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Title: 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

ABSTRACT

Objectives: To review the evidence regarding the most common practices adopted with cardiopulmonary exercise testing (CPET) in individuals with spinal cord injury (SCI), with the following specific aims to: (1) determine the most common averaging strategies of peak oxygen uptake ($\dot{V}O_{2peak}$), (2) review the endpoint criteria adopted to determine a valid $\dot{V}O_{2peak}$, and (3) investigate the effect of averaging strategies on $\dot{V}O_{2peak}$ values in a convenience sample of individuals with SCI (between the fourth cervical and sixth thoracic segments).

Data Sources: Searches for this scoping review were conducted in MEDLINE (PubMed), EMBASE, and Web Science.

Study Selection: Studies were included if (1) were original research on humans published in English, (2) recruited adults with traumatic and non-traumatic SCI, and (3) $\dot{V}O_{2peak}$ reported and measured directly during CPET to volitional exhaustion. Full-text review identified studies published before April 2021 for inclusion.

Data Extraction: Extracted data included authors, journal name, publication year, participant characteristics, and comprehensive information relevant to CPET.

Data Synthesis: We extracted data from a total of 197 studies involving 4,860 participants. We found that more than 50% of studies adopted a 30-sec averaging strategy. A wide range of endpoint criteria were used to confirm the attainment of maximal effort. In the convenience sample of individuals with SCI (n=30), the mean $\dot{V}O_{2peak}$ decreased as epoch (i.e., time) lengths increased. Reported $\dot{V}O_{2peak}$ values differed significantly (*P*<.001) between averaging strategies, with epoch length explaining 56% of the variability.

Conclusions: The adoption of accepted and standardized methods for processing and analyzing CPET data is needed to ensure high-quality, reproducible research, and inform population-specific normative values for individuals with SCI.

Keywords: Averaging strategies, cardiorespiratory fitness, spinal cord injury

List of abbreviations:

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
PA	Physical activity
PRISMA	Reporting Items for Systematic Reviews and Meta-Analyses
$\dot{Q}$	Cardiac output
RER	Respiratory exchange ratio
RPE	Rate of perceived exertion
RPM	Revolutions per minute
SCI	Spinal cord injury
$\dot{V}O_{2peak}$	Peak oxygen uptake
WCE	Wheelchair ergometer

Following a spinal cord injury (SCI), individuals can experience a substantial amplification of multiple risk factors for developing cardiovascular (CV) disease compared with uninjured individuals.[1] Owing to a myriad of factors related to the injury and/or the resultant physical inactivity,[2] a low level of cardiorespiratory fitness (CRF) is common and well-documented following SCI.[3] CRF reflects whole-body health as it represents the integration of numerous bodily systems to uptake, transport, and utilize oxygen (O_2) for metabolic processes.[4] CRF is commonly expressed in metabolic equivalent of tasks (MET) or oxygen consumption ($\dot{V}O_2$), measured by cardiopulmonary exercise testing (CPET) to the point of volitional exhaustion or symptom limitation. Peak or maximal $\dot{V}O_2$ ($\dot{V}O_{2peak}$ or $\dot{V}O_{2max}$) provides the gold standard measurement of CRF and is the most commonly reported outcome.[4] Until now, there is no universal consensus on a clear distinction between $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$.[5] In general, $\dot{V}O_{2max}$ is 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 to the highest $\dot{V}O_2$ attained during a single CPET. We refer readers to a recent discussion, along with *Journal of Applied Physiology* viewpoint and commentaries for further details on this topic.[5-7] $\dot{V}O_{2peak}$ will be used from here forward in this review, as it is the most common terminology reported in clinical populations to express CRF.[7,8] $\dot{V}O_{2peak}$ is reported in the literature as a reliable tool to assess responses to an exercise training intervention. Further, CRF carries clinical importance as a powerful and independent determinant of future and non-fatal 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 MET (i.e., 3.5 mL/kg/min) has been associated with a 10-25% reduction in all-cause and CV mortality in individuals without SCI.[4]

The aforementioned clinical implications regarding $\dot{V}O_{2peak}$ (and other CPET-derived measurements) require its measurement to be reported in a standardized way to ensure valid and reliable results. Modern automated expired gas analysis systems have provided the scientific community with multiple options for generating reports and figures and the flexibility to utilize different averaging strategies. A fundamental consideration of CPET-derived measurements (e.g., $\dot{V}O_{2peak}$) 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 arteriovenous oxygen difference at peak exercise. It is unlikely that this breath-by-breath 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).

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 $\dot{V}O_2$ is truly indicative of maximal effort.[12,16] However, even in adults without SCI these secondary criteria may lack the efficacy to confirm $\dot{V}O_{2max}$ attainment. For example, elevated RER values may occur at submaximal work rates and do not differentiate between participants who do or who do not achieve a plateau in $\dot{V}O_2$.[17,18] Moreover, the type of CPET 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 groups,[21,22] there is currently no universally recommended endpoint criteria for the attainment of a valid $\dot{V}O_{2peak}$ measurement and little is known regarding the most common averaging strategies used to process $\dot{V}O_{2peak}$ in the SCI population specifically.

A recent review by Eerden *et al.*[23] has summarized the application of CPET in individuals with SCI. The authors reviewed characteristics of CPET pertaining to common modalities of exercise testing, protocols, and reporting outcomes. However, post-processing averaging strategies were not reported in this review. Therefore, we aimed to map the SCI-related literature with the goals 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 $\dot{V}O_{2peak}$ criteria, and 3) investigate the influence of using different averaging strategies on obtained $\dot{V}O_{2peak}$ values in a cohort of individuals with SCI.

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 the available literature regardless of study design. We searched the literature using the following electronic databases: MEDLINE (PubMed), EMBASE, and Web of Science. These databases were searched from inception to April 2021. A sample of search terms is provided as an appendix (Appendix 1). Studies were included if they met the following criteria: 1) original research article published in English, 2) adults (≥18 years) with traumatic or non-traumatic SCI, 3) individuals of interest (i.e., SCI) comprise ≥80% of the experimental group, and 4) $\dot{V}O_{2peak}$ was reported and measured directly during peak/maximal CPET (both continuous and discontinuous protocols). The review excluded: 1) non-original articles such as reviews, study protocols, letters to the editor and commentaries, and non-human studies, 2) case-reports and case series with a number of participants <5, 3) articles that performed submaximal and steady-state testing, and 4) articles that assessed $\dot{V}O_{2peak}$ indirectly (e.g., estimation from submaximal testing). There was no attempt to contact authors if we found any insufficient/missing information (e.g., not reporting post-processing strategies), as this lack of reporting will be presented in our results. In the case of duplicated participants across multiple publications (e.g., data from the same clinical trial), we endeavoured to include the most relevant article (i.e., the 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 included articles were primarily performed by a single reviewer (AA) with assistance from (GB and VB). Data charting sheets were created and managed using a pre-approved Microsoft Excel spreadsheet.[a] Key information was extracted pertaining to authors name, journal name, year of publication, neurological characteristics of the included sample, and comprehensive information relevant to CPET such as aim, protocol, measurement device, and the post-processing data management applied. Studies that used Douglas Bags were excluded from the final analysis, as we wanted to focus specifically on the more common and recent breath-by-breath systems approach of capturing $\dot{V}O_{2peak}$ during CPET.

RESULTS

Scoping Review

Figure 1 provides the schematic representation of the research methodology using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). A total of 18,493 citations were initially identified. After removal of duplicates, the remaining articles (n = 12,847) were deemed eligible for title/abstract screening. Of these, 1,839 articles were selected for full-text screening against the eligibility criteria. A total of 352 full-text articles were considered eligible whereby $\dot{V}O_{2peak}$ was reported and measured directly during peak/maximal CPET. Out of these 352 studies, 155 (44%) studies did not provide enough information to extract the data pertaining to the post-processing strategies utilised. Consequently, 197 (56%) studies reported methods of $\dot{V}O_{2peak}$ 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] characteristics is presented in the supplemental material.

General Characteristics of Studies Included

Cross-sectional studies (n = 89) accounted for 45% of included studies in the review, while only 18 (9%) studies were randomized controlled trials. Half of the included articles were conducted during the last ten years and 46 (46%) of these were published during or after 2017. Figure 2 highlights the substantial chronological increase in the numbers of published studies assessing CRF in the SCI population. Collectively, the 197 included studies comprised 4,860 participants 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 223 [143] participants.

Eighty-five percent of the studies (n = 167) performed maximal CPET to study the acute physiological responses of $\dot{V}O_{2peak}$, while the rest (n = 30; 15%) tested the effect of an exercise training intervention on the CPET-obtained outcomes. Arm-crank ergometer (ACE) and wheelchair ergometer (WCE) were the most common modalities of CPET and were used in 98 studies (50%) and 57 studies (29%), respectively. Forty-two studies (21%) used different modes of CPET such as treadmill, leg cycling, hybrid (arm and legs) with and without stimulation. Continuous incremental protocols were the most common and were implemented in 176 (89%) of the included studies. The duration of stages during continuous and discontinuous protocols ranged from 30-sec to three min for each stage, interspersed with 30-sec to three min rest breaks during the discontinuous protocol. The predetermined duration of CPET was reported in 31 (16%) studies; with the duration of 8–12 min used in 20 (65%) of these studies. The majority of studies (91%) reported the reason for CPET termination; volitional fatigue/exhaustion and inability to maintain the desired workload/speed were the most commonly reported reasons for termination.

Common Averaging Strategies Used

$\dot{V}O_{2peak}$ averaging strategies varied among the included articles. In 192 (97%) of these studies, the averaging strategy was expressed using time-interval methods. Thirty-sec averaging was the most common method (n = 102), accounting for 53% of the reported studies. Other methods included 15-, 20-, and 60-sec averaging and were used in (n = 23; 12%), (n = 29; 15%), and (n = 18; 9%) of studies, respectively. The averaging strategy expressed by breath intervals was only 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 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 authors instead of using fixed time intervals, used rolling/moving averages of 10-sec,[52] 15-sec,[123] 30-sec,[62] and 60-sec.[187]

Secondary End-Point Criteria Applied

Sixty-seven studies (34%) reported predetermined endpoint criteria of $\dot{V}O_{2peak}$ (TABLE 2). Some studies clearly distinguished between the endpoint and termination criteria,[186,188] yet, some used them interchangeably.[52,136] Thus, the termination criteria meant that the CPET's was stopped if one of these criteria were met regardless of participants reaching their perceived maximal effort or not. RER as a criterion was reported in 55 (82%) of the studies. Studies used varied cut-off 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 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.

The impact of altering post-processing $\dot{V}O_{2peak}$ strategies: The CHOICES clinical trial example

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 provide an illuminating example of the impact of different post-processing strategies for the determination of $\dot{V}O_{2peak}$ in individuals with SCI. Participant demographics and injury characteristics are presented in TABLE 3. Only data from the Vancouver site and CPET's conducted before the commencement of the training interventions (i.e., baseline data) were included in this current analyses. All CPETs were performed after the ethics approval from the center-specific Institutional Review Board. We analyzed the data retrospectively according to prevalent post-processing strategies used in the wider literature, as identified by our scoping review that included 197 articles.

Cardiopulmonary exercise testing

$\dot{V}O_{2peak}$ was collected during a CPET's on an electrically braked arm-crank ergometer,[b] performed until volitional exhaustion. Respiratory gases were collected using a metabolic cart.[c]

HR was recorded continuously using a chest-strap HR monitor.[d] Participants were asked to empty their bladder prior to the test to avoid the possible development of autonomic dysreflexia. CPET's started after two minutes of resting, after a warm-up with no resistance (i.e., 0 watts (W)) for two minutes and then continued with one-minute stages, where resistance was increased by 5 and10 W per stage for participants with cervical and upper-thoracic NLI, respectively. The Borg scale (6-20) rating of perceived exertion was collected by the end of each sage. The participants were instructed to maintain a cadence of 50 revolutions per minute (rpm) throughout the test. The test continued with verbal encouragement until volitional exhaustion or the cadence dropped below 30 rpm. The test ended with a two-minute cool-down period with zero W.

