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

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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 ≥ 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.

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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: $\sum n * \bar{x} / \sum n$, where $\sum$ and n were the sum and number of participants in each study, respectively and $\bar{x}$ = 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.

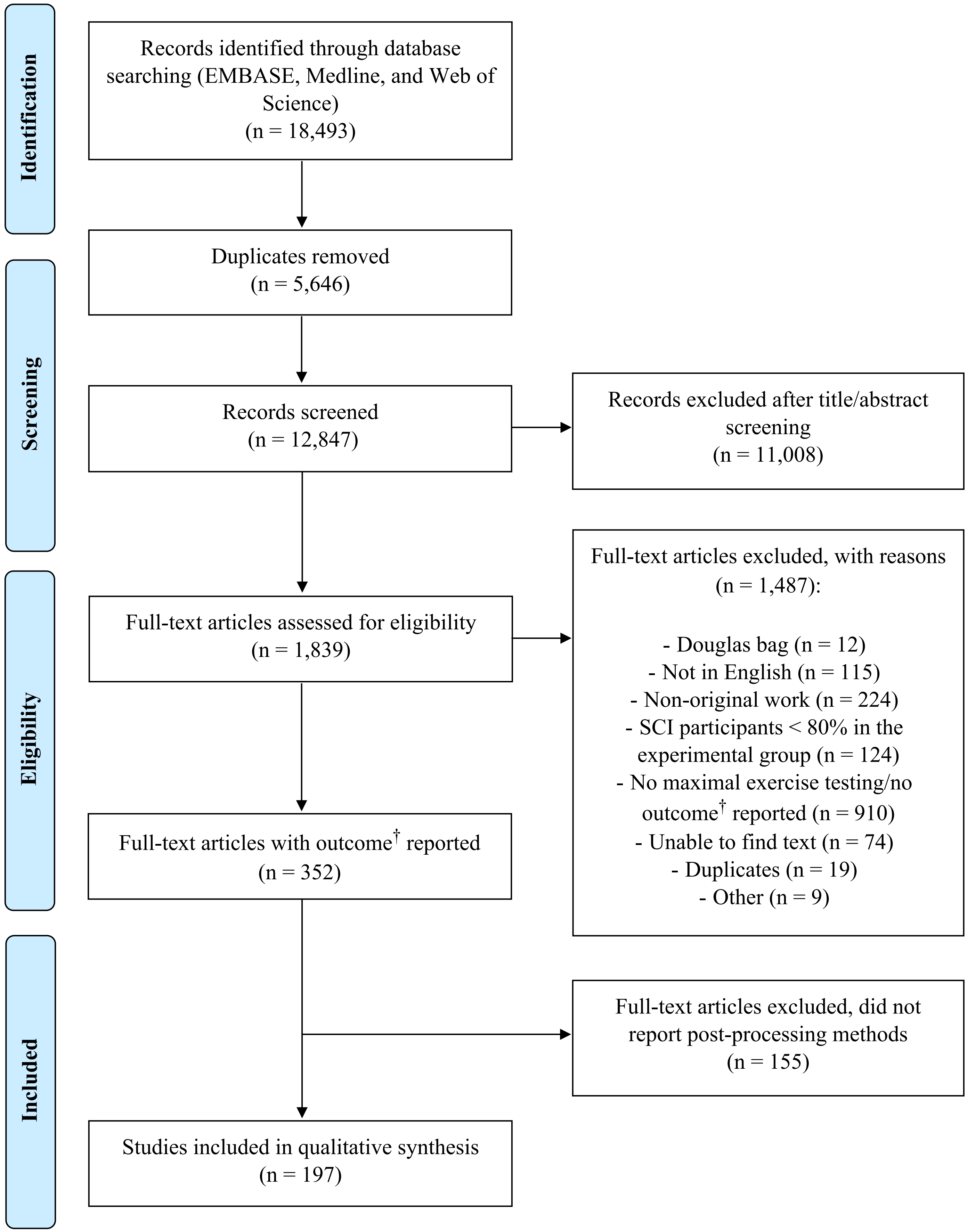
Table 2 Common $\dot{V}O_{2peak}$ end-point criteria reported within the included studies

