Data Processing Strategies to Determine Maximum Oxygen Uptake: A Systematic Scoping Review and Experimental Comparison

Bachelor thesis

from

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Personally signed

Zusammenfassung (German abstract)

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1 Introduction

1.1 Background

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Bassett (2000); Tricco et al. (2018)

2 Methods

The work presented in this thesis was preregistered before the start of the project on the Open Science Framework. Any deviations from the preregistration are indicated in the 'Transparent Changes' document (LINK/Appendix). Major deviations will also explicitly name be named within the methods section. All data and code of this research project can be found at GitHub.

2.1 Systematic Scoping Review

The aim of the Scoping review was to systematically map current practices of data processing for $\dot{V}O_{2max}$ determination in the scientific literature. Since the $\dot{V}O_{2max}$ determination is too common to perform an exhaustive search, I randomly sampled 500 articles that referred to $\dot{V}O_{2max}$ or similar keywords. Data on processing strategies was extracted from all sampled articles that directly measured $\dot{V}O_{2max}$ using an appropriate testing procedure in humans.

The review was performed in accordance to the PRISMA extension for Scoping reviews (Tricco et al., 2018). Appendix A contains the corresponding reporting checklist.

2.1.1 Search & Screening

The article search was conducted on 16th March 2022 using PubMed and Web of Science. The search included articles published from 2017 to 2022 referring to 'maximum oxygen uptake' or equivalent terms in title, abstract or keyword. Table 1 shows the exact search terms used.

Table 1: Search strings for the systematic scoping review.

Source	Search String
PubMed	(((((“maximum oxygen uptake”) OR (“maximal oxygen uptake”)) OR (“VO2max”)) OR (“maximum oxygen consumption”)) OR (“maximal oxygen consumption”)) AND ((“2017/01/01”[Date - Publication] : “3000”[Date - Publication]))
Web of Science	(((((ALL=(“maximum oxygen uptake”)) OR ALL=(“maximal oxygen uptake”)) OR ALL=(“VO2max”)) OR ALL=(“maximum oxygen consumption”)) OR ALL=(“maximal oxygen consumption”)) AND PY=(2017-2022)

The search results from both data bases were joined and checked for the presence of a DOI. Entries without DOI were excluded, to allow for automated removal of duplicates by DOI matching in the next step. After the removal of duplicates I conducted an automated title scanning to remove results that were likely no original research articles. Table 2 displays the exclusion terms during the automated title screening.

Table 2: Exclusion terms during automated title screening after removal of duplicates. If an articles title matched least one of the given terms, it was excluded.

Search terms for exclusion by title
review, correction, meta-analysis, comment, retraction, editorial, erratum, reply

In accordance with the preregistration a random sample was drawn from the search results. The goal of the random sample was to give an unbiased sample of the current state of scientific $\dot{V}O_{2max}$ testing. Based on the procedure described in the preregistration file (LINK), the sample included a total of 500 articles.

The abstracts from the articles included in the random sample were blinded for scanning. This included the removal of any further information not relevant for the screening—such as authors or journals—leaving only the title, abstract and an ID of the article (see Appendix XXX for an example). Two researchers independently scanned the abstracts to filter those that matched one of the exclusion criteria shown in Table 3. When the screeners disagreed in their assessments, conflicts were resolved by discussion.

After the abstract screening I retrieved the full-texts for all articles remaining in the review. The full-texts were again independently scanned by two researchers to include only those articles that measured $\dot{V}O_{2max}$ using an appropriate testing procedure in humans (see Table 3 for the full-text exclusion criteria). Conflicts were resolved by discussion.

All data exclusion steps are documented under XXXLINK.

2.1.2 Data Extraction

I retrieved data from all articles remaining after the abstract and full-text screening. Extraction included the following data:

- metabolic cart used
- type of metabolic cart/data basis (breath-by-breath, mixing chamber, …)
- type of outcome for $\dot{V}O_{2max}$ (primary, secondary, other)
- preprocessing algorithm
- data processing software
- interpolation procedure
- data processing/determination of $\dot{V}O_{2max}$:
  - type (time average, breath average, digital filtering)
  - alignment (rolling, binned, …)
  - interval (in sec/breath, parameters for filtering)
  - interpolation procedure
- reference for the used data processing strategy

All extracted data is available in the Appendix XXX and under XXXLINK.

2.1.3 Data Synthesis

The extracted data is presented in a purely descriptive way. I calculated relative and absolute proportions of the different extracted variables.

2.2 Experimental Comparison

To determine the influence the most common data processing strategies have on the determination $\dot{V}O_{2max}$, I compared them on a set of already collected gas exchange data from running.

