UNIVERSITY OF BIRMINGHAM University of Birmingham Research at Birmingham

Post-processing of peak oxygen uptake data obtained during cardiopulmonary exercise testing in individuals with spinal cord injury

Alrashidi, Abdullah; Nightingale, Tom E.; Bhangu, Gurjeet S.; Bissonnette-Blais, Virgil; Krassioukov, Andrei

DOI doi: 10.1016/j.apmr.2022.11.015

License: Creative Commons: Attribution-NonCommercial-NoDerivs (CC BY-NC-ND)

Document Version Peer reviewed version

Citation for published version (Harvard):

Alrashidi, A, Nightingale, TE, Bhangu, GS, Bissonnette-Blais, V & Krassioukov, A 2022, 'Post-processing of peak oxygen uptake data obtained during cardiopulmonary exercise testing in individuals with spinal cord injury: A scoping review and analysis of different post-processing strategies', Archives of Physical Medicine and Rehabilitation. https://doi.org/doi: 10.1016/j.apmr.2022.11.015

Link to publication on Research at Birmingham portal

Publisher Rights Statement:

This is the Accepted Author manuscript of an article published in Archives of Physical Medicine and Rehabilitation by Elsevier: Abdullah A. Alrashidi, Tom E. Nightingale, Gurjeet S. Bhangu, Virgile Bissonnette-Blais, Andrei V. Krassioukov, Post-processing of peak oxygen uptake data obtained during cardiopulmonary exercise testing in individuals with spinal cord injury: A scoping review and analysis of different post- processing strategies, Archives of Physical Medicine and Rehabilitation, 2022, ISSN 0003-9993, https://doi.org/10.1016/j.apmr.2022.11.015. (https://www.sciencedirect.com/science/article/pii/S0003999322017981)

General rights

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

•Users may freely distribute the URL that is used to identify this publication.

•Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.

•User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?) •Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

1	Title: Post-processing of peak oxygen uptake data obtained during cardiopulmonary exercise
2	testing in individuals with spinal cord injury: A scoping review and analysis of different post-
3	processing strategies
4	
5	ABSTRACT
6	
7	Objectives: To review the evidence regarding the most common practices adopted with
8	cardiopulmonary exercise testing (CPET) in individuals with spinal cord injury (SCI), with the
9	following specific aims to: (1) determine the most common averaging strategies of peak oxygen
10	uptake ($\dot{V}O_{2peak}$), (2) review the endpoint criteria adopted to determine a valid $\dot{V}O_{2peak}$, and (3)
11	investigate the effect of averaging strategies on $\dot{V}O_{2peak}$ values in a convenience sample of
12	individuals with SCI (between the fourth cervical and sixth thoracic segments).
13	
14	Data Sources: Searches for this scoping review were conducted in MEDLINE (PubMed),
15	EMBASE, and Web Science.
16	
17	Study Selection: Studies were included if (1) were original research on humans published in
18	English, (2) recruited adults with traumatic and non-traumatic SCI, and (3) $\dot{V}O_{2peak}$ reported and
19	measured directly during CPET to volitional exhaustion. Full-text review identified studies
20	published before April 2021 for inclusion.
21	
22	Data Extraction: Extracted data included authors, journal name, publication year, participant
23	characteristics, and comprehensive information relevant to CPET.

2	Λ
7	4

25	Data Synthesis:	We extracted data from a total of 197 studies involving 4,860 participants. We
26	found that more t	han 50% of studies adopted a 30-sec averaging strategy. A wide range of
27	endpoint criteria	were used to confirm the attainment of maximal effort. In the convenience
28	sample of individ	huals with SCI (n=30), the mean $\dot{V}O_{2peak}$ decreased as epoch (i.e., time) lengths
29	increased. Report	ted $\dot{V}O_{2peak}$ values differed significantly (P <.001) between averaging strategies,
30	with epoch length	n explaining 56% of the variability.
31		
32	Conclusions: Th	e adoption of accepted and standardized methods for processing and analyzing
33	CPET data is nee	ded to ensure high-quality, reproducible research, and inform population-
34	specific normativ	e values for individuals with SCI.
35 36 37 28	Keywords: Aver	aging strategies, cardiorespiratory fitness, spinal cord injury
38 39	List of abbrevia	tions:
	ACE	Arm-cycle ergometer
	AIS	American Spinal Injury Association Impairment Scale
	APMHR	Age-predicted maximal heart rate
	BP	Blood pressure
	CHOICES	Cardiovascular Health/Outcomes: Improvements Created by Exercise and
		education in SCI
	CRF	Cardiorespiratory fitness
	CPET	Cardiopulmonary exercise testing

CV	Cardiovascular
HR	Heart rate
NLI	Neurological level of injury
РА	Physical activity
PRISMA	Reporting Items for Systematic Reviews and Meta-Analyses
Q	Cardiac output
RER	Respiratory exchange ratio
RPE	Rate of perceived exertion
RPM	Revolutions per minute
SCI	Spinal cord injury
[.] VO _{2peak}	Peak oxygen uptake
WCE	Wheelchair ergometer

41 Following a spinal cord injury (SCI), individuals can experience a substantial amplification of 42 multiple risk factors for developing cardiovascular (CV) disease compared with uninjured 43 individuals.¹ Owing to a myriad of factors related to the injury and/or the resultant physical 44 inactivity,² a low level of cardiorespiratory fitness (CRF) is common and well-documented 45 following SCI.³ CRF reflects whole-body health as it represents the integration of numerous 46 bodily systems to uptake, transport, and utilize oxygen (O₂) for metabolic processes.⁴ CRF is 47 commonly expressed in metabolic equivalent of tasks (MET) or oxygen consumption ($\dot{V}O_2$), 48 measured by cardiopulmonary exercise testing (CPET) to the point of volitional exhaustion or 49 symptom limitation. Peak or maximal VO₂ (VO_{2peak} or VO_{2max}) provides the gold standard 50 measurement of CRF and is the most commonly reported outcome.⁴ Until now, there is no 51 universal consensus on a clear distinction between VO_{2peak} and VO_{2max}.⁵ In general, VO_{2max} is 52 usually evoked during intense CPET that activates larger muscle groups, with individuals reaching a plateau in $\dot{V}O_2$, indicative of a *true* $\dot{V}O_{2max}$ being attained. Conversely, $\dot{V}O_{2peak}$ refers 53 54 to the highest $\dot{V}O_2$ attained during a single CPET. We refer readers to a recent discussion, along 55 with Journal of Applied Physiology viewpoint and commentaries for further details on this topic.⁵⁻⁷ VO_{2peak} will be used from here forward in this review, as it is the most common 56 terminology reported in clinical populations to express CRF.^{7,8} VO_{2peak} is reported in the 57 literature as a reliable tool to assess responses to an exercise training intervention. Further, CRF 58 59 carries clinical importance as a powerful and independent determinant of future and non-fatal 60 CV events and outperforms other traditional CV risk factors (e.g., hypertension, high cholesterol, and physical inactivity) in individuals without SCI.^{9,10} Interestingly, an increase in CRF by 1 61 62 MET (i.e., 3.5 mL/kg/min) has been associated with a 10-25% reduction in all-cause and CV 63 mortality in individuals without SCI.⁴

The aforementioned clinical implications regarding VO_{2peak} (and other CPET-derived 65 66 measurements) require its measurement to be reported in a standardized way to ensure valid and 67 reliable results. Modern automated expired gas analysis systems have provided the scientific 68 community with multiple options for generating reports and figures and the flexibility to utilize 69 different averaging strategies. A fundamental consideration of CPET-derived measurements 70 (e.g., VO_{2peak}) pertains to the concerns of breath-by-breath variability during rest and exercise. In accordance with the Fick equation, ¹¹ $\dot{V}O_{2peak}$ is defined as the product of cardiac output (\dot{Q}) and 71 72 arteriovenous oxygen difference at peak exercise. It is unlikely that this breath-by-breath 73 variability is a result of real variations in the transient processes of central or peripheral O_2

consumption.¹² It has been reported that breath-by-breath variability during exercise testing is a result of irregularities in the rate and depth of ventilation.¹² Respiratory impairments due to paresis/paralysis and lung diseases are common post SCI;^{13,14} hence, breath-by-breath variability during CPET is expected to be higher. Therefore, time and breath averaging strategies have been adopted to attenuate this source of the noise. Time averaging is typically a fixed time interval ranging between 5 and 60 seconds, while breath averaging is computing certain breath intervals (e.g., 5, 8, and 15 breaths).

81

Hill *et al.*¹⁵ introduced the plateau in $\dot{V}O_2$ despite an increasing workload as the classical criterion for reaching $\dot{V}O_{2max}$ during discontinuous CPET's. Years later and due to some issues with this classical criterion, such as definition ambiguity and failing to attain a plateau in $\dot{V}O_2$, a variety of secondary endpoint criteria [e.g., respiratory exchange ratio (RER) and percentage of maximal heart rate (HR)], used separately or in combination, have emerged to confirm that the

obtained VO2 is truly indicative of maximal effort.^{12,16} However, even in adults without SCI 87 these secondary criteria may lack the efficacy to confirm VO_{2max} attainment. For example, 88 89 elevated RER values may occur at submaximal work rates and do not differentiate between 90 participants who do or who do not achieve a plateau in VO2.^{17,18} Moreover, the type of CPET 91 protocol (i.e., ramp and step) may effect these secondary criteria; hence, could impact the resultant data.^{19,20} Similar to the uninjured population ¹² and certain clinical population 92 groups,^{21,22} there is currently no universally recommended endpoint criteria for the attainment of 93 a valid $\dot{V}O_{2peak}$ measurement and little is known regarding the most common averaging strategies 94 used to process VO_{2peak} in the SCI population specifically. 95

96

A recent review by Eerden *et al.*²³ has summarized the application of CPET in individuals with 97 98 SCI. The authors reviewed characteristics of CPET pertaining to common modalities of exercise 99 testing, protocols, and reporting outcomes. However, post-processing averaging strategies were 100 not reported in this review. Therefore, we aimed to map the SCI-related literature with the goals 101 to 1) identify the most common averaging strategies to process $\dot{V}O_{2peak}$ obtained during maximal or peak CPET, 2) provide a brief critique of the current endpoint VO_{2peak} criteria, and 3) 102 103 investigate the influence of using different averaging strategies on obtained $\dot{V}O_{2peak}$ values in a 104 cohort of individuals with SCI.

105

106 METHODS

We developed our scoping review using the five-stage scoping review process (the optional stage was not used) as outlined by Arksey and O'Malley.²⁴ We considered a scoping review to be the most appropriate methodological approach to address our aims given its breadth and coverage of

110	the available literature regardless of study design. We searched the literature using the following
111	electronic databases: MEDLINE (PubMed), EMBASE, and Web of Science. These databases
112	were searched from inception to April 2021. A sample of search terms is provided as an
113	appendix (Appendix 1). Studies were included if they met the following criteria: 1) original
114	research article published in English, 2) adults (≥ 18 years) with traumatic or non-traumatic SCI,
115	3) individuals of interest (i.e., SCI) comprise $\geq 80\%$ of the experimental group, and 4) $\dot{V}O_{2peak}$
116	was reported and measured directly during peak/maximal CPET (both continuous and
117	discontinuous protocols). The review excluded: 1) non-original articles such as reviews, study
118	protocols, letters to the editor and commentaries, and non-human studies, 2) case-reports and
119	case series with a number of participants <5, 3) articles that performed submaximal and steady-
120	state testing, and 4) articles that assessed $\dot{V}O_{2peak}$ indirectly (e.g., estimation from submaximal
121	testing). There was no attempt to contact authors if we found any insufficient/missing
122	information (e.g., not reporting post-processing strategies), as this lack of reporting will be
123	presented in our results. In the case of duplicated participants across multiple publications (e.g.,
124	data from the same clinical trial), we endeavoured to include the most relevant article (i.e., the
125	one that has more detailed information related to post-processing strategies).

Because of the large number of articles, titles and abstracts returned from the search were assessed for eligibility by two independent reviewers (AA) and (GB or VB). In the event of disagreement, a third reviewer (TN) was consulted to make the final decision with regards to article inclusion. Where there were insufficient data provided in titles and abstracts, we retrieved and analysed full texts to determine eligibility. Detailed information was recorded at every stage outlining the reasons for inclusion/exclusion. Data extraction and charting from the final

133 included articles were primarily performed by a single reviewer (AA) with assistance from (GB 134 and VB). Data charting sheets were created and managed using a pre-approved Microsoft Excel 135 spreadsheet.^a Key information was extracted pertaining to authors name, journal name, year of 136 publication, neurological characteristics of the included sample, and comprehensive information 137 relevant to CPET such as aim, protocol, measurement device, and the post-processing data 138 management applied. Studies that used Douglas Bags were excluded from the final analysis, as 139 we wanted to focus specifically on the more common and recent breath-by-breath systems 140 approach of capturing VO_{2peak} during CPET.

141

142 **RESULTS**

143 **Scoping Review**

144 Figure 1 provides the schematic representation of the research methodology using the Preferred 145 Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). A total of 18,493 146 citations were initially identified. After removal of duplicates, the remaining articles (n = 12,847) 147 were deemed eligible for title/abstract screening. Of these, 1,839 articles were selected for full-148 text screening against the eligibility criteria. A total of 352 full-text articles were considered 149 eligible whereby $\dot{V}O_{2peak}$ was reported and measured directly during peak/maximal CPET. Out of 150 these 352 studies, 155 (44%) studies did not provide enough information to extract the data 151 pertaining to the post-processing strategies utilised. Consequently, 197 (56%) studies reported 152 methods of VO_{2peak} averaging and were included in this scoping review, with data regarding the outcomes of interest extracted. A relevant summary of the included studies $(n = 197)^{19,25-220}$ 153 154 characteristics is presented in the supplemental material.

156 General Characteristics of Studies Included

157 Cross-sectional studies (n = 89) accounted for 45% of included studies in the review, while only 158 18 (9%) studies were randomized controlled trials. Half of the included articles were conducted 159 during the last ten years and 46 (46%) of these were published during or after 2017. Figure 2 160 highlights the substantial chronological increase in the numbers of published studies assessing 161 CRF in the SCI population. Collectively, the 197 included studies comprised 4,860 participants 162 and their demographics and injury characteristics are presented in TABLE 1. The sample size of the included studies ranged from five ^{29,40,45,146,172,204,210,214} to 223¹⁴³ participants. 163 164 165 Eighty-five percent of the studies (n = 167) performed maximal CPET to study the acute 166 physiological responses of $\dot{V}O_{2peak}$, while the rest (n = 30; 15%) tested the effect of an exercise 167 training intervention on the CPET-obtained outcomes. Arm-crank ergometer (ACE) and 168 wheelchair ergometer (WCE) were the most common modalities of CPET and were used in 98 169 studies (50%) and 57 studies (29%), respectively. Forty-two studies (21%) used different modes 170 of CPET such as treadmill, leg cycling, hybrid (arm and legs) with and without stimulation. 171 Continuous incremental protocols were the most common and were implemented in 176 (89%) 172 of the included studies. The duration of stages during continuous and discontinuous protocols 173 ranged from 30-sec to three min for each stage, interspersed with 30-sec to three min rest breaks 174 during the discontinuous protocol. The predetermined duration of CPET was reported in 31 175 (16%) studies; with the duration of 8-12 min used in 20 (65%) of these studies. The majority of 176 studies (91%) reported the reason for CPET termination; volitional fatigue/exhaustion and

177 inability to maintain the desired workload/speed were the most commonly reported reasons for

178 termination.

180 Common Averaging Strategies Used

VO_{2peak} averaging strategies varied among the included articles. In 192 (97%) of these studies, 181 182 the averaging strategy was expressed using time-interval methods. Thirty-sec averaging was the 183 most common method (n = 102), accounting for 53% of the reported studies. Other methods 184 included 15-, 20-, and 60-sec averaging and were used in (n = 23; 12%), (n = 29; 15%), and (n = 23; 12%)185 18; 9%) of studies, respectively. The averaging strategy expressed by breath intervals was only 186 reported in five studies (3%) using the following: averaging of 15-breath rolling (three studies), 8-breath (one study), and 5-breath (one study).^{51,53,76,83,99} Some authors, after applying "one of 187 188 the above averaging methods", took an additional step whereby they then averaged a number (e.g., 2 highest values) of the time interval across the CPET.^{94,105,138,148} Additionally, some 189 authors instead of using fixed time intervals, used rolling/moving averages of 10-sec, ⁵² 15-sec, ¹²³ 190

191 30-sec,⁶² and 60-sec.¹⁸⁷

192

193 Secondary End-Point Criteria Applied

Sixty-seven studies (34%) reported predetermined endpoint criteria of VO_{2peak} (TABLE 2). Some 194 studies clearly distinguished between the endpoint and termination criteria,^{186,188} yet, some used 195 196 them interchangeably.^{52,136} Thus, the termination criteria meant that the CPET's was stopped if 197 one of these criteria were met regardless of participants reaching their perceived maximal effort 198 or not. RER as a criterion was reported in 55 (82%) of the studies. Studies used varied cut-off 199 values ranging between 1.0 to 1.15 for this criterion, with an RER of 1.1 being reported in 30 (54%) of included studies. Three studies,^{30,95,153} which recruited cervical and thoracic SCI, used 200 201 verification/supramaximal testing as a criterion. Discontinuous and continuous protocols were

used in two studies and one study, respectively. A 10-min resting period between CPET and the verification test was used in all of these three studies. Forty-seven (70%) of the 67 studies combine at least two criteria for $\dot{V}O_{2peak}$ endpoint criteria. Compared to other criteria, no studies used HR or rating of perceived exertion (RPE) individually as a criterion. Fifty-three (39%) out of 136 studies reported the method used to define the peak workload. Of these, 24 (45%) studies defined the peak workload as the workload that was maintained for at least 30 sec.

208

The impact of altering post-processing VO_{2peak} strategies: The CHOICES clinical trial example

211 CPET's of thirty participants (with neurological level of injury (NLI) between the fourth cervical and sixth thoracic spinal cord segments (C4-T6)) from the CHOICES trial^{221,222} were used to 212 213 provide an illuminating example of the impact of different post-processing strategies for the 214 determination of $\dot{V}O_{2peak}$ in individuals with SCI. Participant demographics and injury 215 characteristics are presented in TABLE 3. Only data from the Vancouver site and CPET's 216 conducted before the commencement of the training interventions (i.e., baseline data) were 217 included in this current analyses. All CPETs were performed after the ethics approval from the 218 center-specific Institutional Review Board. We analyzed the data retrospectively according to 219 prevalent post-processing strategies used in the wider literature, as identified by our scoping 220 review that included 197 articles.

221

222 Cardiopulmonary exercise testing

223 VO_{2peak} was collected during a CPET's on an electrically braked arm-crank ergometer,^b

224 performed until volitional exhaustion. Respiratory gases were collected using a metabolic cart.^c

225 HR was recorded continuously using a chest-strap HR monitor.^d Participants were asked to 226 empty their bladder prior to the test to avoid the possible development of autonomic dysreflexia. 227 CPET's started after two minutes of resting, after a warm-up with no resistance (i.e., 0 watts 228 (W)) for two minutes and then continued with one-minute stages, where resistance was increased 229 by 5 and 10 W per stage for participants with cervical and upper-thoracic NLI, respectively. The 230 Borg scale (6-20) rating of perceived exertion was collected by the end of each sage. The 231 participants were instructed to maintain a cadence of 50 revolutions per minute (rpm) throughout 232 the test. The test continued with verbal encouragement until volitional exhaustion or the cadence 233 dropped below 30 rpm. The test ended with a two-minute cool-down period with zero W.

234

235 Data management and statistical analysis

236 The parent trial collected and processed $\dot{V}O_{2peak}$ using the time-interval of 20-second averaging. 237 In addition to these collected data, we exported individual participants data from the metabolic 238 cart using different averaging strategies according to the common methods reported in our 239 scoping review (i.e., 20-sec, 30-sec, 60-sec, and 15-breath rolling). 15-breath rolling average 240 represented a rolling average of breaths one through 15, breaths two through 16, and so forth 241 throughout the test. We also investigated the influence of achieving a specific RER value (i.e., above or below 1.1) corresponding to VO_{2peak}. All analyses were performed using Statistical 242 Package for Social Sciences.^f Statistical significance was accepted at P < .05. Repeated measure 243 244 analysis of variance (ANOVA) with Bonferroni adjustment (Post-Hoc correction) was used to assess the difference in both relative and absolute $\dot{V}O_{2peak}$ between each average epoch. Partial 245 246 eta squared was calculated to report effect size. Bland-Altman plots, with corresponding 95% 247 limit of agreement (LoA) analyses, were used to compare all averaging strategies (i.e., 15-sec,

248 20-sec, 60-sec, and 15-breath rolling) to 30-sec averaging, the most common averaging strategy 249 as per the findings from our scoping review. To further evaluate variations in VO_{2peak} values, 250 equivalence testing was conducted to examine the equivalence between different averaging 251 strategies and the 30-sec averaging method. For methods to be considered equivalent to 30-sec 252 with 95% precision, the 90% confidence interval of the mean of the other averaging strategies 253 must fall into the proposed equivalence zone of the criterion mean (i.e., $\pm 10\%$ of the mean of 254 30-sec method). Data were presented as Mean \pm Standard deviations unless otherwise 255 mentioned.

256

257 Findings from the CHOICES Example

258 TABLE 4 provides descriptive statistics for all of the different averaging strategies for both 259 absolute and relative $\dot{V}O_{2peak}$. The mean $\dot{V}O_{2peak}$ values reported were significantly reduced as the length of averaging epochs (i.e., time) increased (P<.001 and $\eta_p^2 = 0.562$). Fifty-six percent 260 261 of the variation in the obtained VO_{2peak} values was related to using different averaging strategies. 262 The ANOVA revealed that VO_{2peak} values were significantly different across all averaging 263 strategies, with Bonferroni analyses demonstrating alternative strategies were significantly 264 different from the most commonly used 30-sec averaging strategy (P<.001) (TABLE 4). TABLE 265 5 shows the influence of categorizing individuals based on RER above or below 1.1 on the 266 obtained VO_{2peak} using different averaging strategies. In both categories, VO_{2peak} values decrease 267 as the averaging epoch lengths increase. Categorizing individuals above and below a RER of 1.1 268 had no effect on this trend (RER vs averaging strategies interaction effect, P = .805). However, 269 main effect of averaging strategies was significant (P < .001) and those who reached a RER of 1.1 270 had higher $\dot{V}O_{2peak}$ values (P = .005).

Bland-Altman plots (Figure3) show the absolute bias ± 95% confidence intervals (CI) of the
agreement of all averaging strategies against 30-sec (i.e., 30-sec minus each one of the other
strategies): 15-sec (-0.88 ±1.48 mL/min/kg), 20-sec (-0.43±1.10 mL/min/kg), 60-sec (0.71±1.44
mL/min/kg), 15-breath rolling (-0.87±1.89 mL/min/kg). Equivalence testing (Figure 4)
demonstrates that none of the averaging strategies were equivalent to the 30-sec strategy.

277

278 **DISCUSSION**

279 We aimed in this review to characterize the main methodological features of the SCI literature 280 pertaining to the methods of averaging VO_{2peak} and criteria applied to indicate the attainment of a 281 valid VO_{2peak}. We also investigated the influence of using different averaging strategies on 282 CPET-obtained VO_{2peak} values in a cohort of individuals with SCI \geq T6. This is the first scoping 283 review of VO_{2peak} post-processing in individuals with SCI. One hundred and fifty-five (44%) of 284 the 352 studies that performed maximal CPET did not report the method of VO_{2peak} averaging 285 from breath-by-breath systems. Furthermore, a wide range of VO_{2peak} endpoint criteria were 286 used. Our retrospective analysis of VO_{2peak} data from the CHOICES trial indicates a significant impact of using different averaging strategies on the reported VO_{2peak} values. Therefore, the 287 288 scientific community is recommended to provide detailed information on the post processing 289 strategy used when reporting VO_{2peak} data from CPET's. Simply deferring to manufacturers 290 instruction is not appropriate and researchers should have an appreciation of how utilising 291 different time epochs can influence their data. The number of included articles has doubled over 292 the last ten years, which emphasizes how important it is that laboratories transparently report the

293 post-processing criteria adopted. This is essential to ensure high-quality, reproducible research,

and inform comparisons to population-specific normative values in individuals with SCI.