Data management and statistical analysis

The parent trial collected and processed $\dot{V}O_{2peak}$ using the time-interval of 20-second averaging. In addition to these collected data, we exported individual participants data from the metabolic cart using different averaging strategies according to the common methods reported in our scoping review (i.e., 20-sec, 30-sec, 60-sec, and 15-breath rolling). 15-breath rolling average represented a rolling average of breaths one through 15, breaths two through 16, and so forth throughout the test. We also investigated the influence of achieving a specific RER value (i.e., above or below 1.1) corresponding to $\dot{V}O_{2peak}$. All analyses were performed using Statistical Package for Social Sciences.[f] Statistical significance was accepted at $P < .05$. Repeated measure 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 eta squared was calculated to report effect size. Bland-Altman plots, with corresponding 95% limit of agreement (LoA) analyses, were used to compare all averaging strategies (i.e., 15-sec, 20-sec, 60-sec, and 15-breath rolling) to 30-sec averaging, the most common averaging strategy as per the findings from our scoping review. To further evaluate variations in $\dot{V}O_{2peak}$ values, equivalence testing was conducted to examine the equivalence between different averaging strategies and the 30-sec averaging method. For methods to be considered equivalent to 30-sec with 95% precision, the 90% confidence interval of the mean of the other averaging strategies must fall into the proposed equivalence zone of the criterion mean (i.e., ± 10% of the mean of 30-sec method). Data were presented as Mean ± Standard deviations unless otherwise mentioned.

Findings from the CHOICES Example

TABLE 4 provides descriptive statistics for all of the different averaging strategies for both 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 of the variation in the obtained $\dot{V}O_{2peak}$ values was related to using different averaging strategies. The ANOVA revealed that $\dot{V}O_{2peak}$ values were significantly different across all averaging strategies, with Bonferroni analyses demonstrating alternative strategies were significantly different from the most commonly used 30-sec averaging strategy ($P<.001$) (TABLE 4). TABLE 5 shows the influence of categorizing individuals based on RER above or below 1.1 on the obtained $\dot{V}O_{2peak}$ using different averaging strategies. In both categories, $\dot{V}O_{2peak}$ values decrease as the averaging epoch lengths increase. Categorizing individuals above and below a RER of 1.1 had no effect on this trend (RER vs averaging strategies interaction effect, $P = .805$). However, main effect of averaging strategies was significant ($P<.001$) and those who reached a RER of 1.1 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.

DISCUSSION

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

$\dot{V}O_{2peak}$ averaging strategies

Based on our findings, time-averaging methods were the most common approach for processing $\dot{V}O_{2peak}$ data, which is in line with what is documented in the uninjured population.[12] Of the time-interval strategies, 30-sec was the most common method used to attenuate breath-by-breath variability. Our findings in a cohort of individuals with SCI (i.e., C4-T6) are in agreement with previous literature, indicating that the averaging strategy can significantly alter the derived maximal/peak $\dot{V}O_2$ value.[223,224] In the non-injured population, the general recommendation is to use an averaging strategy larger than a single breath but smaller than 60-sec. Although this represents a broad range, which can impact the derived $\dot{V}O_{2peak}$ value as shown with our data analysis, it seems reasonable to advocate either ≤ 30-sec,[225] and 15- or 8-breath averaging as suitable strategies.[12,226] Averaging strategies gained their importance not only for the ability to smooth breath-by-breath variability, but their influence on accurately identifying the plateau in $\dot{V}O_2$, 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] Given that $\dot{V}O_{2peak}$ 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 $\dot{V}O_{2peak}$.[227] Our analysis showed that up to 56% of the variability in the obtained $\dot{V}O_{2peak}$ value was due to 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 impairments (e.g., paresis or paralysis of the expiratory muscles) are common post SCI with NLI

≥ 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.

In regards to breath-interval methods, Martin-Rincon *et al* [230] suggested that time- and breath-intervals produce similar $\dot{V}O_{2peak}$ values for a given epoch of seconds or breaths. While this suggests these methods can be used interchangeably, further research is required specifically in the SCI population. Normative values of $\dot{V}O_{2peak}$ have been suggested for individuals with SCI.[231,232] Differences in the obtained $\dot{V}O_{2peak}$ value as a result of using different post-processing 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 report the post-processing averaging strategies that were utilized. Furthermore, if using a percentage of $\dot{V}O_{2peak}$ for a prospective exercise training intervention, this could lead to variability in the prescribed relative exercise intensity and thus training adaptations.

Currently used criteria of $\dot{V}O_{2peak}$ attainment

Plateau in $\dot{V}O_{2peak}$

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 reported the percentage of untrained individuals with SCI reaching a plateau in $\dot{V}O_2$. The 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 defined the plateau criteria, even though different definitions were used. Zoeller *et al.*[125] used a discontinuous protocol performed on ACE with ten individuals with paraplegia and defined the 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 individuals with metabolic syndrome suggested using a smaller averaging strategy (i.e., 15-breath rolling average), with a smaller cut-off change in $\dot{V}O_2$ (i.e., ≤ 50 mL/min) to increase the likelihood of detecting a $\dot{V}O_2$ plateau.

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?

Respiratory exchange ratio (RER)

RER is the ratio of carbon dioxide (CO_2) produced to oxygen uptake ($\dot{V}CO_2/\dot{V}O_2$). RER increases with exercise intensity because of the production of lactic acid, which is buffered, plus the excess CO_2 generated from the muscle work. This physiological outcome is the most used-secondary criterion to gauge one’s maximal effort.[16,225] This is in the line with our findings, which shows that RER was applied in up to 82% of the studies whenever $\dot{V}O_{2peak}$ criteria were reported. An RER of 1.10 was the most common cut-off value reported, used in more than half of the studies. However, RER as a criterion was reported using a wide range from 1.0 to 1.15. This range supports that mentioned in the review by Eerden *et al*.[23] and is similar to the range reported with individuals post stroke.[21] Following SCI, daily wheelchair use and reliance on upper-body exercise may result in local adaptations in the upper-body musculature. This adaptation may cause differences in the preference for lipid utilization rather than carbohydrates, which consequently gives rise to a lower RER value with upper-body exercise.[111] While this may suggest using a smaller RER cut-off value (i.e., 1.10) during CPET is necessary to confirm attainment of maximal effort, other research[77,241] has indicated a higher reliance on carbohydrate fuel sources during upper-body exercise in individuals with SCI. Moreover, autonomic impairments in individuals with cervical and upper-thoracic SCI might further contribute to poor lipid substrate utilization in this population.[242] This could result in a higher exercising RER in individuals with SCI that may lead to erroneous conclusions on the attainment of maximal effort.

Future research may want to investigate this criterion in the SCI population to identify the most appropriate cut-off value with consideration to the injury characteristics (i.e., NLI and completeness) and investigate the influence of CPET protocol (i.e., size of increment) on this criterion.[17] Moreover, diet has been shown to alter maximal exercise RER and therefore potentially its use as a secondary criteria to discern whether $\dot{V}O_{2peak}$ has been achieved. Niekamp *et al*,[243] showed that adults on a diet that promotes systemic alkalinity (which effects acid-base regulation) achieve a criterion RER ≥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.

Age-predicted maximal heart rate

Using a certain percentage of age-predicted maximal heart rate (APMHR) is a problematic criterion. The maximal HR response to exercise possesses a wide variability relative to APMHR (± 11 beats/min), making it difficult to justify its use as a criterion.[16] This would be even more problematic with the SCI population, particularly those with a NLI $\geq$ T6. Owing to the 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 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 physical inactivity and the use of β-blocking agents may also challenge the use of this criterion. We found that HR as a criterion of $\dot{V}O_{2peak}$ was not clearly described, using different or unreported formulas and various percentage of APMHR (TABLE 2). Considering the above 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 be recommended as a single criterion to confirm the attainment of $\dot{V}O_{2peak}$ in the SCI population, particularly in those with cervical and high-thoracic injuries. Nevertheless, this criterion is still reported and used in scientific publications as per the result of our review (n = 29; 43%).

Rating of perceived exertion (RPE)

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

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

Post-exercise blood lactate level

Howley *et al.* [16] stated that "*blood lactate is a good choice as an indicator of maximal effort*" as there was a theoretical association between post-exercise blood lactate level and the plateau in $\dot{V}O_2$. High blood lactate is a good indicator of high effort exerted as it is associated with increased recruitment of fast-twitch muscle fibres [253] that occurs with higher exercise intensities. It is noted in our review that only 14 out of 67 studies used the level of blood lactate as a 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 $\dot{V}O_2$, which has also been documented elsewhere.[16] The validity of this criterion warrants further investigation within the SCI population.

Verification testing

A verification test can be performed following a period of rest whereby individuals perform 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 $\dot{V}O_{2peak}$ value during the verification testing is similar to or within a measurement error (i.e., 2%) of the CPET-obtained $\dot{V}O_{2peak}$ this would indicate that the person attained maximal effort.[255] Verification 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] Similar to the other end point criteria, there is no general consensus on the most appropriate verification methodology (e.g., the duration of the resting period between CPET and verification phase) and what is the maximal accepted change in $\dot{V}O_2$ during the verification phase to be considered as a true maximal value. Moreover, pertinent to the SCI population and other clinical populations, the scientific community has to consider the following: 1) how the accumulative fatigue during CPET influence the results from the verification phase, 2) does performing this phase add or change clinical-related decisions, and 3) does detecting such a small change in $V\dot{O}_2$ justify the cost, time, or potential risk to the participants.

Strength and Limitations

Our review provides a broad overview of $\dot{V}O_{2peak}$ post-processing obtained during maximal/peak CPET in the SCI population. Our review adopted an inclusive search strategy and summarized studies from all available years. Despite the fact of this comprehensive search strategy, it is possible that some potential studies may have been missed or excluded due to eligibility criteria. Nevertheless, given the high number of included studies in this review, we are confident that the findings reflect the current practice of using CPET within the SCI population. The disadvantage of this broad searching strategy is that we included studies with a wide diversity of methods and a notable heterogeneity of included participants. Using >80% SCI as an inclusion criterion could be considered a limitation; however, only five studies, which included a total of 12 non-SCI individuals met this criterion and were included. Such a small percentage (i.e., 0.2%) is unlikely to have impacted our overall conclusion. We found that 56% of the variability in the obtained $\dot{V}O_{2peak}$ values in our cohort is due to utilization of different averaging strategies. Other factors 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. Researchers may also want to consider the following factors and their interactions in the interpretation of $\dot{V}O_{2peak}$ data between studies: the specific type of metabolic cart used (e.g., breath-by-breath Vs. mixing chamber, pneumotach Vs. turbine),[60] along with the exercise modes (e.g., treadmill, wheelchair ergometer or arm cycling)[56] and specific CPET protocols (e.g., ramp Vs. step, continuous Vs. discontinuous) used.[234,256] Our analyses were performed on a sample of individuals with high NLI SCI (i.e., ≥T6), this may limit the generalizability of these findings to the wider SCI population. Although, we do not expect a higher $\dot{V}O_{2peak}$ variability when using different averaging strategies with lower NLI due to less respiratory impairment. Our analysis was obtained from a specific exercise *modality, maximal* CPET using arm cycling, which may be seen as a limitation. However, arm cycling CPET was reported in up to half of the included papers in our review, thereby reflecting the most common modality used in the wider literature. Furthermore, a previous publication showed that the obtained $\dot{V}O_{2peak}$ values do not significantly differ compared to wheelchair CPET.[212]

CONCLUSION AND RECOMMENDATIONS

This review emphasizes and discusses the considerable variation in post-processing data management (i.e., averaging strategies and $\dot{V}O_{2peak}$ criteria) used in the SCI literature. The ability to accurately determine criteria for $\dot{V}O_{2peak}$ along with identifying the best averaging strategies of $\dot{V}O_{2peak}$ is of high importance given an increased CV disease risk in this population,[1] which is in part due to the well-documented low level of CRF.[9,10] Formal guidelines for reporting CPET data do not currently exist in the SCI literature and a high number of publications included in our review even failed to report the averaging strategies utilized. Caution should be applied when comparing $\dot{V}O_{2peak}$ values across studies when different averaging strategies have been implemented utilized. A lack of such standardization would result in decreased validity and reliability of CPET-related results. The lack of standardization is also observed with other CPET-related procedures such as the recommended test duration, termination criteria, testing protocols, and method of identifying the peak workload. We recommend that subsequent publications 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 also reporting the pre CPET fasting/dietary status. When using time-interval methods, we recommend using no longer than 30-sec. The use of much smaller time-intervals (<15 seconds), which would include fewer breaths, may influence data due to the high breath-by-breath variability in the SCI population. Therefore, we propose 20 – 30-secs as being the most appropriate time epoch for capturing a true $\dot{V}O_{2peak}$[227] and increase the chance of detecting a plateau in $\dot{V}O_2$.[239] Each secondary endpoint criteria should not be used in isolation, given the aforementioned specific limitations when applied to participants with higher NLI's (i.e., upper-thoracic and cervical SCI), due to autonomic cardiovascular/metabolic impairments,[122] as well as the obligatory of using upper limbs in daily activities, that in turn would challenge using these criteria in isolation. Hence, we recommend using at least two criteria (e.g., RER and RPE) to indicate maximal effort during CPET. Once these recommendations become more consistently applied, with transparent reporting, one can ensure the highest quality CPET results and facilitate comparisons between studies.