2.2.1 Data Source

A total of N = 72 exercise test were analysed for this study. The data was from previous research on the metabolic profile of endurance runners (Quittmann et al., under review, unpubl.). The tested individuals were experienced distance runners (XXX male, XXX female; XXX two times). The $\dot{V}O_{2max}$ tests were conducted in XXX to September 2019 (Quittmann et al., under review) and March to October 2021 (Quittmann et al., unpubl.) using the same protocol. Participants run on a treadmill (XXX) with 1% inclination for ten minutes at a velocity of 2.8 m/s as a warm-up. After placing the mask for the gas exchange measures, they started a ramp protocol with an initial speed of 2.8 m/s for two minutes and subsequently increased velocity by 0.15 m/s every 30 seconds. The researchers provided verbal encouragement and terminated the exercise when the participants reached subjective exhaustion.

Gas exchange data were recorded using a ZAN XXX device (XXX). The device was calibrated with a 3l-syringe pump (XXX) and a reference gas (XXX) before each measurement. The measured breath-by-breath data is available at XXXLINK.

2.2.2 Data Processing

The spiro Package Version XXX for R (Nolte, 2022) processed the raw gas exchange data. It includes various algorithms to calculate $\dot{V}O_{2max}$ with user-defined parameters on given data. Table 4 displays a brief summary of exemplary functions and parameters used for the analysis. The full analysis script is available at XXXLINK.

proc_type	func	parameter
Moving Time Average	`spiro_max()`	`smooth = 30`
Binned Time Average	`spiro_summary()`	XXX
Multiple Binned Time Average	`spiro_summary(); filter()`	XXX
Moving Breath Average	`spiro_max()`	`smooth = "10b"`
Digital Filtering	`spiro_max()`	‘smooth = “XXX”

2.2.2.1 Time based averaging

2.2.2.2 Breath based averaging

2.2.2.3 Butterworth filtering

2.2.3 Comparison of methods

To compare different processing methods within and between individuals, I choose to express the $\dot{V}O_{2max}$ normalized to a reference procedure. The reference procedure was chosen as being the most commonly applied in current literature as determined by the systematic review. Individual $\dot{V}O_{2max}$ values were expressed in reference to this procedure, where a value of 1 means that the processing method yields exactly the same $\dot{V}O_{2max}$ value as the reference method. I calculated the data for all integer parameter values within the range of the values found in the literature during the review. On a group level I calculated the median and 2.5 and 97.5-quantiles of each processing strategy.

3 Results

3.1 Systematic Scoping Review

Initial search yielded 7529 results of which 4364 remained after automated filtering and removal of duplicates (see flow diagramm in Figure 1). Out of the random sample (n = 500), 244 articles were included in the final analysis.

