; GONZALEZ-ALONSO; PARRIS; RAKOBOWCHUK, 2016; WILLIAMS; PATERSON; KOWALCHUK, 2013; YEH; LAW; LIM, 2013), while seven studies (9%) used a maximal-intensity work rate (COLAKOGLU; OZKAYA; BALCI; YAPICIOGLU, 2015; COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A.; YAPICIOGLU, B., 2016; COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS; YAPICIOGLU, BULENT, 2016; NALCAKAN, 2014; NIEMELA; PALATSI; LINNALUOTO; TAKKUNEN, 1980; POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.*, 2019; TUCKER; SAWYER; JARRETT; BHAMMAR *et al.*, 2018), or both maximal or supramaximal (1%) (WINGO; LAFRENZ; GANIO; EDWARDS *et al.*, 2005). Three investigations (4%) examined both submaximal and supramaximal intensities within the same study (MURIAS; POGLIAGHI; PATERSON, 2018; ROSSITER; KOWALCHUK; WHIPP, 2006; SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.*, 2013), or based on a formula (1%) (CHIDNOK; DIMENNA; BAILEY; BURNLEY *et al.*, 2013). Fourteen studies (18%) used only submaximal intensities ranging from 85% to 95% peak work rate (typically two stages below the peak work rate achieved during the CPET) (CLARK; MURRAY; PETTITT, 2013; DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; DICKS; JOE; HACKNEY; PETTITT, 2018; DOGRA; SPENCER; PATERSON, 2012; JAMNICK; BOTELLA; PYNE; BISHOP, 2018; JAMNICK; BY; PETTITT; PETTITT, 2016; JOHNSON; SEXTON; PLACEK; MURRAY *et al.*, 2011; KIRKEBERG; DALLECK; KAMPHOFF; PETTITT, 2011; KRAMER; DU RANDT; WATSON; PETTITT, 2018; MURIAS; KOWALCHUK; PATERSON, 2010a; b; NIEMEYER; BERGMANN; BENEKE, 2020; NIEMEYER; LEITHAEUSER; BENEKE, 2019; STROM; PETTITT; KRYNSKI; JAMNICK *et al.*, 2018) (see Table 2).

Forty-two (54%) studies employed cut-off points to analyze differences between VO_2 values obtained at the CPET and verification phase to confirm VO_{2max} attainment. Criteria for VO_{2max} verification were frequently based on the intra-subject coefficient of variation acquired from the researchers' laboratory or cited elsewhere, including a VO_2 difference $\leq 2\%$

(MIDGLEY; MCNAUGHTON; CARROLL, 2006; SABINO-CARVALHO; LOPES; OBEID-FREITAS; FERREIRA *et al.*, 2017), ≤ 3% (ASTORINO; DEREVERE, 2018; ASTORINO; WHITE, 2010; BELTZ; AMORIM; GIBSON; JANOT *et al.*, 2018; BISI; STAGNI; GNUDI, 2011; DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.*, 2012; DEXHEIMER; SCHROEDER; SAWYER; PETTITT *et al.*, 2019; FREEBERG; BAUGHMAN; VICKEY; SULLIVAN *et al.*, 2019; HOGG; HOPKER; MAUGER, 2015; JOHNSON; SEXTON; PLACEK; MURRAY *et al.*, 2011; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; KRAMER; DU RANDT; WATSON; PETTITT, 2018; MCGAWLEY, 2017; NOLAN; BEAVEN; DALLECK, 2014; POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.*, 2019; SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.*, 2013; STROM; PETTITT; KRYNSKI; JAMNICK *et al.*, 2018; WEATHERWAX, R.; HARRIS, N.; KILDING, A. E.; DALLECK, L., 2019; WEATHERWAX; HARRIS; KILDING; DALLECK, 2018; WEATHERWAX, R. M.; HARRIS, N. K.; KILDING, A. E.; DALLECK, L. C., 2019; WEATHERWAX; RICHARDSON; BELTZ; NOLAN *et al.*, 2016), ≤ 5.0-5.5% (NIEMELA; PALATSI; LINNALUOTO; TAKKUNEN, 1980; NIEMEYER; BERGMANN; BENEKE, 2020; NIEMEYER; LEITHAEUSER; BENEKE, 2019; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011), ≤ 1.5 to 2.2 $mL \cdot kg^{-1} \cdot min^{-1}$ (ASTORINO; MCMILLAN; EDMUNDS; SANCHEZ, 2015; JAMES; TENLLADO VALLEJO; KANTEBEEN; FARRA, 2019; JAMNICK; BY; PETTITT; PETTITT, 2016; MAUGER; METCALFE; TAYLOR; CASTLE, 2013; MIER; ALEXANDER; MAGEEAN, 2012; MURIAS; POGLIAGHI; PATERSON, 2018), ≤ 50 to 150 mL/min (COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A.; YAPICIOGLU, B., 2016; COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS; YAPICIOGLU, BULENT, 2016; HANSON; SCHEADLER; LEE; NEUENFELDT *et al.*, 2016; SCHEADLER; DEVOR, 2015; STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.*, 1992; WINGO; LAFRENZ; GANIO; EDWARDS *et al.*, 2005), or alternative methods (ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2019; BELTRAMI; FROYD; MAUGER; METCALFE *et al.*, 2012; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009). Five studies also incorporated the verification of maximal heart rate based on a difference in the highest attained heart rates of ≤ 2 to 4 bpm between the CPET and verification phase (ASTORINO; DEREVERE, 2018; ASTORINO; WHITE, 2010; DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.*, 2012; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MIDGLEY; MCNAUGHTON; CARROLL, 2006).

Table 2. Characteristics of the cardiopulmonary exercise test (CPET) and verification phase protocols used in the reviewed studies (N = 78).

Study	VO_2 data sampling method	Traditional VO_{2max} criteria adopted	Exercise Modality	CPET Protocol	Recovery Phase Protocol	Verification Phase (VP) Protocol	Verification Criteria Threshold
NIEMELA; PALATSI; LINNALUOTO e TAKKUNEN (1980)	every min	VO_2 plateau (≤60 mL/min for men and ≤50 mL/min for women); adequacy of a subjective criterion for establishing the end point; $RER_{max} \geq 1.15$; HR_{max} within 10 bpm of APMHR	CYC	CSI I CSI II	Different day	1 or 2 submaximal workloads, then 100% of the highest VO_{2max} reached from two CPET	≤5% difference between the ramp test and VP
STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.* (1992)	20-s averaging	VO_2 plateau of 150 mL/min; $RER_{max} \geq 1.10, 1.15$; ≥ 85% APMHR; $La_{max} \geq 8$ mmol	CYC	CSI	Different day	115% WR_{max} reached in the CPET or 125% if the plateau has not been attained	VO_2 plateau of 150 mL/min
DAY; ROSSITER; COATS; SKASICK *et al.* (2003)	30-s time average	NS	CYC	CSI	Different day	90% WR_{max} reached in the CPET	NS
WINGO; LAFRENZ; GANIO; EDWARDS *et al.* (2005)	2×30-s	VO_2 plateau of 135 mL/min; HR within 5 bpm of that on the control test was obtained	CYC	CSI control CSI post-15 min CSI post-45 min	20-min passive	100% WR_{max} (if <1-min was completed during the last stage of the CPET) or 25 Watts > CPET-WR_{max} (if ≥1-min was completed during the last stage of the CPET)	VO_2 plateau of 135 mL/min
MIDGLEY; MCNAUGHTON e CARROLL (2006)	30-s time average	absolute plateau in VO_2; $RER_{max} \geq 1.10$; HR_{max} within 10 bpm of APMHR	TR	CSI	10-min active	0.5 km/h > CPET-$Speed_{max}$	CPET *vs*. VP: VO_{2max} difference ≤ 2% and $HR_{max} \leq 2$ bpm

Table 2 (*cont.*).

ROSSITER; KOWALCHUK e WHIPP (2006)	15-s average	VO_2 plateau (linear least squares fitting technique)	CYC	Ramp	5-min active	105%WR_{max} reached in the CPET 95%WR_{max} reached in the CPET	NS NS
FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.* (2007)	30-s time average	rate of increase in VO_2 during the last min < 50% when compared to the mid portion of the test	CYC TR	CSI CSI	1-min active 3-min active	25 Watts > CPET-WR_{max} 1.6 km/h > CPET-$Speed_{max}$ or 0.8 km/h if in the non-athlete group	NS
HAWKINS; RAVEN; SNELL; STRAY-GUNDERSEN *et al.* (2007)	40-s Douglas bag collection	NS	TR	CSI	Different day	130% WR_{max}	NS
MIDGLEY; MCNAUGHTON e CARROLL (2007b)	15 and 30-s time average	NS	TR	CSI 1-min stages DisCSI 2-min stages DisCSI 3-min stages	5-min passive	one stage > CPET	NS
POOLE; WILKERSON e JONES (2008)	20 s	VO_2 plateau of 100 mL/min; $RER_{max} \geq 1.10$, 1.15; HR_{max} within 10 bpm of APMHR; $La_{max} \geq 8$ mmol	CYC	Ramp	Different day	105%WR_{max} reached in the CPET	NS
ASTORINO; WHITE e DALLECK (2009)	2×15-s 30-s time average	NS NS	CYC	CSI	≥ 24h 1-1.5h	105%WR_{max} reached in the CPET 115%WR_{max} reached in the CPET	NS

Table 2 (*cont.*).

MCKAY; PATERSON e KOWALCHUK (2009)	15-s time average	NS	CYC	Ramp	5-min active	105%WR_{max} reached in the CPET	NS
MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.* (2009)	30-s time average	VO_2 plateau (difference between modelled and actual value > 50% of the regression slope for the linear portion of the VO_2-WR relationship)	CYC TR	CSI	10-min passive	2 min at 50% WR_{max}, 1 min at 70% WR_{max}, and then 1 stage > CPET-WR_{max} 2 min at 50% WR_{max}, 1 min at 70% WR_{max}, and then 1 stage > CPET-WR_{max}	CPET *vs*. VP: modelled and verification VO_2 difference > 50% of the regression slope of the individual VO_2-WR relationship; $HR_{max} \leq 4$ bpm
ASTORINO e WHITE (2010)	15-s time average	NS	CYC	CSI	10-min active	one stage > CPET-$Stage_{final}$	CPET vs. VP: VO_{2max} difference ≤ 3% and $HR_{max} \leq 4$ bpm
MURIAS; KOWALCHUK e PATERSON (2010a)	20-s	NS	CYC	Ramp	5-min active	85%WR_{max} reached in the CPET	NS
MURIAS; KOWALCHUK e PATERSON (2010b)	20-s	NS	CYC	Ramp	5-min active	85%WR_{max} reached in the CPET	NS
ALEXANDER e MIER (2011)	30-s time average	VO_2 plateau of 2.1 $mL \cdot kg^{-1} \cdot min^{-1}$	TR	CSI DisCSI	10-min walking	1st min: ↑ WR until matching the final stage of CPET; then ↑ slope to 2.5% and encouraged to running for 2-min	NS

Table 2 (*cont.*).

BISI; STAGNI e GNUDI (2011)	25-s moving-average	VO_2 plateau (increase < than 3% or 2.1 $mL \cdot kg^{-1} \cdot min^{-1}$ between 2 steps of increment); $RER_{max} \geq 1.08$ or 1.15; HR_{max} within 10 bpm of APMHR	CYC	CSI	6-min active	at least 3 min of cycling at 105% of the WR_{max}	CPET *vs*. VP: VO_{2max} difference ≤ 3%
JOHNSON; SEXTON; PLACEK; MURRAY *et al.* (2011)	15-s intervals	NS	CYC	CSI	3-min active (50%WR_{max})	WR_{max} minus 2 stages	CPET vs. VP: VO_{2max} difference ≤ 3%
KIRKEBERG; DALLECK; KAMPHOFF e PETTITT (2011)	30-s time average	NS	TR	CSI (short-term) CSI (middle-term) CSI (large-term)	3-min active	CPET-$Speed_{end}$ minus 2 stages, where stages were derived using specific equation	NS
SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.* (2011)	3×10-s average	VO_2 plateau (increase < than one-third of the oxygen requirement of a stage change ~ 150 mL/min); $RER_{max} \geq$ 1.10; ± 10 bpm APMHR; La_{max} > 8 mmol	TR	DisCSI	10-min passive (VerifDay1) Different day (VerifDay2)	1 min at 60% CPET-$Speed_{max}$ and then continued at 110% (or 115% if necessary, a second VF bout in VerifDay1) CPET-$Speed_{max}$	CPET *vs*. VP: VO_{2max} difference ≤ 5.5%
VOGIATZIS; LOUVARIS; HABAZETTL; ATHANASOPOULOS *et al.* (2011)	NS	NS	CYC	CSI	20-min passive	110%WR_{max}	NS
BELTRAMI; FROYD; MAUGER; METCALFE *et al.* (2012)	30-s intervals	VO_2 plateau (diff between modelled and actual value >50% of the regression slope for the linear portion of the VO_2-WR relationship	TR	CSI (control) CSI (reverse)	15-min active or passive (self-choose: walk, jog or rest)	1st min at 10 km/h (5% slope) and then ↑ 1 km/h > CPET-$Speed_{max}$	CPET *vs*. VP: VO_{2max} difference ≤ 123 ± 18 mL/min (or 1.7 $mL \cdot kg^{-1} \cdot min^{-1}$)

Table 2 (*cont.*).

DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.* (2012)	2×15-s	NS	CYC	CSI	60-min passive	2-min at 50 Watts; then increased 105% WR_{max}	CPET *vs*. VP: VO_{2max} difference ≤ 3% and HR_{max} ≤ 4 bpm
DOGRA; SPENCER e PATERSON (2012)	every 20 ms	NS	CYC	Ramp	Different day	85%WR_{max} reached in the CPET	NS
GOODALL; GONZALEZ-ALONSO; ALI; ROSS *et al.* (2012)	30-s mean	NS	CYC	CSI	5-min passive	as described by ROSSITER; KOWALCHUK e WHIPP (2006); however, the intensity was not stated (i.e. 95 or 105%WR_{max} reached in the CPET)	NS
MIER; ALEXANDER e MAGEEAN (2012)	30-s	VO_2 plateau (2 $mL \cdot kg^{-1} \cdot min^{-1}$ and ≤ SD of the expected increase); RER_{max} ≥ 1.05, 1.10 and 1.15; ≥ 85% APMHR and HR_{max} within 10 bpm of APMHR	TR	CSI	10-min active (walking at slow pace)	intensity gradually increased over 2-min until match CPET-WR_{peak}; after 1 min, the slope was increased 2.5% to running for 2-min	CPET *vs*. VP: VO_{2max} difference ≤ 2.2 $mL \cdot kg^{-1} \cdot min^{-1}$
CHIDNOK; DIMENNA; BAILEY; BURNLEY *et al.* (2013)	30-s rolling-mean	NS	CYC	Ramp	Different day	See the formula for a proper reporting 3-min of 'all-out' cycling	NS
CLARK; MURRAY e PETTITT (2013)	15-s time average	NS	CYC	CSI	3-min active	WR_{max} minus 2 stages	NS

Table 2 (*cont.*).