References

1. 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

2. 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

3. 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

4. Ross R, Blair SN, Arena R, et al. Importance of Assessing Cardiorespiratory Fitness in Clinical Practice: A Case for Fitness as a Clinical Vital Sign: A Scientific Statement From the American Heart Association. *Circulation*. 12 2016;134(24):e653-e699. doi:10.1161/CIR.0000000000000461

5. Poole DC, Jones AM. Measurement of the maximum oxygen uptake $\dot{V}$o. *J Appl Physiol (1985)*. Apr 01 2017;122(4):997-1002. doi:10.1152/japplphysiol.01063.2016

6. Green S, Askew C. $\dot{V}O_{2peak}$ is and acceptable estimate of cardiorespiratory fitness but not $\dot{V}O_{2max}$ *Journal of Applied Physiology*. 2018;(125):229-232. doi:10.1152/japplphysiol.00850.2017

7. Azevedo P, Bhammar DM, Babb TG, et al. Commentaries on Viewpoint: $\dot{V}$o. *J Appl Physiol (1985)*. 07 2018;125(1):233-240. doi:10.1152/japplphysiol.00319.2018

8. 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

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

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

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

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. doi:10.2165/11319670-000000000-00000

13. 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.

14. Estenne M, De Troyer A. The effects of tetraplegia on chest wall statics. *Am Rev Respir Dis*. Jul 1986;134(1):121-4. doi:10.1164/arrd.1986.134.1.121

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.

16. Howley ET, Bassett DR, Welch HG. Criteria for maximal oxygen uptake: review and commentary. *Med Sci Sports Exerc*. Sep 1995;27(9):1292-301.

17. Poole 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/s-0028-1104588

19. 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

20. Kouwijzer I, Valize M, Valent LJM, Grandjean Perrenod Comtesse P, van der Woude LHV, de Groot S. The influence of protocol design on the identification of ventilatory thresholds and the attainment of peak physiological responses during synchronous arm crank ergometry in able-bodied participants. *Eur J Appl Physiol*. Oct 2019;119(10):2275-2286. doi:10.1007/s00421-019-04211-9

21. van de Port IG, Kwakkel G, Wittink H. Systematic review of cardiopulmonary exercise testing post stroke: Are we adhering to practice recommendations? *J Rehabil Med*. Nov 2015;47(10):881-900. doi:10.2340/16501977-2031

22. 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

23. Eerden S, Dekker R, Hettinga FJ. Maximal and submaximal aerobic tests for wheelchair-dependent persons with spinal cord injury: a systematic review to summarize and identify useful applications for clinical rehabilitation. *Disabil Rehabil*. Mar 2018;40(5):497-521. doi:10.1080/09638288.2017.1287623

24. Hilary A, Lisa OM. Scoping Studies: Towards a Methodological Framework *Int J Social Research Methodology*. 2003;8(1):19-32.

25. Alrashidi AA, Balthazaar SJT, Currie KD, Nightingale TE, Krassioukov AV. Associations between left ventricular structure and function with cardiorespiratory fitness and body composition in individuals with cervical and upper thoracic spinal cord injury. *Spinal Cord*. Dec 2020;doi:10.1038/s41393-020-00591-4

26. Akkurt H, Karapolat HU, Kirazli Y, Kose T. The effects of upper extremity aerobic exercise in patients with spinal cord injury: a randomized controlled study. *Eur J Phys Rehabil Med*. Apr 2017;53(2):219-227. doi:10.23736/S1973-9087.16.03804-1

27. 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

28. Ashley EA, Laskin JJ, Olenik LM, et al. Evidence of autonomic dysreflexia during functional electrical stimulation in individuals with spinal cord injuries. *Paraplegia*. Sep 1993;31(9):593-605. doi:10.1038/sc.1993.95

29. Astorino TA. Hemodynamic and cardiorespiratory responses to various arm cycling regimens in men with spinal cord injury. *Spinal Cord Ser Cases*. 2019;5:2. doi:10.1038/s41394-018-0145-9

30. Astorino TA, Bediamol N, Cotoia S, et al. Verification testing to confirm VO. *J Spinal Cord Med*. Jan 2018:1-8. doi:10.1080/10790268.2017.1422890

31. 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

32. 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):1190-1196. doi:10.1249/MSS.0000000000001203

33. Barfield JP, Malone LA, Arbo C, Jung AP. Exercise intensity during wheelchair rugby training. *J Sports Sci*. Feb 2010;28(4):389-98. doi:10.1080/02640410903508839

34. Bar-On ZH, Nene AV. Relationship between heart rate and oxygen uptake in thoracic level paraplegics. *Paraplegia*. Feb 1990;28(2):87-95. doi:10.1038/sc.1990.11

35. Beillot J, Carré F, Le Claire G, et al. Energy consumption of paraplegic locomotion using reciprocating gait orthosis. *Eur J Appl Physiol Occup Physiol*. 1996;73(3-4):376-81. doi:10.1007/BF02425502

36. Bongers CC, Eijsvogels TM, van Nes IJ, Hopman MT, Thijssen DH. Effects of Cooling During Exercise on Thermoregulatory Responses of Men With Paraplegia. *Phys Ther*. May 2016;96(5):650-8. doi:10.2522/ptj.20150266

37. Brissot R, Gallien P, Le Bot MP, et al. Clinical experience with functional electrical stimulation-assisted gait with Parastep in spinal cord-injured patients. *Spine (Phila Pa 1976)*. Feb 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

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

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

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

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

43. Currie KD, West CR, Hubli M, Gee CM, Krassioukov AV. Peak heart rates and sympathetic function in tetraplegic nonathletes and athletes. *Med Sci Sports Exerc*. Jun 2015;47(6):1259-64. doi:10.1249/MSS.0000000000000514

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

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

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

47. 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

48. 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

49. 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 asynchronous 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

53. Farrow MT, Maher JL, Nightingale TE, Thompson D, Bilzon JLJ. A Single Bout of Upper-Body Exercise Has No Effect on Postprandial Metabolism in Persons with Chronic Paraplegia. *Med Sci Sports Exerc*. 05 2021;53(5):1041-1049. doi:10.1249/MSS.0000000000002561

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):604-9. 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

60. Fukuoka Y, Nakanishi R, Ueoka H, Kitano A, Takeshita K, Itoh M. Effects of wheelchair training on VO2 kinetics in the participants with spinal-cord injury. *Disabil Rehabil Assist Technol*. Jun 2006;1(3):167-74. doi:10.1080/17483100500506033

61. Gass EM, Harvey LA, Gass GC. Maximal physiological responses during arm cranking and treadmill wheelchair propulsion in T4-T6 paraplegic men. *Paraplegia*. May 1995;33(5):267-70. doi:10.1038/sc.1995.60

62. Gee CM, Williams AM, Sheel AW, Eves ND, West CR. Respiratory muscle training in athletes with cervical spinal cord injury: effects on cardiopulmonary function and exercise capacity. *J Physiol*. 07 2019;597(14):3673-3685. doi:10.1113/JP277943

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):287-91. doi:10.1038/sc.2014.6

66. Hagobian TA, Jacobs KA, Kiratli BJ, Friedlander AL. Foot cooling reduces exercise-induced 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

67. Hasnan N, Ektas N, Tanhoffer AI, et al. Exercise responses during functional electrical stimulation cycling in individuals with spinal cord injury. *Med Sci Sports Exerc*. Jun 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 para- and tetraplegia. *PLoS One*. 2019;14(12):e0222542. doi:10.1371/journal.pone.0222542

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

72. Hopman MT, Dallmeijer AJ, Snoek G, van der Woude LH. The effect of training on cardiovascular responses to arm exercise in individuals with tetraplegia. *Eur J Appl Physiol Occup Physiol*. 1996;74(1-2):172-9. doi:10.1007/BF00376510

73. Hopman MT, Dueck C, Monroe M, Philips WT, Skinner JS. Limits to maximal performance in individuals with spinal cord injury. *Int J Sports Med*. Feb 1998;19(2):98-103. doi:10.1055/s-2007-971889

74. Hopman MT, Oeseburg B, Binkhorst RA. Cardiovascular responses in paraplegic subjects during arm exercise. *Eur J Appl Physiol Occup Physiol*. 1992;65(1):73-8. doi:10.1007/BF01466277

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

76. Hutchinson MJ, Valentino SE, Totosy de Zepetnek JO, MacDonald MJ, Goosey-Tolfrey VL. Perceptually regulated training does not influence the differentiated RPE response following 16-weeks of aerobic exercise in adults with spinal cord injury. *Appl Physiol Nutr Metab*. Jun 2019;doi:10.1139/apnm-2019-0062

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

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

79. Jung W, Yamasaki M. Effect of pre-exercise carbohydrate ingestion on substrate consumption in persons with spinal cord injury. *Spinal Cord*. Jun 2009;47(6):464-9. doi:10.1038/sc.2008.140

80. 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 Study. *Arch Phys Med Rehabil*. Nov 2015;96(11):2033-40.e1. 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

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/s41393-020-00548-7

83. 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):669-678. doi:10.1038/s41393-019-0262-8

84. 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. doi:10.1080/09638288.2018.1501097

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. doi:10.1038/sc.1993.87

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. 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

91. 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

92. 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

93. 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

94. 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.

95. 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

96. 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

97. 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

98. Morgan KA, Taylor KL, Tucker SM, Cade WT, Klaesner JW. Exercise testing protocol using a roller system for manual wheelchair users with spinal cord injury. *J Spinal Cord Med*. 05 2019;42(3):288-297. doi:10.1080/10790268.2018.1443542

99. Murray D, Chin LMK, Cowan RE, Groah SL, Keyser RE. Recovery Off-Kinetics Following Exhaustive Upper Body Exercise in Spinal Cord Injury. *Top Spinal Cord Inj Rehabil*. 2020;26(4):304-313. doi:10.46292/sci19-00060

100. Myers JN, Hsu L, Hadley D, Lee MY, Kiratli BJ. Post-exercise heart rate recovery in individuals with spinal cord injury. *Spinal Cord*. Aug 2010;48(8):639-44. doi:10.1038/sc.2009.196

101. Nightingale TE, Walhin JP, Thompson D, Bilzon JL. Biomarkers of cardiometabolic health are associated with body composition characteristics but not physical activity in persons with spinal cord injury. *J Spinal Cord Med*. Sep 2017:1-10. doi:10.1080/10790268.2017.1368203

102. Nooijen CF, Post MW, Spooren AL, et al. Exercise self-efficacy and the relation with 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

103. 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

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 2015;53(10):758-62. doi:10.1038/sc.2015.66

105. Ogonowska-Slodownik A, Geigle PR, Gorman PH, Slodownik R, Scott WH. Aquatic, deep water peak VO. *J Spinal Cord Med*. 09 2019;42(5):631-638. doi:10.1080/10790268.2018.1559494

106. Oviedo GR, Alamo JM, Niño-Mendez OA, et al. Physiological responses in males with and without spinal cord injury to recumbent synchronous

versus seated asynchronous arm crank stress tests. *Retos*. 2021;39:565-571.

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

108. Pelletier CA, Jones G, Latimer-Cheung AE, Warburton DE, Hicks AL. Aerobic capacity, orthostatic tolerance, and exercise perceptions at discharge from inpatient spinal cord injury rehabilitation. *Arch Phys Med Rehabil*. Oct 2013;94(10):2013-9. doi:10.1016/j.apmr.2013.05.011

109. 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.

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

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 Occup Physiol*. Sep 1999;80(4):292-7.