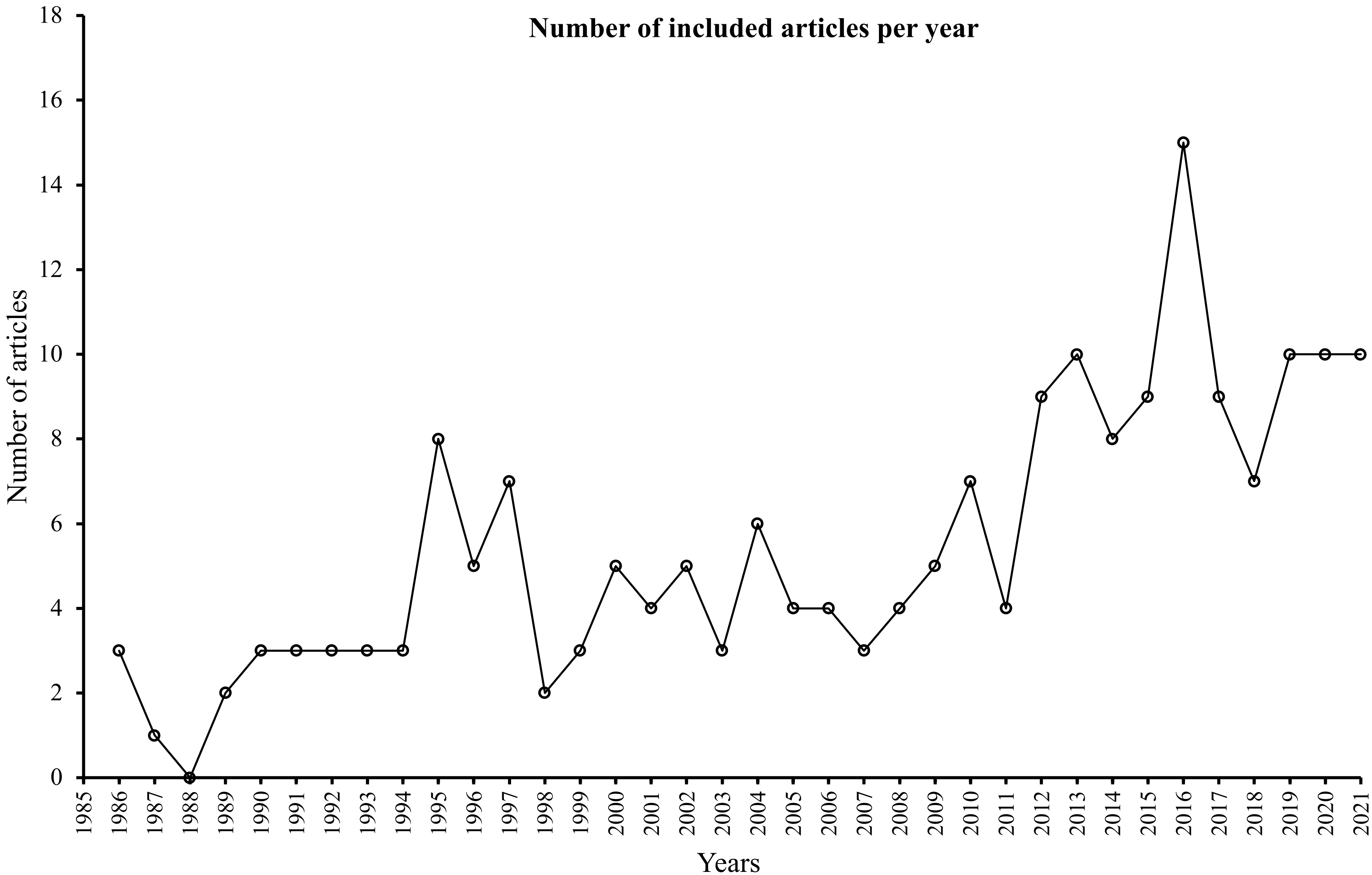
Criterion	Frequency *(%)*
Plateau, *n*=30	
$\dot{V}O_{2peak}$ < 2.0 (mL/kg/min)	2 *(7%)*
$\dot{V}O_{2peak}$ < 2.1 (mL/kg/min)	1 *(3%)*
$\dot{V}O_{2peak}$ < 150 (mL/min)	2 *(7%)*
Unspecified	25 *(83%)*
RER, *n*=55	
1.00	11 *(20%)*
1.05	6 *(11%)*
1.10	30 *(54%)*
1.15	8 *(15%)*
RPE, *n*=24	
15	4 *(17%)*
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 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 assessed for eligibility (n = 1,839)
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
Number of articles
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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	Post-processing strategies: 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.