295

296 **VO_{2peak} averaging strategies**

297 Based on our findings, time-averaging methods were the most common approach for processing VO_{2peak} data, which is in line with what is documented in the uninjured population.¹² Of the time-298 299 interval strategies, 30-sec was the most common method used to attenuate breath-by-breath 300 variability. Our findings in a cohort of individuals with SCI (i.e., C4-T6) are in agreement with 301 previous literature, indicating that the averaging strategy can significantly alter the derived maximal/peak VO₂ value.^{223,224} In the non-injured population, the general recommendation is to 302 303 use an averaging strategy larger than a single breath but smaller than 60-sec. Although this 304 represents a broad range, which can impact the derived VO_{2peak} value as shown with our data analysis it seems reasonable to advocate either \leq 30-sec,²²⁵ and 15- or 8-breath averaging as 305 306 suitable strategies.^{12,226} Averaging strategies gained their importance not only for the ability to 307 smooth breath-by-breath variability, but their influence on accurately identifying the plateau in 308 $\dot{V}O_2$, if this were indeed to happen. In non-injured individuals, a greater incidence of $\dot{V}O_2$ plateau identification was observed with shorter averaging strategies (e.g. 15- and 30- sec).²²³ 309 310 Given that VO_{2peak} can only be sustained for a limited period of time, a shorter time averaging strategy (i.e., ≤ 30 sec) offers a higher probability for capturing an individual's true \dot{VO}_{2peak} .²²⁷ 311 312 Our analysis showed that up to 56% of the variability in the obtained $\dot{V}O_{2peak}$ value was due to 313 employing different averaging strategies. However, this reported variability is higher than that reported in the previous non-SCI literature.^{226,228,229} Respiratory dysfunction and related 314 315 impairments (e.g., paresis or paralysis of the expiratory muscles) are common post SCI with NLI

 \geq T6.¹³ Consequently, this population experience a shallow and rapid breathing pattern; ¹⁴ hence, breath-by-breath variability during CPET is expected to be higher.

318

319 In regards to breath-interval methods, Martin-Rincon et al 230 suggested that time- and breath-320 intervals produce similar $\dot{V}O_{2peak}$ values for a given epoch of seconds or breaths. While this 321 suggests these methods can be used interchangeably, further research is required specifically in 322 the SCI population. Normative values of VO_{2peak} have been suggested for individuals with SCI.^{231,232} Differences in the obtained VO_{2peak} value as a result of using different post-processing 323 324 strategies could influence the individuals' fitness classification and result in misinterpretation. It should be noted that these commonly cited SCI-specific CRF classification papers ^{231,232} did not 325 326 report the post-processing averaging strategies that were utilized. Furthermore, if using a 327 percentage of VO_{2peak} for a prospective exercise training intervention, this could lead to 328 variability in the prescribed relative exercise intensity and thus training adaptations.

329

330 Currently used criteria of VO_{2peak} attainment

331 Plateau in VO_{2peak}

The plateau phenomenon was confirmed using a discontinuous protocol carried out on subsequent days using a Douglas Bag approach. The frequent use of automated gas analysis systems and the utilization of continuous protocols during CPET have challenged this criterion.^{233,234} It has been reported that the occurrence of a plateau in a healthy or clinical population is rare (<50%), despite individuals reporting maximal effort and volitional fatigue during CPET.^{235,237} Likewise, Leicht *et al.*²³⁸ demonstrated that a plateau was reported in only 40% of athletes with SCI during CPET. We are not aware of any previous studies that have 339 reported the percentage of untrained individuals with SCI reaching a plateau in VO₂. The 340 majority (n = 24; 83%) of studies included in our review that reported using a plateau as a criterion did not clearly define the plateau. Only four (13%) studies ^{112,120,125,147} specifically 341 342 defined the plateau criteria, even though different definitions were used. Zoeller et al.¹²⁵ used a 343 discontinuous protocol performed on ACE with ten individuals with paraplegia and defined the 344 plateau as a change in $\dot{V}O_2 < 150$ mL/min. There is currently no universal consensus on which cut-off value to use- ranging from 50 to 100 mL/min.^{239,240} Thomson et al.²³⁹ who tested 345 346 individuals with metabolic syndrome suggested using a smaller averaging strategy (i.e., 15-347 breath rolling average), with a smaller cut-off change in \dot{VO}_2 (i.e., ≤ 50 mL/min) to increase the 348 likelihood of detecting a VO₂ plateau.

349

Future research should be conducted to develop a methodology appropriate for the SCI population to identify a valid and reliable plateau criterion and how other factors (e.g., workload increment and CRF level) could influence plateau detection.³⁰ The potential application of individual slope of the $\dot{V}O_2$ -workload-rate relationship could also be investigated as a criterion for a plateau in $\dot{V}O_2$.⁸ Moreover, a consensus is also needed in case this criterion is met; should the terminology of $\dot{V}O_{2max}$ replace the use of $\dot{V}O_{2peak}$ in this context?

356

357 Respiratory exchange ratio (RER)

358 RER is the ratio of carbon dioxide (CO₂) produced to oxygen uptake ($\dot{V}CO_2/\dot{V}O_2$). RER

359 increases with exercise intensity because of the production of lactic acid, which is buffered, plus

360 the excess CO₂ generated from the muscle work. This physiological outcome is the most used-

361 secondary criterion to gauge one's maximal effort.^{16,225} This is in the line with our findings,

362	which shows that RER was applied in up to 82% of the studies whenever $\dot{V}O_{2peak}$ criteria were
363	reported. An RER of 1.10 was the most common cut-off value reported, used in more than half
364	of the studies. However, RER as a criterion was reported using a wide range from 1.0 to 1.15.
365	This range supports that mentioned in the review by Eerden <i>et al.</i> ²³ and is similar to the range
366	reported with individuals post stroke. ²¹ Following SCI, daily wheelchair use and reliance on
367	upper-body exercise may result in local adaptations in the upper-body musculature. This
368	adaptation may cause differences in the preference for lipid utilization rather than carbohydrates,
369	which consequently gives rise to a lower RER value with upper-body exercise. ¹¹¹ While this may
370	suggest using a smaller RER cut-off value (i.e., 1.10) during CPET is necessary to confirm
371	attainment of maximal effort, other research77,241 has indicated a higher reliance on carbohydrate
372	fuel sources during upper-body exercise in individuals with SCI. Moreover, autonomic
373	impairments in individuals with cervical and upper-thoracic SCI might further contribute to poor
374	lipid substrate utilization in this population. ²⁴² This could result in a higher exercising RER in
375	individuals with SCI that may lead to erroneous conclusions on the attainment of maximal effort.
376	
377	Future research may want to investigate this criterion in the SCI population to identify the most
378	appropriate cut-off value with consideration to the injury characteristics (i.e., NLI and
379	completeness) and investigate the influence of CPET protocol (i.e., size of increment) on this
380	criterion. ¹⁷ Moreover, diet has been shown to alter maximal exercise RER and therefore
381	potentially its use as a secondary criteria to discern whether $\dot{V}O_{2peak}$ has been achieved. Niekamp
382	et al, ²⁴³ showed that adults on a diet that promotes systemic alkalinity (which effects acid-base
383	regulation) achieve a criterion RER \geq 1.10 more easily, resulting in false-positive conclusions

around the attainment of max effort during CPET. RER is also impacted by age and sex,²⁴⁴
which warrant future investigation.

386

387 Age-predicted maximal heart rate

388 Using a certain percentage of age-predicted maximal heart rate (APMHR) is a problematic 389 criterion. The maximal HR response to exercise possesses a wide variability relative to APMHR 390 $(\pm 11 \text{ beats/min})$, making it difficult to justify its use as a criterion.¹⁶ This would be even more 391 problematic with the SCI population, particularly those with a NLI \geq T6. Owing to the 392 supraspinal sympathetic decentralization, this population may experience an attenuated increase in HR (i.e., does not exceed 120-125 beats/min).²⁴⁵ Even those with paraplegia may also 393 394 experience circulatory hypokinesis, exaggerated HR to maintain cardiac output in the face of reduced stroke volume resulting from impaired blood redistribution.^{246,247} Further, SCI-related 395 396 physical inactivity and the use of β -blocking agents may also challenge the use of this criterion. 397 We found that HR as a criterion of $\dot{V}O_{2peak}$ was not clearly described, using different or 398 unreported formulas and various percentage of APMHR (TABLE 2). Considering the above 399 issues with HR as a criterion, the American Heart Association negates the validity of using APMHR to identify an endpoint during maximal CPET. ²²⁵ Therefore, this criterion should not 400 be recommended as a single criterion to confirm the attainment of VO_{2peak} in the SCI population, 401 402 particularly in those with cervical and high-thoracic injuries. Nevertheless, this criterion is still 403 reported and used in scientific publications as per the result of our review (n = 29; 43%). 404

405 Rating of perceived exertion (RPE)

406 RPE, using the Borg scale, is an easy, accessible method and widely used to assess exercise 407 intensity and to regulate work rate.^{248,249} This subjective tool is usually assessed in relation to 408 physiological markers such as HR, blood lactate level and $\dot{V}O_2$.²⁴⁹ However, this criterion might 409 be distorted by non-cardiopulmonary factors such as pain and local muscle fatigue, which are 410 commonly seen with the SCI population during arm-crank CPET.^{250,251}

411

412 There are currently a limited number of studies conducted in the SCI population where the 413 association of this criterion is investigated with other VO_{2peak} criteria during maximal CPET. A recent publication by Hutchinson et al. ²⁵² highlighted that the association between RPE with % 414 VO_{2peak} and % peak HR was influenced by NLI. This study showed that those with cervical SCI 415 416 have greater inter-individual variations relative to thoracic SCI and non-injured individuals. 417 Future studies may want to investigate the association of RPE with objective endpoint measures 418 collected during CPET (i.e., plateau, blood lactate level, and RER) in individuals with SCI. 419 Moreover, future studies may want also to consider a more holistic approach (i.e., 420 psychophysiological factors) that might influence the criterion.

421

422 *Post-exercise blood lactate level*

423 Howley *et al.*¹⁶ stated that *"blood lactate is a good choice as an indicator of maximal effort"* as

424 there was a theoretical association between post-exercise blood lactate level and the plateau in

- 425 VO₂. High blood lactate is a good indicator of high effort exerted as it is associated with
- 426 increased recruitment of fast-twitch muscle fibres ²⁵³ that occurs with higher exercise intensities.
- 427 It is noted in our review that only 14 out of 67 studies used the level of blood lactate as a
- 428 criterion, possibly because of the invasive nature of this procedure. Similar to the concern with

other criteria, a wide range of cut-off values (range: 5 mmol/L to 10 mmol/L) have been used for
post-exercise blood lactate level to indicate the maximal value of VO₂, which has also been
documented elsewhere.¹⁶ The validity of this criterion warrants further investigation within the
SCI population.

433

434 Verification testing

435 A verification test can be performed following a period of rest whereby individuals perform 436 exercise with an intensity greater (i.e., 105-115%) than that attained during the final CPET stage.¹⁸ This is typically performed 5-10 minutes after the CPET.²⁵⁴ If the obtained VO_{2peak} value 437 438 during the verification testing is similar to or within a measurement error (i.e., 2%) of the CPETobtained VO_{2peak} this would indicate that the person attained maximal effort.²⁵⁵ Verification 439 440 testing was claimed to be independent of CPET-related variables (e.g., CPET mode and protocol and participant motivation etc.) that can have an influence on the other end point criteria.⁸ 441 442 Similar to the other end point criteria, there is no general consensus on the most appropriate 443 verification methodology (e.g., the duration of the resting period between CPET and verification phase) and what is the maximal accepted change in \dot{VO}_2 during the verification phase to be 444 445 considered as a true maximal value. Moreover, pertinent to the SCI population and other clinical 446 populations, the scientific community has to consider the following: 1) how the accumulative 447 fatigue during CPET influence the results from the verification phase, 2) does performing this 448 phase add or change clinical-related decisions, and 3) does detecting such a small change in $V\dot{O}_2$ 449 justify the cost, time, or potential risk to the participants.

450

451 Strength and Limitations

452 Our review provides a broad overview of $\dot{V}O_{2peak}$ post-processing obtained during maximal/peak 453 CPET in the SCI population. Our review adopted an inclusive search strategy and summarized 454 studies from all available years. Despite the fact of this comprehensive search strategy, it is 455 possible that some potential studies may have been missed or excluded due to eligibility criteria. 456 Nevertheless, given the high number of included studies in this review, we are confident that the 457 findings reflect the current practice of using CPET within the SCI population. The disadvantage 458 of this broad searching strategy is that we included studies with a wide diversity of methods and 459 a notable heterogeneity of included participants. Using >80% SCI as an inclusion criterion could 460 be considered a limitation; however, only five studies, which included a total of 12 non-SCI 461 individuals met this criterion and were included. Such a small percentage (i.e., 0.2%) is unlikely 462 to have impacted our overall conclusion. We found that 56% of the variability in the obtained VO_{2peak} values in our cohort is due to utilization of different averaging strategies. Other factors 463 464 therefore account for almost half of the remaining variance. These could include respiratory variables (e.g., respiratory rate and tidal volume),⁵⁵ which should be explored in future studies. 465 466 Researchers may also want to consider the following factors and their interactions in the interpretation of VO_{2peak} data between studies: the specific type of metabolic cart used (e.g., 467 breath-by-breath Vs. mixing chamber, pneumotach Vs. turbine),⁶⁰ along with the exercise modes 468 (e.g., treadmill, wheelchair ergometer or arm cycling)⁵⁶ and specific CPET protocols (e.g., ramp 469 Vs. step, continuous Vs. discontinuous) used.^{234,256} Our analyses were performed on a sample of 470 471 individuals with high NLI SCI (i.e., \geq T6), this may limit the generalizability of these findings to the wider SCI population. Although, we do not expect a higher VO_{2peak} variability when using 472 473 different averaging strategies with lower NLI due to less respiratory impairment. Our analysis 474 was obtained from a specific exercise modality, maximal CPET using arm cycling, which may be 475 seen as a limitation. However, arm cycling CPET was reported in up to half of the included

476 papers in our review, thereby reflecting the most common modality used in the wider literature.

Furthermore, a previous publication showed that the obtained VO_{2peak} values do not significantly 477

478 differ compared to wheelchair CPET.²¹²

- 479
- 480

CONCLUSION AND RECOMMENDATIONS

481 This review emphasizes and discusses the considerable variation in post-processing data 482 management (i.e., averaging strategies and VO_{2peak} criteria) used in the SCI literature. The ability 483 to accurately determine criteria for $\dot{V}O_{2veak}$ along with identifying the best averaging strategies of VO_{2peak} is of high importance given an increased CV disease risk in this population,¹ which is in 484 part due to the well-documented low level of CRF.^{9,10} Formal guidelines for reporting CPET data 485 486 do not currently exist in the SCI literature and a high number of publications included in our 487 review even failed to report the averaging strategies utilized. Caution should be applied when 488 comparing VO_{2peak} values across studies when different averaging strategies have been 489 implemented utilized. A lack of such standardization would result in decreased validity and 490 reliability of CPET-related results. The lack of standardization is also observed with other CPET-491 related procedures such as the recommended test duration, termination criteria, testing protocols, 492 and method of identifying the peak workload. We recommend that subsequent publications 493 clearly denote the post-processing strategies used when reporting CPET data. Owing to the possibility that dietary intake would alter some of secondary criteria (i.e., RER),²⁴³ we suggest 494 495 also reporting the pre CPET fasting/dietary status. When using time-interval methods, we 496 recommend using no longer than 30-sec. The use of much smaller time-intervals (<15 seconds), 497 which would include fewer breaths, may influence data due to the high breath-by-breath

498	variability in the SCI population. Therefore, we propose $20 - 30$ -secs as being the most
499	appropriate time epoch for capturing a true $\dot{V}O_{2peak}{}^{227}$ and increase the chance of detecting a
500	plateau in $\dot{V}O_2$. ²³⁹ Each secondary endpoint criteria should not be used in isolation, given the
501	aforementioned specific limitations when applied to participants with higher NLI's (i.e., upper-
502	thoracic and cervical SCI), due to autonomic cardiovascular/metabolic impairments, ¹²² as well as
503	the obligatory of using upper limbs in daily activities, that in turn would challenge using these
504	criteria in isolation. Hence, we recommend using at least two criteria (e.g., RER and RPE) to
505	indicate maximal effort during CPET. Once these recommendations become more consistently
506	applied, with transparent reporting, one can ensure the highest quality CPET results and facilitate
507	comparisons between studies.
508	
509	
510	
511	
512	
513	

514 **References**

Cragg JJ, Noonan VK, Krassioukov A, Borisoff J. Cardiovascular disease and spinal cord
 injury: results from a national population health survey. *Neurology*. Aug 2013;81(8):723-8.
 doi:10.1212/WNL.0b013e3182a1aa68

Nightingale TE, Williams S, Thompson D, Bilzon JLJ. Energy balance components in
 persons with paraplegia: daily variation and appropriate measurement duration. *Int J Behav Nutr Phys Act.* Sep 2017;14(1):132. doi:10.1186/s12966-017-0590-z

Haisma JA, van der Woude LH, Stam HJ, Bergen MP, Sluis TA, Bussmann JB. Physical
 capacity in wheelchair-dependent persons with a spinal cord injury: a critical review of the
 literature. *Spinal Cord.* Nov 2006;44(11):642-52. doi:10.1038/sj.sc.3101915

524 4. Ross R, Blair SN, Arena R, et al. Importance of Assessing Cardiorespiratory Fitness in

525 Clinical Practice: A Case for Fitness as a Clinical Vital Sign: A Scientific Statement From the

- 526 American Heart Association. *Circulation*. 12 2016;134(24):e653-e699.
- 527 doi:10.1161/CIR.000000000000461

5. Poole DC, Jones AM. Measurement of the maximum oxygen uptake Vo. *J Appl Physiol*529 (1985). Apr 01 2017;122(4):997-1002. doi:10.1152/japplphysiol.01063.2016

530 6. Green S, Askew C. $\dot{V}O_2p_{eak}$ is and acceptable estimate of cardiorespiratory fitness but

531 not $\dot{V}O_{2max}$ Journal of Applied Physiology. 2018;(125):229-232.

532 doi:10.1152/japplphysiol.00850.2017

Azevedo P, Bhammar DM, Babb TG, et al. Commentaries on Viewpoint: Vo. *J Appl Physiol (1985)*. 07 2018;125(1):233-240. doi:10.1152/japplphysiol.00319.2018

Midgley AW, McNaughton LR, Polman R, Marchant D. Criteria for determination of
maximal oxygen uptake: a brief critique and recommendations for future research. *Sports Med.*2007;37(12):1019-28. doi:10.2165/00007256-200737120-00002

538 9. Lee DC, Sui X, Artero EG, et al. Long-term effects of changes in cardiorespiratory
539 fitness and body mass index on all-cause and cardiovascular disease mortality in men: the
540 Aerobics Center Longitudinal Study. *Circulation*. Dec 2011;124(23):2483-90.
541 doi:10.1161/CIRCULATIONAHA.111.038422

542 10. Myers J, Prakash M, Froelicher V, Do D, Partington S, Atwood JE. Exercise capacity and
543 mortality among men referred for exercise testing. *N Engl J Med.* Mar 2002;346(11):793-801.
544 doi:10.1056/NEJMoa011858

54511.Stibitz GR. Substance uptake in variable systems with special reference to the use of the546Fick equation. Respir Physiol. Dec 1966;2(1):118-28. doi:10.1016/0034-5687(66)90043-0

547 12. Robergs RA, Dwyer D, Astorino T. Recommendations for improved data processing

from expired gas analysis indirect calorimetry. *Sports Med.* Feb 2010;40(2):95-111.

549 doi:10.2165/11319670-00000000-00000

- Brown R, DiMarco AF, Hoit JD, Garshick E. Respiratory dysfunction and management
 in spinal cord injury. *Respir Care*. Aug 2006;51(8):853-68;discussion 869-70.
- 552 14. Estenne M, De Troyer A. The effects of tetraplegia on chest wall statics. *Am Rev Respir*553 *Dis.* Jul 1986;134(1):121-4. doi:10.1164/arrd.1986.134.1.121
- 554 15. Hill AV, Long CNH, Lupton H. Muscular exercise, lactic acid, and the supply and utilization of oxygen. *Q J Med.* 1923;(16):135–171.
- 556 16. Howley ET, Bassett DR, Welch HG. Criteria for maximal oxygen uptake: review and 557 commentary. *Med Sci Sports Exerc*. Sep 1995;27(9):1292-301.
- Foole DC, Wilkerson DP, Jones AM. Validity of criteria for establishing maximal O2
 uptake during ramp exercise tests. *Eur J Appl Physiol*. Mar 2008;102(4):403-10.
 doi:10.1007/s00421-007-0596-3
- 18. Astorino TA, White AC, Dalleck LC. Supramaximal testing to confirm attainment of
 VO_{2max} in sedentary men and women. *Int J Sports Med.* Apr 2009;30(4):279-84. doi:10.1055/s0028-1104588
- Maher JL, Cowan RE. Comparison of 1- Versus 3-Minute Stage Duration During Arm
 Ergometry in Individuals With Spinal Cord Injury. *Arch Phys Med Rehabil*. 11
 2016;97(11):1895-1900. doi:10.1016/j.apmr.2016.04.020
- 567 20. Kouwijzer I, Valize M, Valent LJM, Grandjean Perrenod Comtesse P, van der Woude
 568 LHV, de Groot S. The influence of protocol design on the identification of ventilatory thresholds
 569 and the attainment of peak physiological responses during synchronous arm crank ergometry in
 570 able-bodied participants. *Eur J Appl Physiol*. Oct 2019;119(10):2275-2286. doi:10.1007/s00421571 019-04211-9
- 572 21. van de Port IG, Kwakkel G, Wittink H. Systematic review of cardiopulmonary exercise
 573 testing post stroke: Are we adhering to practice recommendations? *J Rehabil Med.* Nov
 574 2015;47(10):881-900. doi:10.2340/16501977-2031
- Jones LW, Eves ND, Haykowsky M, Joy AA, Douglas PS. Cardiorespiratory exercise
 testing in clinical oncology research: systematic review and practice recommendations. *Lancet Oncol.* Aug 2008;9(8):757-65. doi:10.1016/S1470-2045(08)70195-5
- 578 23. Eerden S, Dekker R, Hettinga FJ. Maximal and submaximal aerobic tests for wheelchair-579 dependent persons with spinal cord injury: a systematic review to summarize and identify useful 580 applications for clinical rehabilitation. *Disabil Rehabil*. Mar 2018;40(5):497-521.
- 581 doi:10.1080/09638288.2017.1287623
- 582 24. Hilary A, Lisa OM. Scoping Studies: Towards a Methodological Framework *Int J*583 *Social Research Methodology*. 2003;8(1):19-32.
- 584 25. Alrashidi AA, Balthazaar SJT, Currie KD, Nightingale TE, Krassioukov AV.
- 585 Associations between left ventricular structure and function with cardiorespiratory fitness and
- 586 body composition in individuals with cervical and upper thoracic spinal cord injury. *Spinal Cord*.
- 587 Dec 2020;doi:10.1038/s41393-020-00591-4