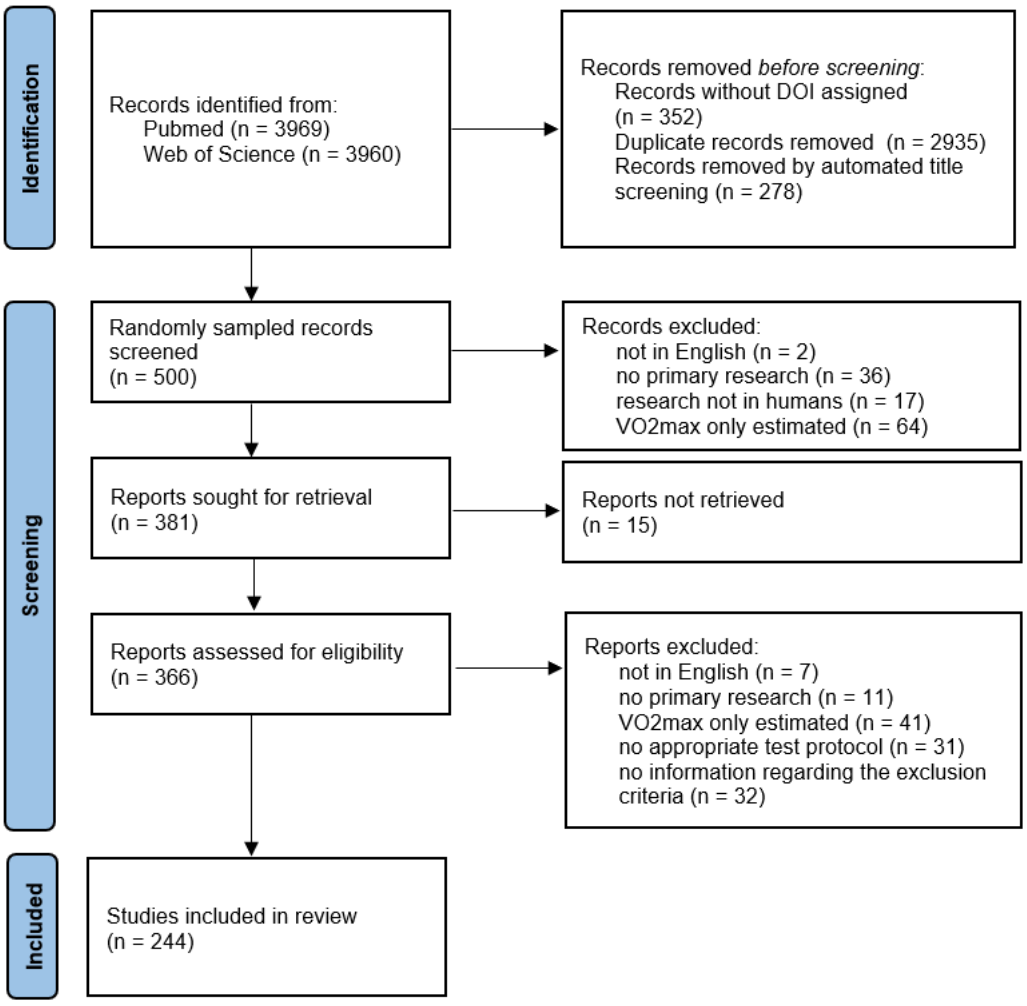

Figure 1: Flow diagram for the systematic scoping review in accordance with the PRISMA 2020 Statement (Page et al., 2021)

Reporting practices of the methodology of gas exchange measures differed widely within the literature (see Table 4). More than half (51.8%) of the articles did not report any information on their data processing strategy. Only one in twenty articles (5.4%) provided a rationale for their used strategy.

Table 4: Percentage of studies that provided details on the different characteristics of oxygen uptake data processing. *only examined within the subgroup of studies using breath-by-breath measurements

Metabolic cart	Preprocessing	Software	Processing Strategy	Reference
76.9%	5.6%*	14.4%*	49.2%	5.4%

Out of the authors that provided information and collected breath-by-breath measurements most (79.5%) utilized binned averages to determine $\dot{V}O_{2max}$. Moving time averages, or breath-based averages were uncommon (see Figure 2). No study used digital filtering methods to determine $\dot{V}O_{2max}$.

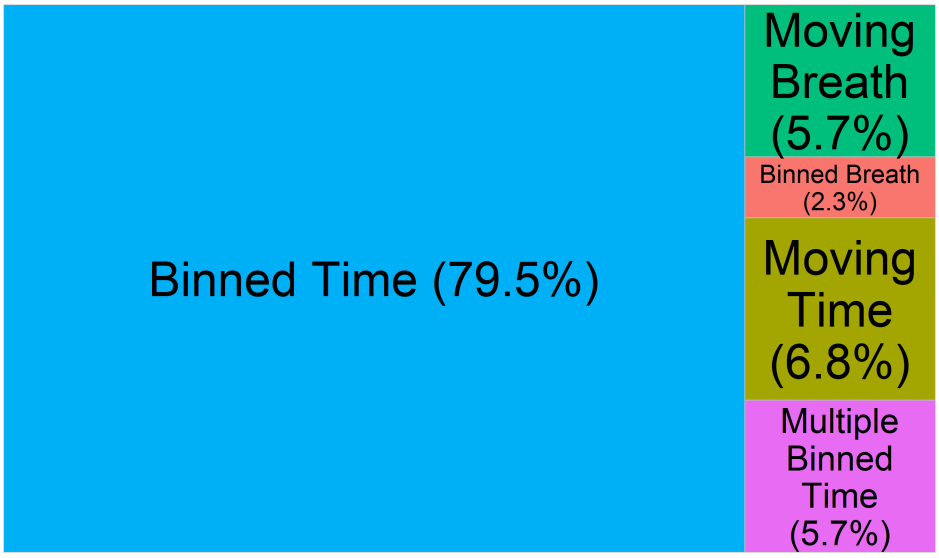

Figure 2: Data strategies for processing breath-by-breath data in the reviewed literature (n = 88).

The calculation interval for time-based averages of mixing chamber and breath-by-breath devices ranged from 5 to 60 seconds (see Figure 3). 30 second length intervals were most common to define $\dot{V}O_{2max}$, while authors also often employed shorter (10-20s) and longer (60s) periods.