MAUGER; METCALFE; TAYLOR e CASTLE (2013)	5-s time average	VO_2 plateau (increase < than 1.8 $mL \cdot kg^{-1} \cdot min^{-1}$ between 2 steps of increment); $RER_{max} \geq 1.10$; HR_{max} within 10 bpm of APMHR; RPE ≥ 17; $La_{max} \geq 8$ mmol	TR	CSI	10-min active	one stage > the last completed stage of the CPET	CPET *vs*. VP: VO_{2max} difference ≤ 1.8 $mL \cdot kg^{-1} \cdot min^{-1}$
SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.* (2013)	15-s time average	VO_2 plateau of 2.1 $mL \cdot kg^{-1} \cdot min^{-1}$ during the last two 15-s average samples	CYC	CSI	3-min active	WR_{max} minus 2-stages 105%WR_{max}	CPET *vs*. VP: VO_{2max} difference ≤ 3%
WILLIAMS; PATERSON e KOWALCHUK (2013)	20-s	NS	CYC	Ramp	5-min active	105%WR_{max}	NS
YEH; LAW e LIM (2013)	NS	NS	TR	CSI	10-min passive	1 km/h > CPET-$Speed_{max}$ or 5 % slope every minute until exhaustion	NS
MANN; WEBSTER; LAMBERTS e LAMBERT (2014)	15-s	NS	TR	CSI	8-10-min	0.5 km/h > CPET-$Speed_{max}$	NS
NALCAKAN (2014)	30-s	VO_2 plateau; $RER_{max} \geq 1.20$; ≥ 90% APMHR	CYC	CSI	Different day	100%WR_{max}	NS
NOLAN; BEAVEN e DALLECK (2014)	2×15-s	NS	TR	CSI	20-min passive 60-min passive	105% WR_{max} 115% WR_{max} 105% WR_{max} 115% WR_{max}	CPET *vs*. VP: VO_{2max} difference ≤ 3%

Table 2 (*cont.*).

STRAUB; MIDGLEY; ZAVORSKY e	15-s time average	NS	CYC	Ramp	10-min passive	1st min: 60% WR_{max} and then 110% WR_{max}	NS
ASTORINO; MCMILLAN;	2×15-s	NS	CYC	Ramp	8-min active	2-min at 40-45% WR_{max} and then 105% WR_{max}	CPET *vs*. VP: difference < 2 mL·kg^{-1}·min^{-1}
COLAKOGLU; OZKAYA; BALCI e YAPICIOGLU (2015)	30-s average	VO_2 plateau of 150 mL/min; $RER_{max} \geq 1.10$; ≥ 90% APMHR	CYC	Ramp	Different day	100%WR_{max}	NS
ELLIOTT; SKOWNO; PRABHU; NOAKES *et al.* (2015)	10-s epochs	NS	CYC	CSI	60-min	110%WR_{max} reached in the CPET	NS
FAULKNER; MAUGER; WOOLLEY e LAMBRICK (2015)	20-s time average	VO_2 plateau of 2 mL·kg^{-1}·min^{-1}; $RER_{max} \geq 1.10$; RPE ≥ 17; HR_{max} within 10 bpm of APMHR; $La_{max} \geq 8$ mmol	TR	CSI	15-min passive	↑ speed over a 30-second period up to a 1 km/h > CPET-$Speed_{max}$	NS
HOGG; HOPKER e MAUGER (2015)	30-s time average	VO_2 plateau (diff between modelled and actual value > 50% of the regression slope for the linear portion of the VO_2-WR relationship); $RER_{max} \geq 1.10$; RPE ≥ 17; HR_{max} within 10 bpm of APMHR	TR	CSI	10-min active (walking around the laboratory and stretching)	↑ speed over a 30-second period up to a speed stage > CPET-$Stage_{final}$	CPET *vs*. VP: VO_{2max} difference ≤ 3%
				Incline-based SPV		speed halfway between $speed_{peak}$ from the $SPV_{incline}$ *vs*. predicted verification-stage speed of the CSI protocol	
				Speed-based SPV		speed halfway between $speed_{peak}$ from the SPV_{speed} vs. predicted stage speed of the CSI protocol	
MANN; PLATT; LAMBERTS e LAMBERT (2015)	15-s	NS	TR	CSI	8-10-min	0.5 km/h > CPET-$Speed_{max}$	NS
SCHEADLER e DEVOR (2015)	30-s	NS	TR	CSI	Different day	8% slope/ individualized WR greater than CPET	CPET *vs*. VP: VO_{2max} difference ≤ 50 mL/min

Table 2 (*cont.*).

COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A. e YAPICIOGLU, B. (2016)	30-s average	VO_2 plateau of 150 mL/min; $RER_{max} \geq 1.10$; HR_{max} within 10 bpm of APMHR; RPE ≥ ?	CYC	CSI	Different day	100%WR_{max}	VO_2 plateau of 150 mL/min; $RER_{max} \geq 1.10$; HR_{max} within 10 bpm of APMHR; RPE ≥ ?
COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS e YAPICIOGLU, BULENT (2016)	30-s average	VO_2 plateau of 150 mL/min; $RER_{max} \geq 1.10$; ≥ 90% APMHR; RPE ≥ 19-20	CYC	CSI	Different day	100%, 105%, and 110% WR_{max} to attain highest VO_{2peak} value	VO_2 plateau of 150 mL/min; $RER_{max} \geq 1.10$; ≥ 90% APMHR; RPE ≥ 19-20
HANSON; SCHEADLER; LEE;	15-breath moving average	VO_2 plateau of 2 $mL \cdot kg^{-1} \cdot min^{-1}$; $RER_{max} \geq 1.10$	TR	CSI	10-min active	one stage > CPET-WR_{max}	CPET *vs*. VP: VO_{2max} difference ≤ 50
JAMNICK; BY; PETTITT e PETTITT (2016)	15-s time average	NS	CYC	CSI	3-min active	mean WR_{max} minus 2 stages	CPET vs. VP: VO_{2max} difference ≤ 1.5 $mL \cdot kg^{-1} \cdot min^{-1}$ (or
TAYLOR; SEEGMILLER e VELLA (2016)	15-breath average	NS	TR	CSI	15-min active or passive	1st min at 10 km/h (5% slope) and then ↑ 1 km/h > CPET-$Speed_{max}$	NS
WEATHERWAX; RICHARDSON; BELTZ; NOLAN *et al.* (2016)	2×15-s	NS	TR	DisCSI	20-min passive	3 min at 4.82 km/h and then ↑ 0.64 km/h > CPET-$Speed_{max}$ (males) 3 min at 4.82 km/h and then ↑ 0.48 km/h > CPET-$Speed_{max}$ (females)	CPET *vs*. VP: VO_{2max} difference ≤ 3%
WILHELM; GONZALEZ-ALONSO; PARRIS e RAKOBOWCHUK (2016)	10-s moving average	NS	CYC	CSI	5-min passive	105%WR_{max}	NS

Table 2 (*cont.*).

MCGAWLEY (2017)	30-s time average	VO_2 plateau (increase < than 3% or 2 $mL \cdot kg^{-1} \cdot min^{-1}$ between 2 steps of increment); $RER_{max} \geq 1.15$; HR_{max} within 10 bpm of APMHR; $La_{max} \geq 8$ mmol	TR	CSI	9-min passive	105% at CPET-WR_{max} (Trials 1 to 5)	CPET *vs*. VP: VO_{2max} difference ≤ 3%
SABINO-CARVALHO; LOPES; OBEID-FREITAS; FERREIRA *et al.* (2017)	20-s average	NS	TR	DisCSI	3-min passive (standing on treadmill) and 7-min active (walking at 5 km/h)	2-min at 60% WR_{max} and then ↑ 0.5 km/h > CPET-$Speed_{max}$	CPET *vs*. VP: VO_{2max} difference ≤ 2%
ASTORINO e DEREVERE (2018)	2×15-s	NS	CYC	CSI	8-min active 10-min active	105% WR_{max} 110% WR_{max}	CPET *vs*. VP: VO_{2max} difference ≤ 3.0% and 3.3% and $HR_{max} \leq 4$ bpm
ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.* (2018)	30-s time average	NS	CYC	CSI	10-min active	105% WR_{max}	NS
BELTZ; AMORIM; GIBSON; JANOT *et al.* (2018)	2×15-s	NS	TR	SPV Ramp	20-min passive	2-min at 30% CPET-WR_{max}, 1-min at 40-45% CPET-WR_{max} and then until exhaustion at 105% CPET-WR_{max}	CPET *vs*. VP: VO_{2max} difference ≤ 3%
DICKS; JOE; HACKNEY e PETTITT (2018)	15-s time average	NS	TR	Pseudo-ramp protocol	3-min active	WR_{max} minus 2 stages	NS

Table 2 (*cont.*).

JAMNICK; BOTELLA; PYNE e BISHOP (2018)	20-s average	NS	CYC	CSI_1 (1-min stage length) CSI_3 (3-min stage length) CSI_5 (5-min stage length) CSI_7 (7-min stage length) CSI_{10} (10-min stage length)	5-min passive	90% WR_{max} - CSI_1	NS
KEILLER e GORDON (2018)	30-s intervals	VO_2 plateau (increase < than 50 or 100 mL/min) and HR plateau (increase < than 2 or 4 bpm) over the final two consecutive 30 s sampling periods	TR	CSI (Trials 1 and 2)	6-min passive	10 (female) and 12 (male) km/h and the ↑ 1% > CPET-Slope	CPET *vs*. VP: HR_{max} difference ≤ 2 or ≤ 4 bpm
KRAMER; DU RANDT; WATSON e PETTITT (2018)	30-s intervals	NS	TR	CSI	3-min active	2 stages < CPET-WR_{max}	CPET *vs*. VP: VO_{2max} difference ≤ 3%
MURIAS; POGLIAGHI e PATERSON (2018)	20-s average time	NS	CYC	Ramp	5-min active	85% WR_{max} 105% WR_{max}	CPET *vs*. VP: VO_{2max} difference ≤ 2.0 $mL \cdot kg^{-1} \cdot min^{-1}$
STROM; PETTITT; KRYNSKI; JAMNICK *et al.* (2018)	30-s time average	NS	TR	CSI	3-min active (walking pace of 67 m/min)	2 stages < CPET-WR_{max}	CPET *vs*. VP: VO_{2max} difference ≤ 3%
TUCKER; SAWYER; JARRETT; BHAMMAR *et al.* (2018)	2×15-s	NS	CYC	CSI	5-10 min active	100%WR_{max}	NS

Table 2 (*cont.*).

WEATHERWAX; HARRIS; KILDING e DALLECK (2018)	2×15-s	NS	TR	Pseudo-ramp protocol	20-min passive	105% WR_{max} (Trials 1 and 2)	CPET *vs*. VP: VO_{2max} difference ≤ 3%
ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.* (2019)	30-s time average	NS	CYC	CSI	10-min active	105% WR_{max}	VO_{2max} identified as the average of CPET and VP values
DEXHEIMER; SCHROEDER; SAWYER; PETTITT *et al.* (2019)	2×15-s	NS	TR	Pseudo-ramp protocol	5-10-min active	105% WR_{max}	CPET vs. VP: VO_{2max} difference ≤ 3%
DUCROCQ; HUREAU; MESTE e BLAIN (2019)	breath-by-breath	NS	TR	CSI	5-min passive	105% WR_{max}	NS
FREEBERG; BAUGHMAN; VICKEY; SULLIVAN *et al.* (2019)	2×15-s	NS	TR	Incline-based protocol	10-min active	110% WR_{max}	CPET vs. VP: VO_{2max} difference ≤ 3%
JAMES; TENLLADO VALLEJO; KANTEBEEN e FARRA (2019)	10-s average	VO_2 plateau of 2 $mL \cdot kg^{-1} \cdot min^{-1}$	TR	CSI	5-min active	↑ 1% > CPET-Slope	VO_2 plateau of 2 $mL \cdot kg^{-1} \cdot min^{-1}$
KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.* (2019)	30-s time average	$RER_{max} \geq 1.10$; ≥ 95% APMHR; RPE ≥ 19; La_{max} ≥ 8 mmol	CYC	CSI	10-min active	2 min at 50% WR_{max}, 1 min at 70% WR_{max}, and then 1 stage > CPET-WR_{max}	CPET vs. VP: VO_{2max} difference ≤ 3%

Table 2 (*cont.*).

KNAIER; NIEMEYER; WAGNER; INFANGER *et al.* (2019)	30-s time average	RER_{max} ≥1.05, 1.10 and 1.15; 90, 95 and 100% APMHR; RPE ≥ 19 and = 20; La_{max} ≥ 8 and 10 mmol	CYC	CSI	10-min active	2 min at 50% WR_{max}, 1 min at 70% WR_{max}, and then 1 stage > CPET-WR_{max}	CPET vs. VP: VO_{2max} difference ≤ 3%
NIEMEYER; LEITHAEUSER e BENEKE (2019)	30-s time average	< half of expected increase in VO_2 (i.e. <4.5 $mL \cdot kg^{-1} \cdot min^{-1}$)	CYC	Ramp	10-min active	90% WR_{max}	CPET vs. VP: VO_{2max} difference ≤ 5%
POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.* (2019)	30-s intervals	plateau in VO_2 and HR (i.e. ≤ 50 mL/min or ≤ 2 bpm) over the final two consecutive 30 s sampling periods; HR_{max} within 10 bpm of APMHR	CYC	CSI	15-min passive	5-min warm-up at the first stage of the CPET; 3-min of passive recovery; 2-min at 20 Watts; then increased 100% WR_{max}	CPET *vs*. VP: VO_{2max} difference ≤ 3%
RIBOLI; RAMPICHINI; CE; LIMONTA *et al.* (2019)	30-s intervals	VO_2 plateau of 2.1 $mL \cdot kg^{-1} \cdot min^{-1}$	TR	CSI with 1 min stages CSI with 2 min stages DisCSI	5-min passive	if the CPET did not show a VO_2 plateau, a verification bout was performed as described by ROSSITER; KOWALCHUK e WHIPP (2006); however, the intensity was not stated (i.e. 95 or 105%WR_{max} reached in the CPET)	NS
WEATHERWAX, R.; HARRIS, N.; KILDING, A. E. e DALLECK, L. (2019)	2×15-s	NS	TR	Pseudo-ramp protocol	20-min passive	105% WR_{max}	CPET *vs*. VP: VO_{2max} difference ≤ 3%

Table 2 (*cont.*).