- 588 26. Akkurt H, Karapolat HU, Kirazli Y, Kose T. The effects of upper extremity aerobic
 589 exercise in patients with spinal cord injury: a randomized controlled study. *Eur J Phys Rehabil*590 *Med.* Apr 2017;53(2):219-227. doi:10.23736/S1973-9087.16.03804-1
- Alexeeva N, Sames C, Jacobs PL, et al. Comparison of training methods to improve
 walking in persons with chronic spinal cord injury: a randomized clinical trial. *J Spinal Cord Med.* 2011;34(4):362-79. doi:10.1179/2045772311Y.0000000018
- September 28. Ashley EA, Laskin JJ, Olenik LM, et al. Evidence of autonomic dysreflexia during
 functional electrical stimulation in individuals with spinal cord injuries. *Paraplegia*. September 1993;31(9):593-605. doi:10.1038/sc.1993.95
- Ser Cases. 2019;5:2. doi:10.1038/s41394O18-0145-9
- 30. Astorino TA, Bediamol N, Cotoia S, et al. Verification testing to confirm VO. J Spinal
 601 Cord Med. Jan 2018:1-8. doi:10.1080/10790268.2017.1422890
- Au JS, Sithamparapillai A, Currie KD, Krassioukov AV, MacDonald MJ, Hicks AL.
 Assessing Ventilatory Threshold in Individuals With Motor-Complete Spinal Cord Injury. *Arch Phys Med Rehabil.* Oct 2018;99(10):1991-1997. doi:10.1016/j.apmr.2018.05.015
- Au JS, Totosy DE Zepetnek JO, Macdonald MJ. Modeling Perceived Exertion during
 Graded Arm Cycling Exercise in Spinal Cord Injury. *Med Sci Sports Exerc.* 06 2017;49(6):11901196. doi:10.1249/MSS.00000000001203
- 60833.Barfield JP, Malone LA, Arbo C, Jung AP. Exercise intensity during wheelchair rugby609training. J Sports Sci. Feb 2010;28(4):389-98. doi:10.1080/02640410903508839
- 61034.Bar-On ZH, Nene AV. Relationship between heart rate and oxygen uptake in thoracic611level paraplegics. *Paraplegia*. Feb 1990;28(2):87-95. doi:10.1038/sc.1990.11
- 612 35. Beillot J, Carré F, Le Claire G, et al. Energy consumption of paraplegic locomotion using
 613 reciprocating gait orthosis. *Eur J Appl Physiol Occup Physiol*. 1996;73(3-4):376-81.
 614 doi:10.1007/BF02425502
- 615 36. Bongers CC, Eijsvogels TM, van Nes IJ, Hopman MT, Thijssen DH. Effects of Cooling
 616 During Exercise on Thermoregulatory Responses of Men With Paraplegia. *Phys Ther.* May
 617 2016;96(5):650-8. doi:10.2522/ptj.20150266
- 618 37. Brissot R, Gallien P, Le Bot MP, et al. Clinical experience with functional electrical
 619 stimulation-assisted gait with Parastep in spinal cord-injured patients. *Spine (Phila Pa 1976)*. Feb
 620 2000;25(4):501-8. doi:10.1097/00007632-200002150-00018
- 38. Brurok B, Tørhaug T, Karlsen T, Leivseth G, Helgerud J, Hoff J. Effect of lower
 extremity functional electrical stimulation pulsed isometric contractions on arm cycling peak
 oxygen uptake in spinal cord injured individuals. *J Rehabil Med.* Mar 2013;45(3):254-9.
 doi:10.2340/16501977-1098

- 625 39. Capodaglio P, Grilli C, Bazzini G. Tolerable exercise intensity in the early rehabilitation
- 626 of paraplegic patients. A preliminary study. *Spinal Cord*. Nov 1996;34(11):684-90.
- 627 doi:10.1038/sc.1996.124

628 40. Castle PC, Kularatne BP, Brewer J, et al. Partial heat acclimation of athletes with spinal
629 cord lesion. *Eur J Appl Physiol.* Jan 2013;113(1):109-15. doi:10.1007/s00421-012-2417-6

630 41. Cowan RE, Ginnity KL, Kressler J, Nash MS. Assessment of the talk test and rating of
631 perceived exertion for exercise intensity prescription in persons with paraplegia. *Top Spinal*632 *Cord Inj Rehabil.* 2012;18(3):212-9. doi:10.1310/sci1803-212

633 42. Cowan RE, Callahan MK, Nash MS. The 6-min push test is reliable and predicts low
634 fitness in spinal cord injury. *Med Sci Sports Exerc*. Oct 2012;44(10):1993-2000.
635 doi:10.1249/MSS.0b013e31825cb3b6

636 43. Currie KD, West CR, Hubli M, Gee CM, Krassioukov AV. Peak heart rates and
637 sympathetic function in tetraplegic nonathletes and athletes. *Med Sci Sports Exerc*. Jun
638 2015;47(6):1259-64. doi:10.1249/MSS.00000000000514

44. Davis GM, Servedio FJ, Glaser RM, Gupta SC, Suryaprasad AG. Cardiovascular
responses to arm cranking and FNS-induced leg exercise in paraplegics. *J Appl Physiol (1985)*.
Aug 1990;69(2):671-7. doi:10.1152/jappl.1990.69.2.671

642 45. Dawson B, Bridle J, Lockwood RJ. Thermoregulation of paraplegic and able bodied men
643 during prolonged exercise in hot and cool climates. *Paraplegia*. Dec 1994;32(12):860-70.
644 doi:10.1038/sc.1994.132

645 46. de Groot S, Postma K, van Vliet L, Timmermans R, Valent LJ. Mountain time trial in
646 handcycling: exercise intensity and predictors of race time in people with spinal cord injury.
647 Spinal Cord. Jun 2014;52(6):455-61. doi:10.1038/sc.2014.58

de Groot S, Hoekstra SP, Grandjean Perrenod Comtesse P, Kouwijzer I, Valent LJ.
Relationships between internal and external handcycle training load in people with spinal cord
injury training for the handbikebattle. *J Rehabil Med*. Feb 2018;50(3):261-268.
doi:10.2340/16501977-2316

de Groot PC, Hjeltnes N, Heijboer AC, Stal W, Birkeland K. Effect of training intensity
on physical capacity, lipid profile and insulin sensitivity in early rehabilitation of spinal cord
injured individuals. *Spinal Cord.* Dec 2003;41(12):673-9. doi:10.1038/sj.sc.3101534

de Groot S, Kouwijzer I, Valent LJM, van der Woude LHV, Nash MS, Cowan RE. Good
association between sprint power and aerobic peak power during asynchronuous arm-crank
exercise in people with spinal cord injury. *Disabil Rehabil*. Feb 2021;43(3):378-385.
doi:10.1080/09638288.2019.1625978

50. De Mello MT, Silva AC, Esteves AM, Tufik S. Reduction of periodic leg movement in
individuals with paraplegia following aerobic physical exercise. *Spinal Cord*. Dec
2002;40(12):646-9. doi:10.1038/sj.sc.3101381

- 51. Davis GBDRW. The relationship between a twelve minute wheelchair push test and
 VO_{2peak} in women wheelchair athletes. Overseas Publishers Association; 1997.
- 52. Escalona MJ, Brosseau R, Vermette M, et al. Cardiorespiratory demand and rate of
 perceived exertion during overground walking with a robotic exoskeleton in long-term manual
 wheelchair users with chronic spinal cord injury: A cross-sectional study. *Ann Phys Rehabil Med.* Jul 2018;61(4):215-223. doi:10.1016/j.rehab.2017.12.008
- 668 53. Farrow MT, Maher JL, Nightingale TE, Thompson D, Bilzon JLJ. A Single Bout of
- 669 Upper-Body Exercise Has No Effect on Postprandial Metabolism in Persons with Chronic
- 670 Paraplegia. Med Sci Sports Exerc. 05 2021;53(5):1041-1049.
- 671 doi:10.1249/MSS.000000000002561
- 54. Fenuta AM, Hicks AL. Metabolic demand and muscle activation during different forms
 of bodyweight supported locomotion in men with incomplete SCI. *Biomed Res Int.*2014;2014:632765. doi:10.1155/2014/632765
- 55. Frey GC, McCubbin JA, Dunn JM, Mazzeo RS. Plasma catecholamine and lactate
 relationship during graded exercise in men with spinal cord injury. *Med Sci Sports Exerc*. Apr
 1997;29(4):451-6. doi:10.1097/00005768-199704000-00005
- 56. Flandrois R, Grandmontagne M, Gerin H, Mayet MH, Jehl JL, Eyssette M. Aerobic
 performance capacity in paraplegic subjects. *Eur J Appl Physiol Occup Physiol*. 1986;55(6):6049. doi:10.1007/BF00423204
- 57. Flueck JL, Gallo A, Moelijker N, Bogdanov N, Bogdanova A, Perret C. Influence of
 Equimolar Doses of Beetroot Juice and Sodium Nitrate on Time Trial Performance in
 Handcycling. *Nutrients*. Jul 2019;11(7)doi:10.3390/nu11071642
- 58. Flueck JL, Liener M, Schaufelberger F, Krebs J, Perret C. Ergogenic Effects of Caffeine
 Consumption in a 3-min All-Out Arm Crank Test in Paraplegic and Tetraplegic Compared With
 Able-Bodied Individuals. *Int J Sport Nutr Exerc Metab.* Dec 2015;25(6):584-93.
 doi:10.1123/ijsnem.2015-0090
- 59. Fukuoka Y, Endo M, Kagawa H, Itoh M, Nakanishi R. Kinetics and steady-state of VO2
 responses to arm exercise in trained spinal cord injury humans. *Spinal Cord*. Dec
 2002;40(12):631-8. doi:10.1038/sj.sc.3101383
- 691 60. Fukuoka Y, Nakanishi R, Ueoka H, Kitano A, Takeshita K, Itoh M. Effects of wheelchair
 692 training on VO2 kinetics in the participants with spinal-cord injury. *Disabil Rehabil Assist*693 *Technol.* Jun 2006;1(3):167-74. doi:10.1080/17483100500506033
- 694 61. Gass EM, Harvey LA, Gass GC. Maximal physiological responses during arm cranking
 695 and treadmill wheelchair propulsion in T4-T6 paraplegic men. *Paraplegia*. May 1995;33(5):267696 70. doi:10.1038/sc.1995.60
- 697 62. Gee CM, Williams AM, Sheel AW, Eves ND, West CR. Respiratory muscle training in
 698 athletes with cervical spinal cord injury: effects on cardiopulmonary function and exercise
 699 capacity. *J Physiol.* 07 2019;597(14):3673-3685. doi:10.1113/JP277943

- 700 63. Martin Ginis KA, Úbeda-Colomer J, Alrashidi AA, et al. Construct validation of the
- leisure time physical activity questionnaire for people with SCI (LTPAQ-SCI). *Spinal Cord*. Oct
 2020;doi:10.1038/s41393-020-00562-9

64. Goll M, Wiedemann MS, Spitzenpfeil P. Metabolic Demand of Paralympic Alpine Skiing in Sit-Skiing Athletes. *J Sports Sci Med.* Dec 2015;14(4):819-24.

65. Gorman PH, Geigle PR, Chen K, York H, Scott W. Reliability and relatedness of peak
VO2 assessments during body weight supported treadmill training and arm cycle ergometry in
individuals with chronic motor incomplete spinal cord injury. *Spinal Cord.* Apr 2014;52(4):28791. doi:10.1038/sc.2014.6

66. Hagobian TA, Jacobs KA, Kiratli BJ, Friedlander AL. Foot cooling reduces exerciseinduced hyperthermia in men with spinal cord injury. *Med Sci Sports Exerc*. Mar
2004;36(3):411-7. doi:10.1249/01.mss.0000117133.75146.66

712 67. Hasnan N, Ektas N, Tanhoffer AI, et al. Exercise responses during functional electrical
713 stimulation cycling in individuals with spinal cord injury. *Med Sci Sports Exerc*. Jun
714 2013;45(6):1131-8. doi:10.1249/MSS.0b013e3182805d5a

68. Hetz SP, Latimer AE, Ginis KA. Activities of daily living performed by individuals with
SCI: relationships with physical fitness and leisure time physical activity. *Spinal Cord.* Jul
2009;47(7):550-4. doi:10.1038/sc.2008.160

69. Hoekstra F, van Nunen MP, Gerrits KH, Stolwijk-Swüste JM, Crins MH, Janssen TW.
Effect of robotic gait training on cardiorespiratory system in incomplete spinal cord injury. J *Rehabil Res Dev.* 2013;50(10):1411-22. doi:10.1682/JRRD.2012.10.0186

70. Holmlund T, Ekblom-Bak E, Franzén E, Hultling C, Wahman K. Intensity of physical
activity as a percentage of peak oxygen uptake, heart rate and Borg RPE in motor-complete paraand tetraplegia. *PLoS One.* 2019;14(12):e0222542. doi:10.1371/journal.pone.0222542

724 71. Hooker SP, Scremin AM, Mutton DL, Kunkel CF, Cagle G. Peak and submaximal
725 physiologic responses following electrical stimulation leg cycle ergometer training. *J Rehabil*726 *Res Dev.* Nov 1995;32(4):361-6.

- 727 72. Hopman MT, Dallmeijer AJ, Snoek G, van der Woude LH. The effect of training on
 728 cardiovascular responses to arm exercise in individuals with tetraplegia. *Eur J Appl Physiol*729 *Occup Physiol*. 1996;74(1-2):172-9. doi:10.1007/BF00376510
- 730 73. Hopman MT, Dueck C, Monroe M, Philips WT, Skinner JS. Limits to maximal
 731 performance in individuals with spinal cord injury. *Int J Sports Med.* Feb 1998;19(2):98-103.
 732 doi:10.1055/s-2007-971889
- 733 74. Hopman MT, Oeseburg B, Binkhorst RA. Cardiovascular responses in paraplegic 734 subjects during arm exercise. *Eur J Appl Physiol Occup Physiol*. 1992;65(1):73-8.
- 735 doi:10.1007/BF01466277

- 736 75. Hopman MT, Houtman S, Groothuis JT, Folgering HT. The effect of varied fractional 737 inspired oxygen on arm exercise performance in spinal cord injury and able-bodied persons.
- 738 Arch Phys Med Rehabil. Feb 2004;85(2):319-23. doi:10.1016/j.apmr.2003.02.001

739 76. Hutchinson MJ, Valentino SE, Totosy de Zepetnek JO, MacDonald MJ, Goosey-Tolfrey
740 VL. Perceptually regulated training does not influence the differentiated RPE response following
741 16-weeks of aerobic exercise in adults with spinal cord injury. *Appl Physiol Nutr Metab.* Jun

742 2019;doi:10.1139/apnm-2019-0062

743 77. Jacobs KA, Burns P, Kressler J, Nash MS. Heavy reliance on carbohydrate across a wide
744 range of exercise intensities during voluntary arm ergometry in persons with paraplegia. *J Spinal*745 *Cord Med.* Sep 2013;36(5):427-35. doi:10.1179/2045772313Y.0000000123

746 78. Jacobs PL, Johnson B, Mahoney ET. Physiologic responses to electrically assisted and
747 frame-supported standing in persons with paraplegia. *J Spinal Cord Med.* 2003;26(4):384-9.
748 doi:10.1080/10790268.2003.11753710

749 79. Jung W, Yamasaki M. Effect of pre-exercise carbohydrate ingestion on substrate 750 consumption in persons with spinal cord injury. *Spinal Cord.* Jun 2009;47(6):464-9.

751 doi:10.1038/sc.2008.140

Kim DI, Lee H, Lee BS, Kim J, Jeon JY. Effects of a 6-Week Indoor Hand-Bike Exercise
Program on Health and Fitness Levels in People With Spinal Cord Injury: A Randomized
Controlled Trial States Analy Plane Med Palachil New 2015 06((11) 2022 40 s1

- 754 Controlled Trial Study. Arch Phys Med Rehabil. Nov 2015;96(11):2033-40.e1.
- 755 doi:10.1016/j.apmr.2015.07.010
- 81. Klimešová I, Machová I, Jakubec A, Corkle J. Effect of caffeine on maximal oxygen
 uptake in wheelchair rugby players:

A randomized, placebo-controlled, double-blind study. *Acta Gymnica*. 2017;47(1): 16–23

- 759 82. Koontz AM, Garfunkel CE, Crytzer TM, Anthony SJ, Nindl BC. Feasibility,
- acceptability, and preliminary efficacy of a handcycling high-intensity interval training program
 for individuals with spinal cord injury. *Spinal Cord.* Jan 2021;59(1):34-43. doi:10.1038/s41393020-00548-7
- Kouwijzer I, Cowan RE, Maher JL, et al. Interrater and intrarater reliability of ventilatory
 thresholds determined in individuals with spinal cord injury. *Spinal Cord*. Aug 2019;57(8):669678. doi:10.1038/s41393-019-0262-8
- Kouwijzer I, Valent L, Osterthun R, van der Woude L, de Groot S, group H. Peak power
 output in handcycling of individuals with a chronic spinal cord injury: predictive modeling,
- validation and reference values. *Disabil Rehabil*. 02 2020;42(3):400-409.
- 769 doi:10.1080/09638288.2018.1501097
- 770 85. Lannem AM, Sørensen M, Lidal IB, Hjeltnes N. Perceptions of exercise mastery in

persons with complete and incomplete spinal cord injury. *Spinal Cord*. May 2010;48(5):388-92.
doi:10.1038/sc.2009.136

- 86. Laskin JJ, Ashley EA, Olenik LM, et al. Electrical stimulation-assisted rowing exercise in
- spinal cord injured people. A pilot study. *Paraplegia*. Aug 1993;31(8):534-41.
- 775 doi:10.1038/sc.1993.87
- 776 87. Lassau-Wray ER, Ward GR. Varying physiological response to arm-crank exercise in
- specific spinal injuries. J Physiol Anthropol Appl Human Sci. Jan 2000;19(1):5-12.
 doi:10.2114/jpa.19.5
- 88. Latimer AE, Ginis KA, Craven BC, Hicks AL. The physical activity recall assessment for
 people with spinal cord injury: validity. *Med Sci Sports Exerc*. Feb 2006;38(2):208-16.
- 781 doi:10.1249/01.mss.0000183851.94261.d2

89. Lovell D, Shields D, Beck B, Cuneo R, McLellan C. The aerobic performance of trained
and untrained handcyclists with spinal cord injury. *Eur J Appl Physiol*. Sep 2012;112(9):3431-7.
doi:10.1007/s00421-012-2324-x

- 90. Machač S, Radvanský J, Kolář P, Kříž J. Cardiovascular response to peak voluntary
 exercise in males with cervical spinal cord injury. *J Spinal Cord Med.* Jul 2016;39(4):412-20.
 doi:10.1080/10790268.2015.1126939
- Maher JL, Baunsgaard CB, van Gerven J, et al. Differences in Acute Metabolic
 Responses to Bionic and Nonbionic Ambulation in Spinal Cord Injured Humans and Controls. *Arch Phys Med Rehabil.* 01 2020;101(1):121-129. doi:10.1016/j.apmr.2019.07.014
- Manns PJ, McCubbin JA, Williams DP. Fitness, inflammation, and the metabolic
 syndrome in men with paraplegia. *Arch Phys Med Rehabil*. Jun 2005;86(6):1176-81.
 doi:10.1016/j.apmr.2004.11.020
- Manns PJ, Chad KE. Determining the relation between quality of life, handicap, fitness,
 and physical activity for persons with spinal cord injury. *Arch Phys Med Rehabil*. Dec
 1999;80(12):1566-71. doi:10.1016/s0003-9993(99)90331-3
- McLean KP, Jones PP, Skinner JS. Exercise prescription for sitting and supine exercise in
 subjects with quadriplegia. *Med Sci Sports Exerc.* Jan 1995;27(1):15-21.
- McLean KP, Skinner JS. Effect of body training position on outcomes of an aerobic
 training study on individuals with quadriplegia. *Arch Phys Med Rehabil*. Feb 1995;76(2):139-50.
 doi:10.1016/s0003-9993(95)80023-9
- McMillan DW, Kressler J, Jacobs KA, Nash MS. Substrate metabolism during recovery
 from circuit resistance exercise in persons with spinal cord injury. *Eur J Appl Physiol*. Jun
 2021;121(6):1631-1640. doi:10.1007/s00421-021-04629-0
- McMillan DW, Maher JL, Jacobs KA, Nash MS, Bilzon JLJ. Physiological responses to
 moderate intensity continuous and high-intensity interval exercise in persons with paraplegia. *Spinal Cord.* Jan 2021;59(1):26-33. doi:10.1038/s41393-020-0520-9
- 808 98. Morgan KA, Taylor KL, Tucker SM, Cade WT, Klaesner JW. Exercise testing protocol
 809 using a roller system for manual wheelchair users with spinal cord injury. *J Spinal Cord Med.* 05
 810 2019;42(3):288-297. doi:10.1080/10790268.2018.1443542

- 811 99. Murray D, Chin LMK, Cowan RE, Groah SL, Keyser RE. Recovery Off-Kinetics
- 812 Following Exhaustive Upper Body Exercise in Spinal Cord Injury. Top Spinal Cord Inj Rehabil.
- 813 2020;26(4):304-313. doi:10.46292/sci19-00060
- 814 100. Myers JN, Hsu L, Hadley D, Lee MY, Kiratli BJ. Post-exercise heart rate recovery in
- 815 individuals with spinal cord injury. *Spinal Cord*. Aug 2010;48(8):639-44.
- 816 doi:10.1038/sc.2009.196
- 817 101. Nightingale TE, Walhin JP, Thompson D, Bilzon JL. Biomarkers of cardiometabolic
- 818 health are associated with body composition characteristics but not physical activity in persons
- 819 with spinal cord injury. *J Spinal Cord Med.* Sep 2017:1-10.
- 820 doi:10.1080/10790268.2017.1368203
- 821 102. Nooijen CF, Post MW, Spooren AL, et al. Exercise self-efficacy and the relation with 822 physical behavior and physical capacity in wheelchair-dependent persons with subacute spinal
- cord injury. *J Neuroeng Rehabil*. Nov 2015;12:103. doi:10.1186/s12984-015-0099-0
- Nooijen CF, Stam HJ, Sluis T, Valent L, Twisk J, van den Berg-Emons RJ. A behavioral
 intervention promoting physical activity in people with subacute spinal cord injury: secondary
 effects on health, social participation and quality of life. *Clin Rehabil*. Jun 2017;31(6):772-780.
 doi:10.1177/0269215516657581
- 828 104. Nooijen CF, Vogels S, Bongers-Janssen HM, et al. Fatigue in persons with subacute
- spinal cord injury who are dependent on a manual wheelchair. Spinal Cord. Oct
- 830 2015;53(10):758-62. doi:10.1038/sc.2015.66
- 831 105. Ogonowska-Slodownik A, Geigle PR, Gorman PH, Slodownik R, Scott WH. Aquatic,
- 832 deep water peak VO. J Spinal Cord Med. 09 2019;42(5):631-638.
- 833 doi:10.1080/10790268.2018.1559494
- 834 106. Oviedo GR, Alamo JM, Niño-Mendez OA, et al. Physiological responses in males with
 835 and without spinal cord injury to recumbent synchronous
- versus seated asynchronous arm crank stress tests. *Retos.* 2021;39:565-571.
- 837 107. Pelletier CA, Totosy de Zepetnek JO, MacDonald MJ, Hicks AL. A 16-week randomized
- controlled trial evaluating the physical activity guidelines for adults with spinal cord injury. *Spinal Cord.* May 2015;53(5):363-7. doi:10.1038/sc.2014.167
- 840 108. Pelletier CA, Jones G, Latimer-Cheung AE, Warburton DE, Hicks AL. Aerobic capacity,
- 841 orthostatic tolerance, and exercise perceptions at discharge from inpatient spinal cord injury
- rehabilitation. Arch Phys Med Rehabil. Oct 2013;94(10):2013-9.
- 843 doi:10.1016/j.apmr.2013.05.011
- Phillips W, Burkett LN. Arm crank exercise with static leg FNS in persons with spinal
 cord injury. *Med Sci Sports Exerc*. Apr 1995;27(4):530-5.
- 846 110. Rodríguez-Gómez I, Martín-Manjarrés S, Martín-García M, et al. Cardiorespiratory
- fitness and arm bone mineral health in young males with spinal cord injury: the mediator role of
 lean mass. J Sports Sci. Apr 2019;37(7):717-725. doi:10.1080/02640414.2018.1522948