112. Shaffer RF, Picard G, Taylor JA. Relationship of Spinal Cord Injury Level and Duration to Peak Aerobic Capacity With Arms-Only and Hybrid Functional Electrical Stimulation Rowing. *Am J Phys Med Rehabil*. 07 2018;97(7):488-491. doi:10.1097/PHM.0000000000000903

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. doi:10.1097/00004356-200509000-00012

114. Steinberg LL, Lauro FA, Sposito MM, et al. Catecholamine response to exercise in individuals with different levels of paraplegia. *Braz J Med Biol Res*. Aug 2000;33(8):913-8. doi:10.1590/s0100-879x2000000800007

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

119. Valent LJ, Dallmeijer AJ, Houdijk H, et al. Effects of hand cycle training on physical capacity in individuals with tetraplegia: a clinical trial. *Phys Ther*. Oct 2009;89(10):1051-60. doi:10.2522/ptj.20080340

120. 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

121. 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

122. 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

123. 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

124. 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

126. 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

127. Bakkum AJ, de Groot S, Stolwijk-Swüste JM, et al. Effects of hybrid cycling versus handcycling on wheelchair-specific fitness and physical activity in people with long-term spinal cord injury: a 16-week randomized controlled trial. *Spinal Cord*. May 2015;53(5):395-401. doi:10.1038/sc.2014.237

128. Bernard PL, Mercier J, Varray A, Prefaut C. Influence of lesion level on the cardioventilatory adaptations in paraplegic wheelchair athletes during muscular exercise. *Spinal Cord*. Jan 2000;38(1):16-25.

129. 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.

130. Bhambhani YN, Burnham RS, Wheeler GD, Eriksson P, Holland LJ, Steadward RD. Physiological correlates of simulated wheelchair racing in trained quadriplegics. *Can J Appl Physiol*. Mar 1995;20(1):65-77. doi:10.1139/h95-005

131. Bhambhani YN, Holland LJ, Eriksson P, Steadward RD. Physiological responses during wheelchair racing in quadriplegics and paraplegics. *Paraplegia*. Apr 1994;32(4):253-60. doi:10.1038/sc.1994.45

132. Bhambhani YN, Eriksson P, Steadward RD. Reliability of peak physiological responses during wheelchair ergometry in persons with spinal cord injury. *Arch Phys Med Rehabil*. Jul 1991;72(8):559-62.

133. Bougenot MP, Tordi N, Betik AC, et al. Effects of a wheelchair ergometer training programme on spinal cord-injured persons. *Spinal Cord*. Aug 2003;41(8):451-6. doi:10.1038/sj.sc.3101475

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

136. Carty A, McCormack K, Coughlan GF, Crowe L, Caulfield B. Increased aerobic fitness after neuromuscular electrical stimulation training in adults with spinal cord injury. *Arch Phys Med Rehabil*. May 2012;93(5):790-5. doi:10.1016/j.apmr.2011.10.030

137. Cooper RA. The contribution of selected anthropometric and physiological variables to 10K performance of wheelchair racers: a preliminary study. *J Rehabil Res Dev*. 1992;29(3):29-34. doi:10.1682/jrrd.1992.07.0029

138. Coutts KD, McKenzie DC. Ventilatory thresholds during wheelchair exercise in individuals with spinal cord injuries. *Paraplegia*. Jul 1995;33(7):419-22. doi:10.1038/sc.1995.85

139. Coutts KD, Stogryn JL. Aerobic and anaerobic power of Canadian wheelchair track athletes. *Med Sci Sports Exerc*. Feb 1987;19(1):62-5.

140. Dallmeijer AJ, Zentgraaff ID, Zijp NI, van der Woude LH. Submaximal physical strain and peak performance in handcycling versus handrim wheelchair propulsion. *Spinal Cord*. Feb 2004;42(2):91-8. doi:10.1038/sj.sc.3101566

141. Dallmeijer AJ, van der Woude LH. Health related functional status in men with spinal cord injury: relationship with lesion level and endurance capacity. *Spinal Cord*. Nov 2001;39(11):577-83. doi:10.1038/sj.sc.3101215

142. Dallmeijer AJ, Hopman MT, van As HH, van der Woude LH. Physical capacity and physical strain in persons with tetraplegia; the role of sport activity. *Spinal Cord*. Dec 1996;34(12):729-35. doi:10.1038/sc.1996.133

143. de Groot S, Adriaansen JJ, Tepper M, Snoek GJ, van der Woude LH, Post MW. Metabolic syndrome in people with a long-standing spinal cord injury: associations with physical activity and capacity. *Appl Physiol Nutr Metab*. Nov 2016;41(11):1190-1196. doi:10.1139/apnm-2016-0269

144. de Groot S, van der Scheer JW, Bakkum AJ, et al. Wheelchair-specific fitness of persons with a long-term spinal cord injury: cross-sectional study on effects of time since injury and physical activity level. *Disabil Rehabil*. 2016;38(12):1180-6. doi:10.3109/09638288.2015.1076072

145. de Groot S, van der Woude LH, Niezen A, Smit CA, Post MW. Evaluation of the physical activity scale for individuals with physical disabilities in people with spinal cord injury. *Spinal Cord*. Jul 2010;48(7):542-7. doi:10.1038/sc.2009.178

146. Gass EM, Gass GC. Thermoregulatory responses to repeated warm water immersion in subjects who are paraplegic. *Spinal Cord*. Mar 2001;39(3):149-55. doi:10.1038/sj.sc.3101117

147. Gauthier C, Arel J, Brosseau R, Hicks AL, Gagnon DH. Reliability and minimal detectable change of a new treadmill-based progressive workload incremental test to measure cardiorespiratory fitness in manual wheelchair users. *J Spinal Cord Med*. 11 2017;40(6):759-767. doi:10.1080/10790268.2017.1369213

148. Gorman PH, Scott W, York H, et al. Robotically assisted treadmill exercise training for improving peak fitness in chronic motor incomplete spinal cord injury: A randomized controlled trial. *J Spinal Cord Med*. 2016;39(1):32-44. doi:10.1179/2045772314Y.0000000281

149. Golding LA, Horvat MA, Beutel-Horvat T, McConnell TJ. A graded exercise test protocol for spinal cord injured individuals. *Journal of Cardiopulmonary Rehabilitation*. 1986;6(9):362-367.

150. Goss FL, McDermott A, Robertson RJ. Changes in peak oxygen uptake following computerized functional electrical stimulation in the spinal cord injured. *Res Q Exerc Sport*. Mar 1992;63(1):76-9. doi:10.1080/02701367.1992.10607559

151. Grange CC, Bougenot MP, Groslambert A, Tordi N, Rouillon JD. Perceived exertion and rehabilitation with wheelchair ergometer: comparison between patients with spinal cord injury and healthy subjects. *Spinal Cord*. Oct 2002;40(10):513-8. doi:10.1038/sj.sc.3101353

152. 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 cord-injured persons. *Med Sci Sports Exerc*. Feb 1989;21(1):18-22. doi:10.1249/00005768-198902000-00004

154. Janssen TW, Dallmeijer AJ, van der Woude LH. Physical capacity and race performance 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

156. 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 cross-sectional study. *Disabil Rehabil*. 01 2020;42(1):114-121. doi:10.1080/09638288.2018.1493545

158. Kilkens OJ, Dallmeijer AJ, De Witte LP, Van Der Woude LH, Post MW. The 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

159. Le Foll-de Moro D, Tordi N, Lonsdorfer E, Lonsdorfer J. Ventilation efficiency and pulmonary function after a wheelchair interval-training program in subjects with recent spinal 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

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

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

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

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

166. Perret C, Wenger M, Leicht CA, Goosey-Tolfrey VL. Locomotor-Respiratory Coupling in Wheelchair Racing Athletes: A Pilot Study. *Front Physiol*. 2016;7:11. doi:10.3389/fphys.2016.00011

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

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

169. Qi L, Ferguson-Pell M, Salimi Z, Haennel R, Ramadi A. Wheelchair users' perceived exertion during typical mobility activities. *Spinal Cord*. Sep 2015;53(9):687-91. doi:10.1038/sc.2015.30

170. Rimaud D, Calmels P, Pichot V, Bethoux F, Roche F. Effects of compression stockings on sympathetic activity and heart rate variability in individuals with spinal cord injury. *J Spinal Cord Med*. Mar 2012;35(2):81-8. doi:10.1179/2045772311Y.0000000054

171. Rimaud D, Calmels P, Roche F, Mongold JJ, Trudeau F, Devillard X. Effects of graduated compression stockings on cardiovascular and metabolic responses to exercise and exercise recovery in persons with spinal cord injury. *Arch Phys Med Rehabil*. Jun 2007;88(6):703-9. doi:10.1016/j.apmr.2007.03.023

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

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

174. Valent L, Dallmeijer A, Houdijk H, Slootman HJ, Janssen TW, Van Der Woude LH. Effects of hand cycle training on wheelchair capacity during clinical rehabilitation in persons with a spinal cord injury. *Disabil Rehabil*. 2010;32(26):2191-200. doi:10.3109/09638288.2010.509461

175. Valent LJ, Dallmeijer AJ, Houdijk H, Slootman HJ, Post MW, van der Woude LH. Influence of hand cycling on physical capacity in the rehabilitation of persons with a spinal cord injury: a longitudinal cohort study. *Arch Phys Med Rehabil*. Jun 2008;89(6):1016-22. doi:10.1016/j.apmr.2007.10.034

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. doi:10.2340/16501977-2037

177. van Koppenhagen CF, de Groot S, Post MW, et al. Wheelchair exercise capacity in spinal cord injury up to five years after discharge from inpatient rehabilitation. *J Rehabil Med*. Jul 2013;45(7):646-52. doi:10.2340/16501977-1149

178. van Velzen JM, de Groot S, Post MW, Slootman JH, van Bennekom CA, van der Woude LH. Return to work after spinal cord injury: is it related to wheelchair capacity at discharge from clinical rehabilitation? *Am J Phys Med Rehabil*. Jan 2009;88(1):47-56. doi:10.1097/PHM.0b013e31818e6140

179. Veeger HE, Hadj Yahmed M, van der Woude LH, Charpentier P. Peak oxygen uptake and maximal power output of Olympic wheelchair-dependent athletes. *Med Sci Sports Exerc*. Oct 1991;23(10):1201-9.

180. Vinet A, Le Gallais D, Bernard PL, et al. Aerobic metabolism and cardioventilatory responses in paraplegic athletes during an incremental wheelchair exercise. *Eur J Appl Physiol Occup Physiol*. 1997;76(5):455-61. doi:10.1007/s004210050275

181. West CR, Goosey-Tolfrey VL, Campbell IG, Romer LM. Effect of abdominal binding on respiratory mechanics during exercise in athletes with cervical spinal cord injury. *J Appl Physiol (1985)*. Jul 2014;117(1):36-45. doi:10.1152/japplphysiol.00218.2014

182. Zacharakis ED, Kounalakis SN, Nassis GP, Geladas ND. Cardiovascular drift in trained paraplegic and able-bodied individuals during prolonged wheelchair exercise: effect of fluid replacement. *Appl Physiol Nutr Metab*. Apr 2013;38(4):375-81. doi:10.1139/apnm-2012-0131

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

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

185. Brazg G, Fahey M, Holleran CL, et al. Effects of Training Intensity on Locomotor Performance in Individuals With Chronic Spinal Cord Injury: A Randomized Crossover Study. *Neurorehabil Neural Repair*. 2017 Oct-Nov 2017;31(10-11):944-954. doi:10.1177/1545968317731538

186. Brurok B, Helgerud J, Karlsen T, Leivseth G, Hoff J. Effect of aerobic high-intensity hybrid training on stroke volume and peak oxygen consumption in men with spinal cord injury. *Am J Phys Med Rehabil*. May 2011;90(5):407-14. doi:10.1097/PHM.0b013e31820f960f

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

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

189. Forbes SC, Chilibeck PD, Craven B, Bhambhani Y. Comparison of a double poling ergometer and field test for elite cross country sit skiers. *N Am J Sports Phys Ther*. Jun 2010;5(2):40-6.