WEATHERWAX, R. M.; HARRIS, N. K.; KILDING, A. E. e DALLECK, L. C. (2019)	2×15-s	NS	TR	Pseudo-ramp protocol	20-min passive	105% WR_{max}	CPET *vs*. VP: VO_{2max} difference ≤ 3%
DEL GIUDICE; BONAFIGLIA; ISLAM; PREOBRAZENSKI *et al.* (2020)	30-s time average	NS	TR	CSI	10-min passive	0.8 km/h > CPET-$Speed_{max}$	NS
NIEMEYER; BERGMANN e BENEKE (2020)	30-s time average	VO_2 plateau (diff between modelled and actual value > 50% of the regression slope for the linear portion of the VO_2-WR relationship)	CYC	Ramp	Different day	90% WR_{max}	CPET vs. VP: VO_{2max} difference ≤ 5%

APMHR = age-predicted maximal heart rate; *CSI* = continuous step-incremented; *CV* = coefficient of variation; *DisCSI* = discontinuous step-incremented; *HR* = heart rate; HR_{max} = maximal heart rate; La_{max} = maximal blood lactate concentration; *NS* = not stated; CYC = XXXX; TR = XXXX; RER_{max} = maximal respiratory exchange ratio; *RPE* = rating of perceived exertion; *SD* = standard deviation; *SPV* = self-paced maximal oxygen uptake; VO_2 = oxygen uptake; VO_{2max} = maximal oxygen uptake; *VP* = verification phase; *WR* = work rate; WR_{max} = maximal work rate.

Note: whenever possible, authors were contacted to provide unavailable data.

Quantitative data synthesis: Highest VO_2 and heart rate differences between the CPET and verification phase

Tables 3 and 4 show, respectively, comparisons between the highest VO_2 and heart rate values elicited in the CPET and verification phase for each study, while Figures 2 and 3 display Forest plots of effect sizes and 95% CIs for the highest VO_2 (52 studies) and heart rate (36 studies) values based on the random effects meta-analysis results. Only maximal heart rate was significantly lower in the verification phase compared to the CPET [mean difference = 2.7 (95% CI = 2.0 to 3.5) bpm, $P < 0.00001$]. Notably, the mean highest VO_2 values were similar between the CPET and verification phase [mean difference = 0.02 (95% CI = -0.01 to 0.06) L/min, $P = 0.17$]. Pooled data for both VO_{2max} and maximal heart rate following the CPET and verification phase demonstrated no significant heterogeneity among the studies overall (see Figures 2 and 3).

Table 3: Overall comparisons in the reviewed studies for the highest VO_2 values attained in the cardiopulmonary exercise test (CPET) and verification phase (VP) (N = 52).

Study	Specific Experimental Condition	CPET			VP			% Weight	Mean Difference
		Mean [L/min]	SD [L/min]	Total	Mean [L/min]	SD [L/min]	Total		IV, Random, 95%CI [L/min]
NIEMELA; PALATSI; LINNALUOTO e TAKKUNEN (1980)	N/A	3.05	0.55	16	3.05	0.49	16	1.00%	0.00 [-0.36, 0.35]
DAY; ROSSITER; COATS; SKASICK *et al.* (2003)	N/A	3.64	0.70	38	3.64	0.70	38	1.30%	0.00 [-0.31, 0.31]
MIDGLEY; MCNAUGHTON e CARROLL (2006)	N/A	4.03	0.42	16	4.01	0.44	16	1.50%	0.01 [-0.28, 0.31]
ROSSITER; KOWALCHUK e WHIPP (2006)	VP intensity (105%WR_{max})	4.15	0.50	5	4.09	0.45	5	0.40%	0.06 [-0.53, 0.65]
	VP intensity (95%WR_{max})	4.11	0.48	5	4.12	0.53	5	0.30%	-0.01 [-0.64, 0.61]
FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.* (2007)	VP exercise modality (TR)	4.09	0.97	20	4.03	1.16	20	0.30%	0.06 [-0.60, 0.72]
	VP exercise modality (CYC)	3.95	0.75	20	4.06	0.75	20	0.60%	-0.11 [-0.57, 0.35]
MIDGLEY; MCNAUGHTON e CARROLL (2007b)	CPET protocol (CSI 1-min stages)	4.09	0.54	9	4.07	0.53	9	0.50%	0.03 [-0.47, 0.52]
	CPET protocol (DisCSI 2-min stages)	4.10	0.52	9	4.08	0.52	9	0.60%	0.02 [-0.46, 0.50]
	CPET protocol (DisCSI 3-min stages)	3.98	0.49	9	4.07	0.53	9	0.60%	-0.09 [-0.56, 0.38]
POOLE; WILKERSON e JONES (2008)	N/A	4.03	0.28	7	3.95	0.29	7	1.50%	0.08 [-0.22, 0.38]
ASTORINO; WHITE e DALLECK (2009)	CPET-VP recovery (at least 24h)	2.37	0.69	15	2.31	0.75	15	0.50%	0.06 [-0.45, 0.58]
	CPET-VP recovery (60 to 90 min)	2.72	0.65	9	2.73	0.72	9	0.30%	-0.01 [-0.64, 0.62]
MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.* (2009)	VP exercise modality (CYC)	3.86	0.39	10	3.92	0.47	10	0.90%	-0.05 [-0.43, 0.33]
	VP exercise modality (TR)	4.05	0.47	10	3.96	0.38	10	0.90%	0.10 [-0.28, 0.47]

Table 3 (*cont.*).									
ASTORINO e WHITE (2010)	N/A	3.00	0.45	30	3.00	0.45	30	2.50%	0.00 [-0.23, 0.23]
ALEXANDER e MIER (2011)	CPET protocol (CSI)	3.79	0.39	11	3.80	0.49	11	1.00%	-0.01 [-0.38, 0.36]
	CPET protocol (DisCSI)	3.94	0.40	11	3.84	0.45	11	1.00%	0.10 [-0.25, 0.46]
BISI; STAGNI e GNUDI (2011)	N/A	2.41	0.13	11	2.56	0.36	11	2.60%	-0.15 [-0.38, 0.08]
JOHNSON; SEXTON; PLACEK; MURRAY *et al.* (2011)	N/A	3.31	0.76	11	3.34	0.82	11	0.30%	-0.03 [-0.69, 0.63]
KIRKEBERG; DALLECK; KAMPHOFF e PETTITT (2011)	CPET protocol (short-term CSI)	4.43	0.48	12	4.41	0.54	12	0.80%	0.03 [-0.38, 0.43]
	CPET protocol (middle-term CSI)	4.40	0.46	12	4.27	0.40	12	1.00%	0.13 [-0.21, 0.47]
	CPET protocol (large-term CSI)	4.42	0.42	12	4.36	0.45	12	1.00%	0.06 [-0.29, 0.41]
SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.* (2011)	CPET-VP recovery (same day after 10 min)	3.82	0.99	34	3.72	0.99	34	0.60%	0.10 [-0.37, 0.57]
	CPET-VP recovery (different day)	3.82	0.99	34	3.75	1.00	34	0.60%	0.07 [-0.40, 0.54]
BELTRAMI; FROYD; MAUGER; METCALFE *et al.* (2012)	Experimental groups (control group)	4.50	0.58	13	4.43	0.46	13	0.80%	0.07 [-0.33, 0.47]
	Experimental groups (reverse group)	4.52	0.36	13	4.54	0.33	13	1.90%	-0.02 [-0.28, 0.24]
DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.* (2012)	N/A	2.33	0.76	18	2.31	0.76	18	0.50%	0.02 [-0.48, 0.52]
GOODALL; GONZALEZ-ALONSO; ALI; ROSS *et al.* (2012)	N/A	4.11	0.56	9	3.82	0.71	9	0.40%	0.29 [-0.30, 0.88]
MIER; ALEXANDER e MAGEEAN (2012)	N/A	3.64	0.38	10	3.77	0.38	10	1.20%	-0.13 [-0.46, 0.20]
CHIDNOK; DIMENNA; BAILEY; BURNLEY *et al.* (2013)	N/A	4.32	0.61	7	4.32	0.69	7	0.30%	0.00 [-0.68, 0.68]

Table 3 (*cont.*).

MAUGER; METCALFE; TAYLOR e CASTLE (2013)	N/A	4.66	0.55	14	4.65	0.59	14	0.70%	0.01 [-0.42, 0.43]
SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.* (2013)	VP intensity (WR_{max} minus 2-stages)	3.69	0.41	13	3.70	0.49	13	1.10%	-0.01 [-0.36, 0.34]
	VP intensity (105%WR_{max})	3.71	0.51	13	3.64	0.50	13	0.90%	0.07 [-0.31, 0.46]
MANN; WEBSTER; LAMBERTS e LAMBERT (2014)	N/A	3.80	0.87	32	3.78	0.92	32	0.70%	0.03 [-0.41, 0.46]
NOLAN; BEAVEN e DALLECK (2014)	CPET-VP recovery (20 min) VP intensity (105%	3.64	0.61	12	3.66	0.58	12	0.60%	-0.02 [-0.50, 0.46]
	CPET-VP recovery (20 min) VP intensity (115%	3.68	0.59	12	3.64	0.61	12	0.60%	0.04 [-0.44, 0.52]
	CPET-VP recovery (60 min) VP intensity (105%	3.60	0.58	12	3.60	0.58	12	0.60%	0.00 [-0.46, 0.46]
	CPET-VP recovery (60 min) VP intensity (115%	3.65	0.54	12	3.58	0.60	12	0.60%	0.07 [-0.38, 0.52]
STRAUB; MIDGLEY; ZAVORSKY e HILLMAN (2014)	N/A	3.86	0.73	16	3.84	0.68	16	0.60%	0.02 [-0.47, 0.51]
ASTORINO; MCMILLAN; EDMUNDS e SANCHEZ (2015)	Experimental groups (low CRF)	2.35	0.37	10	2.36	0.33	10	1.40%	-0.01 [-0.32, 0.30]
	Experimental groups (moderate CRF)	3.32	0.58	10	3.28	0.60	10	0.50%	0.04 [-0.48, 0.56]
	Experimental groups (high CRF)	4.38	0.70	10	4.29	0.74	10	0.30%	0.09 [-0.54, 0.72]
ELLIOTT; SKOWNO; PRABHU; NOAKES *et al.* (2015)	N/A	4.26	0.61	8	4.26	0.70	8	0.30%	0.00 [-0.64, 0.64]
HOGG; HOPKER e MAUGER (2015)	N/A	4.87	0.43	14	4.82	0.48	14	1.20%	0.05 [-0.29, 0.39]
MANN; PLATT; LAMBERTS e LAMBERT (2015)	N/A	4.11	0.78	10	4.13	0.85	10	0.30%	-0.02 [-0.74, 0.70]

Table 3 (*cont.*).									
COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS e YAPICIOGLU, BULENT (2016)	N/A	4.11	0.69	9	4.56	0.60	9	0.40%	-0.45 [-1.05, 0.15]
JAMNICK; BY; PETTITT e PETTITT (2016)	N/A	3.24	0.57	57	3.25	0.57	57	3.00%	-0.02 [-0.23, 0.19]
TAYLOR; SEEGMILLER e VELLA (2016)	N/A	4.03	0.53	19	3.83	0.52	19	1.20%	0.21 [-0.13, 0.54]
WEATHERWAX; RICHARDSON; BELTZ; NOLAN *et al.* (2016)	Experimental groups (males)	3.98	0.36	18	3.94	0.32	18	2.60%	0.04 [-0.19, 0.26]
	Experimental groups (females)	2.68	0.13	6	2.67	0.10	6	8.00%	0.01 [-0.12, 0.14]
MCGAWLEY (2017)	N/A	4.08	0.47	10	4.01	0.46	10	0.80%	0.08 [-0.33, 0.48]
SABINO-CARVALHO; LOPES; OBEID-FREITAS; FERREIRA *et al.* (2017)	Pre-CPET intervention (IPC)	4.24	0.46	16	4.23	0.40	16	1.50%	0.01 [-0.29, 0.31]
	Pre-CPET intervention (Sham)	4.23	0.48	16	4.23	0.43	16	1.30%	0.01 [-0.31, 0.32]
	Pre-CPET intervention (Control)	4.23	0.38	16	4.15	0.32	16	2.20%	0.08 [-0.17, 0.32]
ASTORINO e DEREVERE (2018)	CPET-VP recovery (8 min) VP intensity (105%	3.35	1.01	30	3.32	1.00	30	0.50%	0.03 [-0.48, 0.54]
	CPET-VP recovery (10 min) VP intensity (110% WR$_{max}$)	2.82	0.62	79	2.78	0.59	79	3.70%	0.04 [-0.15, 0.23]
ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.* (2018)	Training effect (HIIT-Baseline)	2.51	0.62	14	2.50	0.61	14	0.60%	0.01 [-0.45, 0.47]
	Training effect (HIIT - Week 3)	2.66	0.67	14	2.60	0.64	14	0.60%	0.06 [-0.43, 0.55]
	Training effect (Control - Baseline)	2.94	0.72	14	2.87	0.71	14	0.50%	0.07 [-0.46, 0.60]
	Training effect (Control - Week 3)	2.97	0.74	14	2.84	0.69	14	0.50%	0.13 [-0.40, 0.66]
BELTZ; AMORIM; GIBSON; JANOT *et al.* (2018)	CPET protocol (SPV)	3.84	0.28	16	3.74	0.50	16	1.70%	0.10 [-0.18, 0.38]
	CPET protocol (Ramp)	3.86	0.28	16	3.77	0.50	16	1.70%	0.09 [-0.19, 0.37]
DICKS; JOE; HACKNEY e PETTITT (2018)	N/A	3.84	0.65	28	3.72	0.60	28	1.20%	0.12 [-0.21, 0.45]

Table 3 (*cont.*).