- 849 111. Schneider DA, Sedlock DA, Gass E, Gass G. VO2peak and the gas-exchange anaerobic
- threshold during incremental arm cranking in able-bodied and paraplegic men. *Eur J Appl Physiol Ocean Physiol* Sop 1000:80(4):202.7
- 851 *Physiol Occup Physiol*. Sep 1999;80(4):292-7.
- 852 112. Shaffer RF, Picard G, Taylor JA. Relationship of Spinal Cord Injury Level and Duration
- 853 to Peak Aerobic Capacity With Arms-Only and Hybrid Functional Electrical Stimulation
- 854 Rowing. *Am J Phys Med Rehabil*. 07 2018;97(7):488-491.
- 855 doi:10.1097/PHM.0000000000000903
- 856 113. Sutbeyaz ST, Koseoglu BF, Gokkaya NK. The combined effects of controlled breathing
- techniques and ventilatory and upper extremity muscle exercise on cardiopulmonary responses in
 patients with spinal cord injury. *Int J Rehabil Res.* Sep 2005;28(3):273-6.
- 859 doi:10.1097/00004356-200509000-00012
- 860 114. Steinberg LL, Lauro FA, Sposito MM, et al. Catecholamine response to exercise in
 861 individuals with different levels of paraplegia. *Braz J Med Biol Res.* Aug 2000;33(8):913-8.
 862 dai:10.1500/c0100.870:200000000007
- 862 doi:10.1590/s0100-879x200000800007
- 115. Taylor AW, McDonell E, Brassard L. The effects of an arm ergometer training
 programme on wheelchair subjects. *Paraplegia*. Apr 1986;24(2):105-14. doi:10.1038/sc.1986.14
- 116. Tosi AB, de Sousa JCS, de Moraes Forjaz CL, Torriani-Pasin C. Physiological responses
 during active video games in spinal cord injury: a preliminary study. *Physiother Theory Pract*.
 Dec 2020:1-8. doi:10.1080/09593985.2020.1852635
- 117. Totosy de Zepetnek JO, Au JS, Hol AT, Eng JJ, MacDonald MJ. Predicting peak oxygen
 uptake from submaximal exercise after spinal cord injury. *Appl Physiol Nutr Metab.* Jul
 2016;41(7):775-81. doi:10.1139/apnm-2015-0670
- 118. Valent LJ, Dallmeijer AJ, Houdijk H, et al. The individual relationship between heart rate
 and oxygen uptake in people with a tetraplegia during exercise. *Spinal Cord.* Jan
 2007;45(1):104-11. doi:10.1038/sj.sc.3101946
- 874 119. Valent LJ, Dallmeijer AJ, Houdijk H, et al. Effects of hand cycle training on physical
 875 capacity in individuals with tetraplegia: a clinical trial. *Phys Ther*. Oct 2009;89(10):1051-60.
 876 doi:10.2522/ptj.20080340
- Wang JS, Yang CF, Wong MK. Effect of strenuous arm crank exercise on platelet
 function in patients with spinal cord injury. *Arch Phys Med Rehabil*. Feb 2002;83(2):210-6.
 doi:10.1053/apmr.2002.28033
- Wecht JM, Marsico R, Weir JP, Spungen AM, Bauman WA, De Meersman RE.
 Autonomic recovery from peak arm exercise in fit and unfit individuals with paraplegia. *Med Sci Sports Exerc.* Jul 2006;38(7):1223-8. doi:10.1249/01.mss.0000227306.34149.ba
- West CR, Romer LM, Krassioukov A. Autonomic function and exercise performance in
 elite athletes with cervical spinal cord injury. *Med Sci Sports Exerc*. Feb 2013;45(2):261-7.
 doi:10.1249/MSS.0b013e31826f5099

- Williams AMM, Chisholm AE, Lynn A, Malik RN, Eginyan G, Lam T. Arm crank
 ergometer "spin" training improves seated balance and aerobic capacity in people with spinal
 cord injury. *Scand J Med Sci Sports*. Feb 2020;30(2):361-369. doi:10.1111/sms.13580
- Yamasaki M, Komura T, Tahara Y, et al. Peak oxygen uptake and respiratory function in
 persons with spinal cord injury. *Appl Human Sci.* Jan 1996;15(1):14-7. doi:10.2114/jpa.15.13
- 125. Zoeller RF, Riechman SE, Dabayebeh IM, Goss FL, Robertson RJ, Jacobs PL. Relation
 between muscular strength and cardiorespiratory fitness in people with thoracic-level paraplegia. *Arch Phys Med Rehabil.* Jul 2005;86(7):1441-6. doi:10.1016/j.apmr.2004.11.032
- Arabi H, Vandewalle H, Pitor P, de Lattre J, Monod H. Relationship between maximal
 oxygen uptake on different ergometers, lean arm volume and strength in paraplegic subjects. *Eur J Appl Physiol Occup Physiol*. 1997;76(2):122-7. doi:10.1007/s004210050223
- 897 127. Bakkum AJ, de Groot S, Stolwijk-Swüste JM, et al. Effects of hybrid cycling versus
 898 handcycling on wheelchair-specific fitness and physical activity in people with long-term spinal
 899 cord injury: a 16-week randomized controlled trial. *Spinal Cord.* May 2015;53(5):395-401.
- 900 doi:10.1038/sc.2014.237
- 901 128. Bernard PL, Mercier J, Varray A, Prefaut C. Influence of lesion level on the
 902 cardioventilatory adaptations in paraplegic wheelchair athletes during muscular exercise. *Spinal*903 *Cord.* Jan 2000;38(1):16-25.
- N. BY, S. BR, D. WG, Peter E, J. HL, D SR. Ventilatory Threshold During
 Wheelchair Exercise in Untrained and Endurance-Trained Subjects With Quadriplegia. *Adapted Physical Activity Quarterly*. 1995;12:333-343.
- 907 130. Bhambhani YN, Burnham RS, Wheeler GD, Eriksson P, Holland LJ, Steadward RD.
 908 Physiological correlates of simulated wheelchair racing in trained quadriplegics. *Can J Appl*909 *Physiol.* Mar 1995;20(1):65-77. doi:10.1139/h95-005
- 910 131. Bhambhani YN, Holland LJ, Eriksson P, Steadward RD. Physiological responses during
 911 wheelchair racing in quadriplegics and paraplegics. *Paraplegia*. Apr 1994;32(4):253-60.
 912 doi:10.1038/sc.1994.45
- 913 132. Bhambhani YN, Eriksson P, Steadward RD. Reliability of peak physiological responses
 914 during wheelchair ergometry in persons with spinal cord injury. *Arch Phys Med Rehabil*. Jul
 915 1991;72(8):559-62.
- 916 133. Bougenot MP, Tordi N, Betik AC, et al. Effects of a wheelchair ergometer training
 917 programme on spinal cord-injured persons. *Spinal Cord.* Aug 2003;41(8):451-6.
- 918 doi:10.1038/sj.sc.3101475
- 919 134. Campbell IG, Williams C, Lakomy HK. Physiological and metabolic responses of
- wheelchair athletes in different racing classes to prolonged exercise. *J Sports Sci.* May
 2004;22(5):449-56. doi:10.1080/02640410410001675298
- 135. Campbell IG, Williams C, Lakomy HK. Physiological responses of wheelchair athletes at
 percentages of top speed. *Br J Sports Med.* Mar 1997;31(1):36-40. doi:10.1136/bjsm.31.1.36
- 924 Carty A, McCormack K, Coughlan GF, Crowe L, Caulfield B. Increased aerobic fitness 136.
- 925 after neuromuscular electrical stimulation training in adults with spinal cord injury. Arch Phys 926 Med Rehabil. May 2012;93(5):790-5. doi:10.1016/j.apmr.2011.10.030
- 927 Cooper RA. The contribution of selected anthropometric and physiological variables to 137.
- 928 10K performance of wheelchair racers: a preliminary study. J Rehabil Res Dev. 1992;29(3):29-929 34. doi:10.1682/jrrd.1992.07.0029
- 930 Coutts KD, McKenzie DC. Ventilatory thresholds during wheelchair exercise in 138. 931 individuals with spinal cord injuries. Paraplegia. Jul 1995;33(7):419-22. doi:10.1038/sc.1995.85
- 932 139. Coutts KD, Stogryn JL. Aerobic and anaerobic power of Canadian wheelchair track 933 athletes. Med Sci Sports Exerc. Feb 1987;19(1):62-5.
- 934 140. Dallmeijer AJ, Zentgraaff ID, Zijp NI, van der Woude LH. Submaximal physical strain 935 and peak performance in handcycling versus handrim wheelchair propulsion. Spinal Cord. Feb 936 2004;42(2):91-8. doi:10.1038/sj.sc.3101566
- 937 Dallmeijer AJ, van der Woude LH. Health related functional status in men with spinal 141. 938 cord injury: relationship with lesion level and endurance capacity. Spinal Cord. Nov
- 939 2001;39(11):577-83. doi:10.1038/sj.sc.3101215
- 940 Dallmeijer AJ, Hopman MT, van As HH, van der Woude LH. Physical capacity and 142. 941 physical strain in persons with tetraplegia; the role of sport activity. Spinal Cord. Dec 942 1996;34(12):729-35. doi:10.1038/sc.1996.133
- 943 143. de Groot S, Adriaansen JJ, Tepper M, Snoek GJ, van der Woude LH, Post MW.
- 944 Metabolic syndrome in people with a long-standing spinal cord injury: associations with physical 945 activity and capacity. Appl Physiol Nutr Metab. Nov 2016;41(11):1190-1196. doi:10.1139/apnm-946 2016-0269
- 947 de Groot S, van der Scheer JW, Bakkum AJ, et al. Wheelchair-specific fitness of persons 144. 948 with a long-term spinal cord injury: cross-sectional study on effects of time since injury and
- 949 physical activity level. Disabil Rehabil. 2016;38(12):1180-6.
- 950 doi:10.3109/09638288.2015.1076072
- 951 145. de Groot S, van der Woude LH, Niezen A, Smit CA, Post MW. Evaluation of the
- 952 physical activity scale for individuals with physical disabilities in people with spinal cord injury. 953 Spinal Cord. Jul 2010;48(7):542-7. doi:10.1038/sc.2009.178
- 954 146. Gass EM, Gass GC. Thermoregulatory responses to repeated warm water immersion in 955 subjects who are paraplegic. Spinal Cord. Mar 2001;39(3):149-55. doi:10.1038/sj.sc.3101117
- 956 147. Gauthier C, Arel J, Brosseau R, Hicks AL, Gagnon DH. Reliability and minimal
- 957 detectable change of a new treadmill-based progressive workload incremental test to measure
- 958 cardiorespiratory fitness in manual wheelchair users. J Spinal Cord Med. 11 2017;40(6):759-767.
- 959 doi:10.1080/10790268.2017.1369213

- 960 148. Gorman PH, Scott W, York H, et al. Robotically assisted treadmill exercise training for
 961 improving peak fitness in chronic motor incomplete spinal cord injury: A randomized controlled
 962 trial. J Spinal Cord Med. 2016;39(1):32-44. doi:10.1179/2045772314Y.0000000281
- 963 149. Golding LA, Horvat MA, Beutel-Horvat T, McConnell TJ. A graded exercise test
 964 protocol for spinal cord injured individuals. *Journal of Cardiopulmonary Rehabilitation*.
- 965 1986;6(9):362-367.
- 966 150. Goss FL, McDermott A, Robertson RJ. Changes in peak oxygen uptake following
 967 computerized functional electrical stimulation in the spinal cord injured. *Res Q Exerc Sport*. Mar
 968 1992;63(1):76-9. doi:10.1080/02701367.1992.10607559
- 969 151. Grange CC, Bougenot MP, Groslambert A, Tordi N, Rouillon JD. Perceived exertion and
 970 rehabilitation with wheelchair ergometer: comparison between patients with spinal cord injury
 971 and healthy subjects. *Spinal Cord*. Oct 2002;40(10):513-8. doi:10.1038/sj.sc.3101353
- Haisma JA, Bussmann JB, Stam HJ, et al. Changes in physical capacity during and after
 inpatient rehabilitation in subjects with a spinal cord injury. *Arch Phys Med Rehabil*. Jun
 2006;87(6):741-8. doi:10.1016/j.apmr.2006.02.032
- 153. Hooker SP, Wells CL. Effects of low- and moderate-intensity training in spinal cordinjured persons. *Med Sci Sports Exerc*. Feb 1989;21(1):18-22. doi:10.1249/00005768198902000-00004
- 978 154. Janssen TW, Dallmeijer AJ, van der Woude LH. Physical capacity and race performance
 979 of handcycle users. *J Rehabil Res Dev.* 2001 Jan-Feb 2001;38(1):33-40.
- 155. Janssen TW, van Oers CA, Veeger HE, Hollander AP, van der Woude LH, Rozendal RH.
 Relationship between physical strain during standardised ADL tasks and physical capacity in
 men with spinal cord injuries. *Paraplegia*. Dec 1994;32(12):844-59. doi:10.1038/sc.1994.131
- Janssen TW, van Oers CA, Hollander AP, Veeger HE, van der Woude LH. Isometric
 strength, sprint power, and aerobic power in individuals with a spinal cord injury. *Med Sci Sports Exerc.* Jul 1993;25(7):863-70. doi:10.1249/00005768-199307000-00016
- 157. Kirby RL, de Groot S, Cowan RE. Relationship between wheelchair skills scores and
 peak aerobic exercise capacity of manual wheelchair users with spinal cord injury: a crosssectional study. *Disabil Rehabil*. 01 2020;42(1):114-121. doi:10.1080/09638288.2018.1493545
- 989 158. Kilkens OJ, Dallmeijer AJ, De Witte LP, Van Der Woude LH, Post MW. The
- 990 Wheelchair Circuit: Construct validity and responsiveness of a test to assess manual wheelchair
- mobility in persons with spinal cord injury. *Arch Phys Med Rehabil.* Mar 2004;85(3):424-31.
 doi:10.1016/j.apmr.2003.05.006
 - 993 159. Le Foll-de Moro D, Tordi N, Lonsdorfer E, Lonsdorfer J. Ventilation efficiency and
 - 994 pulmonary function after a wheelchair interval-training program in subjects with recent spinal
 - 995 cord injury. Arch Phys Med Rehabil. Aug 2005;86(8):1582-6. doi:10.1016/j.apmr.2005.03.018

160. Leicht CA, Griggs KE, Lavin J, Tolfrey K, Goosey-Tolfrey VL. Blood lactate and
ventilatory thresholds in wheelchair athletes with tetraplegia and paraplegia. *Eur J Appl Physiol*.
Aug 2014;114(8):1635-43. doi:10.1007/s00421-014-2886-x

161. Leving MT, de Groot S, Woldring FAB, Tepper M, Vegter RJK, van der Woude LHV.
Motor learning outcomes of handrim wheelchair propulsion during active spinal cord injury
rehabilitation in comparison with experienced wheelchair users. *Disabil Rehabil*. Oct 2019:1-14.
doi:10.1080/09638288.2019.1668484

1003 162. Litchke LG, Russian CJ, Lloyd LK, Schmidt EA, Price L, Walker JL. Effects of
1004 respiratory resistance training with a concurrent flow device on wheelchair athletes. *J Spinal*1005 *Cord Med.* 2008;31(1):65-71. doi:10.1080/10790268.2008.11753983

1006 163. Morgulec-Adamowicz N, Kosmol A, Molik B, Yilla AB, Laskin JJ. Aerobic, anaerobic,
1007 and skill performance with regard to classification in wheelchair rugby athletes. *Res Q Exerc*1008 *Sport*. Mar 2011;82(1):61-9. doi:10.1080/02701367.2011.10599722

1009 164. Nooijen CF, de Groot S, Postma K, et al. A more active lifestyle in persons with a recent
spinal cord injury benefits physical fitness and health. *Spinal Cord.* Apr 2012;50(4):320-3.
doi:10.1038/sc.2011.152

1012 165. Paulson TA, Bishop NC, Leicht CA, Goosey-Tolfrey VL. Perceived exertion as a tool to
1013 self-regulate exercise in individuals with tetraplegia. *Eur J Appl Physiol.* Jan 2013;113(1):201-9.
1014 doi:10.1007/s00421-012-2426-5

1015 166. Perret C, Wenger M, Leicht CA, Goosey-Tolfrey VL. Locomotor-Respiratory Coupling
1016 in Wheelchair Racing Athletes: A Pilot Study. *Front Physiol.* 2016;7:11.

1017 doi:10.3389/fphys.2016.00011

1018 167. Perret C, Labruyère R, Mueller G, Strupler M. Correlation of heart rate at lactate
1019 minimum and maximal lactate steady state in wheelchair-racing athletes. *Spinal Cord.* Jan
1020 2012;50(1):33-6. doi:10.1038/sc.2011.97

1021 168. Postma K, Haisma JA, de Groot S, et al. Changes in pulmonary function during the early
1022 years after inpatient rehabilitation in persons with spinal cord injury: a prospective cohort study.
1023 *Arch Phys Med Rehabil.* Aug 2013;94(8):1540-6. doi:10.1016/j.apmr.2013.02.006

- 1024 169. Qi L, Ferguson-Pell M, Salimi Z, Haennel R, Ramadi A. Wheelchair users' perceived
 1025 exertion during typical mobility activities. *Spinal Cord.* Sep 2015;53(9):687-91.
 1026 doi:10.1038/sc.2015.30
- 1027 170. Rimaud D, Calmels P, Pichot V, Bethoux F, Roche F. Effects of compression stockings
 1028 on sympathetic activity and heart rate variability in individuals with spinal cord injury. *J Spinal*1029 *Cord Med.* Mar 2012;35(2):81-8. doi:10.1179/2045772311Y.0000000054
- 1030 171. Rimaud D, Calmels P, Roche F, Mongold JJ, Trudeau F, Devillard X. Effects of

1031 graduated compression stockings on cardiovascular and metabolic responses to exercise and

1032 exercise recovery in persons with spinal cord injury. Arch Phys Med Rehabil. Jun

1033 2007;88(6):703-9. doi:10.1016/j.apmr.2007.03.023

- 1034 172. Tordi N, Dugue B, Klupzinski D, Rasseneur L, Rouillon JD, Lonsdorfer J. Interval 1035 training program on a wheelchair ergometer for paraplegic subjects. *Spinal Cord*. Oct
- 1036 2001;39(10):532-7. doi:10.1038/sj.sc.3101206

1037 173. Tørhaug T, Brurok B, Hoff J, Helgerud J, Leivseth G. The effect from maximal bench
1038 press strength training on work economy during wheelchair propulsion in men with spinal cord
1039 injury. *Spinal Cord*. Oct 2016;54(10):838-842. doi:10.1038/sc.2016.27

- 1040 174. Valent L, Dallmeijer A, Houdijk H, Slootman HJ, Janssen TW, Van Der Woude LH.
- 1041 Effects of hand cycle training on wheelchair capacity during clinical rehabilitation in persons 1042 with a spinal cord injury. *Disabil Rehabil*. 2010;32(26):2191-200.
- 1043 doi:10.3109/09638288.2010.509461
- 1044 175. Valent LJ, Dallmeijer AJ, Houdijk H, Slootman HJ, Post MW, van der Woude LH.
- 1045 Influence of hand cycling on physical capacity in the rehabilitation of persons with a spinal cord
- 1046 injury: a longitudinal cohort study. Arch Phys Med Rehabil. Jun 2008;89(6):1016-22.
- 1047 doi:10.1016/j.apmr.2007.10.034
- 1048 176. van der Scheer JW, de Groot S, Tepper M, et al. Low-intensity wheelchair training in
- inactive people with long-term spinal cord injury: A randomized controlled trial on fitness,
 wheelchair skill performance and physical activity levels. *J Rehabil Med.* Jan 2016;48(1):33-42.
- 1051 doi:10.2340/16501977-2037
- 1052 177. van Koppenhagen CF, de Groot S, Post MW, et al. Wheelchair exercise capacity in spinal
 1053 cord injury up to five years after discharge from inpatient rehabilitation. *J Rehabil Med.* Jul
 1054 2013;45(7):646-52. doi:10.2340/16501977-1149
- 1055 178. van Velzen JM, de Groot S, Post MW, Slootman JH, van Bennekom CA, van der Woude
 1056 LH. Return to work after spinal cord injury: is it related to wheelchair capacity at discharge from
 1057 clinical rehabilitation? *Am J Phys Med Rehabil.* Jan 2009;88(1):47-56.
- 1058 doi:10.1097/PHM.0b013e31818e6140
- 1059 179. Veeger HE, Hadj Yahmed M, van der Woude LH, Charpentier P. Peak oxygen uptake
 1060 and maximal power output of Olympic wheelchair-dependent athletes. *Med Sci Sports Exerc*.
 1061 Oct 1991;23(10):1201-9.
- 1062 180. Vinet A, Le Gallais D, Bernard PL, et al. Aerobic metabolism and cardioventilatory
 1063 responses in paraplegic athletes during an incremental wheelchair exercise. *Eur J Appl Physiol*1064 *Occup Physiol*. 1997;76(5):455-61. doi:10.1007/s004210050275
- 1065 181. West CR, Goosey-Tolfrey VL, Campbell IG, Romer LM. Effect of abdominal binding on
 1066 respiratory mechanics during exercise in athletes with cervical spinal cord injury. *J Appl Physiol*1067 (1985). Jul 2014;117(1):36-45. doi:10.1152/japplphysiol.00218.2014
- 1068 182. Zacharakis ED, Kounalakis SN, Nassis GP, Geladas ND. Cardiovascular drift in trained
 1069 paraplegic and able-bodied individuals during prolonged wheelchair exercise: effect of fluid
- 1070 replacement. *Appl Physiol Nutr Metab.* Apr 2013;38(4):375-81. doi:10.1139/apnm-2012-0131

- 1071 183. Abilmona SM, Gorgey AS. Associations of the trunk skeletal musculature and dietary
- intake to biomarkers of cardiometabolic health after spinal cord injury. *Clin Physiol Funct Imaging*. Feb 2018;doi:10.1111/cpf.12505
- 1074 184. Bhambhani Y, Tuchak C, Burnham R, Jeon J, Maikala R. Quadriceps muscle
- deoxygenation during functional electrical stimulation in adults with spinal cord injury. *Spinal Cord.* Oct 2000;38(10):630-8. doi:10.1038/sj.sc.3101079
- 1077 185. Brazg G, Fahey M, Holleran CL, et al. Effects of Training Intensity on Locomotor
- 1078 Performance in Individuals With Chronic Spinal Cord Injury: A Randomized Crossover Study.
- 1079 Neurorehabil Neural Repair. 2017 Oct-Nov 2017;31(10-11):944-954.
- 1080 doi:10.1177/1545968317731538
- 1081 186. Brurok B, Helgerud J, Karlsen T, Leivseth G, Hoff J. Effect of aerobic high-intensity
 1082 hybrid training on stroke volume and peak oxygen consumption in men with spinal cord injury.
 1083 Am J Phys Med Rehabil. May 2011;90(5):407-14. doi:10.1097/PHM.0b013e31820f960f
- 1084 187. Berry HR, Perret C, Saunders BA, et al. Cardiorespiratory and power adaptations to
 stimulated cycle training in paraplegia. *Med Sci Sports Exerc*. Sep 2008;40(9):1573-80.
 doi:10.1249/MSS.0b013e318176b2f4
- 1087 188. DiPiro ND, Embry AE, Fritz SL, Middleton A, Krause JS, Gregory CM. Effects of
 aerobic exercise training on fitness and walking-related outcomes in ambulatory individuals with
 chronic incomplete spinal cord injury. *Spinal Cord.* Sep 2016;54(9):675-81.
 doi:10.1038/sc.2015.212
- 1091 189. Forbes SC, Chilibeck PD, Craven B, Bhambhani Y. Comparison of a double poling
 1092 ergometer and field test for elite cross country sit skiers. *N Am J Sports Phys Ther.* Jun
 1093 2010;5(2):40-6.
- 1094 190. Gayle GW, Pohlman RL, Glaser RM, Davis GM. Cardiorespiratory and perceptual
 1095 responses to arm crank and wheelchair exercise using various handrims in male paraplegics. *Res*1096 *Q Exerc Sport*. Sep 1990;61(3):224-32. doi:10.1080/02701367.1990.10608683
- 1097 191. Gurney AB, Robergs RA, Aisenbrey J, Cordova JC, McClanahan L. Detraining from
 1098 total body exercise ergometry in individuals with spinal cord injury. *Spinal Cord.* Nov
 1099 1998;36(11):782-9. doi:10.1038/sj.sc.3100698
- Holm NJ, Biering-Sørensen F, Schou LH, Møller T. The test-retest reliability of
 individualized VO. *Spinal Cord.* Jan 2021;59(1):82-91. doi:10.1038/s41393-020-00540-1
- 1102 193. Jack LP, Purcell M, Allan DB, Hunt KJ. Comparison of peak cardiopulmonary
 1103 performance parameters during robotics-assisted treadmill exercise and arm crank ergometry in
 1104 incomplete spinal cord injury. *Technol Health Care*. 2010;18(4-5):285-96. doi:10.3233/THC1105 2010-0591
- 1106 194. Jacobs PL, Klose KJ, Guest R, Needham-Shropshire B, Broton JG, Green BA.
- 1107 Relationships of oxygen uptake, heart rate, and ratings of perceived exertion in persons with
- 1108 paraplegia during functional neuromuscular stimulation assisted ambulation. Spinal Cord. May
- 1109 1997;35(5):292-8. doi:10.1038/sj.sc.3100435