190. Gayle GW, Pohlman RL, Glaser RM, Davis GM. Cardiorespiratory and perceptual responses to arm crank and wheelchair exercise using various handrims in male paraplegics. *Res Q Exerc Sport*. Sep 1990;61(3):224-32. doi:10.1080/02701367.1990.10608683

191. Gurney AB, Robergs RA, Aisenbrey J, Cordova JC, McClanahan L. Detraining from total body exercise ergometry in individuals with spinal cord injury. *Spinal Cord*. Nov 1998;36(11):782-9. doi:10.1038/sj.sc.3100698

192. 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

193. Jack LP, Purcell M, Allan DB, Hunt KJ. Comparison of peak cardiopulmonary performance parameters during robotics-assisted treadmill exercise and arm crank ergometry in incomplete spinal cord injury. *Technol Health Care*. 2010;18(4-5):285-96. doi:10.3233/THC-2010-0591

194. Jacobs PL, Klose KJ, Guest R, Needham-Shropshire B, Broton JG, Green BA. Relationships of oxygen uptake, heart rate, and ratings of perceived exertion in persons with paraplegia during functional neuromuscular stimulation assisted ambulation. *Spinal Cord*. May 1997;35(5):292-8. doi:10.1038/sj.sc.3100435

195. Janssen TW, Pringle DD. Effects of modified electrical stimulation-induced leg cycle ergometer training for individuals with spinal cord injury. *J Rehabil Res Dev*. 2008;45(6):819-30. doi:10.1682/jrrd.2007.09.0153

196. Jung DW, Park DS, Lee BS, Kim M. Development of a motor driven rowing machine with automatic functional electrical stimulation controller for individuals with paraplegia; a preliminary study. *Ann Rehabil Med*. Jun 2012;36(3):379-85. doi:10.5535/arm.2012.36.3.379

197. Leech KA, Hornby TG. High-Intensity Locomotor Exercise Increases Brain-Derived Neurotrophic Factor in Individuals with Incomplete Spinal Cord Injury. *J Neurotrauma*. 03 2017;34(6):1240-1248. doi:10.1089/neu.2016.4532

198. Leech KA, Kinnaird CR, Hornby TG. Effects of serotonergic medications on locomotor performance in humans with incomplete spinal cord injury. *J Neurotrauma*. Aug 2014;31(15):1334-42. doi:10.1089/neu.2013.3206

199. Lundgaard E, Wouda MF, Strøm V. A comparative study of two protocols for treadmill walking exercise testing in ambulating subjects with incomplete spinal cord injury. *Spinal Cord*. Oct 2017;55(10):935-939. doi:10.1038/sc.2017.34

200. Martel G, Noreau L, Jobin J. Physiological responses to maximal exercise on arm cranking and wheelchair ergometer with paraplegics. *Paraplegia*. Sep 1991;29(7):447-56. doi:10.1038/sc.1991.61

201. McConnell TJ, Horvat MA, Beutel-Horvat TA, Golding LA. Arm crank versus wheelchair treadmill ergometry to evaluate the performance of paraplegics. *Paraplegia*. Aug 1989;27(4):307-13. doi:10.1038/sc.1989.46

202. Mercier HW, Picard G, Taylor JA, Vivodtzev I. Gains in aerobic capacity with whole-body 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

203. Mutton DL, Scremin AM, Barstow TJ, Scott MD, Kunkel CF, Cagle TG. Physiologic responses during functional electrical stimulation leg cycling and hybrid exercise in spinal cord injured subjects. *Arch Phys Med Rehabil*. Jul 1997;78(7):712-8. doi:10.1016/s0003-9993(97)90078-2

204. Paulson TA, Bishop NC, Smith BM, Goosey-Tolfrey VL. Inflammation-mediating cytokine response to acute handcycling exercise with/without functional electrical stimulation-evoked lower-limb cycling. *J Rehabil Res Dev*. 2014;51(4):645-54. doi:10.1682/JRRD.2013.08.0184

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. doi:10.1080/09638280802621424

206. Price MJ, Campbell IG. Thermoregulatory and physiological responses of wheelchair athletes to prolonged arm crank and wheelchair exercise. *Int J Sports Med*. Oct 1999;20(7):457-63. doi:10.1055/s-1999-8831

207. Qiu S, Alzhab S, Picard G, Taylor JA. Ventilation Limits Aerobic Capacity after Functional Electrical Stimulation Row Training in High Spinal Cord Injury. *Med Sci Sports Exerc*. 06 2016;48(6):1111-8. doi:10.1249/MSS.0000000000000880

208. Taylor JA, Picard G, Porter A, Morse LR, Pronovost MF, Deley G. Hybrid functional 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. doi:10.1016/j.apmr.2014.07.412

209. Taylor JA, Picard G, Widrick JJ. Aerobic capacity with hybrid FES rowing in spinal cord injury: comparison with arms-only exercise and preliminary findings with regular training. *PM R*. Sep 2011;3(9):817-24. doi:10.1016/j.pmrj.2011.03.020

210. Theisen D, Fornusek C, Raymond J, Davis GM. External power output changes during prolonged cycling with electrical stimulation. *J Rehabil Med*. Jul 2002;34(4):171-5. doi:10.1080/16501970213238

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

212. Tørhaug T, Brurok B, Hoff J, Helgerud J, Leivseth G. Arm Crank and Wheelchair Ergometry Produce Similar Peak Oxygen Uptake but Different Work Economy Values in Individuals with Spinal Cord Injury. *Biomed Res Int*. 2016;2016:5481843. doi:10.1155/2016/5481843

213. Verellen J, Theisen D, Vanlandewijck Y. Influence of crank rate in hand cycling. *Med Sci Sports Exerc*. Oct 2004;36(10):1826-31. doi:10.1249/01.mss.0000142367.04918.5a

214. Verellen J, Vanlandewijck Y, Andrews B, Wheeler GD. Cardiorespiratory responses 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

215. Vivodtzev I, Picard G, Cepeda FX, Taylor JA. Acute Ventilatory Support During Whole-Body Hybrid Rowing in Patients With High-Level Spinal Cord Injury: A Randomized Controlled Crossover Trial. *Chest*. May 2020;157(5):1230-1240. doi:10.1016/j.chest.2019.10.044

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/s00421-020-04536-w

217. Wilbanks SR, Rogers R, Pool S, Bickel CS. Effects of functional electrical stimulation assisted rowing on aerobic fitness and shoulder pain in manual wheelchair users with spinal cord injury. *J Spinal Cord Med*. 11 2016;39(6):645-654. doi:10.1179/2045772315Y.0000000052

218. Wouda MF, Lundgaard E, Becker F, Strøm V. Effects of moderate- and high-intensity aerobic training program in ambulatory subjects with incomplete spinal cord injury-a

randomized controlled trial. *Spinal Cord*. Oct 2018;56(10):955-963. doi:10.1038/s41393-018-0140-9

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

220. 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

221. Krassioukov AV, Currie KD, Hubli M, et al. Effects of exercise interventions on cardiovascular health in individuals with chronic, motor complete spinal cord injury: protocol for a randomised controlled trial [Cardiovascular Health/Outcomes: Improvements Created by Exercise and education in SCI (CHOICES) Study]. *BMJ Open*. Jan 2019;9(1):e023540. doi:10.1136/bmjopen-2018-023540

222. Alrashidi AA, Nightingale TE, Currie KD, et al. Exercise Improves Cardiorespiratory 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

223. 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.1475-097X.2008.00835.x

224. Smart NA, Jeffriess L, Giallauria F, et al. Effect of duration of data averaging interval on reported peak VO2 in patients with heart failure. *Int J Cardiol*. Mar 2015;182:530-3. doi:10.1016/j.ijcard.2014.12.174

225. Balady GJ, Arena R, Sietsema K, et al. Clinician's Guide to cardiopulmonary exercise testing in adults: a scientific statement from the American Heart Association. *Circulation*. Jul 2010;122(2):191-225. doi:10.1161/CIR.0b013e3181e52e69

226. Myers J, Walsh D, Sullivan M, Froelicher V. Effect of sampling on variability and plateau in oxygen uptake. *J Appl Physiol (1985)*. Jan 1990;68(1):404-10. doi:10.1152/jappl.1990.68.1.404

227. Martin-Rincon MLC, Jose. Progress Update and Challenges on $\dot{V}O_{2max}$ Testing and Interpretation. *Frontiers in Physiology*. 2020;11doi:https://doi.org/10.3389/fphys.2020.01070

228. Matthews JI, Bush BA, Morales FM. Microprocessor exercise physiology systems vs a nonautomated system. A comparison of data output. *Chest*. Oct 1987;92(4):696-703. doi:10.1378/chest.92.4.696

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 1998;113(3):816-9. doi:10.1378/chest.113.3.816

230. Martin-Rincon M, González-Henríquez JJ, Losa-Reyna J, et al. Impact of data averaging strategies on $\dot{V}O$. *Scand J Med Sci Sports*. Oct 2019;29(10):1473-1488. doi:10.1111/sms.13495

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.

232. Simmons OL, Kressler J, Nash MS. Reference fitness values in the untrained spinal cord injury population. *Arch Phys Med Rehabil*. Dec 2014;95(12):2272-8. doi:10.1016/j.apmr.2014.06.015

233. Rossiter HB, Kowalchuk JM, Whipp BJ. A test to establish maximum O2 uptake despite no plateau in the O2 uptake response to ramp incremental exercise. *J Appl Physiol (1985)*. Mar 2006;100(3):764-70. doi:10.1152/japplphysiol.00932.2005

234. Duncan GE, Howley ET, Johnson BN. Applicability of VO2max criteria: discontinuous versus continuous protocols. *Med Sci Sports Exerc*. Feb 1997;29(2):273-8. doi:10.1097/00005768-199702000-00017

235. Wagner J, Niemeyer M, Infanger D, et al. New Data-based Cutoffs for Maximal Exercise Criteria across the Lifespan. *Med Sci Sports Exerc*. 09 2020;52(9):1915-1923. doi:10.1249/MSS.0000000000002344

236. Wood RE, Hills AP, Hunter GR, King NA, Byrne NM. Vo2max in overweight and obese adults: do they meet the threshold criteria? *Med Sci Sports Exerc*. Mar 2010;42(3):470-7. doi:10.1249/MSS.0b013e3181b666ad

237. Lucía A, Rabadán M, Hoyos J, et al. Frequency of the VO2max plateau phenomenon in world-class cyclists. *Int J Sports Med*. Dec 2006;27(12):984-92. doi:10.1055/s-2006-923833

238. Leicht CA, Tolfrey K, Lenton JP, Bishop NC, Goosey-Tolfrey VL. The verification phase and reliability of physiological parameters in peak testing of elite wheelchair athletes. *Eur J Appl Physiol*. Feb 2013;113(2):337-45. doi:10.1007/s00421-012-2441-6

239. Thomson AC, Ramos JS, Fassett RG, Coombes JS, Dalleck LC. Optimal criteria and sampling interval to detect a V̇O2 plateau at V̇O2max in patients with metabolic syndrome. *Res Sports Med*. 2015;23(4):337-50. doi:10.1080/15438627.2015.1076411

240. Astorino TA, Robergs RA, Ghiasv F, Marks D. Incidence of the oxygen plateau at VO$_{2\text{max}}$ during exercise testing to volitional fatigue. *Journal of Exercise Physiology*. 2000;3(4)

241. Astorino TA, Harness ET. Substrate metabolism during exercise in the spinal cord injured. *Eur J Appl Physiol*. May 2009;106(2):187-93. doi:10.1007/s00421-009-1005-x

242. Shea JR, Shay BL, Leiter J, Cowley KC. Energy Expenditure as a Function of Activity Level After Spinal Cord Injury: The Need for Tetraplegia-Specific Energy Balance Guidelines. *Front Physiol*. 2018;9:1286. doi:10.3389/fphys.2018.01286

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 2012;44(4):709-15. doi:10.1249/MSS.0b013e3182366f6c

244. Edvardsen E, Hem E, Anderssen SA. End criteria for reaching maximal oxygen uptake 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

245. Krassioukov A, West C. The role of autonomic function on sport performance in athletes with spinal cord injury. *PM R*. Aug 2014;6(8 Suppl):S58-65. doi:10.1016/j.pmrj.2014.05.023

246. Hopman MT, Monroe M, Dueck C, Phillips WT, Skinner JS. Blood redistribution and circulatory responses to submaximal arm exercise in persons with spinal cord injury. *Scand J Rehabil Med*. Sep 1998;30(3):167-74. doi:10.1080/003655098444101

247. Schmid A, Huonker M, Barturen JM, et al. Catecholamines, heart rate, and oxygen uptake during exercise in persons with spinal cord injury. *J Appl Physiol (1985)*. Aug 1998;85(2):635-41. doi:10.1152/jappl.1998.85.2.635

248. Eston RG, Faulkner JA, Mason EA, Parfitt G. The validity of predicting maximal oxygen uptake from perceptually regulated graded exercise tests of different durations. *Eur J Appl Physiol*. Jul 2006;97(5):535-41. doi:10.1007/s00421-006-0213-x

249. Eston RG, Lamb KL, Parfitt G, King N. The validity of predicting maximal oxygen uptake from a perceptually-regulated graded exercise test. *Eur J Appl Physiol*. Jun 2005;94(3):221-7. doi:10.1007/s00421-005-1327-2

250. van Drongelen S, de Groot S, Veeger HE, et al. Upper extremity musculoskeletal pain during and after rehabilitation in wheelchair-using persons with a spinal cord injury. *Spinal Cord*. Mar 2006;44(3):152-9. doi:10.1038/sj.sc.3101826

251. Nash MS, van de Ven I, van Elk N, Johnson BM. Effects of circuit resistance training on fitness attributes and upper-extremity pain in middle-aged men with paraplegia. *Arch Phys Med Rehabil*. Jan 2007;88(1):70-5. doi:10.1016/j.apmr.2006.10.003

252. Hutchinson MJ, Goosey-Tolfrey VL. Rethinking aerobic exercise intensity prescription in adults with spinal cord injury: time to end the use of "moderate to vigorous" intensity? *Spinal Cord*. Dec 08 2021;doi:10.1038/s41393-021-00733-2

253. Armstrong RB, Laughlin MH. Metabolic indicators of fibre recruitment in mammalian muscles during locomotion. *J Exp Biol*. Mar 1985;115:201-13.