JAMNICK; BOTELLA; PYNE e BISHOP (2018)	CPET protocol (CSI_1: 1-min stage length)	4.72	0.41	17	4.65	0.45	17	1.60%	0.07 [-0.22, 0.36]
	CPET protocol (CSI_3: 3-min stage length)	4.62	0.42	17	4.56	0.46	17	1.50%	0.06 [-0.23, 0.36]
	CPET protocol (CSI_5: 5-min stage length)	4.55	0.46	17	4.55	0.47	17	1.30%	0.00 [-0.31, 0.31]
	CPET protocol (CSI_7: 7-min stage length)	4.44	0.42	17	4.37	0.46	17	1.50%	0.07 [-0.22, 0.36]
	CPET protocol (CSI_{10}: 10-min stage length)	4.35	0.43	17	4.23	0.51	17	1.30%	0.12 [-0.20, 0.43]
KEILLER e GORDON (2018)	N/A	3.65	0.71	11	3.50	0.58	11	0.50%	0.15 [-0.39, 0.69]
KRAMER; DU RANDT; WATSON e PETTITT (2018)	N/A	3.45	0.29	15	3.42	0.25	15	3.50%	0.03 [-0.16, 0.22]
MURIAS; POGLIAGHI e PATERSON (2018)	VP intensity (younger: 85% WR_{max})	3.73	0.51	8	3.76	0.48	8	0.60%	-0.03 [-0.52, 0.45]
	VP intensity (younger: 105% WR_{max})	3.90	0.65	22	3.89	0.64	22	0.90%	0.02 [-0.36, 0.40]
	VP intensity (older: 85% WR_{max})	2.18	0.55	8	2.18	0.55	8	0.50%	0.00 [-0.54, 0.54]
	VP intensity (older: 105% WR_{max})	2.52	0.54	23	2.57	0.51	23	1.40%	-0.05 [-0.36, 0.25]
WEATHERWAX; HARRIS; KILDING e DALLECK (2018)	N/A	2.29	0.73	16	2.29	0.73	16	0.50%	0.00 [-0.50, 0.51]
ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.* (2019)	N/A	2.55	0.62	14	2.57	0.61	14	0.60%	-0.02 [-0.47, 0.43]
DUCROCQ; HUREAU; MESTE e BLAIN (2019)	N/A	3.73	0.47	13	3.76	0.45	13	1.10%	-0.03 [-0.39, 0.32]
FREEBERG; BAUGHMAN; VICKEY; SULLIVAN *et al.* (2019)	N/A	3.49	0.85	30	3.49	0.85	30	0.70%	0.00 [-0.43, 0.43]
NIEMEYER; LEITHAEUSER e BENEKE (2019)	N/A	4.06	0.43	24	4.06	0.46	24	2.10%	0.00 [-0.25, 0.24]

Table 3 (*cont.*).

POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.* (2019)	N/A	3.83	0.41	19	3.72	0.42	19	1.90%	0.11 [-0.15, 0.37]
WEATHERWAX, R.; HARRIS, N.; KILDING, A. E. e DALLECK, L. (2019)	Training effect (standardized - baseline)	2.03	0.62	20	2.03	0.60	20	0.90%	0.00 [-0.38, 0.38]
	Training effect (standardized - week 12)	2.17	0.62	20	2.18	0.63	20	0.90%	-0.01 [-0.40, 0.38]
	Training effect (individualized - baseline)	2.37	0.79	19	2.37	0.77	19	0.50%	0.00 [-0.50, 0.50]
	Training effect (individualized - week 12)	2.63	0.89	19	2.65	0.89	19	0.40%	-0.02 [-0.59, 0.55]
WEATHERWAX, R. M.; HARRIS, N. K.; KILDING, A. E. e DALLECK, L. C. (2019)	Training effect (control - baseline)	2.18	0.74	8	2.16	0.73	8	0.30%	0.02 [-0.70, 0.74]
	Training effect (control - week 12)	2.11	0.73	8	2.10	0.69	8	0.30%	0.01 [-0.69, 0.71]
	Training effect (standardized - baseline)	2.03	0.62	20	2.03	0.60	20	0.90%	0.00 [-0.38, 0.38]
	Training effect (standardized - week 12)	2.17	0.62	20	2.18	0.63	20	0.90%	-0.01 [-0.40, 0.38]
	Training effect (individualized - baseline)	2.37	0.79	19	2.37	0.77	19	0.50%	0.00 [-0.50, 0.50]
	Training effect (individualized - week 12)	2.63	0.89	19	2.65	0.89	19	0.40%	-0.02 [-0.59, 0.55]
NIEMEYER; BERGMANN e BENEKE (2020)	N/A	4.01	0.47	46	3.95	0.51	46	3.30%	0.06 [-0.14, 0.26]

CI = confidence interval; *CRF* = cardiorespiratory fitness level; *CSI* = continuous step-incremented; CYC = cycling; *DisCSI* = discontinuous step-incremented; *IPC* = ischemic preconditioning; *N/A* = not applicable; *TR* = treadmill; *SD* = standard deviation; *SPV* = self-paced maximal oxygen uptake; VO_2 = oxygen uptake; *VP* = verification phase; WR_{max} = maximal work rate.

Note: whenever possible, authors were contacted to provide unavailable data. %Weight = weight attributed to each study due to its statistical power.

Table 4: Overall comparisons for each study for the highest heart values attained in the cardiopulmonary exercise test (CPET) and verification phase (VP) (N = 36).

Study	Specific Experimental Condition	CPET			VP				Mean Difference
		Mean [bpm]	SD [bpm]	Total	Mean [bpm]	SD [bpm]	Total	% Weight	IV, Random, 95%CI [bpm]
NIEMELA; PALATSI; LINNALUOTO e TAKKUNEN (1980)	N/A	190	9	16	186	9	16	1.40%	4.00 [-2.24, 10.24]
MIDGLEY; MCNAUGHTON e CARROLL (2006)	N/A	178	10	16	177	10	16	1.20%	1.00 [-5.93, 7.93]
ROSSITER; KOWALCHUK e WHIPP (2006)	VP intensity (105%WR_{max})	184	10	5	179	9	5	0.40%	5.00 [-6.79, 16.79]
	VP intensity (95%WR_{max})	184	8	5	183	9	5	0.50%	1.00 [-9.55, 11.55]
FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.* (2007)	VP exercise modality (TR)	184	6	20	181	10	20	2.10%	3.00 [-2.11, 8.11]
	VP exercise modality (CYC)	179	14	20	180	13	20	0.80%	-1.00 [-9.37, 7.37]
ASTORINO; WHITE e DALLECK (2009)	CPET-VP recovery (at least 24h)	191	12	15	187	12	15	0.80%	4.00 [-4.59, 12.59]
	CPET-VP recovery (60 to 90 min)	191	9	9	186	9	9	0.80%	5.00 [-3.32, 13.32]
MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.* (2009)	VP exercise modality (CYC)	177	17	10	178	15	10	0.30%	-1.00 [-15.05, 13.05]
	VP exercise modality (TR)	183	8	10	184	8	10	1.10%	-1.00 [-8.01, 6.01]
ASTORINO e WHITE (2010)	N/A	187	10	30	186	10	30	2.20%	1.00 [-4.06, 6.06]
KIRKEBERG; DALLECK; KAMPHOFF e PETTITT (2011)	CPET protocol (short-term CSI)	188	10	12	185	10	12	0.90%	3.00 [-5.00, 11.00]
	CPET protocol (middle-term CSI)	187	10	12	186	9	12	1.00%	1.00 [-6.61, 8.61]
	CPET protocol (large-term CSI)	189	7	12	189	7	12	1.80%	0.00 [-5.60, 5.60]

Table 4 (*cont.*).									
SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.* (2011)	CPET-VP recovery (same day after 10 min)	192	7	34	190	6	34	5.80%	2.00 [-1.10, 5.10]
	CPET-VP recovery (different day)	192	7	34	186	7	34	5.00%	6.00 [2.67, 9.33]
BELTRAMI; FROYD; MAUGER; METCALFE *et al.* (2012)	Experimental groups (control group)	186	11	13	180	14	13	0.60%	6.00 [-3.68, 15.68]
	Experimental groups (reverse group)	183	15	13	182	10	13	0.60%	1.00 [-8.80, 10.80]
DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.* (2012)	N/A	165	12	18	164	10	18	1.10%	1.00 [-6.22, 8.22]
GOODALL; GONZALEZ-ALONSO; ALI; ROSS *et al.* (2012)	N/A	178	4	9	177	11	9	0.90%	1.00 [-6.65, 8.65]
MIER; ALEXANDER e MAGEEAN (2012)	N/A	187	7	10	187	6	10	1.80%	0.00 [-5.71, 5.71]
MAUGER; METCALFE; TAYLOR e CASTLE (2013)	N/A	191	10	14	188	7	14	1.40%	3.00 [-3.39, 9.39]
MANN; WEBSTER; LAMBERTS e LAMBERT (2014)	N/A	186	10	32	182	9	32	2.60%	4.00 [-0.66, 8.66]
NOLAN; BEAVEN e DALLECK (2014)	CPET-VP recovery (20 min) VP intensity (105% WR_{max})	191	9	12	190	9	12	1.10%	1.00 [-6.20, 8.20]
	CPET-VP recovery (20 min) VP intensity (115% WR_{max})	192	10	12	192	9	12	1.00%	0.00 [-7.61, 7.61]
	CPET-VP recovery (60 min) VP intensity (105% WR_{max})	190	10	12	188	8	12	1.10%	2.00 [-5.25, 9.25]
	CPET-VP recovery (60 min) VP intensity (115% WR_{max})	189	10	12	187	9	12	1.00%	2.00 [-5.61, 9.61]

Table 4 (*cont.*).									
ASTORINO; MCMILLAN; EDMUNDS e SANCHEZ (2015)	Experimental groups (low CRF)	187	9	10	185	6	10	1.20%	2.00 [-4.70, 8.70]
	Experimental groups (moderate CRF)	183	13	10	184	13	10	0.40%	-1.00 [-12.39, 10.39]
	Experimental groups (high CRF)	184	13	10	182	12	10	0.50%	2.00 [-8.97, 12.97]
ELLIOTT; SKOWNO; PRABHU; NOAKES *et al.* (2015)	N/A	189	10	8	190	13	8	0.40%	-1.00 [-12.37, 10.37]
MANN; PLATT; LAMBERTS e LAMBERT (2015)	N/A	185	11	10	180	14	10	0.50%	5.00 [-6.04, 16.04]
COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS e YAPICIOGLU, BULENT (2016)	N/A	191	7	9	192	7	9	1.30%	-1.00 [-7.47, 5.47]
TAYLOR; SEEGMILLER e VELLA (2016)	N/A	190	10	19	174	14	19	0.90%	16.00 [8.26, 23.74]
WEATHERWAX; RICHARDSON; BELTZ; NOLAN *et al.* (2016)	Experimental groups (males)	192	8	18	188	8	18	2.00%	4.00 [-1.23, 9.23]
	Experimental groups (females)	191	9	6	192	7	6	0.70%	-1.00 [-10.12, 8.12]
SABINO-CARVALHO; LOPES; OBEID-FREITAS; FERREIRA *et al.* (2017)	Pre-CPET intervention (IPC)	190	12	16	188	11	16	0.90%	2.00 [-5.98, 9.98]
	Pre-CPET intervention (Sham)	191	10	16	188	11	16	1.00%	3.00 [-4.28, 10.28]
	Pre-CPET intervention (Control)	189	11	16	188	9	16	1.10%	1.00 [-5.96, 7.96]
ASTORINO e DEREVERE (2018)	CPET-VP recovery (8 min) VP intensity (105% WR_{max})	186	11	30	186	11	30	1.80%	0.00 [-5.57, 5.57]
	CPET-VP recovery (10 min) VP intensity (110% WR_{max})	186	9	79	183	9	79	7.10%	3.00 [0.19, 5.81]

Table 4 (*cont.*).									
ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.* (2018)	Training effect (HIIT-Baseline)	183	12	14	182	12	14	0.70%	1.00 [-7.89, 9.89]
	Training effect (HIIT - Week 3)	183	12	14	182	12	14	0.70%	1.00 [-7.89, 9.89]
	Training effect (Control - Baseline)	185	6	14	181	5	14	3.30%	4.00 [-0.09, 8.09]
	Training effect (Control - Week 3)	183	7	14	180	7	14	2.10%	3.00 [-2.19, 8.19]
BELTZ; AMORIM; GIBSON; JANOT *et al.* (2018)	CPET protocol (SPV)	198	5	16	192	5	16	4.60%	6.00 [2.54, 9.46]
	CPET protocol (Ramp)	200	6	16	193	5	16	3.80%	7.00 [3.17, 10.83]
KEILLER e GORDON (2018)	N/A	190	9	11	186	8	11	1.10%	4.00 [-3.12, 11.12]
KRAMER; DU RANDT; WATSON e PETTITT (2018)	N/A	189	4	15	189	5	15	5.30%	0.00 [-3.24, 3.24]
MURIAS; POGLIAGHI e PATERSON (2018)	VP intensity (younger: 85% WR_{max})	192	6	8	189	7	8	1.40%	3.00 [-3.39, 9.39]
	VP intensity (younger: 105% WR_{max})	186	8	22	184	10	22	1.90%	2.00 [-3.35, 7.35]
	VP intensity (older: 85% WR_{max})	151	14	8	148	15	8	0.30%	3.00 [-11.22, 17.22]
	VP intensity (older: 105% WR_{max})	154	11	23	153	13	23	1.10%	1.00 [-5.96, 7.96]
WEATHERWAX; HARRIS; KILDING e DALLECK (2018)	N/A	163	20	16	163	21	16	0.30%	0.00 [-14.21, 14.21]
ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.* (2019)	N/A	183	12	14	182	12	14	0.70%	1.00 [-7.89, 9.89]
DUCROCQ; HUREAU; MESTE e BLAIN (2019)	N/A	182	11	13	185	12	13	0.70%	-3.00 [-11.85, 5.85]