- 1110195.Janssen TW, Pringle DD. Effects of modified electrical stimulation-induced leg cycle1111ergometer training for individuals with spinal cord injury. J Rehabil Res Dev. 2008;45(6):819-
- 1112 30. doi:10.1682/jrrd.2007.09.0153
- 1113 196. Jung DW, Park DS, Lee BS, Kim M. Development of a motor driven rowing machine 1114 with automatic functional electrical stimulation controller for individuals with paraplegia; a 1115 preliminary study. *Ann Rehabil Med.* Jun 2012;36(3):379-85. doi:10.5535/arm.2012.36.3.379
- 1116 197. Leech KA, Hornby TG. High-Intensity Locomotor Exercise Increases Brain-Derived
 1117 Neurotrophic Factor in Individuals with Incomplete Spinal Cord Injury. *J Neurotrauma*. 03
- 1118 2017;34(6):1240-1248. doi:10.1089/neu.2016.4532
- 1119 198. Leech KA, Kinnaird CR, Hornby TG. Effects of serotonergic medications on locomotor
 1120 performance in humans with incomplete spinal cord injury. *J Neurotrauma*. Aug
 1121 2014;31(15):1334-42. doi:10.1089/neu.2013.3206
- 1122 199. Lundgaard E, Wouda MF, Strøm V. A comparative study of two protocols for treadmill
 1123 walking exercise testing in ambulating subjects with incomplete spinal cord injury. *Spinal Cord*.
 1124 Oct 2017;55(10):935-939. doi:10.1038/sc.2017.34
- 1125 200. Martel G, Noreau L, Jobin J. Physiological responses to maximal exercise on arm
 1126 cranking and wheelchair ergometer with paraplegics. *Paraplegia*. Sep 1991;29(7):447-56.
 1127 doi:10.1038/sc.1991.61
- 1128 201. McConnell TJ, Horvat MA, Beutel-Horvat TA, Golding LA. Arm crank versus
 1129 wheelchair treadmill ergometry to evaluate the performance of paraplegics. *Paraplegia*. Aug
 1130 1989;27(4):307-13. doi:10.1038/sc.1989.46
- 1131 202. Mercier HW, Picard G, Taylor JA, Vivodtzev I. Gains in aerobic capacity with wholebody functional electrical stimulation row training and generalization to arms-only exercise after
 spinal cord injury. *Spinal Cord.* Jan 2021;59(1):74-81. doi:10.1038/s41393-020-0527-2
- 1134 203. Mutton DL, Scremin AM, Barstow TJ, Scott MD, Kunkel CF, Cagle TG. Physiologic
- 1135 responses during functional electrical stimulation leg cycling and hybrid exercise in spinal cord
- 1136 injured subjects. Arch Phys Med Rehabil. Jul 1997;78(7):712-8. doi:10.1016/s0003-
- 1137 9993(97)90078-2
- 1138 204. Paulson TA, Bishop NC, Smith BM, Goosey-Tolfrey VL. Inflammation-mediating
- 1139 cytokine response to acute handcycling exercise with/without functional electrical stimulation-
- 1140 evoked lower-limb cycling. J Rehabil Res Dev. 2014;51(4):645-54.
- 1141 doi:10.1682/JRRD.2013.08.0184
- 1142 205. Perret C, Berry H, Hunt KJ, Grant S, Kakebeeke TH. Determination and possible
- application of the aerobic gas exchange threshold in aerobically untrained paraplegic subjects
- based on stimulated cycle ergometry. *Disabil Rehabil*. 2009;31(17):1432-6.
- 1145 doi:10.1080/09638280802621424
- 1146 206. Price MJ, Campbell IG. Thermoregulatory and physiological responses of wheelchair 1147 athletes to produce and wheelchair eventies. Int I Sports Med. Oct 1000-20(7):457
- athletes to prolonged arm crank and wheelchair exercise. *Int J Sports Med.* Oct 1999;20(7):45763. doi:10.1055/s-1999-8831

- 1149 207. Qiu S, Alzhab S, Picard G, Taylor JA. Ventilation Limits Aerobic Capacity after
- 1150 Functional Electrical Stimulation Row Training in High Spinal Cord Injury. Med Sci Sports
- 1151 Exerc. 06 2016;48(6):1111-8. doi:10.1249/MSS.00000000000880
- 1152 208. Taylor JA, Picard G, Porter A, Morse LR, Pronovost MF, Deley G. Hybrid functional
- 1153 electrical stimulation exercise training alters the relationship between spinal cord injury level and
- aerobic capacity. Arch Phys Med Rehabil. Nov 2014;95(11):2172-9.
- 1155 doi:10.1016/j.apmr.2014.07.412
- 1156 209. Taylor JA, Picard G, Widrick JJ. Aerobic capacity with hybrid FES rowing in spinal cord
 1157 injury: comparison with arms-only exercise and preliminary findings with regular training. *PM*1158 *R*. Sep 2011;3(9):817-24. doi:10.1016/j.pmrj.2011.03.020
- 1159 210. Theisen D, Fornusek C, Raymond J, Davis GM. External power output changes during 1160 prolonged cycling with electrical stimulation. *J Rehabil Med*. Jul 2002;34(4):171-5.
- 1161 doi:10.1080/16501970213238
- 1162 211. Tørhaug T, Brurok B, Hoff J, Helgerud J, Leivseth G. Arm Cycling Combined with
- Passive Leg Cycling Enhances VO. *Top Spinal Cord Inj Rehabil*. 2018;24(1):86-95.doi:10.1310/sci17-00029
- 1165 212. Tørhaug T, Brurok B, Hoff J, Helgerud J, Leivseth G. Arm Crank and Wheelchair
- 1166 Ergometry Produce Similar Peak Oxygen Uptake but Different Work Economy Values in
- 1167 Individuals with Spinal Cord Injury. *Biomed Res Int.* 2016;2016:5481843.
- 1168 doi:10.1155/2016/5481843
- 1169 213. Verellen J, Theisen D, Vanlandewijck Y. Influence of crank rate in hand cycling. *Med Sci*1170 *Sports Exerc.* Oct 2004;36(10):1826-31. doi:10.1249/01.mss.0000142367.04918.5a
- 1171 214. Verellen J, Vanlandewijck Y, Andrews B, Wheeler GD. Cardiorespiratory responses
- 1172 during arm ergometry, functional electrical stimulation cycling, and two hybrid exercise
- conditions in spinal cord injured. *Disabil Rehabil Assist Technol*. Mar 2007;2(2):127-32.
 doi:10.1080/09638280600765712
- 1175 215. Vivodtzev I, Picard G, Cepeda FX, Taylor JA. Acute Ventilatory Support During Whole-
- 1176 Body Hybrid Rowing in Patients With High-Level Spinal Cord Injury: A Randomized
- 1177 Controlled Crossover Trial. *Chest.* May 2020;157(5):1230-1240.
- 1178 doi:10.1016/j.chest.2019.10.044
- 1179 216. Vivodtzev I, Picard G, O'Connor K, Taylor JA. Serotonin 1A agonist and
- cardiopulmonary improvements with whole-body exercise in acute, high-level spinal cord injury:
 a retrospective analysis. *Eur J Appl Physiol*. Feb 2021;121(2):453-463. doi:10.1007/s00421-020-
- 1182 04536-w
- 1183 217. Wilbanks SR, Rogers R, Pool S, Bickel CS. Effects of functional electrical stimulation
 1184 assisted rowing on aerobic fitness and shoulder pain in manual wheelchair users with spinal cord
- 1185 injury. J Spinal Cord Med. 11 2016;39(6):645-654. doi:10.1179/2045772315Y.000000052
- 1186 218. Wouda MF, Lundgaard E, Becker F, Strøm V. Effects of moderate- and high-intensity
 1187 aerobic training program in ambulatory subjects with incomplete spinal cord injury-a

- 1188 randomized controlled trial. *Spinal Cord.* Oct 2018;56(10):955-963. doi:10.1038/s41393-0181189 0140-9
- 219. Wouda MF, Wejden L, Lundgaard E, Strøm V. Energetic and cardiovascular responses to
 treadmill walking and stationary cycling in subjects with incomplete spinal cord injury. *Spinal Cord.* Jan 2016;54(1):51-6. doi:10.1038/sc.2015.120
- Wouda MF, Lundgaard E, Becker F, Strøm V. Changes in cardiorespiratory fitness and
 activity levels over the first year after discharge in ambulatory persons with recent incomplete
 spinal cord injury. *Spinal Cord*. Mar 2021;59(3):354-360. doi:10.1038/s41393-020-0514-7
- 1196 221. Krassioukov AV, Currie KD, Hubli M, et al. Effects of exercise interventions on
 1197 cardiovascular health in individuals with chronic, motor complete spinal cord injury: protocol for
 1198 a randomised controlled trial [Cardiovascular Health/Outcomes: Improvements Created by
 1199 Exercise and education in SCI (CHOICES) Study]. *BMJ Open.* Jan 2019;9(1):e023540.
 1200 doi:10.1136/bmjopen-2018-023540
- 1201 222. Alrashidi AA, Nightingale TE, Currie KD, et al. Exercise Improves Cardiorespiratory
 1202 Fitness, but Not Arterial Health, after Spinal Cord Injury: The CHOICES Trial. *J Neurotrauma*.
 11 01 2021;38(21):3020-3029. doi:10.1089/neu.2021.0071
- Astorino TA. Alterations in VOmax and the VO plateau with manipulation of sampling
 interval. *Clin Physiol Funct Imaging*. Jan 2009;29(1):60-7. doi:10.1111/j.1475097X.2008.00835.x
- 1207 224. Smart NA, Jeffriess L, Giallauria F, et al. Effect of duration of data averaging interval on
 1208 reported peak VO2 in patients with heart failure. *Int J Cardiol.* Mar 2015;182:530-3.
 1209 doi:10.1016/j.ijcard.2014.12.174
- 1210 225. Balady GJ, Arena R, Sietsema K, et al. Clinician's Guide to cardiopulmonary exercise
 1211 testing in adults: a scientific statement from the American Heart Association. *Circulation*. Jul
 1212 2010;122(2):191-225. doi:10.1161/CIR.0b013e3181e52e69
- 1213 226. Myers J, Walsh D, Sullivan M, Froelicher V. Effect of sampling on variability and
 1214 plateau in oxygen uptake. *J Appl Physiol (1985)*. Jan 1990;68(1):404-10.
- 1215 doi:10.1152/jappl.1990.68.1.404
- 1216 227. Martin-Rincon MLC, Jose. Progress Update and Challenges on VO_{2max} Testing and
 1217 Interpretation. *Frontiers in Physiology*. 2020;11doi:<u>https://doi.org/10.3389/fphys.2020.01070</u>
- 1218 228. Matthews JI, Bush BA, Morales FM. Microprocessor exercise physiology systems vs a
 1219 nonautomated system. A comparison of data output. *Chest*. Oct 1987;92(4):696-703.
 1220 doi:10.1378/chest.92.4.696
- 1221 229. Johnson JS, Carlson JJ, VanderLaan RL, Langholz DE. Effects of sampling interval on
 - peak oxygen consumption in patients evaluated for heart transplantation. *Chest.* Mar
 1223 1998;113(3):816-9. doi:10.1378/chest.113.3.816
 - 1224 230. Martin-Rincon M, González-Henríquez JJ, Losa-Reyna J, et al. Impact of data averaging 1225 strategies on VO. *Scand J Med Sci Sports*. Oct 2019;29(10):1473-1488. doi:10.1111/sms.13495

- 1226 231. Janssen TW, Dallmeijer AJ, Veeger DJ, van der Woude LH. Normative values and
- determinants of physical capacity in individuals with spinal cord injury. *J Rehabil Res Dev.* 2002
 Jan-Feb 2002;39(1):29-39.
- 1229 232. Simmons OL, Kressler J, Nash MS. Reference fitness values in the untrained spinal cord
- 1230 injury population. Arch Phys Med Rehabil. Dec 2014;95(12):2272-8.
- 1231 doi:10.1016/j.apmr.2014.06.015
- 1232 233. Rossiter HB, Kowalchuk JM, Whipp BJ. A test to establish maximum O2 uptake despite
 1233 no plateau in the O2 uptake response to ramp incremental exercise. *J Appl Physiol (1985)*. Mar
 1234 2006;100(3):764-70. doi:10.1152/japplphysiol.00932.2005
- 1235 234. Duncan GE, Howley ET, Johnson BN. Applicability of VO2max criteria: discontinuous
 1236 versus continuous protocols. *Med Sci Sports Exerc*. Feb 1997;29(2):273-8.
 1237 doi:10.1097/00005768-199702000-00017
- 1238 235. Wagner J, Niemeyer M, Infanger D, et al. New Data-based Cutoffs for Maximal Exercise
 1239 Criteria across the Lifespan. *Med Sci Sports Exerc.* 09 2020;52(9):1915-1923.
- 1240 doi:10.1249/MSS.00000000002344
- 1241 236. Wood RE, Hills AP, Hunter GR, King NA, Byrne NM. Vo2max in overweight and obese
 1242 adults: do they meet the threshold criteria? *Med Sci Sports Exerc*. Mar 2010;42(3):470-7.
 1243 doi:10.1249/MSS.0b013e3181b666ad
- 1244 237. Lucía A, Rabadán M, Hoyos J, et al. Frequency of the VO2max plateau phenomenon in
 1245 world-class cyclists. *Int J Sports Med.* Dec 2006;27(12):984-92. doi:10.1055/s-2006-923833
- 1246 238. Leicht CA, Tolfrey K, Lenton JP, Bishop NC, Goosey-Tolfrey VL. The verification
 1247 phase and reliability of physiological parameters in peak testing of elite wheelchair athletes. *Eur*1248 *J Appl Physiol.* Feb 2013;113(2):337-45. doi:10.1007/s00421-012-2441-6
- 1249 239. Thomson AC, Ramos JS, Fassett RG, Coombes JS, Dalleck LC. Optimal criteria and
 1250 sampling interval to detect a VO2 plateau at VO2max in patients with metabolic syndrome. *Res*1251 *Sports Med.* 2015;23(4):337-50. doi:10.1080/15438627.2015.1076411
- 1252 240. Astorino TA, Robergs RA, Ghiasv F, Marks D. Incidence of the oxygen plateau at
 1253 VO_{2max} during exercise testing to volitional fatigue. *Journal of Exercise Physiology*. 2000;3(4)
- 1254 241. Astorino TA, Harness ET. Substrate metabolism during exercise in the spinal cord
 1255 injured. *Eur J Appl Physiol.* May 2009;106(2):187-93. doi:10.1007/s00421-009-1005-x
- 1256 242. Shea JR, Shay BL, Leiter J, Cowley KC. Energy Expenditure as a Function of Activity
 1257 Level After Spinal Cord Injury: The Need for Tetraplegia-Specific Energy Balance Guidelines.
 1258 Front Physiol. 2018;9:1286. doi:10.3389/fphys.2018.01286
- 1259 243. Niekamp K, Zavorsky GS, Fontana L, McDaniel JL, Villareal DT, Weiss EP. Systemic
- acid load from the diet affects maximal-exercise RER. Med Sci Sports Exerc. Apr
- 1261 2012;44(4):709-15. doi:10.1249/MSS.0b013e3182366f6c

- 1262 244. Edvardsen E, Hem E, Anderssen SA. End criteria for reaching maximal oxygen uptake 1263 must be strict and adjusted to sex and age: a cross-sectional study. *PLoS One*. 2014;9(1):e85276.
- doi:10.1371/journal.pone.0085276
- 1265 245. Krassioukov A, West C. The role of autonomic function on sport performance in athletes
 1266 with spinal cord injury. *PM R*. Aug 2014;6(8 Suppl):S58-65. doi:10.1016/j.pmrj.2014.05.023
- 1267 246. Hopman MT, Monroe M, Dueck C, Phillips WT, Skinner JS. Blood redistribution and
 1268 circulatory responses to submaximal arm exercise in persons with spinal cord injury. *Scand J*1269 *Rehabil Med.* Sep 1998;30(3):167-74. doi:10.1080/003655098444101
- 1270 247. Schmid A, Huonker M, Barturen JM, et al. Catecholamines, heart rate, and oxygen
 1271 uptake during exercise in persons with spinal cord injury. *J Appl Physiol (1985)*. Aug
 1272 1998;85(2):635-41. doi:10.1152/jappl.1998.85.2.635
- 1273 248. Eston RG, Faulkner JA, Mason EA, Parfitt G. The validity of predicting maximal oxygen
 1274 uptake from perceptually regulated graded exercise tests of different durations. *Eur J Appl*1275 *Physiol.* Jul 2006;97(5):535-41. doi:10.1007/s00421-006-0213-x
- 1276 249. Eston RG, Lamb KL, Parfitt G, King N. The validity of predicting maximal oxygen
 1277 uptake from a perceptually-regulated graded exercise test. *Eur J Appl Physiol*. Jun
 1278 2005;94(3):221-7. doi:10.1007/s00421-005-1327-2
- 1279 250. van Drongelen S, de Groot S, Veeger HE, et al. Upper extremity musculoskeletal pain
 1280 during and after rehabilitation in wheelchair-using persons with a spinal cord injury. *Spinal*1281 *Cord.* Mar 2006;44(3):152-9. doi:10.1038/sj.sc.3101826
- 1282 251. Nash MS, van de Ven I, van Elk N, Johnson BM. Effects of circuit resistance training on
 1283 fitness attributes and upper-extremity pain in middle-aged men with paraplegia. *Arch Phys Med*1284 *Rehabil.* Jan 2007;88(1):70-5. doi:10.1016/j.apmr.2006.10.003
- 1285 252. Hutchinson MJ, Goosey-Tolfrey VL. Rethinking aerobic exercise intensity prescription
 1286 in adults with spinal cord injury: time to end the use of "moderate to vigorous" intensity? *Spinal*1287 *Cord.* Dec 08 2021;doi:10.1038/s41393-021-00733-2
- 1288 253. Armstrong RB, Laughlin MH. Metabolic indicators of fibre recruitment in mammalian
 1289 muscles during locomotion. *J Exp Biol.* Mar 1985;115:201-13.
- 1290 254. Hawkins MN, Raven PB, Snell PG, Stray-Gundersen J, Levine BD. Maximal oxygen
 1291 uptake as a parametric measure of cardiorespiratory capacity. *Med Sci Sports Exerc*. Jan
 1292 2007;39(1):103-7. doi:10.1249/01.mss.0000241641.75101.64
- 1293 255. Midgley AW, McNaughton LR, Carroll S. Verification phase as a useful tool in the
 1294 determination of the maximal oxygen uptake of distance runners. *Appl Physiol Nutr Metab*. Oct
 1295 2006;31(5):541-8. doi:10.1139/h06-023
- 1296 256. Smith PM, Doherty M, Drake D, Price MJ. The influence of step and ramp type protocols
 1297 on the attainment of peak physiological responses during arm crank ergometry. *Int J Sports Med.*1298 Nov 2004;25(8):616-21. doi:10.1055/s-2004-817880

- 1299 Compliance with Ethical Standards
- 1300
- 1301 Data availability: The data sets that were collected and analyzed for the purpose of this study1302 are available from the corresponding author upon a reasonable request.
- 1303 **Ethical Approval:** Not applicable for the scoping review. The CHOICES trial: CPET was
- 1304 conducted after the ethical approval of the University of British Columbia (H12-02945-11).
- 1305 Author Contributions: AA and TN were responsible for conceptualizing the review idea and
- 1306 performing data analyses. Material preparation and data collection were performed by AA, TN,
- 1307 GB, and VBB. The first draft of the manuscript was written by AA and all authors commented
- 1308 on previous versions of the manuscript. AK is the principal investigator for the CHOICES trial.
- 1309 All authors read and approved the final manuscript.
- 1310
- 1311 Suppliers:
- 1312 a. Microsoft Corp, Redmond, USA.
- 1313 b. Lode BV, Groningen, The Netherlands
- 1314 c. Parvomedics Truemax 2400, Sandy, UT, USA.
- 1315 d. T31; Polar Electro Inc., Woodbury, NY, USA.
- 1316 f. Statistical Package for the Social Sciences (SPSS), version 25; IBM Corporation, Armonk,
- 1317 USA.
- 1318
- 1319
- 1320
- 1321
- 1322

1323 Figure Legends:

- 1324 **Fig 1** Literature flow diagram representing study identification, review, and selection process.
- 1325 Records excluded studies were SCI participants < 80% of the sample, poster or conference
- 1326 proceedings, non-original. [†] Peak oxygen uptake (VO_{2peak}).
- 1327 Fig 2 Number of publications per year. This figure represents the included articles over time and
- 1328 highlights the increase of publications in the last ten years, with 46% of these published recently
- 1329 (i.e., during or after 2017).
- 1330 Fig 3 Bland-Altman plots. Bland-Altman depicting absolute bias and 95% limit of agreement
- 1331 (LoA) of different averaging strategies relative to the 30-sec criterion. Dotted line represent
- 1332 mean bias and dashed lines represent the upper and lower 95% LoA.
- 1333 Fig 4 Equivalence testing. All averaging strategies are depicted relative to the 30-sec criterion,
- 1334 showing as the mean and 90% confidence intervals. The area between the two dashed lines
- 1335 represents $\pm 10\%$ of the 30-sec (i.e., a proposed equivalence zone). None of the averaging
- 1336 strategies fall within the proposed equivalence zone, which indicates that these averaging
- 1337 strategies deemed not equivalent to 30-sec averaging strategy.

	<i>n (%)</i> or weighted mean \pm SD
Total participants	4,860
Age, years	37 ± 6
Time since injury, years	9 ± 5
Sex	
Male	3,704 (83)
Female	781 (17)
Mixed*	4 studies
Did not report	6 studies
Neurological level of injury	
Tetraplegia	1,489 (37)
Paraplegia	2,567 (63)
Mixed*	18 studies
Injury severity	
Complete	2,503(69)
Incomplete	1,105 (31)
Mixed*	11 studies
Different tool**	13 studies
Did not report	27 studies

Table 1 Characteristics of participants reported within the included studies (n = 197)

* Mixed means that the characteristics (i.e., sex, neurological level of injury, and injury severity) were not distinctly reported. Weighted means were reported for continuous variables (i.e., age and time since injury) and calculated to

account for differences in sample size between studies as follows: $\sum n^* \overline{x} / \sum n$, where \sum and n were the sum and number of participants in each study, respectively

and $\overline{\mathbf{x}}$ = mean age or time since injury.

** Other than American Spinal Injury Association Impairment Scaledetermined by International Standard for Neurological Classification of Spinal Cord Injury.