254. Hawkins MN, Raven PB, Snell PG, Stray-Gundersen J, Levine BD. Maximal oxygen uptake as a parametric measure of cardiorespiratory capacity. *Med Sci Sports Exerc*. Jan 2007;39(1):103-7. doi:10.1249/01.mss.0000241641.75101.64

255. Midgley AW, McNaughton LR, Carroll S. Verification phase as a useful tool in the determination of the maximal oxygen uptake of distance runners. *Appl Physiol Nutr Metab*. Oct 2006;31(5):541-8. doi:10.1139/h06-023

256. Smith PM, Doherty M, Drake D, Price MJ. The influence of step and ramp type protocols on the attainment of peak physiological responses during arm crank ergometry. *Int J Sports Med*. Nov 2004;25(8):616-21. doi:10.1055/s-2004-817880

Compliance with Ethical Standards

Data availability: The data sets that were collected and analyzed for the purpose of this study are available from the corresponding author upon a reasonable request.

Ethical Approval: Not applicable for the scoping review. The CHOICES trial: CPET was conducted after the ethical approval of the University of British Columbia (H12-02945-11).

Author Contributions: AA and TN were responsible for conceptualizing the review idea and performing data analyses. Material preparation and data collection were performed by AA, TN, GB, and VBB. The first draft of the manuscript was written by AA and all authors commented on previous versions of the manuscript. AK is the principal investigator for the CHOICES trial. All authors read and approved the final manuscript.

Suppliers:

a. Microsoft Corp, Redmond, USA.

b. Lode BV, Groningen, The Netherlands

c. Parvomedics Truemax 2400, Sandy, UT, USA.

d. T31; Polar Electro Inc., Woodbury, NY, USA.

f. Statistical Package for the Social Sciences (SPSS), version 25; IBM Corporation, Armonk, USA.

Figure Legends:

Fig 1 Literature flow diagram representing study identification, review, and selection process. Records excluded studies were SCI participants < 80% of the sample, poster or conference proceedings, non-original. † Peak oxygen uptake ($\dot{V}O_{2peak}$).

Fig 2 Number of publications per year. This figure represents the included articles over time and highlights the increase of publications in the last ten years, with 46% of these published recently (i.e., during or after 2017).

Fig 3 Bland-Altman plots. Bland-Altman depicting absolute bias and 95% limit of agreement (LoA) of different averaging strategies relative to the 30-sec criterion. Dotted line represent mean bias and dashed lines represent the upper and lower 95% LoA.

Fig 4 Equivalence testing. All averaging strategies are depicted relative to the 30-sec criterion, showing as the mean and 90% confidence intervals. The area between the two dashed lines represents ±10% of the 30-sec (i.e., a proposed equivalence zone). None of the averaging strategies fall within the proposed equivalence zone, which indicates that these averaging strategies deemed not equivalent to 30-sec averaging strategy.

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

	n (%) or weighted mean ± 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

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

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

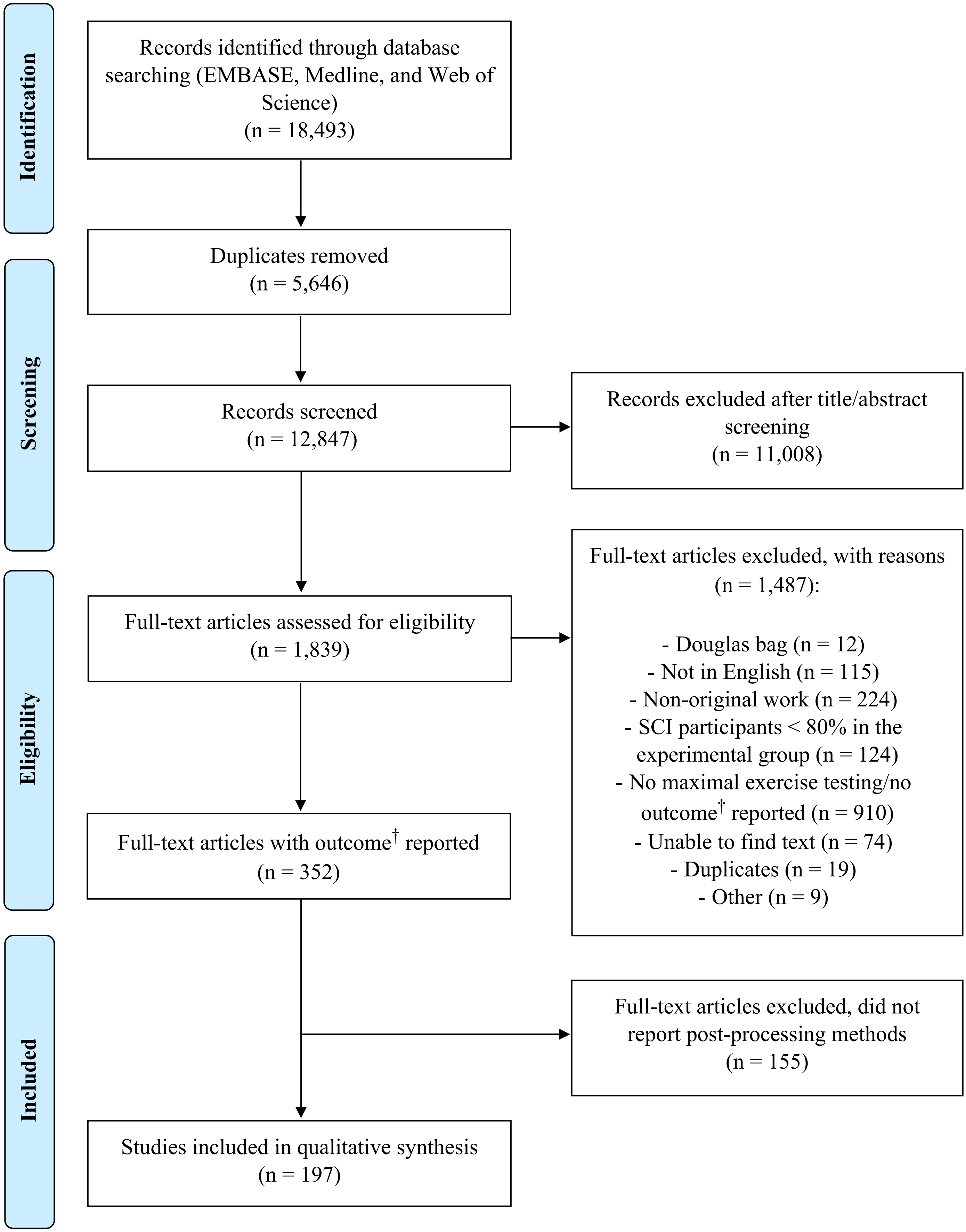
Table 2 Common $\dot{V}O_{2peak}$ end-point criteria reported within the included studies

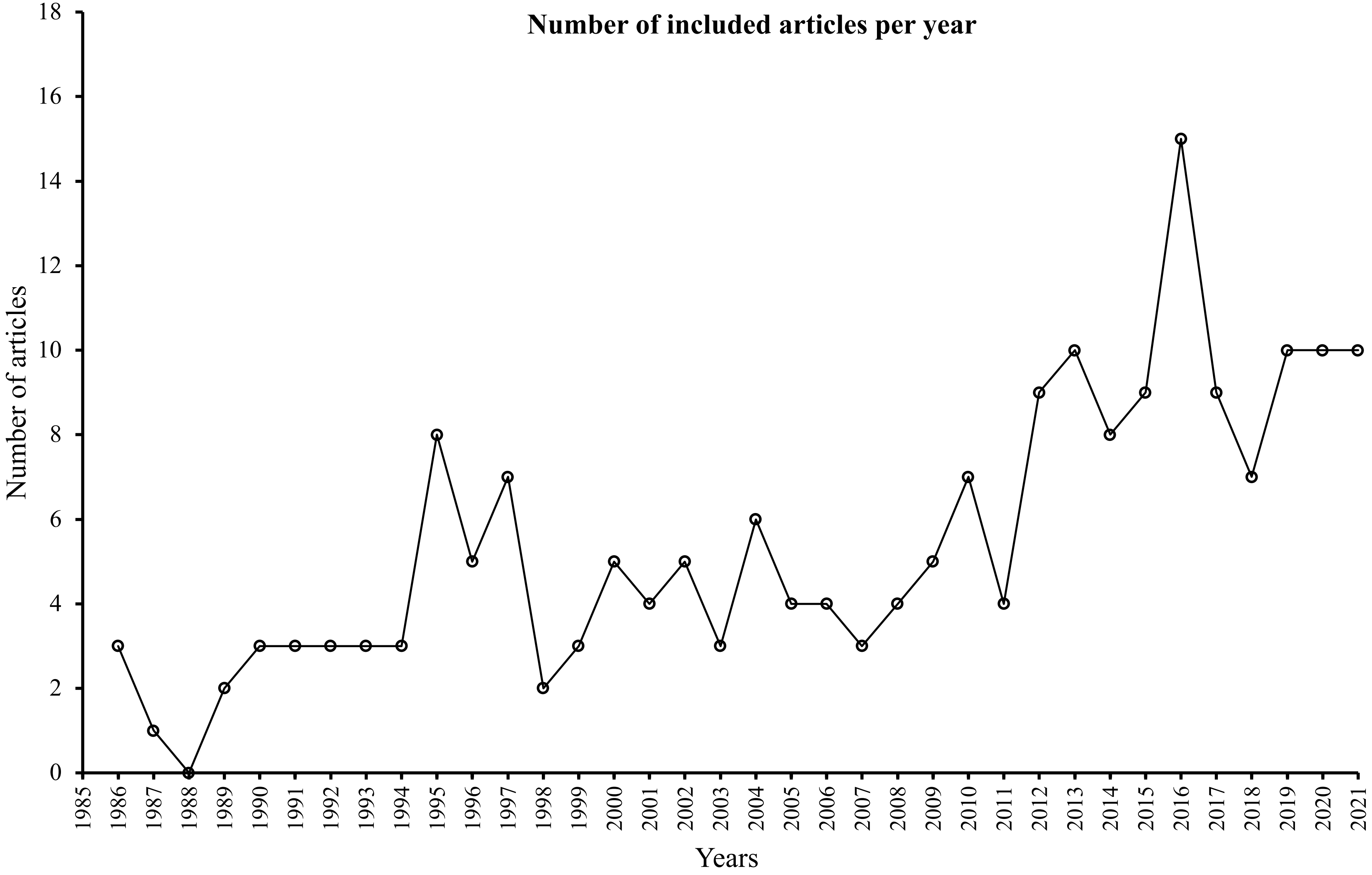
Criterion	Frequency *(%)*
Plateau, *n*=30	
$\dot{V}O_{2peak}$ < 2.0 (mL/kg/min)	2 *(7%)*
$\dot{V}O_{2peak}$ < 2.1 (mL/kg/min)	1 *(3%)*
$\dot{V}O_{2peak}$ < 150 (mL/min)	2 *(7%)*
Unspecified	25 *(83%)*
RER, *n*=55	
1.00	11 *(20%)*
1.05	6 *(11%)*
1.10	30 *(54%)*
1.15	8 *(15%)*
RPE, *n*=24	
15	4 *(17%)*
16	1 *(4%)*
17	12 *(50%)*
18	2 *(8%)*
19	5 *(21%)*
HR, *n*=29	
85% APMHR (220−age)	6 *(21%)*
95% APMHR (220−age)	4 *(14%)*
Other	16 *(55%)*
Unspecified	3 *(10%)*
Lactate level, *n*=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%)*

Abbreviations: APMHR, age-predicted maximal heart rate; HR, heart rate; RER, respiratory exchange ratio; RPE, rate of perceived exertion; $\dot{V}O_{2peak}$, peak oxygen uptake; W, watts.