Table 4 (*cont.*).									
FREEBERG; BAUGHMAN; VICKEY; SULLIVAN *et al.* (2019)	N/A	194	8	30	190	8	30	3.40%	4.00 [-0.05, 8.05]
POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.* (2019)	N/A	192	7	19	186	6	19	3.20%	6.00 [1.85, 10.15]
WEATHERWAX, R.; HARRIS, N.; KILDING, A. E. e DALLECK, L. (2019)	Training effect (standardized - baseline)	165	16	20	165	16	20	0.60%	0.00 [-9.92, 9.92]
	Training effect (standardized - week 12)	165	15	20	165	15	20	0.60%	0.00 [-9.30, 9.30]
	Training effect (individualized - baseline)	171	18	19	169	18	19	0.40%	2.00 [-9.45, 13.45]
	Training effect (individualized - week 12)	169	14	19	169	14	19	0.70%	0.00 [-8.90, 8.90]
WEATHERWAX, R. M.; HARRIS, N. K.; KILDING, A. E. e DALLECK, L. C. (2019)	Training effect (control - baseline)	174	13	8	174	13	8	0.30%	0.00 [-12.74, 12.74]
	Training effect (control - week 12)	171	11	8	169	11	8	0.50%	2.00 [-8.78, 12.78]
	Training effect (standardized - baseline)	165	16	20	165	16	20	0.60%	0.00 [-9.92, 9.92]
	Training effect (standardized - week 12)	165	15	20	165	15	20	0.60%	0.00 [-9.30, 9.30]
	Training effect (individualized - baseline)	171	18	19	169	18	19	0.40%	2.00 [-9.45, 13.45]
	Training effect (individualized - week 12)	169	14	19	169	14	19	0.70%	0.00 [-8.90, 8.90]

CI = confidence interval; *CRF* = cardiorespiratory fitness level; *CSI* = continuous step-incremented; CYC = cycling; *DisCSI* = discontinuous step-incremented; *HR* = heart rate; *IPC* = ischemic preconditioning; *N/A* = not applicable; *TR* = treadmill; *SD* = standard deviation; *SPV* = self-paced maximal oxygen uptake; *VP* = verification phase; WR_{max} = maximal work rate.

Note: whenever possible, authors were contacted to provide unavailable data. %Weight = weight attributed to each study due to its statistical power.

Figure 2: Forest plot of all studies included in the meta-analysis (n = 52) for the highest VO_2 responses attained in the cardiopulmonary exercise test and verification phase using random effects analyses. Data are reported as mean differences adjusted for control data (95% CIs). MD = mean difference.

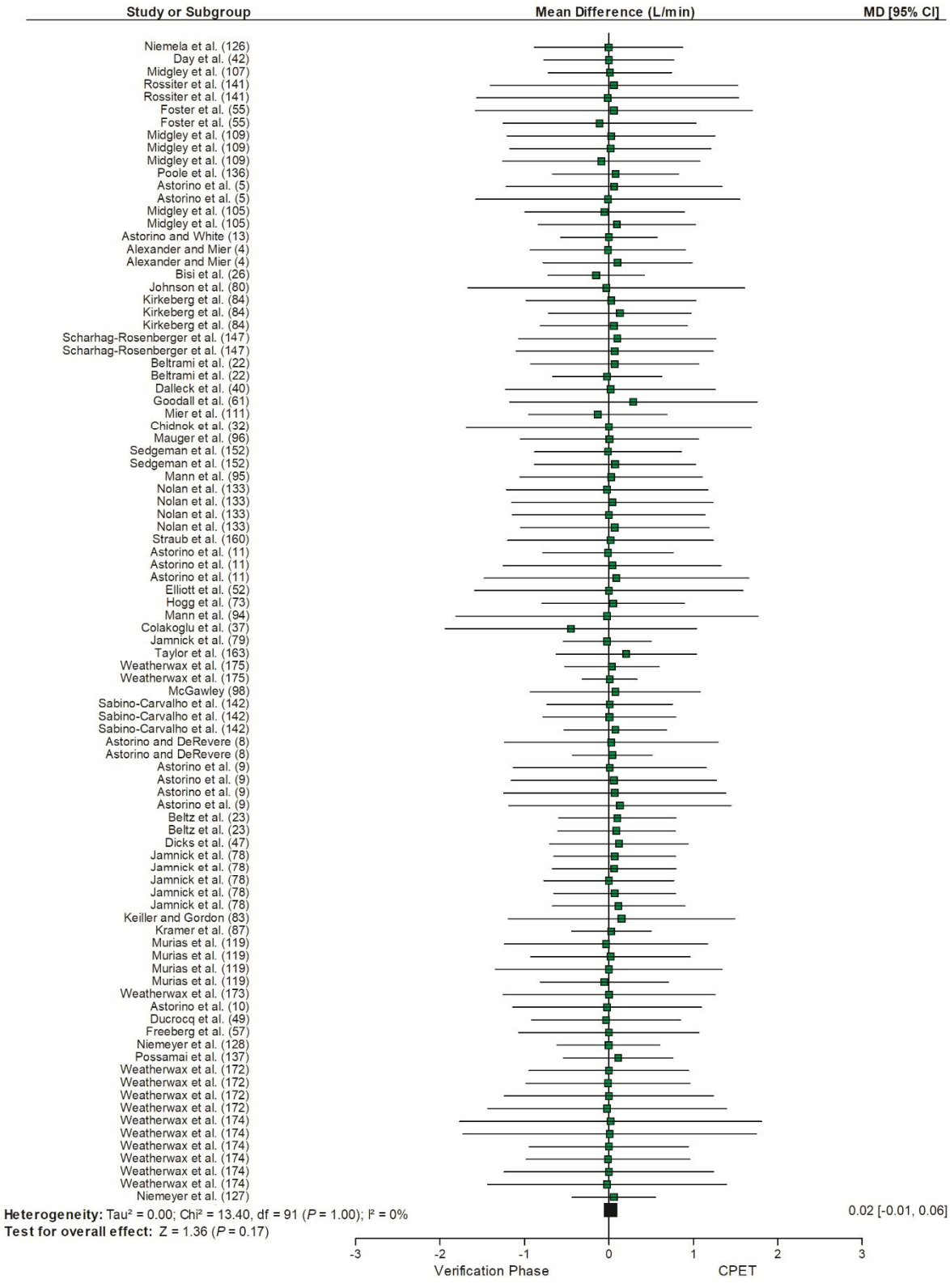
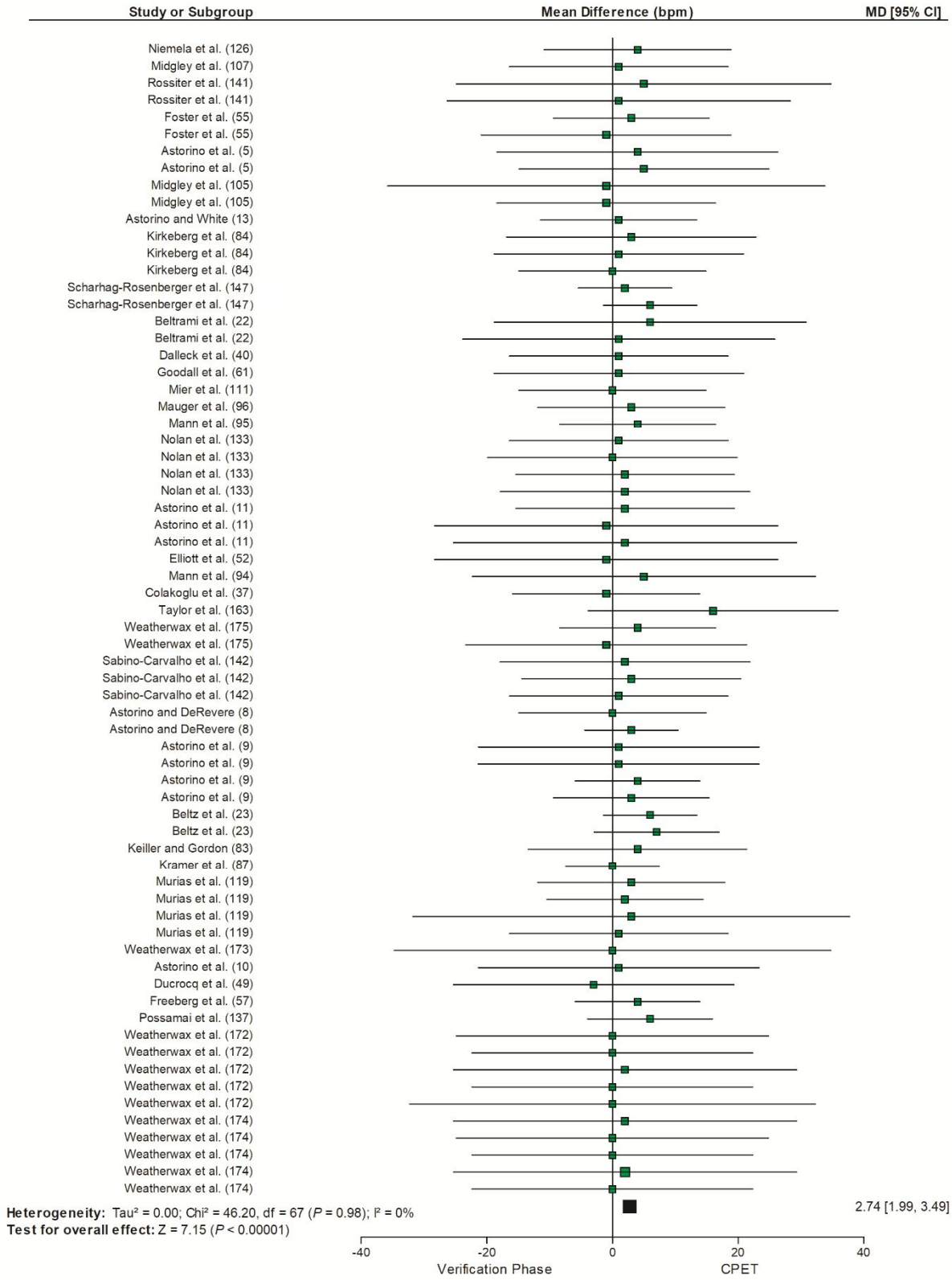
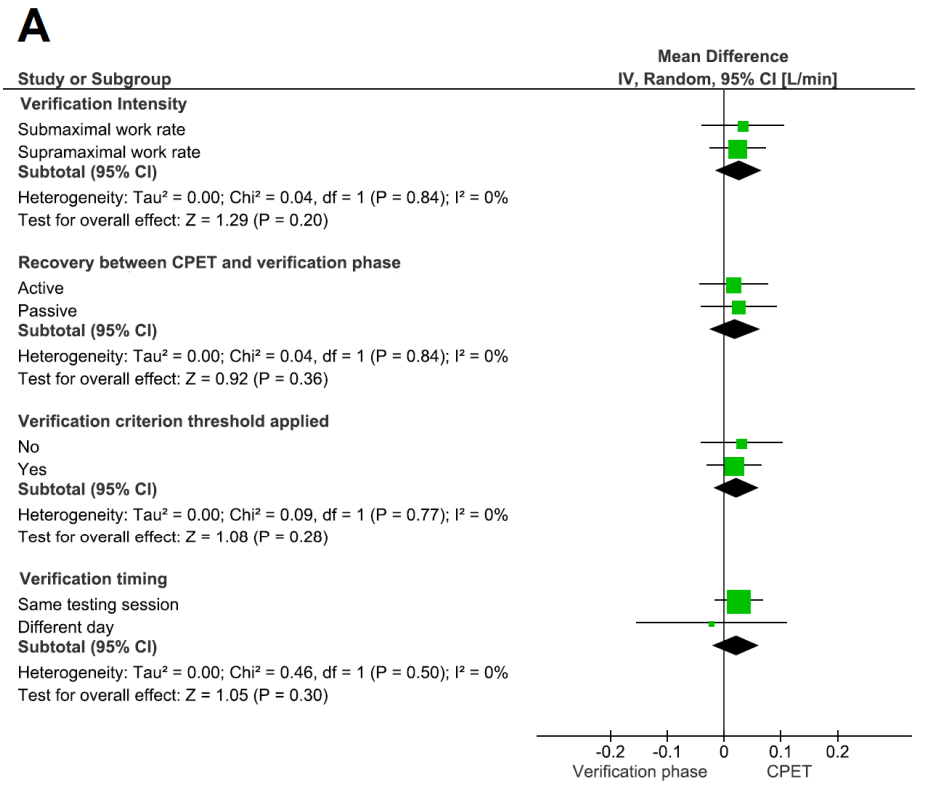


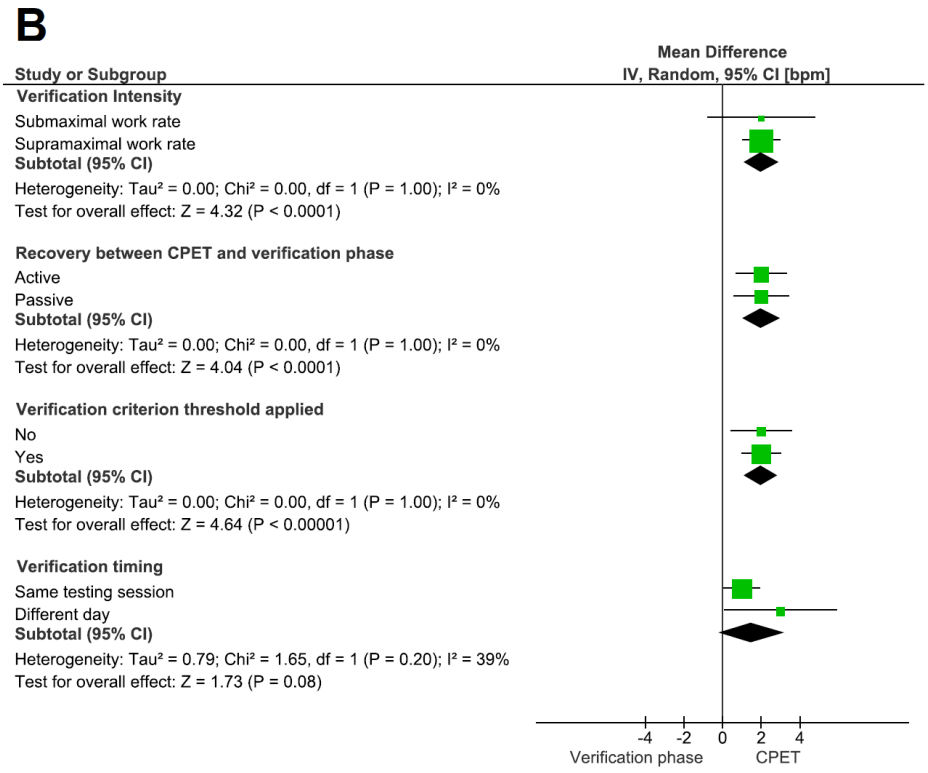
Figure 3: Forest plot of all studies included in the meta-analysis (n = 36) for the highest heart rate responses attained in the cardiopulmonary exercise test and verification phase using random effects analyses. Data are reported as mean differences adjusted for control data (95% CIs). MD = mean difference.