Criterion	Frequency (%)
Plateau, <i>n</i> =30	
$\dot{V}O_{2peak} < 2.0 \text{ (mL/kg/min)}$	2 (7%)
$\dot{VO}_{2peak} < 2.1 \text{ (mL/kg/min)}$	1 (3%)
$\dot{V}O_{2peak} < 150 (mL/min)$	2 (7%)
Unspecified	25 (83%)
RER, <i>n</i> =55	
1.00	11 (20%)
1.05	6 (11%)
1.10	30 (54%)
1.15	8 (15%)
RPE, <i>n</i> =24	
15	4 (17%)
16	1 (4%)
17	12 (50%)
18	2 (8%)
19	5 (21%)
HR, <i>n</i> =29	
85% APMHR (220-age)	6 (21%)
95% APMHR (220-age)	4 (14%)
Other	16 (55%)
Unspecified	3 (10%)
Lactate level, <i>n</i> =14	
5 mmol/L	1 (7%)
7 mmol/L	5 (36%)
8 mmol/L	5 (36%)
9, 10 mmol/L	1 each (7%)
>50 mg/dL*	1 (7%)
Verification test, n=3	5-10 W higher (33%), 1 stage higher
	(33%), 105% higher (33%)

Table 2 Common $\dot{V}O_{2peak}$ end-point criteria reported within the included studies

Abbreviations: APMHR, age-predicted maximal heart rate; HR, heart rate; RER, respiratory exchange ratio; RPE, rate of perceived exertion;

^VO_{2peak}, peak oxygen uptake; W, watts. ^{*}Equal to 5.55 mmol/L.

Fig 1





Years

- 1 Title: Post-processing of peak oxygen uptake data obtained during cardiopulmonary exercise
- 2 testing in individuals with spinal cord injury: A scoping review and analysis of different post-
- 3 processing strategies

4 Supplementary file

6

5 **Appendix 1** Example of a search strategy

#	Searches	Results
Sea	rch keywords for spinal cord injury	
1	tetrapleg*.mp.	10390
2	parapleg*.mp.	54624
3	quadripleg*.mp.	28777
4	spinal cord injur\$.mp.	115169
5	spinal cord lesion*.mp.	11612
6	spinal cord transection*.mp.	3210
7	spinal cord impair*.mp.	221
8	spinal injur*.mp.	21219
9	spinal lesion*.mp.	4411
10	spinal transection*.mp.	1614
11	spinal impairm*.mp.	58
12	brown-sequard syndrome.mp.	1513
13	central cord.mp.	1077
14	myelitis.mp.	17262
15	spinal cord diseas*.mp.	28458
16	myelopath*.mp.	32787
17	spinal paraly*.mp.	554
18	hemipleg*.mp.	39444
19	syringomy* mp	11027
20	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or	299341
	15 or 16 or 17 or 18 or 19	277541
Sea	rch keywords for exercise/fitness	
21	exercise*.mp.	890673
22	aerobic exercise*.mp.	30817
23	exercise condition*.mp.	3085
24	exercise prescription*.mp.	5323
25	exercise therap*.mp.	47160
26	exercise train*.mp.	40975
27	physical activit*.mp.	320696
28	sport*.mp.	245779
29	strength train*.mp.	12596
30	resistance train*.mp.	34189
31	endurance exercise*.mp.	10161
32	endurance train*.mp.	18024
33	interval train*.mp.	7209
34	activity level.mp.	29251
35	neuromuscular electrical stimulation*.mp.	3583
36	functional electrical stimulation*.mp.	6349
37	power output*.mp.	17348
38	cardiorespiratory fitness mp	13449

	Characteristics		Post-processing strategies		
Paper		VO _{2peak} criteria	VO _{2peak} epoch used	PPO identification	
ACE					
Alrashidi et al, 2020 ²⁵	<i>n</i> (female): 32 (8) Age (yrs): $M\pm SD$; (39 \pm 11) TSI: (yrs): <i>Median (IQR)</i> ; 9 (18) NLI: range; C4-T6 Completeness: AIS A and B	NR	20-sec	NR	
Akkurt et al, 2017 ²⁶	n (female): 33 (4) Age (yrs): range; (15-62) TSI: (yrs): range; (2-144 months) NLI: range; C5-L5 Completeness: AIS A-E Training status: NR	NR	30-sec	NR	
Alexeeva et al, 2011 ²⁷	n (female): 35 (5) Age (yrs): range; (19-63) TSI: (yrs): range; (1-37) NLI: range; C3-T10 Completeness: AIS C and D Training status: NR	NR	10-sec	NR	
Ashley et al, 1993 ²⁸	n (female): 10 (3) Age (yrs): range; (18-40) TSI: (yrs): range; (3-20) NLI: range; C3-T5 Completeness: complete and incomplete Training status: NR	NR	15-sec	NR	
Astorino et al, 2019 ²⁹	n (female): 5 (0) Age (yrs): M±SD; (42±16) TSI: (yrs): M±SD; (10±8) NLI: range; C5-T10 Completeness: complete and incomplete Training status: Habitually active	NR	15-sec	Intensity coincident with exhaustion	
Astorino et al, 2018 ³⁰	n (female): 10 (1) Age (yrs): M±SD; (33±11) TSI: (yrs): M±SD; (7±6) NLI: range; >C2 Completeness: complete and incomplete Training status: Habitually active	Verification testing	15-sec	NR	
Au et al, 2018 ³¹	<i>n</i> (female): 38 (11) Age (yrs): $M \pm SD$; (42 \pm 10) TSI: (yrs): >1 NLI: range; (C4-T6) Completeness: AIS A and B Training status: NR	NR	20-sec	NR	
Au et al, 2017 ³²	n (female): 36 (3) Age (yrs): M±SD; (41±12) TSI: (yrs): M±SD; (13±10) NLI: range; (C1-T11) Completeness: AIS A-D	NR	30-sec	NR	

7 Appendix 2 Study characteristics of 197 included intervention studies

	Characteristics	żo · ·	Post-processing strategies	
Paper		VO _{2peak} criteria	VO _{2peak} epoch used	PPO identification
	Training status: recreationally active			
Barfield et al, 2010 ³³	<i>n</i> (female): 9 (0) Age (yrs): $M \pm SD$: (33±8) TSI: (yrs): $M \pm SD$: (12±7) NLI: range; (C5-C7) Completeness: all complete except one Training status: competitive wheelchair rugby	NR	5-sec	NR
Bar-On et al, 1990 ³⁴	n (female): 44 (4) Age (yrs): range; (15-46) TSI: (yrs): range; (?->10) NLI: range; (T3-T10) Completeness: all complete Training status: rehabilitated	NR	15-sec	NR
Beillot et al, 1996 ³⁵	n (female): 14 (1) Age (yrs): range; (19-42) TSI: (yrs): range; (4-77 months) NLI: range; (T2-T12) Completeness: NR Training status: NR	NR	30-sec	NR
Bongers et al, 2016 ³⁶	<i>n</i> (female): 10 (0) Age (yrs): $M\pm SD$: (44±11) TSI: (yrs): $M\pm SD$: (17±8) NLI: range; (T4-L1) Completeness: AIS A and B Training status: NR	NR	30-sec	Highest workload maintained for >30s
Brissot et al, 2000 ³⁷	<i>n</i> (female): 15 (4) Age (yrs): $M \pm SD$: (28 \pm 9) TSI: $M \pm SD$: (53 \pm 59 months) NLI: range; (T3-T11) Completeness: complete and incomplete (Frankel A-C) Training status: NR	NR	30-sec	NR
Brurok et al, 2013 ³⁸	n (female): 15 (2) Age (yrs): M±SD: (35±12, 44±13) TSI: (yrs): M±SD: (13±11, 14±12) NLI: range; (C4-T5, T8-T12) Completeness: AIS A Training status: NR	2 of: RER \geq 1.05, RPE \geq 15, Lactate \geq 7mmol/L	3 consecutive 10-sec	Highest power maintained for last 60s
Capodaglio et al, 1996 ³⁹	<i>n</i> (female): 8 (0) Age (yrs): <i>M</i> ; (31) TSI: $M \pm SD$ (3 months) NLI: range; (T6-T8) Completeness: All complete Training status: NR	NR	30-sec	NR
Castle et al, 2013 ⁴⁰	<i>n</i> (female): 5 (2) Age (yrs): $M \pm SD$: (40±2) TSI: (yrs): M ; (3.2 months) NLI: range; (C5-T10) Completeness: All complete	NR	15-sec	NR

n		**•	Post-processing strategies		
raper	Characteristics	VO _{2peak} criteria	VO _{2peak} epoch used	PPO identification	
	Training status: Paralympic athletes				
Cowan et al, 2012 ⁴¹	n (female): 12 (3) Age (yrs): M±SD: (29±7) TSI: (yrs): M±SD: (13±7) NLI: range; (T3-L1) Completeness: All complete Training status: Untrained	NR	30-sec	NR	
Cowan et al, 2012 ⁴²	n (female): 40 (6) Age (yrs): $M \pm SD$: (34 \pm 10) TSI: (yrs): $M \pm SD$: (13 \pm 10) NLI: range; (C6-T11) Completeness: NR Training status: untrained	NR	30-sec	NR	
Currie et al, 2015 ⁴³	n (female): 21 (0) Age (yrs): $M \pm SD$: (47 \pm 9, 37 \pm 8) TSI: (yrs): $M \pm SD$: (16 \pm 9,16 \pm 6) NLI: range; (C4-C8) Completeness: All AIS A except 2 B Training status: Athletes and untrained	NR	20-sec	NR	
Davis et al, 1990 ⁴⁴	n (female): 12 (0) Age (yrs): $M \pm SD$; (26 \pm 5) TSI: $M \pm SD$; (91 \pm 32,69 \pm 12 months) NLI: range; (T5-L2) Completeness: NR Training status: NR	NR	30-sec	NR	
Dawson et al, 1994 ⁴⁵	n (female): 10 (0) Age (yrs): M±SD; (25±3.7,26±3) TSI: (yrs): NR NLI: range; (T12-L3) Completeness: All incomplete except 1 Training status: Athletes	NR	30-sec	NR	
de Groot et al, 2018 ⁴⁷	n (female): 10 (0) Age (yrs): M±SD; (40±12) TSI: (yrs): NR NLI: range; (T4-L2) Completeness: All complete except 4 Training status: Trained for 12 weeks	NR	30-sec	NR	
de Groot et al, 2014 ⁴⁶	n (female): 40 (8) Age (yrs): range; (19-62) TSI: (yrs): range; (1-29) NLI: range; (C6-L3) Completeness: range; (AIS A-D) Training status: Recreational handcycling	NR	30-sec	Highest PO maintained for at least 30s	
de Groot et al, 2003 ⁴⁸	n (female): 11 (3) Age (yrs): $M \pm SD$; (36 \pm 13) TSI: (yrs): $M \pm SD$; (116 \pm 77 days) NLI: range; (C5-L1) Completeness: range; (AIS A-D) Training status: Athletes	NR	30-sec	NR	

	Characteristics		Post-processing strategies		
Paper		VO _{2peak} criteria	ὑO _{2peak} epoch used	PPO identification	
De Groot et al, 2021 ⁴⁹	<i>n</i> (female): 93 (12) Age (yrs): $M\pm SD$; (38 \pm 12) TSI: (yrs): $M\pm SD$; (12 \pm 10) NLI: tetraplegia and paraplegia Completeness: NR	NR	30-sec	Maintained for 30 seconds	
De Mello et al, 2007 ⁵⁰	<i>n</i> (female): 12 (0) Age (yrs): $M\pm SD$; (32 \pm 8) TSI: (yrs): Chronic NLI: range; (T7-T12) Completeness: All AIS A Training status: NR	NR	20-sec	NR	
Dwyer et al, 997 ⁵¹	n (female): 13 (13) Age (yrs): M±SD; (27±6) TSI: (yrs): Chronic NLI: NR Completeness: range; (BBC Scale Class 1- 3) Training status: National athletes	RER ≥ 1.1	5 breath mean	NR	
scalona et al, 018 ⁵²	n (female): 13 (5) Age (yrs): range; (27-63) TSI: (yrs): range; (0.8-31) NLI: range; (C6-T10) Completeness: All AIS A except 1 B Training status: NR	Any of: $RPE \ge 8$, RER ≥ 1.1	10-sec	NR	
Farrow et al, 2021 ⁵³	<i>n</i> (female): 10 (2) Age (yrs): $M \pm SD$; (49 \pm 10) TSI: (yrs): $M \pm SD$; (22 \pm 13) NLI: range; (T3-T12) Completeness: AIS A and B Training status: PAL 1 5 \pm 0 17	RER≥1.1, RPE≥19, and HR≥95% (220- age)	15 breath rolling	Achieved before termination	
⁷ enuta et al, 2014) ⁵⁴	<i>n</i> (female): 7 (0) Age (yrs): $M\pm SD$; (43±4) TSI: (yrs): $M\pm SD$; (4±0.6) NLI: range; tetraplegia and paraplegia Completeness: AIS C-D	NR	30-sec	NR	
Frey et al, 1997 ⁵⁵	I raining status: NR n (female): 7 (0) Age (yrs): $M\pm SD$; (30±3, 28±4) TSI: (yrs): range; (9-20) NLI: range; (C7-T12) Completeness: range; (Frankel scale A-C) Training status: Competitive athletes and recreationally active	NR	20-sec	NR	
Flandrois et al, 1986 ⁵⁶	n (female): 9 (0) Age (yrs): M±SD; (38±3) TSI: (yrs): NR NLI: range; (T4-L2) Completeness: NR Training status: Participate in sport event (5-10 hrs/week)	Plateau, maximal HR related to age, RER ≥1.05, lactate ≥9 mmol/l	30-sec	NR	

_	Characteristics		Post-processing strategies	
Paper		VO _{2peak} criteria	ὑO _{2peak} epoch used	PPO identification
Flueck et al, 2019 ⁵⁷	n (female): 8 (0) Age (yrs): M±SD; (40±11) TSI: (yrs): NR NLI: range; (C6-L4) Completeness: NR Training status: Paracyclists	NR	15-sec	NR
Flueck et al, 2015 ⁵⁸	n (female): 17 (0) Age (yrs): range; (22-65) TSI: (yrs): range; (3-45) NLI: range; (C5-L4) Completeness: All AIS A Training status: Physically active (4-6.5 hrs/week)	NR	15-sec	NR
Fukuoka et al, 2002 ⁵⁹	n (female): 9 (1) Age (yrs): M±SD; (35±3) TSI: M±SD; (176±37 months) NLI: range; (T6-L1) Completeness: Complete and Incomplete Training status: Physically active (2 hrs/day, 3 days/week)	RPM≥40, RER >1.05)	30-sec	Highest obtained
Fukuoka et al, 2006 ⁶⁰	n (female): 8 (1) Age (yrs): M±SD; (46±8) TSI: (yrs): Chronic NLI: range; (T7-L1) Completeness: AIS B Training status: Not performing regular exercise	RER>1.1, HR within 90% of predicted HRmax	30-sec	NR
Gass et al, 1995 ⁶¹	n (female): 9 (0) Age (yrs): M±SD; (31±2) TSI: (yrs): >3 NLI: range; (T4-T6) Completeness: All complete Training status: Inactive to active (ADL- daily strenuous exercise)	NR	20-sec	NR
Gee et al, 2019 ⁶²	n (female): 6 (1) Age (yrs): M±SD; (33±5) TSI: 157±63 months NLI: Cervical Completeness: NR Training status: Wheelchair rugby athletes			
Ginis et al, 2020 ⁶³	<i>n</i> (female): 39 (10) Age (yrs): $M \pm SD$; (42±10) TSI: $M \pm SD$; 13±11 years NLI: C4-T6 Completeness: AIS A and B Training status: community (used LTPA)	RER>1.0	20-sec	Maintained for 30 seconds
Goll et al, 2015 ⁶⁴	n (female): 6 (2) Age (yrs): $M\pm SD$; (31 \pm 2) TSI: (yrs): $M\pm SD$; (9 \pm 3) NLI: NR Completeness: NR	NR	30-sec	NR

_	Characteristics		Post-processing strategies		
Paper		VO _{2peak} criteria	[.] VO _{2peak} epoch used	PPO identification	
	Training status: National athletes				
Gorman et al, 2014 ⁶⁵	<i>n</i> (female): 21 (2) Age (yrs): $M \pm SD$; (51 \pm 14) TSI: $M \pm SD$; (129 \pm 150 months) NLI: C1-Lumbar Completeness: AIS C, D Training status: NR	NR	20-sec	NR	
Hagobian et al, 2004 ⁶⁶	n (female): 6 (0) Age (yrs): M±SD; (43±4) TSI: (yrs): >5 NLI: range; (C5-T5) Completeness: NR Training status: NR	NR	30-sec	NR	
Hasnan et al, 2013 ⁶⁷	<i>n</i> (female): 9 (0) Age (yrs): $M \pm SD$: (39 \pm 11) TSI: (yrs): $M \pm SD$: (11 \pm 10) NLI: range; (C2-T12) Completeness: Complete and incomplete Training status: \leq C5	NR	30-sec	Power attained during last 60s	
Hetz et al, 2009 ⁶⁸	n (female): 48 (0) Age (yrs): M±SD: (41±1) TSI: (yrs): M±SD: (7±0.4) NLI: range; (C2-T12) Completeness: A-C Training status: NR	Both: RER ≥1.00, self reported "heavy intensity"	30-sec	PO associated with $\dot{V}O_{2max}$	
Hoekstra et al, 2013 ⁶⁹	<i>n</i> (female): 10 (6) Age (yrs): $M \pm SD$: (49 \pm 14) TSI: (yrs): range; (<1-35) NLI: range; (C3-L2) Completeness: C-D Training status: NR	NR	20-sec	NR	
Holmlund et al, 2019 ⁷⁰	<i>n</i> (female): 63 (17) Age (yrs): $M \pm SD$: (42 \pm 134) TSI: (yrs): $M \pm SD$ (15 \pm 13) NLI: range; (C5-C8 and T7-T12) Completeness: AIS A-B Training status: NR	Plateau, RER>1.1, and RPE>16	10-sec	NR	
Hooker et al, 1995 ⁷¹	n (female): 8 (0) Age (yrs): $M \pm SD$: (36 \pm 5) TSI: (yrs): $M \pm SD$: (10 \pm 4) NLI: range; (C5-L1) Completeness: Frankel class A Training status: inactive	NR	15-sec	NR	
Hopman et al, 1996 ⁷²	<i>n</i> (female): 21 (3) Age (yrs): $M \pm SD$: (32 \pm 12, 26.6 \pm 6, 36 \pm 10) TSI: (yrs): $M \pm SD$: (8.1 \pm 10, 7 \pm 5, 10 \pm 4) NLI: range; (C4-C8) Completeness: All complete except 4 Training status: trained, untrained, and sedentary	NR	30-sec	Highest PO maintained >1min	

			Post-processing strategies		
Paper	Characteristics	VO _{2peak} criteria	VO_{2peak} epoch used	PPO identification	
Hopman et al, 1998 ⁷³	<i>n</i> (female): 9 (0) Age (yrs): $M\pm SD$: (34 \pm 9, 28 \pm 7) TSI: (yrs): $M\pm SD$: (11.4 \pm 8, 7 \pm 5) NLI: range; (C5-T12) Completeness: All but one was complete Training status: low-moderately trained	NR	20-sec	Mean of last 60s	
Hopman et al, 1992 ⁷⁴	n (female): 11 (0) Age (yrs): M±SD: (29±8) TSI: (yrs): range; >4 NLI: range; (T6-T12) Completeness: All complete Training status: trained	2 of: HR >170bpm, RER>1.00, base excess < 10mmol/L	30-sec	NR	
Hopman et al, 2004 ⁷⁵	n (female): 12 (0) Age (yrs): M±SD; (29±5) TSI: (yrs): chronic (<2 yesrs) NLI: range; (C4-T12)) Completeness: Mixed using AIS Training status: NR	2 of: HR >170bpm, RER>1.00, base excess < 10mEq/L	30-sec	NR	
Hutchinson et al, 2019 ⁷⁶	n (female): 19 (?) Age (yrs): $M\pm SD$: (41±11) TSI: (yrs): $M\pm SD$: (12±10) NLI: range; (C3-T11) Completeness: AIS A, B, C Training status: 39±45 min/day (PARA-SCI)	NR	15 breath rolling	NR	
lacobs et al, 2013 ⁷⁷	n (female): 10 (0) Age (yrs): $M \pm SD$: (45 \pm 10) TSI: (yrs): $M \pm SD$: (15.1 \pm 9) NLI: range; (T4-T12) Completeness: AIS A-B Training status: NR	2 of: RER ≥ 1.10, plateau, volitional exhaustion	60-sec	NR	
facobs et al, 2003 ⁷⁸	n (female): 15 (2) Age (yrs): $M\pm SD$: (28 \pm 7) TSI: (yrs): $M\pm SD$: (4 \pm 3) NLI: range; (T6-T11) Completeness: NR Training status: NR	NR	15-sec	NR	
Jung et al, 2009 ⁷⁹	<i>n</i> (female): 6 (0) Age (yrs): $M \pm SD$: (46 \pm 7) TSI: (yrs): $M \pm SD$: (20 \pm 6.) NLI: range; (T3-L1) Completeness: NR Training status: Physically active	NR	30-sec	NR	
Kim et al, 2015 ⁸⁰	n (female): 15 (6) Age (yrs): M±SD: (33±5) TSI: >6 months NLI: range; (T5-T11) Completeness: range; (AIS A-B) Training status: Physically active	2 of: RER >1.15, RPE 19-20, HR (200-age)	5-sec	NR	

_

Daman	Channestonistics	VO_{2peak} criteria	Post-processing strategies		
Paper	Characteristics		VO _{2peak} epoch used	PPO identification	
Klimesova et al, 2017 ⁸¹	<i>n</i> (female): 7 (0) Age (yrs): $M\pm SD$: (28±5.42) TSI: (yrs): range; (4-16.5) NLI: range; (C4-T1) Completeness: All complete Training status: Elite athletes	NR	30-sec	NR	
Koontz et al, 2021 ⁸²	<i>n</i> (female): 10 (3) Age (yrs): $M\pm SD$: (39 \pm 14) TSI: (yrs): $M\pm SD$: (12 \pm 11) NLI: range; (C2-S1) Completeness: 8 incomplete, 2 complete Training status: NR	RER>1.1 and RPE≥15	20-sec	NR	
Kouwijzer et al, 2019 ⁸³	<i>n</i> (female): 33 (5) Age (yrs): $M\pm SD$: (4±6) TSI: (yrs): $M\pm SD$: (19±6) NLI: Tetraplegia and paraplegia Completeness: NR Training status: Trained at least once a week	NR	15 breath rolling	Last completed workload plus half times the workload for any 3-sec block in the non-completed step	
Kouwijzer et al, 2020 ⁸⁴	<i>n</i> (female): 128 (22) Age (yrs): $M\pm SD$: (39±12) TSI: (yrs): $M\pm SD$: (10±10) NLI: above and below T6, 10 were spina bifida Completeness: complete an incomplete Training status: Handcycling classification (H1-H5)	NR	30-sec	Highest maintained for at least 30 sec.	
Lannem et al, 2010 ⁸⁵	n (female): 116 (19) Age (yrs): M±SD: (48±8, 48±13) TSI: (yrs): M±SD: (29±5, 18±8) NLI: NR Completeness: range; (AIS A-B, D) Training status: range; (Exercise <1x/week->1x/week)	NR	15-sec	NR	
Laskin et al, 1993 ⁸⁶	<i>n</i> (female): 8 (1) Age (yrs): $M\pm SD$: (28 \pm 4) TSI: (yrs): $M\pm SD$: (8 \pm 6) NLI: range; (C6-T1) Completeness: NR Training status: NR	NR	15-sec	NR	
Lassau-Wray et al, 1993 ⁸⁷	n (female): 20 (0) Age (yrs): M±SD: (32±3, 30±1, 33±4, 28±3) TSI: (yrs): >1 NLI: range; (C4-T12) Completeness: NR Training status: NR	All of: plateau, RER >1.1	10-sec	NR	
Latimer et al, 2006 ⁸⁸	n (female): 73 (21) Age (yrs): M±SD: (39±11.) TSI: (yrs): M±SD: (11.27±10) NLI: 37 tetraplegia, 36 paraplegia	RER >1.0, self- reported heavy intensity	30-sec	Power output corresponding to VO _{2peak}	