* Equal to 5.55 mmol/L.

Fig 1


Identification
Screening
Eligibility
Included
Records identified through database searching (EMBASE, Medline, and Web of Science) (n = 18,493)
Duplicates removed (n = 5,646)
Records screened (n = 12,847)
Records excluded after title/abstract screening (n = 11,008)
Full-text articles assessed for eligibility (n = 1,839)
Full-text articles excluded, with reasons (n = 1,487):
- Douglas bag (n = 12)
- Not in English (n = 115)
- Non-original work (n = 224)
- SCI participants < 80% in the experimental group (n = 124)
- No maximal exercise testing/no outcome† reported (n = 910)
- Unable to find text (n = 74)
- Duplicates (n = 19)
- Other (n = 9)
Full-text articles with outcome† reported (n = 352)
Full-text articles excluded, did not report post-processing methods (n = 155)
Studies included in qualitative synthesis (n = 197)


Number of included articles per year
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Title: 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

Supplementary file

Appendix 1 Example of a search strategy

#	Searches	Results
Search 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 15 or 16 or 17 or 18 or 19	299341
Search 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

Appendix 2 Study characteristics of 197 included intervention studies

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ epoch used	PPO identification
ACE				
Alrashidi et al, 2020 [25]	*n* (female): 32 (8) Age (yrs): *M±SD*; (39±11) TSI: (yrs): *Median (IQR)*; 9 (18) NLI: range; C4-T6 Completeness: AIS A and B Training status: community (used LTPA)	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]	*n* (female): 38 (11) Age (yrs): *M±SD;* (42±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

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ epoch used	PPO identification
	Training status: recreationally active			
Barfield et al, 2010 [33]	*n* (female): 9 (0) Age (yrs): *M*±*SD:* (33±8) TSI: (yrs): *M*±*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]	*n* (female): 10 (0) Age (yrs): *M*±*SD:* (44±11) TSI: (yrs): *M*±*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]	*n* (female): 15 (4) Age (yrs): *M*±*SD:* (28±9) TSI: *M*±*SD:* (53±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 ≥ 1.05, RPE ≥ 15, Lactate ≥ 7mmol/L	3 consecutive 10-sec	Highest power maintained for last 60s
Capodaglio et al, 1996 [39]	*n* (female): 8 (0) Age (yrs): *M;* (31) TSI: *M*±*SD* (3 months) NLI: range; (T6-T8) Completeness: All complete Training status: NR	NR	30-sec	NR
Castle et al, 2013 [40]	*n* (female): 5 (2) Age (yrs): *M*±*SD:* (40±2) TSI: (yrs): *M*; (3.2 months) NLI: range; (C5-T10) Completeness: All complete	NR	15-sec	NR

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ 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±SD:* (34±10) TSI: (yrs): *M±SD:* (13±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±SD:* (47±9, 37±8) TSI: (yrs): *M±SD:* (16±9,16±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±SD;* (26±5) TSI: *M±SD;* (91±32,69±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±SD;* (36±13) TSI: (yrs): *M±SD;* (116±77 days) NLI: range*;* (C5-L1) Completeness: range*;* (AIS A-D) Training status: Athletes	NR	30-sec	NR

Paper	**Characteristics**	**$\dot{V}O_{2peak}$ criteria**	**Post-processing strategies**	
			$\dot{V}O_{2peak}$ epoch used	**PPO identification**
De Groot et al, 2021 [49]	*n* (female): 93 (12) Age (yrs): *M±SD;* (38±12) TSI: (yrs): *M±SD;* (12±10) NLI: tetraplegia and paraplegia Completeness: NR Training status: NR	NR	30-sec	Maintained for 30 seconds
De Mello et al, 2007 [50]	*n* (female): 12 (0) Age (yrs): *M±SD;* (32±8) TSI: (yrs): Chronic NLI: range; (T7-T12) Completeness: All AIS A Training status: NR	NR	20-sec	NR
Dwyer et al, 1997 [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
Escalona et al, 2018 [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 ≥ 8, RER ≥ 1.1	10-sec	NR
Farrow et al, 2021 [53]	*n* (female): 10 (2) Age (yrs): *M±SD;* (49±10) TSI: (yrs): *M±SD;* (22±13) NLI: range; (T3-T12) Completeness: AIS A and B Training status: PAL 1.5±0.17	RER≥1.1, RPE≥19, and HR≥95% (220-age)	15 breath rolling	Achieved before termination
Fenuta et al, (2014) [54]	*n* (female): 7 (0) Age (yrs): *M±SD;* (43±4) TSI: (yrs): *M±SD;* (4±0.6) NLI: range; tetraplegia and paraplegia Completeness: AIS C-D Training status: NR	NR	30-sec	NR
Frey et al, 1997 [55]	*n* (female): 7 (0) Age (yrs): *M±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

Paper	**Characteristics**	**$\dot{V}O_{2peak}$ criteria**	**Post-processing strategies**	
			$\dot{V}O_{2peak}$ 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]	*n* (female): 39 (10) Age (yrs): *M±SD;* (42±10) TSI: *M±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±SD;* (31±2) TSI: (yrs): *M±SD;* (9±3) NLI: NR Completeness: NR	NR	30-sec	NR

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ epoch used	PPO identification
	Training status: National athletes			
Gorman et al, 2014 [65]	*n* (female): 21 (2) Age (yrs): *M*±*SD;* (51±14) TSI: *M*±*SD;* (129±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]	*n* (female): 9 (0) Age (yrs): *M*±*SD:* (39±11) TSI: (yrs): *M*±*SD:* (11±10) NLI: range; (C2-T12) Completeness: Complete and incomplete Training status: ≤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]	*n* (female): 10 (6) Age (yrs): *M*±*SD:* (49±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]	*n* (female): 63 (17) Age (yrs): *M*±*SD:* (42±134) TSI: (yrs): *M*±*SD* (15±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*±*SD:* (36±5) TSI: (yrs): *M*±*SD:* (10±4) NLI: range; (C5-L1) Completeness: Frankel class A Training status: inactive	NR	15-sec	NR
Hopman et al, 1996 [72]	*n* (female): 21 (3) Age (yrs): *M*±*SD:* (32±12, 26.6±6, 36±10) TSI: (yrs): *M*±*SD:* (8.1±10, 7±5, 10±4) NLI: range; (C4-C8) Completeness: All complete except 4 Training status: trained, untrained, and sedentary	NR	30-sec	Highest PO maintained >1min

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ epoch used	PPO identification
Hopman et al, 1998 [73]	*n* (female): 9 (0) Age (yrs): *M±SD:* (34±9, 28±7) TSI: (yrs): *M±SD:* (11.4±8, 7±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±SD:* (41±11) TSI: (yrs): *M±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
Jacobs et al, 2013 [77]	*n* (female): 10 (0) Age (yrs): *M±SD:* (45±10) TSI: (yrs): *M±SD:* (15.1±9) NLI: range; (T4-T12) Completeness: AIS A-B Training status: NR	2 of: RER ≥ 1.10, plateau, volitional exhaustion	60-sec	NR
Jacobs et al, 2003 [78]	*n* (female): 15 (2) Age (yrs): *M±SD:* (28±7) TSI: (yrs): *M±SD:* (4±3) NLI: range; (T6-T11) Completeness: NR Training status: NR	NR	15-sec	NR
Jung et al, 2009 [79]	*n* (female): 6 (0) Age (yrs): *M±SD:* (46±7) TSI: (yrs): *M±SD:* (20±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

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ epoch used	PPO identification
Klimesova et al, 2017 [81]	*n* (female): 7 (0) Age (yrs): *M±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]	*n* (female): 10 (3) Age (yrs): *M±SD:* (39±14) TSI: (yrs): *M±SD:* (12±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]	*n* (female): 33 (5) Age (yrs): *M±SD:* (4±6) TSI: (yrs): *M±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]	*n* (female): 128 (22) Age (yrs): *M±SD:* (39±12) TSI: (yrs): *M±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]	*n* (female): 8 (1) Age (yrs): *M±SD:* (28±4) TSI: (yrs): *M±SD:* (8±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 $\dot{V}O_{2peak}$

Paper	**Characteristics**	**$\dot{V}O_{2peak}$ criteria**	**Post-processing strategies**	
			$\dot{V}O_{2peak}$ epoch used	**PPO identification**
	Completeness: Complete and incomplete Training status: NR			
Lovell et al, 2012 [89]	*n* (female): 20 (0) Age (yrs): *M±SD:* (41±8, 37±6) TSI: (yrs): *M±SD:* (17±13, 9±4) NLI: range; (T4-L5) Completeness: NR Training status: Trained hand cyclists, some untrained but physically active	All of: RER >1.15, HR within 10bpm of predicted MHR, lactate >8mmol/L	Last 60-sec	Power output corresponding to $\dot{V}O_{2peak}$
Machač et al, 2016 [90]	*n* (female): 47 (0), 20 SCI Age (yrs): *M±SD:* (31±5) TSI: (yrs): *M±SD:* (8±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±SD:* (33±111) TSI: (yrs): *M±SD:* (24±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±SD:* (35.9±9.3) TSI: (yrs): *M±SD:* (12.8±7.3,15.8±7.4) NLI: Tetraplegia and paraplegia Completeness: NR Training status: 32.1±19.4; 55.5±30.8 (units not specified)	All of: plateau, RER >1.0, reported exhaustion	20-sec	NR
McLean et al, 1995 [94]	*n* (female): 11 (1) Age (yrs): *M±SD:* (29±6) TSI: (yrs): *M±SD:* (10±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): *M±SD:* (34.3±12.1, 33.3±7) TSI: (yrs): *M±SD:* (9.3±12.5, 14.1±6.4)	NR	20-sec	NR

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ 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 Completeness: AIS A, B, C and D Training status: Recreationally active	NR	60-sec	NR
McMillan et al, 2021 [97]	*n* (female): 10 (0) Age (yrs): *M±SD:* (39±10) TSI: (yrs): *M±SD:* (13±9) NLI: T2-T10 Completeness: AIS A, B and C Training status: Good CRF	NR	20-sec	NR
Morgan et al, 2019 [98]	*n* (female): 10 (0) Age (yrs): *M±SD:* (33±20) TSI: (yrs): Chronic NLI: C6-T11 Completeness: AIS A, B, C Training status: MVPA, sport participation	RER≥1.1, RPE≥17	60-sec	NR
Murray et al, 2020 [99]	*n* (female): 19 (NR) Age (yrs): *M±SD:* (44.6±14.2) TSI: (yrs): Chronic NLI: Tetraplegia and paraplegia Completeness: AIS A, B, C Training status: NR	NR	8 breath	NR
Myers et al, 2010 [100]	*n* (female): 63 (NR) Age (yrs): *M±SD:* (54±15, 50±11, 50±10) TSI: (yrs): *M±SD:* (22±11, 13±12, 19±12) NLI: range; (T2-T6, T4-T7, T2-S1) Completeness: AIS A, B and C Training status: Mostly sedentary	NR	30-sec	NR
Nightingale et al, 2017 [101]	*n* (female): 33 (6) Age (yrs): *M±SD:* (44±9) TSI: (yrs): *M±SD:* (15±10) NLI: range; (T1-L4) Completeness: range; (AIS A-D) Training status: NR	NR	30-sec	NR
Nooijen et al, 2015 [102]	*n* (female): 37 (6) Age (yrs): *MED (IRQ):* 44(30-56) TSI: (yrs): *MED (IRQ):* 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]	*n* (female): 39 (4) Age (yrs): *M±SD;* (44±15) TSI: (day): *M±SD*; (150±74) NLI: range*;* Tetraplegia and paraplegia Completeness: Complete and incomplete Training status: NR	NR	30-sec	Highest maintained for 30 sec

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ epoch used	PPO identification
Nooijen et al, 2015 [104]	*n* (female): 36 (6) Age (yrs): *M*±*SD;* (43±15) TSI: (months): *M*±*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*±*SD:* (46±12) TSI: (yrs): *M*±*SD:* (14±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