Results of subgroup analyses, according to the characteristics of the verification phase protocol, are summarized in Figure 4A-B. No significant differences in VO_{2max} were observed between the CPET and verification phase after stratifying studies for verification phase intensity [mean difference = 0.03 (95% CI = -0.01 to 0.07) L/min, $P = 0.20$), type of recovery utilized [mean difference = 0.02 (95%CI = -0.02 to 0.07) L/min, $P = 0.36$], VO_{2max} verification criterion adoption [mean difference = 0.02 (95% CI = -0.02 to 0.06) L/min, $P = 0.28$], or verification procedure with regards to whether or not it was performed on the same day as the CPET [mean difference = 0.02 (95%CI -0.02 to 0.06) L/min, $P = 0.30$] (see Figure 4A). Conversely, the subgroup analysis for maximal heart rate (Figure 4B) revealed significant differences between the CPET and verification phase for submaximal versus supramaximal-intensity bouts [mean difference = 2.0 (95% CI = 1.1 to 2.9) bpm, $P < 0.0001$], passive versus active recovery [mean difference = 2.0 (1.0 to 3.0) bpm, $P < 0.0001$], and verification threshold criteria [mean difference = 2.0 (1.2 to 2.8) bpm, $P < 0.00001$], but not for the verification phase performed in the same testing session as the CPET versus performing it on a different day [mean difference = 1.51 (-0.2 to 3.2) bpm, $P = 0.08$].

Figure 4: Mean differences (95% CIs) in the highest VO_2 (**A**) and heart rate (**B**) responses between the cardiopulmonary exercise test (CPET) and verification phase according to the verification phase characteristics for intensity (i.e. submaximal *vs*. supramaximal work rate), recovery (i.e. active *vs*. passive), adoption of criterion threshold (i.e. yes *vs*. no), and timing (performed on the same day as the CPET *vs*. a different day).





Subgroup analyses regarding sex, cardiorespiratory fitness level, exercise modality, and CPET protocol are summarized in Table 2. The median observed time to exhaustion for the CPET was 661 s (IQR, 600) and 150 s (IQR, 116) for the verification phase. There were no significant differences between the CPET and verification phase for VO_{2max}. Unlike VO_{2max}, statistically significant subgroup random effects were found for maximal heart rate with respect to sex (i.e. males or combined males and females, $P \leq 0.00001$), cardiorespiratory fitness (i.e. moderate and high, $P \leq 0.05$), exercise modality (i.e. cycling and running, $P < 0.0001$), and CPET protocol (i.e. discontinuous step-incremented, continuous step-incremented, and ramp-incremented, $P \leq 0.005$).

Table 5. Subgroup analyses for the cardiopulmonary exercise test (CPET) and verification phase (VP). Group weighted mean differences in maximal oxygen uptake (VO_{2max}) and heart rate according to sex, cardiorespiratory fitness level, exercise testing modality, and CPET protocol.

	Time to exhaustion (s)			**VO_{2max} (L/min)**					**Maximal heart rate (bpm)**				
	N	CPET Mean ± SD	VP Mean ± SD	N	CPET Mean ± SD	VP Mean ± SD	Effect Size (95% CI)	*P*-value	N	CPET Mean ± SD	VP Mean ± SD	Effect Size (95% CI)	*P*-value
Sex													
Male	146	734 ± 90	244 ± 43	630	3.95 ± 0.48	3.93 ± 0.50	0.02 (-0.02 to 0.08)	0.25	307	185 ± 9	182 ± 9	3 (2 to 4)	< 0.00001
Female	23	659 ± 119	152 ± 46	68	2.63 ± 0.39	2.58 ± 0.40	0.05 (-0.08 to 0.12)	0.71	31	189 ± 9	185 ± 11	4 (-5 to 13)	0.38
Both	532	682 ± 108	164 ± 32	796	3.22 ± 0.67	3.20 ± 0.67	0.02 (-0.05 to 0.08)	0.59	727	181 ± 12	178 ± 11	3 (2 to 4)	< 0.00001
Cardiorespiratory fitness level													
Low	135	623 ± 112	149 ± 36	287	2.32 ± 0.65	2.33 ± 0.65	0.01 (-0.06 to 0.13)	0.50	276	169 ± 14	168 ± 14	1 (-1 to 3)	0.35
Moderate	362	790 ± 101	200 ± 40	565	3.49 ± 0.61	3.45 ± 0.63	0.04 (-0.02 to 0.11)	0.21	445	190 ± 9	186 ± 8	4 (3 to 5)	< 0.00001
High	236	667 ± 102	197 ± 303	606	4.05 ± 0.52	4.02 ± 0.52	0.03 (-0.02 to 0.08)	0.25	392	187 ± 10	185 ± 10	2 (1 to 3)	0.004
Exercise modality													
CYC	332	720 ± 96	188 ± 35	771	3.52 ± 0.56	3.50 ± 0.58	0.02 (-0.03 to 0.07)	0.50	443	183 ± 10	181 ± 10	2 (1 to 4)	< 0.0001
TR	386	688 ± 110	189 ± 34	771	3.59 ± 0.58	3.56 ± 0.58	0.03 (-0.02 to 0.08)	0.22	670	184 ± 11	181 ± 11	3 (2 to 4)	< 0.00001
CPET protocol													
DisCSI	92	876 ± 120	156 ± 28	169	3.90 ± 0.52	3.87 ± 0.51	0.03 (-0.05 to 0.11)	0.49	140	191 ± 9	188 ± 8	3 (2 to 5)	0.0004
CSI	472	696 ± 105	209 ± 40	924	3.71 ± 0.56	3.69 ± 0.58	0.02 (-0.03 to 0.07)	0.38	652	186 ± 10	184 ± 10	2 (1 to 3)	< 0.00001
Ramp	139	645 ± 91	146 ± 29	433	3.10 ± 0.61	3.08 ± 0.61	0.02 (-0.05 to 0.10)	0.53	305	175 ± 13	172 ± 13	3 (1 to 4)	0.005

CI = confidence interval; *CSI* = continuous step-incremented; CYC = cycling; *DisCSI* = discontinuous step-incremented; *TR* = treadmill; *SD* = standard deviation.

5.5 **Discussion**

To the best of our knowledge, the present study is the first systematic review and meta-analysis to compare VO_{2max} values obtained from a CPET and verification phase, as well as document the efficacy of the verification phase procedure to verify the achievement of the 'true' VO_{2max} during cycling and treadmill CPETs performed by apparently healthy adults. The major findings were: (a) in general, the verification phases confirmed the highest VO_{2max} obtained in CPETs; (b) the concordance between the VO_{2max} in CPETs and verification phases were not affected by potential moderators as sex, cardiorespiratory fitness level, exercise modality, CPET or verification phase protocols; and (c) highest heart values were typically found in CPETs over verification phases, irrespective of the subgroup comparisons.

There is a growing body of literature applying the verification phase procedure for increasing the confidence that apparently healthy adults elicit a true VO_{2max}, with 87% of the studies reviewed published since 2009 (Table 1). This review comprised apparently healthy adults ranging from those with low cardiorespiratory fitness to highly trained endurance athletes. No studies reported any adverse events related to the CPET or verification phases across the range of adult cardiorespiratory fitness levels. Although not the focus of the present review, there also were a large number of studies that used a verification phase in special or clinical populations, such as obese adults (SAWYER; TUCKER; BHAMMAR; GAESSER, 2015; WOOD; HILLS; HUNTER; KING *et al.*, 2010), breast and prostate cancer survivors (SCHNEIDER; SCHLUTER; WISKEMANN; ROSENBERGER, 2020), wheelchair athletes (LEICHT; TOLFREY; LENTON; BISHOP *et al.*, 2013), those with spinal cord injuries (ASTORINO; BEDIAMOL; COTOIA; INES *et al.*, 2019), patients with heart failure (BOWEN; CANNON; BEGG; BALIGA *et al.*, 2012) or cystic fibrosis (CAUSER; SHUTE; CUMMINGS; SHEPHERD *et al.*, 2018; SAYNOR; BARKER; OADES; WILLIAMS, 2013a; b), and pediatric populations (BARKER; JONES; ARMSTRONG, 2010; BARKER; TREBILCOCK; BREESE; JONES *et al.*, 2014; BARKER; WILLIAMS; JONES; ARMSTRONG, 2011; BHAMMAR; STICKFORD; BERNHARDT; BABB, 2017; LAMBRICK; JAKEMAN; GRIGG; KAUFMANN *et al.*, 2017; ROBBEN; POOLE; HARMS, 2013; SANSUM; WESTON; BOND; COCKCROFT *et al.*, 2019), including children with spina bifida in an outpatient condition (DE GROOT; TAKKEN; DE GRAAFF; GOOSKENS *et al.*, 2009), and adolescents with cystic fibrosis (WERKMAN; HULZEBOS; VAN DE WEERT-VAN LEEUWEN; ARETS *et al.*, 2011). Since no adverse effects were

reported in any of these studies, current evidence suggests that the verification phase is a safe and well-tolerated procedure to confirm attainment of true VO_{2max} in both apparently healthy children and adults and across a wide variety of clinical groups.

The significant increase in publications involving the verification phase procedure for determination of VO_{2max} over the past decade may be underpinned by the serious concerns about the validity of traditional VO_{2max} criteria (DAVIS; WHIPP; LAMARRA; HUNTSMAN *et al.*, 1982; MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007; POOLE; WILKERSON; JONES, 2008; ROSSITER; KOWALCHUK; WHIPP, 2006). The first issue is the frequent absence of the VO_2 plateau during ramp-incremented CPETs, which contrast with the discontinuous CPET protocols used when the VO_2 plateau concept was conceived. Continuous ramp or pseudo-ramp protocols to determine VO_{2max} via modern breath-by-breath data-acquisition systems often promote an accelerated VO_2 response close to the end of the test (POOLE; JONES, 2017), not allowing the development of the VO_2 slow component expressed as an upward curvilinearity of the VO_2-work rate relationship. In practical terms, this results in an inability to identify a clear VO_2 plateau (DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; POOLE; JONES, 2017; POOLE; WILKERSON; JONES, 2008; ROSSITER; KOWALCHUK; WHIPP, 2006). DAY; ROSSITER; COATS; SKASICK *et al.* (2003) investigated whether a VO_2 plateau would be a consistent manifestation of ramp-incremented cycling CPET in 71 apparently healthy men, aged 19-61 years. The authors reported that near the end of the CPET, a plateau-like VO_2 response (or deceleration of the VO_2 response) was seen in only 12 (17%) of the 71 participants, while in 19 (27%) of the participants there was an accelerated VO_2 response, and in 40 (56%) the linear increase in VO_2 observed earlier in the test continued until test termination. Moreover, the authors observed that participants with lower cardiorespiratory fitness had a lower tendency to exhibit a VO_2 plateau than those participants with a high cardiorespiratory fitness. Notably, 38 of the 71 participants performed a square-wave verification bout at ~90% of the highest work rate attained in the CPET and five of the participants performed five more verification bouts at increasing intensities on a further five visits. No significant differences were observed between the highest VO_2 values elicited in the CPET and verification phases. Similarly, ROSSITER; KOWALCHUK e WHIPP (2006) reported the occurrence of a deceleration in the VO_2 response at the limit of exercise tolerance in only 17% (2 of the 12) of cycling ramp-incremented CPETs, while 33% of participants demonstrated an accelerated VO_2 response, and 50% demonstrated a linear VO_2 response throughout the CPET. To establish the existence

of a VO_{2max}, the authors also incorporated square-wave verification phases performed at 95% and 105% of the peak work rate attained in the CPET and observed no significant mean differences between VO_{2max} values obtained in the CPET and the verification phase performed at either verification intensity. These findings support those observed by POOLE; WILKERSON e JONES (2008) and MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.* (2009) using similar approaches for the detection of the VO_2 plateau based on the difference between the predicted VO_2 for the last stage of the test (calculated from the VO_2-work rate relationship in the earlier linear portion of the test) and the observed VO_2 value that was actually obtained.

Another issue concerns the use of so-called secondary VO_{2max} criteria as a means of validating true VO_{2max}, which include attaining threshold values for RER, percentage of the age-predicted maximal heart rate, post-exercise blood lactate concentration, and RPE. These criteria are severely limited due to their lack of specificity in identifying participants who have not exercised to their limit of tolerance, since they can be satisfied at a VO_2 much lower than the participant's eventual highest VO_2 attained in the CPET (DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007; POOLE; JONES, 2017; POOLE; WILKERSON; JONES, 2008; ROSSITER; KOWALCHUK; WHIPP, 2006). Furthermore, as a result of considerable inter-subject variability in maximal physiological responses, some participants may not satisfy a particular criterion even when a VO_2 plateau is observed to confirm the VO_{2max} (MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; POOLE; WILKERSON; JONES, 2008). Finally, the absence of standardization for the use of secondary criteria may also result in researchers making *a posteriori* decisions regarding the cut-off points to ensure that no participants have to be omitted from their study. All of these issues in the application of secondary VO_{2max} criteria limits the confidence that the participants in an experimental study elicited a true VO_{2max}, or that a maximum effort was given (KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; MIDGLEY; CARROLL, 2009; MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007).