			Post-processing strategies		
Paper	Characteristics	VO _{2peak} criteria	[.] VO _{2peak} epoch used	PPO identification	
Lovell et al, 2012 ⁸⁹	Completeness: Complete and incomplete Training status: NR n (female): 20 (0) Age (yrs): $M\pm SD$: (41±8, 37±6) TSI: (yrs): $M\pm SD$: (17±13, 9±4) NLI: range; (T4-L5) Completeness: NR Training status: Trained hand cyclists,	All of: RER >1.15, HR within 10bpm of predicted MHR, lactate >8mmol/L	Last 60-sec	Power output corresponding to VO _{2peak}	
Machač et al, 2016 ⁹⁰	some untrained but physically active n (female): 47 (0), 20 SCI Age (yrs): $M \pm SD$: (31 \pm 5) TSI: (yrs): $M \pm SD$: (8 \pm 5) NLI: range; (C5-C7) Completeness: range; (AIS A-B, 1 C) Training status: 420 m/week of physical activity for SCI group	NR	30-sec	NR	
Maher et al, 2016 ¹⁹	n (female): 38 (16) Age (yrs): M±SD: (37±1) TSI: (yrs): M±SD: (12±9) NLI: range; (C5-C8, T1-L2) Completeness: NR Training status: NR	NR	20-sec	Highest workload maintained for ≥30s	
Maher et al, 2020 ⁹¹	n (female): 10 (0) Age (yrs): $M \pm SD$: (33 \pm 111) TSI: (yrs): $M \pm SD$: (24 \pm 8) NLI: range; (C7-L1) Completeness: AIS A, B, C Training status: NR	NR	20-sec	NR	
Manns et al, 2005 ⁹²	n (female): 22 (0) Age (yrs): M±SD: (39±9) TSI: (yrs): M±SD: (17±9) NLI: range; (T2-L2) Completeness: All complete Training status: 88.7±80.6 (arbitrary units)	NR	20-sec	NR	
Manns et al, 1999 ⁹³	n (female): 38 (10) Age (yrs): $M\pm SD$: (35.9 \pm 9.3) TSI: (yrs): $M\pm SD$: (12.8 \pm 7.3,15.8 \pm 7.4) NLI: Tetraplegia and paraplegia Completeness: NR Training status: 32.1 \pm 19.4; 55.5 \pm 30.8 (units not specified)	All of: plateau, RER >1.0, reported exhaustion	20-sec	NR	
McLean et al, 1995 ⁹⁴	<i>n</i> (female): 11 (1) Age (yrs): $M \pm SD$: (29 \pm 6) TSI: (yrs): $M \pm SD$: (10 \pm 76) NLI: 6 above C7, 5 C7 and below Completeness: All complete Training status: NR	NR	30-sec (mean of last 3)	NR	
McLean et al, 1995 ⁹⁵	n (female): 14 (NR) Age (yrs): <i>M</i> ± <i>SD</i> : (34.3±12.1, 33.3±7) TSI: (yrs): <i>M</i> ± <i>SD</i> : (9.3±12.5, 14.1±6.4)	NR	20-sec	NR	

Paper	Characteristics	VO2mask criteria	rost-processing strategies	
			VO _{2peak} epoch used	PPO identification
	NLI: All complete			
	Completeness: All complete Training status: Sedentary			
McMillan et al, 2021 ⁹⁶	n (female): 16 (2) Age (yrs): M±SD: (36.8±11) TSI: (yrs): M±SD: (11±6.5) NLI: C4-T11	NR	60-sec	NR
McMillan et al, 2021 ⁹⁷	Completeness: AIS A, B, C and D Training status: Recreationally active n (female): 10 (0) Age (yrs): $M\pm SD$: (39±10) TSI: (yrs): $M\pm SD$: (13±9) NLI: T2-T10	NR	20-sec	NR
Morgan et al, 2019 ⁹⁸	Completeness: AIS A, B and C Training status: Good CRF n (female): 10 (0) Age (yrs): $M\pm SD$: (33±20) TSI: (yrs): Chronic NLI: C6-T11	RER≥1.1, RPE≥17	60-sec	NR
	Completeness: AIS A, B, C Training status: MVPA, sport participation			
Murray et al, 2020 ⁹⁹	<i>n</i> (female): 19 (NR) Age (yrs): $M \pm SD$: (44.6±14.2) TSI: (yrs): Chronic NLI: Tetraplegia and paraplegia Completeness: AIS A, B, C	NR	8 breath	NR
Myers et al, 2010 ¹⁰⁰	Training status: NR <i>n</i> (female): 63 (NR) Age (yrs): $M\pm SD$: (54 \pm 15, 50 \pm 11, 50 \pm 10) TSI: (yrs): $M\pm SD$: (22 \pm 11, 13 \pm 12, 19 \pm 12) NLI: range; (T2-T6, T4-T7, T2-S1) Completeness: AIS A, B and C Training status: Mostly codentery	NR	30-sec	NR
Nightingale et al, 2017 ¹⁰¹	n (female): 33 (6) Age (yrs): $M\pm SD$: (44 \pm 9) TSI: (yrs): $M\pm SD$: (15 \pm 10) NLI: range; (T1-L4) Completeness: range; (AIS A-D) Training status: NR	NR	30-sec	NR
Nooijen et al, 2015 ¹⁰²	<i>n</i> (female): 37 (6) Age (yrs): <i>MED</i> (<i>IRQ</i>): 44(30-56) TSI: (yrs): <i>MED</i> (<i>IRQ</i>): 124(89-160 d) NLI: range; (C5-T1, T2-L3) Completeness: 24 complete, 13 incomplete Training status: Rehab	NR	30-sec	NR
Nooijen et al, 2017 ¹⁰³	<i>n</i> (female): 39 (4) Age (yrs): $M\pm SD$; (44±15) TSI: (day): $M\pm SD$; (150±74) NLI: range; Tetraplegia and paraplegia Completeness: Complete and incomplete Training status: NR	NR	30-sec	Highest maintained for 30 sec

P	Characteristics	ὑO 2peak criteria	Post-processing strategies	
Paper			VO _{2peak} epoch used	PPO identification
Nooijen et al, 2015 ¹⁰⁴	<i>n</i> (female): 36 (6) Age (yrs): $M\pm SD$; (43±15) TSI: (months): $M\pm SD$; (5±2) NLI: range; Tetraplegia and paraplegia Completeness: AIS A-D Training status: NR	NR	30-sec	Highest maintained for 30 sec
Ogonowska- Slodownik et al, 2019 ¹⁰⁵	n (female): 17 (3) Age (yrs): $M\pm SD$: (46 \pm 12) TSI: (yrs): $M\pm SD$: (14 \pm 13) NLI: range; C4-L1 Completeness: AIS A, B, C, D Training status: NR	NR	10-sec (highest three consecutive)	NR
Oviedo et al, 2021 ¹⁰⁶	n (female): 10 (0) Age (yrs): M±SD: (46±12) TSI: (yrs): M±SD: (14±13) NLI: range; C4-L1 Completeness: AIS A, B, C, D Training status: NR	Plateau in HR, RER ≥1.1	30-sec	NR
Pelletier et al, 2015 ¹⁰⁷	n (female): 23 (2) Age (yrs): M±SD: (40.0±12.3, 45.9±11.5) TSI: (yrs): M±SD: (15.0±8.52, 9.25±10.0) NLI: range; (C1-T11) Completeness: AIS A, B, C, D Training status: NR	NR	30-sec	Highest power output maintained for 15s
Pelletier et al, 2013 ¹⁰⁸	n (female): 41 (14) Age (yrs): M±SD: (38.9±13.7) TSI: (yrs): M±SD: (112.9±52.5 d) NLI: range; (C3-L5) Completeness: AIS A, B, C, D Training status: NR	NR	20-sec	Highest power output maintained for 15s
Philips et al, 1995 ¹⁰⁹	n (female): 8 (1) Age (yrs): M±SD: (33±8) TSI: (yrs): M±SD: (6±4) NLI: range; (C6-T12) Completeness: 7 complete, 1 incomplete Training status: Recreationally active	NR	30-sec	Highest power output maintained for 15s
Rodriguez- Gomez et al, 2019 ¹¹⁰	n (female): 30 (0) Age (yrs): M±SD: (30±6) TSI: (yrs): Chronic NLI: T1-L1 Completeness: AIS A and B Training status: 4.6±6.7 hour/week	2 of: RER≥1.0, RPE≥17, >95% APMHR (220- age)	10-sec	NR
Schneider et al, 1999 ¹¹¹	n (female): 6 (1) Age (yrs): M±SD: (28±2) TSI: (yrs): NR NLI: T12, T10 Completeness: NR Training status: Recreationally active and athletes	NR	30-sec	Highest power output achieved

_	Characteristics	[.] VO _{2peak} criteria	Post-processing strategies		
Paper			^ἰ O _{2peak} epoch used	PPO identification	
Schaffer et al, 2018 ¹¹²	n (female): 24 (2) Age (yrs): range; (25-35) TSI: range; (3-8 mo) NLI: range; (C4-T8) Completeness: range; (AIS A-C) Training status: NR	3 of: plateau (150ml/min), lactate >8.0 mmol/L, RER >1.1, RPE >17, >20W decrease in power for max stimulation	30-sec	NR	
Sutbeyaz et al, 2005 ¹¹³	<i>n</i> (female): 20 (8) Age (yrs): $M \pm SD$: (31.31 \pm 8.17) TSI: $M \pm SD$: (3.81 \pm 5.8 mo) NLI: range; (T6-T12) Completeness: 14 complete, 6 incomplete Training status: Minimally active	NR	20-sec	Highest power output achieved	
Steinberg et al, 2000 ¹¹⁴	n (female): 26 (0) Age (yrs): M±SD: (31±12) TSI: M±SD: (84±68 mo) NLI: range; (T1-T12) Completeness: All AIS A Training status: Recreationally active except16 sedentary	NR	20-sec	NR	
Taylor et al, 1986 ¹¹⁵	n (female): 10 (0) Age (yrs): M±SD: (30±3) TSI: (yrs): M±SD: (11.5±10) NLI: NR Completeness: NR Training status: Recreationally active	NR	Last 60-sec	NR	
Tosi et al, 2020 ¹¹⁶	n (female): 8 (0) Age (yrs): <i>range</i> ; (22-42) TSI: (yrs): range; (1-48 months) NLI: T3-S5 Completeness: AIS A and B Training status: NR	NR	30-sec	NR	
Totosky de Zepetnek et al, 2016 ¹¹⁷	n (female): 52 (8) Age (yrs): $M\pm SD$: (38 \pm 10) TSI: (yrs): $M\pm SD$: (13 \pm 10) NLI: range; (C1-L2) Completeness: AIS A, B, C, D Training status: Recreationally active	NR	30-sec	NR	
Valent et al, 2007 ¹¹⁸	<i>n</i> (female): 20 (2) Age (yrs): $M\pm SD$; (39.7±11.6) TSI: (yrs): $M\pm SD$; (9.4±10.2) NLI: range; (C5-C8) Completeness: range; (AIS A-B) Training status: Untrained to moderately recreationally trained	NR	60-sec	NR	
Valent et al, 2009 ¹¹⁹	n (female): 22 (4) Age (yrs): <i>M</i> ± <i>SD</i> ; (39±12) TSI: (yrs): <i>M</i> ± <i>SD</i> ; (10±7) NLI: range; (C5-T1) Completeness: range; (AIS A-D)	NR	30-sec	Highest power output maintained for 30s	

Paper	Characteristics	VO- anitania	Post-processing strategies	
		VO _{2peak} criteria	VO 2peak epoch used	PPO identification
	Training status: 0-1.5 hrs/week of physical activity			
Wang et al, 2002 ¹²⁰	n (female): 10 (3) Age (yrs): range; (18-50) TSI: (yrs): range; (6.1-60.7 w) NLI: range; (T11-L2) Completeness: NR Training status: NR	3 of: plateau (<2mL/kg/min), RER >1.1, exceed MHR (NR), lactate >50mg/dL	60-sec	NR
Wecht et al, 2006 ¹²¹	<i>n</i> (female): 18 (0) Age (yrs): $M\pm SD$; (36 \pm 9, 42 \pm 6) TSI: (yrs): $M\pm SD$; (12 \pm 7, 10 \pm 7) NLI: <t6 Completeness: NR Training status: Physically active and inactive</t6 	NR	20-sec	NR
West et al, 2013 ¹²²	n (female): 7 (0) Age (yrs): M±SD; (32±4 TSI: (yrs): M±SD; (12±5) NLI: range; (C6-C7) Completeness: range; (AIS A-B) Training status: Paralympic athletes	NR	30-sec	NR
Williams et al, 2020 ¹²³	<i>n</i> (female): 14 (6) Age (yrs): $M\pm SD$; (44 \pm 10) TSI: (yrs): $M\pm SD$; (22 \pm 13) NLI: range; (C4-T12) Completeness: AIS A, B, C, D Training status: Paralympic athletes	NR	15-sec rolling	Workload maintained at least 30 sec, otherwise taken from the previous stage
Yamasaki et al, 1996 ¹²⁴	n (female): 14 (0) Age (yrs): M±SD; (31±7 33±7) TSI: (yrs): M±SD; (9.7±6.4, 10.7±8.8) NLI: range; (L1-Th12) Completeness: range; (ISMGF 2-4) Training status: NR	NR	30-sec	NR
Zoeller et al, 2005 ¹²⁵	<i>n</i> (female): 10 (0) Age (yrs): $M\pm SD$; (33.5±8.8) TSI: (yrs): $M\pm SD$; (13.3±6.4) NLI: range; (T3-T10) Completeness: Complete, incomplete Training status: high to low physical activity	3 of: plateau (<150mL/min), RER >1.15, 90% of MHR (NR), lactate >10 mmol/L	30-sec	NR
WCE				
Arabi et al, 1997 ¹²⁶	n (female): 13 (2) Age (yrs): M±SD; (29.8±8.7) TSI: (yrs): chronic NLI: paraplegia Completeness: ISMGF I, III, IV Training status: regular home and work activities	NR	30-sec	Power output sustained for 30s

P	Characteristics	VO_{2peak} criteria	Post-processing strategies	
Paper			VO_{2peak} epoch used	PPO identification
Bakkum et al, 2015 ¹²⁷	n (female): 20 (1) Age (yrs): range; (30-64) TSI: (yrs): range; (9-34) NLI: range; (C2-L11) Completeness: AIS A-D Training status: Inactive (PASIPS score <30)	NR	30-sec	Highest power output maintained >30s
Bernard et al, 2000 ¹²⁸	n (female): 12 (0) Age (yrs): range; (24-37) TSI: (yrs): NR NLI: range; (T4-L3) Completeness: all complete except 2 incompletes Training status: competitive athletes	NR	20-sec	NR
Bhambani et al, 1995 ¹²⁹	<i>n</i> (female): 16 (0) Age (yrs): $M \pm SD$; (33.6 \pm 8.7, 31.8 \pm 6.9) TSI: (yrs): NR NLI: NR Completeness: NR Training status: half were trained athletes	All of: RER >1.1, RPE ≥18	30-sec	NR
Bhambani et al, 1995 ¹³⁰	n (female): 8 (0) Age (yrs): M±SD; (31.8±6.5) TSI: (yrs): NR NLI: range; (C5-C8) Completeness: NR Training status: marathon athletes	NR	30-sec	NR
Bhambani et al, 1994 ¹³¹	n (female): 11(0) Age (yrs): M±SD; (30.6±5.2, 29.0±4.6) TSI: (yrs): range; (1-30) NLI: range; (C5-L4) Completeness: NR Training status: inactive	NR	30-sec	NR
Bhambani et al, 1991 ¹³²	n (female): 7 (2) Age (yrs): M±SD; (26.5±3.5) TSI: (yrs): M±SD; (9.5±4.1) NLI: C6-L2 Completeness: NR Training status: NR	NR	30-sec	NR
Bougenot et al, 2003 ¹³³	n (female): 7 (0) Age (yrs): M±SD; (35±13) TSI: (yrs): NR NLI: range; (L4-L2) Completeness: AIS A Training status: "physically active"	NR	30-sec	NR
Campbell et al, 2004 ¹³⁴	n (female): 20 (NR) Age (yrs): M±SD; (32±7) TSI: (yrs): NR NLI: range; (C6-T7 and below) Completeness: NR Training status: athletes	NR	60-sec	NR

_	Characteristics	॑॑॑॑॑॑॑॑॑ <mark>॑</mark> VO _{2peak} criteria	Post-processing strategies	
Paper			VO_{2peak} epoch used	PPO identification
Campbell et al, 1997 ¹³⁵	n (female): 12 (0) Age (yrs): M±SD; (28±7) TSI: (yrs): NR, chronic NLI: range; (C7-L2) Completeness: NR Training status: wheelchair racers	NR	60-sec	NR
Carty et al, 2012 ¹³⁶	n (female): 14 (3) Age (yrs): $M \pm SD$; (45 \pm 10) TSI: (yrs): $M \pm SD$; (11 \pm 11) NLI: range; (T2-T11) Completeness: All A except 3 were B Training status: NR	2 of: RER >1.1, RPE ≥19, HR (NR), inability to maintain speed	30-sec	NR
Cooper et al, 1992 ¹³⁷	n (female): 11 (0) Age (yrs): M±SD; (31±9) TSI: (yrs): All chronic NLI: range; (T3-L1) Completeness: NR Training status: Athletes	All of: RER >1.0, plateau	30-sec	NR
Coutts et al, 1995 ¹³⁸	n (female): 30 (0) Age (yrs): All adults TSI: (yrs): NR, assume chronic NLI: NR Completeness: range; ISMGF 1A-5 Training status: untrained	All of: RER >1.05, HR (>165, only for paraplegia and amputee)	15-sec	NR
Coutts et al, 1987 ¹³⁹	n (female): 6 (2) Age (yrs): range; (22-31) TSI: (yrs): range; (4-29) NLI: range; (C6-T12) Completeness: range; (competitive classification IA-V) Training status: athletes	All of: RER >1.0, plateau	60-sec	Mean mechanical PC during the 60-sec of $\dot{VO}_{2 \text{ peak}}$
Dallmeijer et al, 2004 ¹⁴⁰	n (female): 9 (0) Age (yrs): $M \pm SD$; (36.3 \pm 7.8) TSI: (yrs): $M \pm SD$; (13.3 \pm 13.5) NLI: range; (T6-L3) Completeness: All complete except 3 Training status: athletes	NR	60-sec	Highest achieved
Dallmeijer et al, 2001 ¹⁴¹	n (female): 37 (0) Age (yrs): $M\pm SD$; (36.5±13.9) TSI: (yrs): $M\pm SD$; (4.3±5.6) NLI: range; (C5-L4) Completeness: All complete except 18 Training status: NR	NR	30-sec	Highest achieved
Dallmeijer et al, 1996 ¹⁴²	n (female): 25 (3) Age (yrs): M±SD; (28.7±8.4, 39.1±11.7,33.5±11.2) TSI: (yrs): M±SD; (5.3±3.1, 10.1±11.4,3.1±0.9) NLI: NR Completeness: All complete except 6	NR	60-sec	Highest achieved

Paper	Characteristics	żo state	Post-processing strategies	
		v O _{2peak} criteria	VO _{2peak} epoch used	PPO identification
	Training status: range; (0-6hrs of exercise per week)			
de Groot et al, 2016 ¹⁴³	n (female): 223 (25%, 26%) Age (yrs): M±SD; (50.9±8.5, 46.6±8.3) TSI: (yrs): >10 NLI: 51% >T1, 57% >T1 Completeness: 84% AIS A-B, 79% AIS A-B Training status: M±SD; (PASIPD: 19.3±18.1, 20.9±23.2)	NR	30-sec	NR
de Groot et al, 2016 ¹⁴⁴	<i>n</i> (female): 158 (30%) Age (yrs): $M \pm SD$; (47.9 \pm 8.6) TSI: (yrs): $M \pm SD$; (23.5 \pm 8.5) NLI: NR Completeness: 58-85% complete Training status: Active and Inactive (PASIPD <30 MET h/day)	NR	30-sec	Highest PO maintained for >30s
de Groot et al, 2010 ¹⁴⁵	<i>n</i> (female): 139 (27%) Age (yrs): $M \pm SD$; (41.6±14.1) TSI: (yrs): $M \pm SD$; (705±169d) NLI: 68% paraplegia Completeness: 64% complete Training status: $M \pm SD$; (PASIPD 17.8±18.6)	NR	30-sec	Highest PO maintained for >30s
Gass et al, 2001 ¹⁴⁶	n (female): 5 (0) Age (yrs): M±SD; (37±4) TSI: (yrs): range; (5-34) NLI: range; (T5-T12) Completeness: NR Training status: Physically active	NR	30-sec	NR
Gauthier et al, 2017 ¹⁴⁷	<i>n</i> (female): 25 (4) Age (yrs): $M \pm SD$; (35.3 \pm 14.9) TSI: (yrs): $M \pm SD$; (7.64 \pm 10.84) NLI: range; (C5-L5) Completeness: AIS A, B, C, D Training status: All inactive except 11 were physically active	1 of: RER >1.1, plateau	20-sec	NR
Gorman et al, 2016 ¹⁴⁸	n (female): 18 (NR) Age (yrs): M±SD; (51.5±12.7, 52±15.4) TSI: (yrs): Chronic NLI: range; (C4-L2) Completeness: AIS C, D Training status: NR	NR	20-sec	NR
Golding et al, 1986 ¹⁴⁹	n (female): 27 (6) Age (yrs): M; (23.5, 26.8), range; (21-28, 18-37) TSI: (yrs): M; (6.2), range; (7mo-15yrs) NLI: range; (C5-L4) Completeness: 11 complete	Plateau	Last 30-sec	NR

Paper	Characteristics	VO amitamia	Post-processing strategies	
		v O _{2peak} criteria	VO 2peak epoch used	PPO identification
	Training status: All inactive except 2 athletes			
Goss et al, 1992 ¹⁵⁰	<i>n</i> (female): 5 (2) Age (yrs): $M\pm SD$; (29.6±6.9) TSI: (yrs): $M\pm SD$; (99.6±118.2 mo) NLI: range; (C5-T10) Completeness: All complete Training status: NR	NR	Mean of 2x Highest 15- sec	NR
Grange et al, (2002) ¹⁵¹	<i>n</i> (female): 7 (0) Age (yrs): $M \pm SD$; (35.2±15.9) TSI: (yrs): $M \pm SD$; (12.3±10) NLI: All paraplegia Completeness: AIS A Training status: Physically active	Highest workload maintained at constant speed for 1min	30-sec	NR
Haisma et al, 2006 ¹⁵²	n (female): 186 (74-75%) Age (yrs): M±SD; (39±13, 41±15) TSI: (yrs): M±SD; (108±67d, 102±62d) NLI: NR Completeness: AIS A-B (66-69%) Training status: NR	NR	30-sec	PO at the highest inclination maintained for >30s
Hooker et al, 1989 ¹⁵³	n (female): 11 (5) Age (yrs): range; (23-36) TSI: (yrs): range; (0.25-19) NLI: C5-T9 Completeness: NR Training status: inactive	Supramaximal test	30-sec	NR
Janssen et al, 2001 ¹⁵⁴	<i>n</i> (female): 16 (0) Age (yrs): $M \pm SD$; (37 \pm 11) TSI: (yrs): $M \pm SD$; (141 \pm 133 mo) NLI: range; (C5-T10) Completeness: NR Training status: 4.2 \pm 3.1 hours of activity per week	NR	30-sec	Highest power maintained for 30-sec
Janssen et al, 1994 ¹⁵⁵	n (female): 44 (0) Age (yrs): M±SD; (32.9±9.4, 38.8±9.0, 33.4±12.4, 33.9±15.5) TSI: (yrs): M±SD; (14.6±8.8, 15.3±8.5, 10.8±8.4, 7.3±6.2) NLI: range; (C3-L5) Completeness: NR Training status: NR	NR	30-sec	PO associated with VO _{2peak}
Janssen et al, 1993 ¹⁵⁶	<i>n</i> (female): 44 (0) Age (yrs): $M \pm SD$; (34 \pm 12) TSI: (yrs): $M \pm SD$; (11.1 \pm 8) NLI: range; (C4-L5) Completeness: NR Training status: 2.6 \pm 2.9 hours of activity per week	NR	30-sec	Highest calculation: rolling resistance * belt velocity
Kirby et al, 2020 ¹⁵⁷	n (female): 26 (2) Age (yrs): <i>M</i> ± <i>SD</i> ; (36±3)	RER≥1.1, RPE≥9	30-sec	Highest power output maintained for >30s