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ 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]	*n* (female): 20 (8) Age (yrs): *M±SD:* (31.31±8.17) TSI: *M±SD:* (3.81±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): *range;* (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±SD:* (38±10) TSI: (yrs): *M±SD:* (13±10) NLI: range; (C1-L2) Completeness: AIS A, B, C, D Training status: Recreationally active	NR	30-sec	NR
Valent et al, 2007 [118]	*n* (female): 20 (2) Age (yrs): *M±SD;* (39.7±11.6) TSI: (yrs): *M±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): *M±SD;* (39±12) TSI: (yrs): *M±SD;* (10±7) NLI: range; (C5-T1) Completeness: range; (AIS A-D)	NR	30-sec	Highest power output maintained for 30s

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ 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]	*n* (female): 18 (0) Age (yrs): *M±SD;* (36±9, 42±6) TSI: (yrs): *M±SD;* (12±7, 10±7) NLI: <T6 Completeness: NR Training status: Physically active and inactive	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]	*n* (female): 14 (6) Age (yrs): *M±SD;* (44±10) TSI: (yrs): *M±SD;* (22±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]	*n* (female): 10 (0) Age (yrs): *M±SD;* (33.5±8.8) TSI: (yrs): *M±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

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ 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]	*n* (female): 16 (0) Age (yrs): *M*±*SD;* (33.6±8.7, 31.8±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

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ 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±SD;* (45±10) TSI: (yrs): *M±SD;* (11±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 PO during the 60-sec of $\dot{V}O_{2\,peak}$
Dallmeijer et al, 2004 [140]	*n* (female): 9 (0) Age (yrs): *M±SD;* (36.3±7.8) TSI: (yrs): *M±SD;* (13.3±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±SD;* (36.5±13.9) TSI: (yrs): *M±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	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ 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]	*n* (female): 158 (30%) Age (yrs): *M±SD;* (47.9±8.6) TSI: (yrs): *M±SD;* (23.5±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]	*n* (female): 139 (27%) Age (yrs): *M±SD;* (41.6±14.1) TSI: (yrs): *M±SD;* (705±169d) NLI: 68% paraplegia Completeness: 64% complete Training status: *M±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]	*n* (female): 25 (4) Age (yrs): *M±SD;* (35.3±14.9) TSI: (yrs): *M±SD;* (7.64±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	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ epoch used	PPO identification
	Training status: All inactive except 2 athletes			
Goss et al, 1992 [150]	*n* (female): 5 (2) Age (yrs): *M±SD;* (29.6±6.9) TSI: (yrs): *M±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]	*n* (female): 7 (0) Age (yrs): *M±SD;* (35.2±15.9) TSI: (yrs): *M±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]	*n* (female): 16 (0) Age (yrs): *M±SD;* (37±11) TSI: (yrs): *M±SD;* (141±133 mo) NLI: range; (C5-T10) Completeness: NR Training status: 4.2±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 $\dot{V}O_{2peak}$
Janssen et al, 1993 [156]	*n* (female): 44 (0) Age (yrs): *M±SD;* (34±12) TSI: (yrs): *M±SD;* (11.1±8) NLI: range; (C4-L5) Completeness: NR Training status: 2.6±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): *M±SD;* (36±3)	RER≥1.1, RPE≥9	30-sec	Highest power output maintained for >30s

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ epoch used	PPO identification
	TSI: (yrs): range; 3.5-14 NLI: Tetraplegia and paraplegia Completeness: NR Training status: NR			
Kilkens et al, 2004 [158]	*n* (female): 74 (23) Age (yrs): *M*±*SD;* (41±15) TSI: (yrs): Acute NLI: NR Completeness: range; (AIS A-D) Training status:NR	NR	30-sec	Highest power output maintained for >30s
Le Foll-de Moro et al, 2005 [159]	*n* (female): 6 (1) Age (yrs): *M*±*SD;* (29±14) TSI: (yrs): *M*±*SD;* (94±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]	*n* (female): 19 (2) Age (yrs): *M*±*SD;* (28±4, 26±6) TSI: (yrs): NR NLI: range; (C5-L4) Completeness: NR Training status: National athletes	NR	20-sec	NR
Leving et al, 2019 [161]	*n* (female): 24 (6) Age (yrs): *M*±*SD;* (40±17, 41±11) TSI: (yrs): *M*±*SD;* (0.2±0.05, 7±5) NLI: range; (C5-L3) Completeness: AIS A, B, C, D Training status: NR	NR	30-sec	NR
Litchke et al, 2008 [162]	*n* (female): 9 (0) Age (yrs): *M*±*SD;* (30±7, 30±10) TSI: (yrs): *M*±*SD;* (18±15, 6.8±5) NLI: range; (C5-T12) Completeness: NR Training status: Recreationally active	NR	60-sec	NR
Morgulec-Adamowicz et al, 2011 [163]	*n* (female): 30 (0) Age (yrs): *M*±*SD;* (32±9, 31±8, 30±5, 32±5) TSI: (yrs): *M*±*SD;* (9±6, 10±5, 11±4, 13±6) NLI: NR Completeness: range; (IWRF 0.5-3.5 points) Training status: Rugby athletes	NR	10-sec	NR
Nooijen et al, 2012 [164]	*n* (female): 30 (8) Age (yrs): *M*±*SD;* (42±15) TSI: (months): range; (5±2) NLI: range*;* () Completeness: Training status:	NR	30-sec	Highest maintained for 30sec

Paper	**Characteristics**	**$\dot{V}O_{2peak}$ criteria**	**Post-processing strategies**	
			$\dot{V}O_{2peak}$ epoch used	**PPO identification**
Paulson et al, 2013 [165]	*n* (female): 8 (0) Age (yrs): *M±SD;* (31±8) TSI: (yrs): *M±SD;* (11±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]	*n* (female): 8 (1) Age (yrs): *M±SD;* (33±12) TSI: (yrs): *M±SD;* (19±8) NLI: range; (Th4-Th12) Completeness: range; (AIS A-D) Training status: Athletes	NR	15-sec	NR
Postma et al, 2013 [168]	*n* (female): 180 (26.1%) Age (yrs): *M±SD;* (40±14) TSI: *M±SD;* (101.8±62.1 days) NLI: range; (C3-T7) Completeness: range; (AIS A-D) Training status: Rehab	NR	30-sec	NR
Qi et al, 2015 [169]	*n* (female): 11 (3) Age (yrs): *M±SD;* (42±8) TSI: (yrs): *M±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]	*n* (female): 9 (NR) Age (yrs): *M±SD;* (34±11) TSI: (yrs): *M±SD;* (*10*±10) NLI: range; (T4-L1) Completeness: All complete Training status: Recreationally active	NR	30-sec	Highest load maintained for 1 min 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 min at a constant speed
Tordi et al, 2001 [172]	*n* (female): 5 (0) Age (yrs): *M±SD;* (27±8.1) TSI: (yrs): NR NLI: range; (T6-L4)	All of: MHR, (220-age) plateau, RER >1.0	15-sec	NR

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ epoch used	PPO identification
	Completeness: All AIS A Training status: Physically active			
Torhaug et al, 2016 [173]	*n* (female): 17 (0) Age (yrs): *MED;* (48, 46) TSI: (yrs): *MED;* (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 Completeness: range; (AIS A-D) Training status: Hand cycle trained	NR	30-sec	Highest power output maintained for 30s
Valent et al, 2008 [175]	*n* (female): 131 (30%) Age (yrs): *M±SD;* (48±15, 39±15, 38±14, 33±7) TSI: (yrs): Acute NLI: Paraplegia and tetraplegia Completeness: range; (AIS A-B) Training status: Active rehab	NR	30-sec	Highest power output maintained for 30s
van der Scheer et al, 2016 [176]	*n* (female): 29 (7) Age (yrs): *MED, IQR;* (47, 45-64) TSI: (yrs): *MED, IQR;* (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]	*n* (female): 162 (24%) Age (yrs): *M±SD;* (39±14) TSI: (yrs): *M±SD;* (6±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]	*n* (female): 118 (26) Age (yrs): *M±SD;* (40±13, 36±13) TSI: (yrs): Acute NLI: 70 <T1, 18 ≥T1 Completeness: range; (AIS A-D) Training status: NR	NR	30-sec	Highest power output maintained for 30s
Veeger et al, 1991 [179]	*n* (female): 45 (8) Age (yrs): *M±SD;* (33±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

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ 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]	*n* (female): 8 (0) Age (yrs): *M*±*SD;* (31±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*±*SD;* (36±10) TSI: (yrs): *M*±*SD;* (8±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]	*n* (female): 6 (0) Age (yrs): *M*±*SD;* (40±11) TSI: (yrs): *M*±*SD;* (17.5±8) NLI: range; (C7-T8) Completeness: AIS A Training status: untrained aerobically	All of: RER ≥ 1.05, RPE ≥ 15, Lactate ≥ 7mmol/L	30-sec	NR
Berry et al, 2008 [187]	*n* (female): 12 (3) Age (yrs): *M*±*SD;* (42±8) TSI: (yrs): *M*±*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 ≥ 1.15, RPE ≥ 17, plateau	15-sec	NR

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ epoch used	PPO identification
	Training status: NR			
Forbes et al, 2010 [189]	*n* (female): 6 (3) Age (yrs): *M±SD;* (37±13) TSI: (yrs): Chronic NLI: range*;* (T7-L11) Completeness: All complete Training status: National Nordic ski team	NR	20-sec	NR
Gayle et al, 1990 [190]	*n* (female): 15 (0) Age (yrs): *M±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±SD;* (37±13) TSI: (yrs): *M±SD;* (4±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±SD;* (28±7) TSI: (yrs): *M±SD;* (4±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±SD;* (36±16) TSI: (yrs): *M±SD;* (11±9) NLI: range; (C4-T11) Completeness: NR Training status: NR	NR	30-sec	Highest calculation: resistance × crank rate
Jung et al, 2012 [196]	*n* (female): 10 (3) Age: *M±SD;* (37±12 months) TSI: *M±SD; (*29±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

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ epoch used	PPO identification
Leech et al, 2017 [197]	*n* (female): 11 (2) Age (yrs): *M±SD;* (41±14) TSI: *M±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]	*n* (female): 10 (0) Age (yrs): *M±SD;* (44±10) TSI: *M±SD;* (95±87 months) NLI: range; (C2-C7) Completeness: All AIS D Training status: NR	NR	Last 60-sec	NR
Lundgaard et al, 2017 [199]	*n* (female): 19 (0) Age (yrs): *M±SD;* (46±14) TSI: (yrs): *M±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]	*n* (female): 20 (0) Age (yrs): *M±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]	*n* (female): 27 (1) Age (yrs): *M±SD:* (39±10) TSI: (yrs): *M±SD:* (13±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]	*n* (female): 11 (0) Age (yrs): *M±SD;* (36±6.6) TSI: (yrs): *M±SD;* (10±4) NLI: range; (C5-L1) Completeness: All AIS A Training status: Inactive	NR	Last 60-sec	NR
Paulson et al, 2014 [204]	*n* (female): 5 (1) Age (yrs): *M±SD;* (44±15) TSI: (yrs): *M±SD;* (8±10) NLI: range; (T5-T6) Completeness: All complete Training status: Recreationally active	NR	30-sec	Highest power output

Paper	**Characteristics**	**$\dot{V}O_{2peak}$ criteria**	**Post-processing strategies**	
			$\dot{V}O_{2peak}$ 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, >20W power decline during max stimulation	Last 30-sec	NR
Taylor et al, 2014 [208]	*n* (female): 14 (1) Age (yrs): *M±SD;* (39±3.3) TSI: (yrs): *M±SD;* (10±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

Paper	Characteristics	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ epoch used	PPO identification
	Training status: NR			
Torhaug et al, 2016 [212]	*n* (female): 12 (0) Age (yrs): *MED;* (46.5) TSI: (yrs): *MED;* (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]	*n* (female): 5 (0) Age (yrs): *M±SD;* (47±19) TSI: (yrs): *M±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 ≥1.1, RPE ≥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±SD;* (40±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	$\dot{V}O_{2peak}$ criteria	Post-processing strategies	
			$\dot{V}O_{2peak}$ epoch used	PPO identification
Wouda et al, 2021 [220]	*n* (female): 30 (5) Age (yrs): *M*±*SD;* (4±17) TSI: *M*±*SD* (69±29 days) NLI: Tetraplegia and paraplegia Completeness: AIS A and D Training status: NR	RER>1.15, 85% (male> 220-0.88×age, female 220-0.66×age), lactate> 8 mmol/L	30-sec	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; $\dot{V}O_{2peak}$, peak oxygen uptake.