Only three studies to-date have reported significant mean differences between the highest VO_2 values observed in the CPET and verification phase (ASTORINO; DEREVERE, 2018; COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS;

YAPICIOGLU, BULENT, 2016; KEILLER; GORDON, 2018). In a study split into two parts [i.e. Part 1: 11 women and 19 men (age: 26 ± 5 yr.; VO_{2max}: 47.2 ± 10.2 mL·kg^{-1}·min^{-1}); Part 2: 38 women and 41 men (age: 23.3 ± 4.8 yr.; VO_{2max}: 40.5 ± 4.9 mL·kg^{-1}·min^{-1})], ASTORINO e DEREVERE (2018) investigated the efficacy of the verification phase to confirm the incidence of true VO_{2max} through retrospective analysis of data from a large sample of individuals heterogeneous for cardiorespiratory fitness. Each participant underwent a ramp-incremented cycle CPET, followed by 8-10 min of active recovery at 20-30% of the peak work rate attained in the CPET, and then a verification phase at 105-110% of the peak work rate attained in the CPET. Overall, both parts of the study revealed significantly higher VO_2 values during the CPET than in the verification phase [mean difference = 0.03 L/min (P = 0.004) for Part 1 and 0.04 L/min (P = 0.001) for Part 2], although the authors did report high intraclass correlation coefficients of 0.99 between the CPET and verification phase. In Part 1 of the study, *post hoc* analyses also revealed that the highest VO_2 attained in the verification phase was significantly lower than in the CPET in participants with moderate and high cardiorespiratory fitness, whereas in those with lower cardiorespiratory fitness it was significantly higher than in the CPET. Indeed, analysis of the individual data showed that 4 out of 5 participants that achieved higher VO_2 values during the verification phase were classified as low cardiorespiratory fitness. Similar findings were reported in Part 2 of the study, especially among low cardiorespiratory fitness participants. For example, 4 of the 7 participants (9%) who displayed higher VO_2 values in the CPET than in the verification phase were classified as low fitness, while only 3 were classified as having moderate fitness. In another study with 11 participants (9 men; age: 22.4 ± 3.21yr.; VO_{2max}: 51.6 ± 4.47 mL·kg^{-1}·min^{-1}), KEILLER e GORDON (2018) also reported significantly higher VO_2 values during the CPET versus the verification phase during treadmill CPETs [Trials 1 and 2: mean difference = 0.2 (P < 0.05) and 0.1 (P < 0.01) L/min, respectively]. On the other hand, the findings of COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS e YAPICIOGLU, BULENT (2016) from 9 moderate to well-trained male athletes who compete in cycling and track and field events at a regional level (age: 23.6 ± 4.1 yr.; VO_{2max}: 60.2 ± 7.0 mL·kg^{-1}·min^{-1}), indicated significantly lower VO_2 values in the CPET compared to those attained during the verification phase (mean difference = -0.45 L/min, P = 0.002). A question therefore arises as to what could explain the difference among the aforementioned studies? Two issues may help provide a plausible explanation: a) the difference between the CPET protocols; and b) the verification phase procedures that were used. According to MIDGLEY; MCNAUGHTON e CARROLL (2006), if the mean highest

VO_2 attained in the verification phase is significantly higher than in the CPET, the investigator should consider that the CPET protocol was inadequate in eliciting a true VO_{2max} in all, or at least some, of the participants. For example, after 1-hr of recovery from a submaximal CPET of at least four 5-min stages, COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS e YAPICIOGLU, BULENT (2016) applied a prolonged step-incremented CPET, which consisted of one 4-min, three 2-min, and then 1-min increments of approximately 25-30 watts for each stage. It is feasible that the procedures performed before the maximal CPET may have led to poor participant motivation and lack of effort. Regarding the verification phase procedure, COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS e YAPICIOGLU, BULENT (2016) carried out four verification phase bouts at 100%, 105%, 110%, and 115% of the peak work rate attained in the CPET on four different days to the CPET, without any previous procedure involving exercise. This also may have positively favored the significantly higher VO_2 values in the verification phase compared to the CPET, contrasting with the same-day verification phase VO_2 data reported by ASTORINO e DEREVERE (2018) and KEILLER e GORDON (2018).

In the present review, most studies have shown the effectiveness of the verification phase procedure for confirming that the highest VO_2 observed in continuous ramp or pseudo-ramp CPET protocols represents the participant's true VO_{2max} (ASTORINO; WHITE; DALLECK, 2009; ASTORINO; DEREVERE, 2018; ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2019; ASTORINO; MCMILLAN; EDMUNDS; SANCHEZ, 2015; ASTORINO; WHITE, 2010; BELTRAMI; FROYD; MAUGER; METCALFE *et al.*, 2012; BISI; STAGNI; GNUDI, 2011; CHIDNOK; DIMENNA; BAILEY; BURNLEY *et al.*, 2013; CLARK; MURRAY; PETTITT, 2013; COLAKOGLU; OZKAYA; BALCI; YAPICIOGLU, 2015; COLAKOGLU, M.; OZKAYA, O.; BALCI, G. A.; YAPICIOGLU, B., 2016; DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.*, 2012; DAY; ROSSITER; COATS; SKASICK *et al.*, 2003; DEL GIUDICE; BONAFIGLIA; ISLAM; PREOBRAZENSKI *et al.*, 2020; DEXHEIMER; SCHROEDER; SAWYER; PETTITT *et al.*, 2019; DICKS; JOE; HACKNEY; PETTITT, 2018; DOGRA; SPENCER; PATERSON, 2012; DUCROCQ; HUREAU; MESTE; BLAIN, 2019; ELLIOTT; SKOWNO; PRABHU; NOAKES *et al.*, 2015; FAULKNER; MAUGER; WOOLLEY; LAMBRICK, 2015; FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.*, 2007; FREEBERG; BAUGHMAN; VICKEY; SULLIVAN *et al.*, 2019; GOODALL; GONZALEZ-ALONSO; ALI; ROSS *et al.*, 2012; HANSON; SCHEADLER; LEE; NEUENFELDT *et al.*, 2016; HAWKINS; RAVEN; SNELL;

STRAY-GUNDERSEN *et al.*, 2007; JAMES; TENLLADO VALLEJO; KANTEBEEN; FARRA, 2019; JAMNICK; BOTELLA; PYNE; BISHOP, 2018; JAMNICK; BY; PETTITT; PETTITT, 2016; JOHNSON; SEXTON; PLACEK; MURRAY *et al.*, 2011; KEILLER; GORDON, 2018; KIRKEBERG; DALLECK; KAMPHOFF; PETTITT, 2011; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; KRAMER; DU RANDT; WATSON; PETTITT, 2018; MAUGER; METCALFE; TAYLOR; CASTLE, 2013; MCGAWLEY, 2017; MCKAY; PATERSON; KOWALCHUK, 2009; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MIDGLEY; MCNAUGHTON; CARROLL, 2006; MIER; ALEXANDER; MAGEEAN, 2012; MURIAS; KOWALCHUK; PATERSON, 2010a; b; NALCAKAN, 2014; NIEMELA; PALATSI; LINNALUOTO; TAKKUNEN, 1980; NIEMEYER; BERGMANN; BENEKE, 2020; NIEMEYER; LEITHAEUSER; BENEKE, 2019; NOLAN; BEAVEN; DALLECK, 2014; POOLE; WILKERSON; JONES, 2008; POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.*, 2019; RIBOLI; RAMPICHINI; CE; LIMONTA *et al.*, 2019; ROSSITER; KOWALCHUK; WHIPP, 2006; SCHEADLER; DEVOR, 2015; SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.*, 2013; STACHENFELD; ESKENAZI; GLEIM; COPLAN *et al.*, 1992; STRAUB; MIDGLEY; ZAVORSKY; HILLMAN, 2014; STROM; PETTITT; KRYNSKI; JAMNICK *et al.*, 2018; TAYLOR; SEEGMILLER; VELLA, 2016; TUCKER; SAWYER; JARRETT; BHAMMAR *et al.*, 2018; VOGIATZIS; LOUVARIS; HABAZETTL; ATHANASOPOULOS *et al.*, 2011; WEATHERWAX, R.; HARRIS, N.; KILDING, A. E.; DALLECK, L., 2019; WEATHERWAX; HARRIS; KILDING; DALLECK, 2018; WEATHERWAX, R. M.; HARRIS, N. K.; KILDING, A. E.; DALLECK, L. C., 2019; WILHELM; GONZALEZ-ALONSO; PARRIS; RAKOBOWCHUK, 2016; WILLIAMS; PATERSON; KOWALCHUK, 2013; WINGO; LAFRENZ; GANIO; EDWARDS *et al.*, 2005; YEH; LAW; LIM, 2013). Albeit in theory we agree with this premise, it must be noted that the present meta-analysis did not confirm the existence of differences between the highest VO_2 values attained in a CPET and verification phase [n = 52; mean difference = 0.02 (95% CI = -0.01 to 0.06) L/min, P = 0.17] (see Figure 2). For example, the mean absolute difference of 0.02 L/min represents a relative error of only 0.56% between the highest VO_2 values attained in the CPET and verification phase. Furthermore, among the 92 specific experimental conditions included for overall comparisons (see Table 3 and Figure 2), only 25 (i.e. 27%) reported average values of VO_{2max} in the CPET lower than in the verification phase [mean diff = -0.06 (-1.6%) L/min], while 67 conditions reported similar or higher average VO_{2max} values in the CPET versus the verification phase [mean diff. 0.05 (1.5%) L/min]. In

addition, the present findings also revealed that the utility of the verification phase does not appear to be affected by sex, cardiorespiratory fitness, exercise modality, or CPET protocol design (see Table 5). This contrasts with traditional VO_{2max} criteria, which are test protocol dependent and vary according to the individual's physical characteristics (MIDGLEY; CARROLL, 2009; MIDGLEY; MCNAUGHTON; POLMAN; MARCHANT, 2007). Our findings therefore support the recommendation by POOLE e JONES (2017) that the lack of difference between the highest VO_2 values observed during ramp-incremented CPET and the verification phase provides circumstantial evidence of the attainment of a true VO_{2max}.

The considerable increase of publications in the last 10 years that incorporated a verification phase (see Table 1) indicates a possible shift from its use as merely an emerging procedure, as originally highlighted in 2009 (see MIDGLEY; CARROLL, 2009 for a review), to its recommendation as a gold standard procedure, as recently advocated by POOLE e JONES (2017). The use of the verification phase for confirming true VO_{2max} may be especially important in experimental research for avoiding false negative and false positive findings, particularly when VO_{2max} is the primary outcome. Interestingly, MURIAS; POGLIAGHI e PATERSON (2018) offered a different interpretation to the similar (and highly correlated) highest VO_2 values observed in the CPET and verification phase, based on data from a multicentre study involving 31 younger and 30 older healthy males, which underwent ramp-incremented cycle CPET with different square wave verification phases (85% or 105% of the peak work rate attained in the CPET) in a single visit. In most cases, the highest VO_2 during the CPET was similar *vs.* verification phase. The authors suggested that there might be instances in which older, less experienced, or unfit individuals are unable or unwilling to endure maximal effort in both CPET and verification phase. In this case, similar peak VO_2 values would simply represent submaximal VO_2 values.

According to MIDGLEY; MCNAUGHTON e CARROLL (2006), if the mean highest VO_2 attained in the verification phase is higher than in the CPET, the investigator should consider that the CPET protocol was inadequate in eliciting a true VO_{2max} in all, or at least some, of the participants. However, it is important to mention that this situation happened in only one of the included studies (COLAKOGLU, MUZAFFER; OZKAYA, OZGUR; BALCI, GORKEM AYBARS; YAPICIOGLU, BULENT, 2016). Therefore, our findings can be interpreted in two ways: a) on the one hand, they support the recommendation by Poole and Jones (POOLE; JONES, 2017) in the sense that the comparison between the highest VO_2

values observed during ramp or continuous step-incremented CPET and verification phase provides circumstantial evidence of the attainment of a 'true' VO_{2max}; b) on the other, they also provide evidence that, at least in healthy individuals, ramp or continuous step-incremented CPET actually elicit maximal effort and 'true' VO_{2max}, which in general are not refuted by verification phases. In practical terms, this put into question the mandatory application of this procedure to validate prior CPETs. Further research is warranted to address this feature, as well as to define the contexts in which the use of the verification phase concept would be ideally indicated, for example, clinical practice *vs*. scientific research.

This meta-analysis also endeavored to suggest best practices for the application of verification phase protocols. The subgroup analyses revealed no systematic bias between the highest VO_2 values observed in the CPET and verification phase according to the verification phase intensity (i.e. submaximal *vs*. supramaximal work rate), type of recovery between the CPET and verification phase (i.e. active *vs*. passive), whether a criterion threshold was used for VO_{2max} during the CPET (i.e. yes *vs*. no), or whether the verification phase is performed in the same testing session or on a different day (see Figure 4A). Considering that differences in the verification procedure itself do not appear to influence the utility of the procedure, a specific verification procedure cannot be currently recommended. Researchers are therefore encouraged to use procedures that are within the scope of the reviewed studies.

Most studies used verification phase protocols incorporating work rates above 100% of the maximum achieved in the CPET (ASTORINO; DEREVERE; ANDERSON; KELLOGG *et al.*, 2019; ASTORINO; WHITE, 2010; HOGG; HOPKER; MAUGER, 2015; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MIDGLEY; MCNAUGHTON; CARROLL, 2006; NOLAN; BEAVEN; DALLECK, 2014), however, this varied between 85% (MURIAS; POGLIAGHI; PATERSON, 2018) and 130% (HAWKINS; RAVEN; SNELL; STRAY-GUNDERSEN *et al.*, 2007). According to MIDGLEY e CARROLL (2009) and MIDGLEY; MCNAUGHTON; POLMAN e MARCHANT (2007), the verification phase must incorporate a work rate greater than that achieved in the CPET to conform to the original concept of VO_{2max} (HILL, A. V.; LUPTON, H., 1923). Similarly, POOLE e JONES (2017) recommended that the verification phase should apply 105% of the peak work rate attained in the CPET to satisfy the definition of a VO_2 plateau (i.e. that VO_2 does not increase or only increases a little despite the increased work rate and associated increased metabolic demand). It should be noted, however, that due to the slow component of

VO_2 kinetics, any work rate above critical power should result in VO_{2max}, as long as the time to exhaustion is sufficiently prolonged (POOLE; JONES, 2012).