Paper	Characteristics	VO₂ _{peak} criteria	Post-processing strategies		
			VO _{2peak} epoch used	PPO identification	
	TSI: (yrs): range; 3.5-14 NLI: Tetraplegia and paraplegia Completeness: NR Training status: NR				
Kilkens et al, 2004 ¹⁵⁸	<i>n</i> (female): 74 (23) Age (yrs): $M \pm SD$; (41 \pm 15) TSI: (yrs): Acute NLI: NR Completeness: range; (AIS A-D) Training status; MB	NR	30-sec	Highest power output maintained for >30s	
Le Foll-de Moro et al, 2005 ¹⁵⁹	rianning status:NK n (female): 6 (1) Age (yrs): $M \pm SD$; (29 \pm 14) TSI: (yrs): $M \pm SD$; (94 \pm 23 days) NLI: range; (T6-T12) Completeness: range; (AIS A-D) Training status:NR	All of: RER ≥1.15, HR (220- age), plateau	20-sec	Highest load maintained for 1 min at a constant speed	
Leicht et al, 2014 ¹⁶⁰	<i>n</i> (female): 19 (2) Age (yrs): $M \pm SD$; (28 \pm 4, 26 \pm 6) TSI: (yrs): NR NLI: range; (C5-L4) Completeness: NR Training status: National athletes	NR	20-sec	NR	
Leving et al, 2019 ¹⁶¹	<i>n</i> (female): 24 (6) Age (yrs): $M \pm SD$; (40 \pm 17, 41 \pm 11) TSI: (yrs): $M \pm SD$; (0.2 \pm 0.05, 7 \pm 5) NLI: range; (C5-L3) Completeness: AIS A, B, C, D Training status: NR	NR	30-sec	NR	
Litchke et al, 2008 ¹⁶²	<i>n</i> (female): 9 (0) Age (yrs): $M \pm SD$; (30 \pm 7, 30 \pm 10) TSI: (yrs): $M \pm SD$; (18 \pm 15, 6.8 \pm 5) NLI: range; (C5-T12) Completeness: NR Training status: Recreationally active	NR	60-sec	NR	
Morgulec- Adamowicz et al, 2011 ¹⁶³	<i>n</i> (female): 30 (0) Age (yrs): $M \pm SD$; (32 \pm 9, 31 \pm 8, 30 \pm 5, 32 \pm 5) TSI: (yrs): $M \pm SD$; (9 \pm 6, 10 \pm 5, 11 \pm 4, 13 \pm 6) NLI: NR Completeness: range; (IWRF 0.5-3.5 points) Training status: Rugby athletes	NR	10-sec	NR	
Nooijen et al, 2012 ¹⁶⁴	<i>n</i> (female): 30 (8) Age (yrs): $M \pm SD$; (42 \pm 15) TSI: (months): range; (5 \pm 2) NLI: range; () Completeness: Training status:	NR	30-sec	Highest maintained for 30sec	

D	Characteristics	VO₂ _{peak} criteria	Post-processing strategies		
raper			VO_{2peak} epoch used	PPO identification	
Paulson et al, 2013 ¹⁶⁵	<i>n</i> (female): 8 (0) Age (yrs): $M \pm SD$; (31 \pm 8) TSI: (yrs): $M \pm SD$; (11 \pm 6) NLI: range; (C5-T2) Completeness: All AIS A Training status: National and regional rugby athletes	NR	30-sec	NR	
Perret et al, 2016 ¹⁶⁶	n (female): 8 (2) Age (yrs): M±SD; (34±10) TSI: (yrs): NR NLI: T53/54 wheelchair racing category Completeness: T53/54 wheelchair racing category Training status: Athletes	NR	15-sec	NR	
Perret et al, 2012 ¹⁶⁷	<i>n</i> (female): 8 (1) Age (yrs): $M\pm SD$; (33±12) TSI: (yrs): $M\pm SD$; (19±8) NLI: range; (Th4-Th12) Completeness: range; (AIS A-D) Training status: Athletes	NR	15-sec	NR	
Postma et al, 2013 ¹⁶⁸	<i>n</i> (female): 180 (26.1%) Age (yrs): $M\pm SD$; (40 \pm 14) TSI: $M\pm SD$; (101.8 \pm 62.1 days) NLI: range; (C3-T7) Completeness: range; (AIS A-D) Training status: Rehab	NR	30-sec	NR	
Qi et al, 2015 ¹⁶⁹	<i>n</i> (female): 11 (3) Age (yrs): $M\pm SD$; (42±8) TSI: (yrs): $M\pm SD$; (10±6) NLI: range; (T6-L2) Completeness: range; (AIS A-B) Training status: Inactive except 2 recreationally active	NR	Last 30-sec	NR	
Rimaud et al, 2012 ¹⁷⁰	<i>n</i> (female): 9 (NR) Age (yrs): $M\pm SD$; (34±11) TSI: (yrs): $M\pm SD$; (10±10) NLI: range; (T4-L1) Completeness: All complete Training status: Recreationally active	NR	30-sec	Highest load maintained for 1 mir at a constant speed	
Rimaud et al, 2007 ¹⁷¹	n (female): 14 (0) Age (yrs): M±SD; (37±11) TSI: (yrs): M±SD; (12±9) NLI: range; (T4-T12) Completeness: range; (AIS A-B) Training status: International and national athletes, and recreationally active	NR	30-sec	Highest load maintained for 1 mir at a constant speed	
Tordi et al, 2001 ¹⁷²	<i>n</i> (female): 5 (0) Age (yrs): <i>M</i> ± <i>SD</i> ; (27±8.1) TSI: (yrs): NR NLI: range; (T6-L4)	All of: MHR, (220-age) plateau, RER >1.0	15-sec	NR	
D		vo ···	Post-processing strategies		
--	--	--	--	---	--
Paper	Characteristics	VO _{2peak} criteria	VO _{2peak} epoch used	PPO identification	
	Completeness: All AIS A Training status: Physically active				
Torhaug et al, 2016 ¹⁷³	n (female): 17 (0) Age (yrs): <i>MED</i> ; (48, 46) TSI: (yrs): <i>MED</i> ; (12) NLI: range; (T4-L1) Completeness: range; (AIS A-D) Training status: NR, 1 paralympic athlete	All of: RER ≥1.1, RPE ≥15, lactate ≥7 mmol/L	Mean of consecutive 3x10-sec	NR	
Valent et al, 2010 ¹⁷⁴	n (female): 17 (4) Age (yrs): M±SD; (46±15) TSI: (yrs): Acute NLI: <c5< td=""><td>NR</td><td>30-sec</td><td>Highest power output maintained for 30s</td></c5<>	NR	30-sec	Highest power output maintained for 30s	
	Completeness: range; (AIS A-D) Training status: Hand cycle trained				
Valent et al, 2008 ¹⁷⁵	n (female): 131 (30%) Age (yrs): M±SD; (48±15, 39±15, 38±14, 33±7)	NR	30-sec	Highest power output maintained for 30s	
	TSI: (yrs): Acute NLI: Paraplegia and tetraplegia Completeness: range; (AIS A-B) Training status: Active rehab				
van der Scheer et al, 2016 ¹⁷⁶	n (female): 29 (7) Age (yrs): <i>MED, IQR</i> ; (47, 45-64) TSI: (yrs): <i>MED, IQR</i> ; (17, 14-29) NLI: range; (C4-L5) Completeness: range; (AIS A-D) Training status: Inactive	RER >1	30-sec	Highest power output maintained for 30s	
van Koppenhagen et al, 2013 ¹⁷⁷	<i>n</i> (female): 162 (24%) Age (yrs): $M\pm SD$; (39 \pm 14) TSI: (yrs): $M\pm SD$; (6 \pm 2) NLI: 96 tetraplegia, 23 paraplegia Completeness: range; (AIS A-D) Training status: NR	NR	30-sec	Highest power output maintained for 30s	
Van Velzen et al, 2009 ¹⁷⁸	<i>n</i> (female): 118 (26) Age (yrs): $M\pm SD$; (40±13, 36±13) TSI: (yrs): Acute NLI: 70 <t1, 18="" <math="">\geqT1 Completeness: range; (AIS A-D) Training status: NR</t1,>	NR	30-sec	Highest power output maintained for 30s	
Veeger et al, 1991 ¹⁷⁹	<i>n</i> (female): 45 (8) Age (yrs): $M\pm SD$; (33 \pm 7) TSI: (yrs): NR NLI: range; (>C6-S1) Completeness: range; (ISMG 1-5) Training status: Athletes	All of: failure to maintain speed and slope, RER >1.0, HR (220- age) for low paraplegia	Last 30-sec	Pmax=Fslope *Vmean	
Vinet et al, 1997 ¹⁸⁰	n (female): 8 (0) Age (yrs): M±SD; (28±2) TSI: (yrs): >2 NLI: range; (T8-L5) Completeness: range; (ISMG 3-5)	3 of: plateau, near MHR (210- 0.65*age), RER >1.1, inability to maintain speed	Last 20-sec	NR	

			Post-processing strategies		
Paper	Characteristics	VO _{2peak} criteria	VO _{2peak} epoch used	PPO identification	
	Training status: Recreationally active				
West et al, 2014 ¹⁸¹	n (female): 8 (1) Age (yrs): M±SD; (29±2) TSI: (yrs): M±SD; (9±3) NLI: range; (C5-C7) Completeness: range; (AIS A-B) Training status: Paralympic athletes	NR	30-sec	NR	
Zacharakis et al, 2013 ¹⁸²	<i>n</i> (female): 8 (0) Age (yrs): $M \pm SD$; (31 \pm 8) TSI: (yrs): range; (4.5-23) NLI: range; (C7-T6) Completeness: range; (IWBF 1-2.5) Training status: Athletes	NR	30-sec	NR	
Other					
Abilmona et al, 2018 ¹⁸³	n (female): 22 (0) Age (yrs): $M \pm SD$; (36 \pm 10) TSI: (yrs): $M \pm SD$; (8 \pm 8) NLI: range; (C5-C11) Completeness: range; (AIS A-B) Training status: NR	NR	30-sec	NR	
Bhambani et al, 2000 ¹⁸⁴	n (female): 7 (1) Age (yrs): range; (26-65) TSI: (yrs): range; (1-29) NLI: range; C5-T12 Completeness: all complete Training status: NR	NR	15-sec	NR	
Brazg et al, 2017 ¹⁸⁵	n (female): 7 (1) Age (yrs): range; (26-65) TSI: (yrs): range; (1-29) NLI: C1-T10 Completeness: AIS C and D Training status: NR	NR	30-sec	NR	
Brurok et al, 2011 ¹⁸⁶	<i>n</i> (female): 6 (0) Age (yrs): $M \pm SD$; (40 \pm 11) TSI: (yrs): $M \pm SD$; (17.5 \pm 8) NLI: range; (C7-T8) Completeness: AIS A Training status: untrained aerobically	All of: RER \geq 1.05, RPE \geq 15, Lactate \geq 7mmol/L	30-sec	NR	
Berry et al, 2008 ¹⁸⁷	<i>n</i> (female): 12 (3) Age (yrs): $M\pm SD$; (42±8) TSI: (yrs): $M\pm SD$; (11±7) NLI: range; (T3-T9) Completeness: All AIS A Training status:	NR	60-sec rolling average	NR	
DiPiro et al, 2016 ¹⁸⁸	n (female): 9 (5) Age (yrs): M±SD; (58±9) TSI: (yrs): M±SD; (11.11±10) NLI: range; (C2-T9) Completeness: All AIS C except 1 D	All of: RER \geq 1.15, RPE \geq 17, plateau	15-sec	NR	

Paper	Characteristics		Post-processing strategies	
		VO _{2peak} criteria	VO _{2peak} epoch used	PPO identification
	Training status: NR			
Forbes et al, 2010 ¹⁸⁹	<i>n</i> (female): 6 (3) Age (yrs): $M \pm SD$; (37 \pm 13) TSI: (yrs): Chronic NLI: range; (T7-L11) Completeness: All complete	NR	20-sec	NR
Gayle et al, 1990 ¹⁹⁰	Training status: National Nordic ski team n (female): 15 (0) Age (yrs): $M \pm SD$; (27±96) TSI: (yrs): NR NLI: range; (T5-L4) Completeness: NR Training status: Inactive except 12 recreationally active	NR	30-sec	NR
Gurney et al, 1998 ¹⁹¹	n (female): 6 (0) Age (yrs): range; (23-41) TSI: (yrs): range; (5-24) NLI: range; (C4-T10) Completeness: All paraplegia Training status: NR	NR	60-sec	NR
Holm et al, 2021 ¹⁹²	n (female): 6 (0) Age (yrs): range; (21-83) TSI: (yrs): range; (2-12) NLI: range; (C2-L4) Completeness: AIS A, B and C Training status: NR	RER>1.0	30-sec	NR
Jack et al, 2010 ¹⁹³	n (female): 10 (1) Age (yrs): $M \pm SD$; (37 \pm 13) TSI: (yrs): $M \pm SD$; (4 \pm 6) NLI: range; (C4-L4) Completeness: AIS C-D Training status: NR	NR	20 sec moving average	NR
Jacobs, P. L., 1997 ¹⁹⁴	n (female): 11 (1) Age (yrs): $M \pm SD$; (28 \pm 7) TSI: (yrs): $M \pm SD$; (4 \pm 1) NLI: range; (T4-T11) Completeness: NR Training status: NR	All of: plateau, RER (NR), HR (NR)	15-sec	NR
Janssen et al, 2008 ¹⁹⁵	n (female): 12 (0) Age (yrs): $M \pm SD$; (36 \pm 16) TSI: (yrs): $M \pm SD$; (11 \pm 9) NLI: range; (C4-T11) Completeness: NR Training status: NR	NR	30-sec	Highest calculation: resistance × crank rate
Jung et al, 2012 ¹⁹⁶	<i>n</i> (female): 10 (3) Age: $M \pm SD$; (37 \pm 12 months) TSI: $M \pm SD$; (29 \pm 38.months) NLI: range; (T2-L5) Completeness: range; (AIS A-C) Training status: NR	1 of: plateau, RER> 1.15, HR (220-age), RPE 19-20	30-sec	NR

Damas	Characteristics	vo si i	Post-process	ing strategies
raper		VO _{2peak} criteria	VO _{2peak} epoch used	PPO identification
Leech et al, 2017 ¹⁹⁷	<i>n</i> (female): 11 (2) Age (yrs): $M \pm SD$; (41±14) TSI: $M \pm SD$; (103±85 months) NLI: range; (C3-T4) Completeness: range; (AIS C-D) Training status: All independent ambulators	NR	Last 30-sec	NR
Leech et al, 2014 ¹⁹⁸	<i>n</i> (female): 10 (0) Age (yrs): $M \pm SD$; (44 \pm 10) TSI: $M \pm SD$; (95 \pm 87 months) NLI: range; (C2-C7) Completeness: All AIS D Training status: NR	NR	Last 60-sec	NR
Lundgaard et al, 2017 ¹⁹⁹	<i>n</i> (female): 19 (0) Age (yrs): $M\pm SD$; (46±14) TSI: (yrs): $M\pm SD$; (5±5) NLI: range; (C1-L5) Completeness: range; (AIS C-D) Training status: All independent ambulators	All of: RER >1.05, plateau, ≥95% predicted MHR (220-age), lactate ≥5mmol/L	30-sec	NR
Martel et al, 1991 ²⁰⁰	<i>n</i> (female): 20 (0) Age (yrs): $M \pm SD$; (26.8±1.6) TSI: (yrs): range; (2-38) NLI: range; (T3-L5) Completeness: range; (ISMGF 1-6) Training status: Recreationally active	1 of: RPE 17, exhaustion, HR (220-age)	30-sec	NR
McConnell et al, 1989 ²⁰¹	n (female): 11 (0) Age (yrs): range; (19-34) TSI: (yrs): Chronic NLI: range; (T1-L2) Completeness: NR Training status: NR	NR	30-sec	NR
Mercier et al, 2021 ²⁰²	<i>n</i> (female): 27 (1) Age (yrs): $M\pm SD$: (39 \pm 10) TSI: (yrs): $M\pm SD$: (13 \pm 9) NLI: T2-T10 Completeness: AIS A, B and C Training status: Good CRF	3 of: Plateau, RER>1.1, RPE>17, 85%HR (220-age), and lactate >8 mmol/L	30-sec rolling	NR
Mutton et al, 1997 ²⁰³	<i>n</i> (female): 11 (0) Age (yrs): $M\pm SD$; (36 \pm 6.6) TSI: (yrs): $M\pm SD$; (10 \pm 4) NLI: range; (C5-L1) Completeness: All AIS A Training status: Inactive	NR	Last 60-sec	NR
Paulson et al, 2014 ²⁰⁴	<i>n</i> (female): 5 (1) Age (yrs): $M\pm SD$; (44±15) TSI: (yrs): $M\pm SD$; (8±10) NLI: range; (T5-T6) Completeness: All complete Training status: Recreationally active	NR	30-sec	Highest power output

			Post-processing strategies		
Paper	Characteristics	VO _{2peak} criteria	VO _{2peak} epoch used	PPO identification	
Perret et al, 2009 ²⁰⁵	n (female): 12 (2) Age (yrs): M±SD; (42±9) TSI: (yrs): M±SD; (10±7) NLI: range; (T3-T9) Completeness: All AIS A Training status: NR	NR	15-sec	Highest power output	
Price et al, 1999 ²⁰⁶	n (female): 7 (NR) Age (yrs): M±SD; (29±6) TSI: (yrs): NR NLI: range; (T3-L1) Completeness: All paraplegia Training status: National and international athletes	NR	Last 60-sec	NR	
Qiu et al, 2016 ²⁰⁷	n (female): 12 (1) Age (yrs): M±SD; (33±4) TSI: (yrs): M±SD; (8±3) NLI: range; (C4-T2) Completeness: Complete and incomplete Training status: NR	3 of: RER ≥ 1.1 , plateau, 85% of HRmax (220- age), RPE ≥ 17 , $\ge 20W$ power decline during max stimulation	Last 30-sec	NR	
Taylor et al, 2014 ²⁰⁸	n (female): 14 (1) Age (yrs): $M\pm SD$; (39 \pm 3.3) TSI: (yrs): $M\pm SD$; (10 \pm 3) NLI: range; (T3-T11) Completeness: All AIS A Training status: NR	3 of: plateau, >85% of MHR (220-age), RER >1.1, plateau, 85% of MHR (220-age), RPE ≥17, >20W power decline during max stimulation	30-sec	NR	
Taylor et al, 2011 ²⁰⁹	n (female): 6 (0) Age (yrs): M±SD; (33±5) TSI: (yrs): M±SD; (9±6) NLI: range; (T4-T9) Completeness: All AIS A Training status: NR	3 of: plateau, >85% of MHR (220-age), RER >1.1, plateau, 85% of MHR (220-age), RPE ≥17, >20W power decline during max stimulation	30-sec	NR	
Theisen et al, 2002 ²¹⁰	n (female): 5 (1) Age (yrs): M±SD; (33±8) TSI: (yrs): M±SD; (6±3) NLI: range; (T4-T9) Completeness: All AIS A Training status: All physically active except 1	NR	30-sec	NR	
Torhaug et al, 2018 ²¹¹	n (female): 15 (2) Age (yrs): M±SD; (36±14, 43±13) TSI: (yrs): M±SD; (13±11, 13.6±12) NLI: range; (C4-T12) Completeness: All AIS A	All of: RER ≥1.1, RPE ≥15, lactate ≥7 mmol/L	Mean of consecutive 3x10-sec	NR	

			Post-processing strategies		
Paper	Characteristics	VO _{2peak} criteria	VO _{2peak} epoch used	PPO identification	
	Training status: NR				
Torhaug et al, 2016 ²¹²	n (female): 12 (0) Age (yrs): <i>MED;</i> (46.5) TSI: (yrs): <i>MED;</i> (22) NLI: range; (T3-L1) Completeness: range; (AIS A-C) Training status: NR, non-athletes	All of: RER ≥1.1, RPE ≥15, lactate ≥7 mmol/L	Mean of consecutive 3x10-sec	NR	
Verellen et al, 2004 ²¹³	n (female): 9 (0) Age (yrs): M±SD; (30±6) TSI: (yrs): M±SD; (5±3) NLI: range; (T4-L1) Completeness: 7 complete, 2 incomplete Training status: moderate to very active	NR	Last 30-sec	NR	
Verellen et al, 2007 ²¹⁴	<i>n</i> (female): 5 (0) Age (yrs): $M\pm SD$; (47±19) TSI: (yrs): $M\pm SD$; (12±12) NLI: range; (C7-T12) Completeness: range; (AIS A-C) Training status: moderately active	NR	5-sec	NR	
Vivodtzev et al, 2020 ²¹⁵	n (female): 19 (NR) Age (yrs): (39±13) TSI: (yrs): range; 1-42 NLI: Tetraplegia and paraplegia Completeness: AIS A, B, C Training status: NR	3 of: RER>1.1, plateau, 85%APMHR (220-age), RPE≥17, decline power >20W	30-sec	NR	
Vivodtzev et al, 2021 ²¹⁶	n (female): 21 (NR) Age (yrs): (30±7) TSI: (yrs): range (0.3-1.9) NLI: C5-T3 Completeness: AIS A, B, C Training status: NR	3 of: 85% HR(220-age), RER>1.1, Plateau, lactate>8 mmol/l, decline of power >20W	30-sec	NR	
Wilbanks et al, 2016 ²¹⁷	n (female): 10 (2) Age (yrs): M±SD; (47±18) TSI: (yrs): M±SD; (18±14) NLI: range; (T4-T12) Completeness: range; (AIS A-C) Training status: NR	3 of: RER \geq 1.1, RPE \geq 17, >85% of MHR (NR), plateau	15-sec	NR	
Wouda et al, 2018 ²¹⁸	n (female): 30 (5) Age (yrs): M±SD; (41±17) TSI: M±SD; (69±29 days) NLI: C: 18, T1-5: 3, T6-12: 3, L: 5, S: 1 Completeness: All AIS D except 1 A Training status: Rehab	All of: RER >1.15, >85% of MHR (m:220- .88×age, f:220- .66×age), lactate (NR)	30-sec	NR	
Wouda et al, 2018 ²¹⁹	n (female): 15 (3) Age (yrs): $M\pm SD$; (40 \pm 11.9) TSI: range; (4 mo-14 yrs) NLI: range; (C3-L5) Completeness: All AIS D Training status: NR	NR	60-sec	NR	

Paper	Characteristics	••••	Post-processing strategies		
		VO _{2peak} criteria	VO _{2peak} epoch used	PPO identification	
Wouda et al,	<i>n</i> (female): 30 (5)	RER>1.15, 85%	30-sec	NR	
2021 220	Age (yrs): <i>M</i> ± <i>SD</i> ; (4±17)	(male> 220-			
	TSI: <i>M</i> ± <i>SD</i> (69±29 days)	0.88×age, female			
	NLI: Tetraplegia and paraplegia	220-0.66×age),			
	Completeness: AIS A and D	lactate> 8 mmol/L			
	Training status: NR				

Abbreviations: AIS, American Spinal Cord Association Impairment Scale; APMHR, age
predicted maximal heart rate; C, cervical; CRF, cardiorespiratory fitness; HR, heart rate; ISMG,
International Stoke Mandeville Games; IWBF, International Wheelchair Basketball Federation;
IQR, interquartile; LTPA, leisure time physical activity; L, lumbar; MHR, maximal heart rate;
MED, median; MVPA, moderate-vigorous physical activity; NLI, neurological level of injury;
NR, not recorded; PPO, peak power output; RER, respiratory exchange ratio; RPE, rate of
perceived exertion; T, thoracic; TSI, time since injury; VO_{2peak}, peak oxygen uptake.

15