Only the study of NOLAN; BEAVEN e DALLECK (2014) reported a significant influence of the verification phase intensity upon the main outcomes. The authors investigated the effect of two different verification intensities (as a percentage of the peak work rate observed in the CPET) and rest periods (i.e. A = 105% intensity, 20 min rest; B = 105% intensity, 60 min rest; C = 115% intensity, 20 min rest; D = 115% intensity, 60 min rest) for confirming true VO_{2max} after a continuous step-incremented treadmill CPET in 12 active participants. The incidence of verification of true VO_{2max} was 12/12 (100%), 12/12 (100%), 8/12 (66.70%), and 7/12 (58.33%) for protocols A, B, C, and D, respectively. Thus, the authors concluded that the intensity of the verification protocol directly impacts the ability to confirm true VO_{2max} and recommended the use of 105% of the peak work rate attained in the CPET. One concern is that an inappropriately high intensity in the verification phase protocol would result in a short test duration that results in insufficient time to reach VO_{2max}, especially in untrained individuals characterized by slow VO_2 kinetics (CAPUTO; MELLO; DENADAI, 2003). MIDGLEY; MCNAUGHTON e CARROLL (2006) stated that this is a plausible explanation for the recommendation made by THODEN (1991) that individuals who do not reach 3 min in the verification phase should undertake subsequent verification phases at the same or one stage lower than the last completed stage in the CPET. Alternatively, MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.* (2009) suggested the use of multistage verification phase protocols, such as a 2 min warm-up at 50% of the peak work rate attained in the CPET and then 1 min at 70%, before exercising to the limit of tolerance at a supramaximal intensity. This approach has since been adopted in other studies (ALEXANDER; MIER, 2011; ASTORINO; MCMILLAN; EDMUNDS; SANCHEZ, 2015; BELTRAMI; FROYD; MAUGER; METCALFE *et al.*, 2012; BELTZ; AMORIM; GIBSON; JANOT *et al.*, 2018; CHIDNOK; DIMENNA; BAILEY; BURNLEY *et al.*, 2013; DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.*, 2012; FAULKNER; MAUGER; WOOLLEY; LAMBRICK, 2015; HOGG; HOPKER; MAUGER, 2015; KEILLER; GORDON, 2018; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009; MIER; ALEXANDER; MAGEEAN, 2012; NIEMELA; PALATSI; LINNALUOTO; TAKKUNEN, 1980; POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.*, 2019; SABINO-CARVALHO; LOPES; OBEID-FREITAS; FERREIRA *et*

al., 2017; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011; STRAUB; MIDGLEY; ZAVORSKY; HILLMAN, 2014; TAYLOR; SEEGMILLER; VELLA, 2016; WEATHERWAX; RICHARDSON; BELTZ; NOLAN *et al.*, 2016) (see Table 2).

Regarding the recovery time between the CPET and verification phase, intervals between 10 to 20 min have been commonly adopted, although a wide range of intervals from 1-3 min (CLARK; MURRAY; PETTITT, 2013; FOSTER; KUFFEL; BRADLEY; BATTISTA *et al.*, 2007; KIRKEBERG; DALLECK; KAMPHOFF; PETTITT, 2011; SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.*, 2013) to 90 min (ASTORINO, 2009) have been used. Although the verification phase may be better tolerated if performed on a separate day, the additional visit to the laboratory considerably reduces the utility of this approach. In addition, the daily variation in VO_{2max}, which has been suggested to be 90% due to biological variability and 10% due to technical measurement error (KATCH; SADY; FREEDSON, 1982), would reduce the robustness of the verification procedure. SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.* (2011) specifically investigated this issue by submitting 40 participants (20 men, age: 24 ± 4 yr.; VO_{2max}: 50 ± 7 $mL \cdot kg^{-1} \cdot min^{-1}$) to the following procedures: a) CPET on a treadmill followed by 10 min of recovery and a verification phase at 110% of the peak work rate attained in the CPET (VerifDay1); and b) a CPET similar to VerifDay1, but with the verification phase performed on a separate day (VerifDay2). There was no difference between the highest VO_2 values attained in the two conditions (VerifDay1 vs. VerifDay2: 3722 ± 991 vs. 3752 ± 995 mL/min), even though the time to exhaustion was significantly longer in VerifDay2 (2:06 ± 0:22 min vs. 2:42 ± 0:38 min, $P < 0.001$, n = 34). These findings suggest there is no advantage in performing the CPET and verification phase on different days.

Inadequate data processing may negatively impact the utility of the verification phase procedure. MYERS; WALSH; SULLIVAN e FROELICHER (1990) claimed that the choice of the VO_2 sampling interval can have a profound effect on the VO_2 obtained. Small sampling intervals (e.g. 5 to 10 s) result in unacceptable variability, while very large intervals (e.g. 60 s) may not be sufficiently sensitive to accurately track rapidly changes in VO_2 such as those observed in ramp and pseudo-ramp CPET protocols. MIDGLEY; MCNAUGHTON e CARROLL (2007a) observed that the reproducibility of VO_{2max} during continuous step-incremented treadmill CPETs is not affected by the length of the VO_2 time-average interval (i.e. 10, 15, 20, 30 and 60 s), however, the actual VO_{2max} values were significantly different

between time averages. The authors suggested that a 30-s stationary time-average for CPETs provides a good compromise between removing noise while maintaining the underlying trend in the VO_2 data. Despite this, no study to-date has directly addressed the effect of the VO_2 sampling interval on the utility of the verification phase.

A final issue to be addressed refers to appropriate criteria to accept that a true VO_{2max} has been achieved. The most commonly used criterion in the presently reviewed studies stated that the highest VO_2 observed in the verification phase should not be exceed 3% of the VO_{2max} obtained in the CPET. This threshold can be justified by the technical error of measurement and intra-individual biological variation observed in the determination of VO_{2max} (ASTORINO; DEREVERE, 2018; ASTORINO; WHITE, 2010; BELTZ; AMORIM; GIBSON; JANOT *et al.*, 2018; BISI; STAGNI; GNUDI, 2011; DALLECK; ASTORINO; ERICKSON; MCCARTHY *et al.*, 2012; DEXHEIMER; SCHROEDER; SAWYER; PETTITT *et al.*, 2019; FREEBERG; BAUGHMAN; VICKEY; SULLIVAN *et al.*, 2019; HOGG; HOPKER; MAUGER, 2015; JOHNSON; SEXTON; PLACEK; MURRAY *et al.*, 2011; KNAIER; INFANGER; NIEMEYER; CAJOCHEN *et al.*, 2019; KNAIER; NIEMEYER; WAGNER; INFANGER *et al.*, 2019; KRAMER; DU RANDT; WATSON; PETTITT, 2018; MCGAWLEY, 2017; NOLAN; BEAVEN; DALLECK, 2014; POSSAMAI; CAMPOS; SALVADOR; AGUIAR *et al.*, 2019; SEDGEMAN; DALLECK; CLARK; JAMNICK *et al.*, 2013; STROM; PETTITT; KRYNSKI; JAMNICK *et al.*, 2018; WEATHERWAX, R.; HARRIS, N.; KILDING, A. E.; DALLECK, L., 2019; WEATHERWAX; HARRIS; KILDING; DALLECK, 2018; WEATHERWAX, R. M.; HARRIS, N. K.; KILDING, A. E.; DALLECK, L. C., 2019; WEATHERWAX; RICHARDSON; BELTZ; NOLAN *et al.*, 2016). The more restrictive value of ≤ 2% (MIDGLEY; MCNAUGHTON; CARROLL, 2006; SABINO-CARVALHO; LOPES; OBEID-FREITAS; FERREIRA *et al.*, 2017) and the less restrictive values of ≤ 5-5.5% (NIEMELA; PALATSI; LINNALUOTO; TAKKUNEN, 1980; NIEMEYER; BERGMANN; BENEKE, 2020; NIEMEYER; LEITHAEUSER; BENEKE, 2019; SCHARHAG-ROSENBERGER; CARLSOHN; CASSEL; MAYER *et al.*, 2011) may also be appropriate for single or different day variability. In this context, for example, some studies investigated the test-retest reliability of VO_{2max} attainment applying two (KEILLER; GORDON, 2018; MIDGLEY; MCNAUGHTON; CARROLL, 2006; WEATHERWAX; HARRIS; KILDING; DALLECK, 2018) or even five (MCGAWLEY, 2017) trials with the same CPET and verification protocols, reporting a coefficient of variation of less than 5% between the highest

VO_2 values observed in the CPET and verification phase. However, further research is required before recommendations can be made.

Unlike the verification of VO_{2max}, the highest heart rate values seemed to be systematically observed in CPETs *vs.* verification phases (see Table 3 and Figure 3). This may be due to slower heart rate than VO_2 uptake kinetics (MIDGLEY; CARROLL; MARCHANT; MCNAUGHTON *et al.*, 2009), which suggests that the utility of maximal heart rate verification may be dependent the duration of verification phases. In addition, differences in the highest heart rates observed in CPETs and verifications phase were affected by sex, exercise modality, CPET protocol design, intensity of the verification phase (submaximal or maximal), and type of recovery between CPET and verification phase (active or passive) (see Table 4 and Figure 4B). Within a practical context, the verification of maximal heart rate cannot be currently recommended until further research has been conducted. However, the use of maximal heart rate as a criterion for maximal effort seems to be more adequate in CPETs than verification phases, particularly when they are short.

Some limitations of the present review need to be acknowledged. Firstly, it was not possible to meta-analyze all the 78 studies included in the systematic review, given the lack of all required data and unsuccessful attempts to acquire information from the authors. However, the meta-analysis included 78% of the participants undergoing CPET with verification phase protocols located by our literature search. Secondly, the current systematic review and meta-analysis was based upon group-level data, comparing the mean values of the highest VO_2 and heart rate responses between the CPET and verification phase for confirming whether a true VO_{2max} was attained. NOAKES (2008b) criticized this approach, stating that the CPET is performed on individuals and not groups and, therefore, the group average approach does not identify individuals who may not have attained a true VO_{2max}. The findings of the current review, therefore, focus on the validity of different verification protocols for verifying the attainment of true VO_{2max} in a CPET, rather than the question of whether an individual has elicited a 'true' VO_{2max}.

CONCLUSION

The present meta-analysis showed that the effect sizes calculated from the highest mean VO_2 in apparently healthy adults were similar between CPETs and verification phases performed in cycle ergometer and treadmill. Furthermore, unlike traditional VO_2 plateau and

secondary VO_{2max} criteria, the verification phase procedure was not affected by cardiorespiratory fitness, exercise modality, or CPET protocol design. From a practical perspective, our findings indicate that different procedures may be applied in verification phase protocols without compromising its ability in identifying a 'true' VO_{2max} – in other words, a specific verification phase protocol cannot currently be recommended and researchers are encouraged to use procedures that are within the scope of the reviewed studies. In addition, the highest heart rate values were greater in CPETs *vs.* verification phases, irrespective of sex, cardiorespiratory fitness, exercise modality, CPET design, or verification phase protocol. This means that the verification of maximal heart rate should not be currently recommended to help confirm whether a true VO_{2max} has likely been elicited during a CPET and further research is required to establish robust unbiased procedures.

Our data reinforce the notion that a verification phase applied after ramp or step-incremented CPETs may offer additional and unbiased evidence that a 'true' VO_{2max} has been achieved. On the other hand, the invalidation of the highest VO_2 obtained in CPETs by verification phases was unlikely. The mandatory application of the verification phase in all situations may be therefore questioned. Official recommendations should consider the context in which CPETs are applied (e.g. clinical and research sets), to optimize the relationship between time spent on assessments and the accuracy of VO_{2max} determination.

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CONCLUSÃO

Com base no exposto e nos achados obtidos pelo estudo de revisão sistemática e meta-análise que compôs a presente Dissertação de Mestrado, pode-se concluir que:

1) A fase de verificação parece ser um procedimento robusto para confirmação do "*verdadeiro*" $VO_{2máx}$ em adultos aparentemente saudáveis, uma vez que os dados meta-analisados para o VO_2 não revelaram diferença significativa entre os valores obtidos no TCPE e na fase de verificação (*ou seja*, $VO_{2máx} = VO_{2verif}$).

2) Ao contrário dos critérios tradicionais para confirmação do $VO_{2máx}$ [ex.: platô no VO_2, concentração de lactato sanguíneo pós-TCPE, percentual atingido da $FC_{máx}$ predita pela idade, R (razão entre VCO_2 e VO_2) e PSE], o VO_2 atingido na fase de verificação parece não ser afetado por sexo, nível de aptidão cardiorrespiratória, modalidade de exercício, tipo do protocolo para TCPE, ou como a fase de verificação é delineada. Logo, a fase de verificação tem a vantagem de ser robusta às diferenças nas características dos participantes e nos procedimentos para delineamento do TCPE e da fase de verificação.

3) Como a fase de verificação é robusta às diferenças nos procedimentos metodológicos, um único procedimento de verificação atualmente não pode ser recomendado. Os pesquisadores são incentivados a usar os procedimentos utilizados nos estudos revisados, incorporando uma fase de verificação de onda quadrada (ex.: uma única carga constante) ou com múltiplos estágios.

4) Embora vários pesquisadores tenham recomendado protocolos de verificação com $CT_{supramáx}$ (*ou seja*, > TCPE), com a maioria usando até 110%$CT_{máx}$, análises de subgrupo revelaram validade equivalente da fase de verificação com $CT_{submáx}$ (~85-95%$CT_{máx}$) realizada até a exaustão voluntária máxima. Outrossim, não há vantagem distinta para o tipo de recuperação ativa *vs*. passiva, bem como o intervalo de recuperação entre o TCPE e a fase de verificação. Contudo, a maioria dos estudos fez uso de intervalos entre e 10 a 20 min.

5) Diferentemente das respostas do VO_2, a meta-análise revelou diferenças significativas entre $FC_{máx}$ e FC_{verif}. Em média, a FC_{verif} foi 3 bpm menor do que no TCPE, independentemente das comparações dos subgrupos. Portanto, a adoção da FC como critério para confirmação do "*verdadeiro*" $VO_{2máx}$ nas fases incremental e de verificação do TCPE não pode ser recomendada.

6) Por fim, a concordância elevada entre $VO_{2máx}$ *vs*. VO_{2verif}, por outro lado, sugere que os procedimentos adotados para o delineamento do TCPE foram capazes de provocar um "*verdadeiro*" $VO_{2máx}$. O uso da fase de verificação deve, portanto, ser avaliado de acordo com o contexto (*por exemplo*, contexto clínico *vs*. pesquisa), ponderando a necessidade de precisão com a otimização da duração do teste.

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