3.2 Experimental Comparison

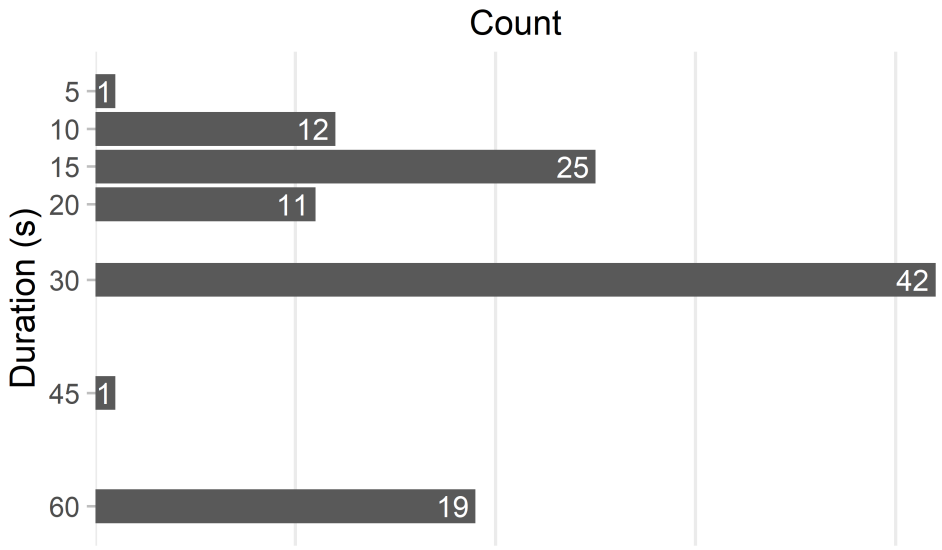

Figure 3: Total durations of the calculation interval of $\dot{V}O_{2max}$ in the reviewed studies.

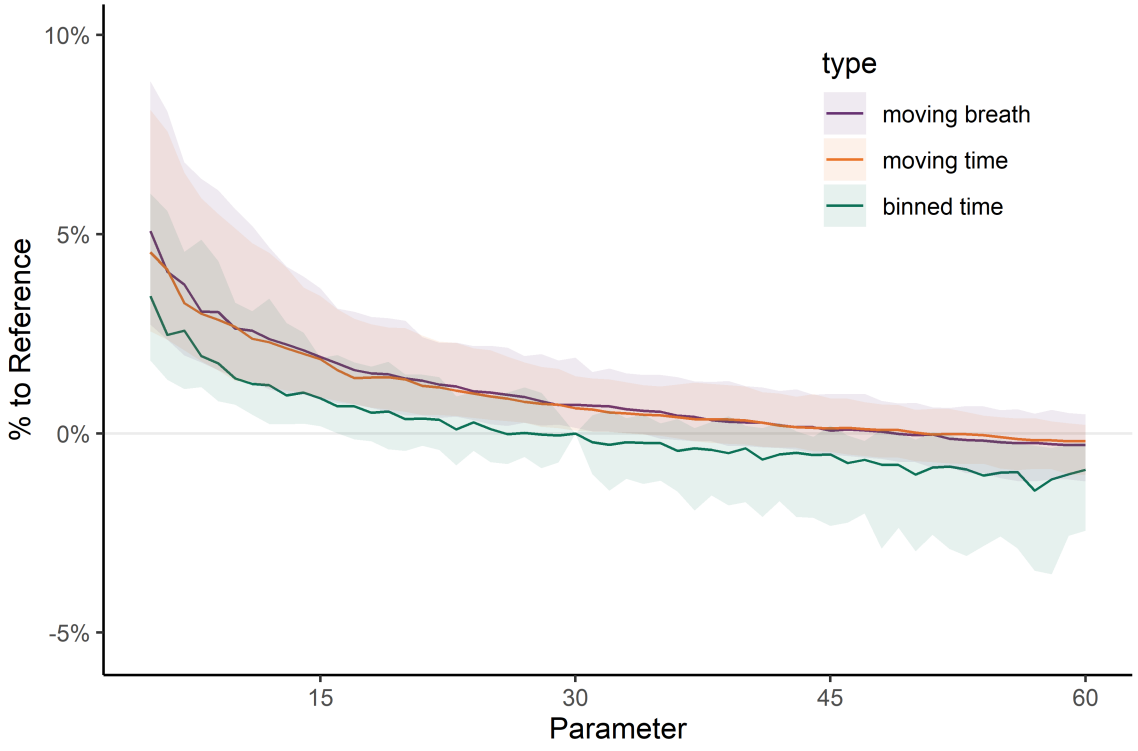

Figure 4: VO2max varies by data processing strategy. Values are expressed relative to the VO2max from a 30-second binned average — the most common strategy as determined by the review. Solid lines display the median, the shaded area marks the interval between 10th and 90th percentile. Using moving average leads to systematically higher VO2max values compared to binned time averages. Changing the averaging interval (in seconds or breaths) can lead to changes in VO2max as large as 5%.

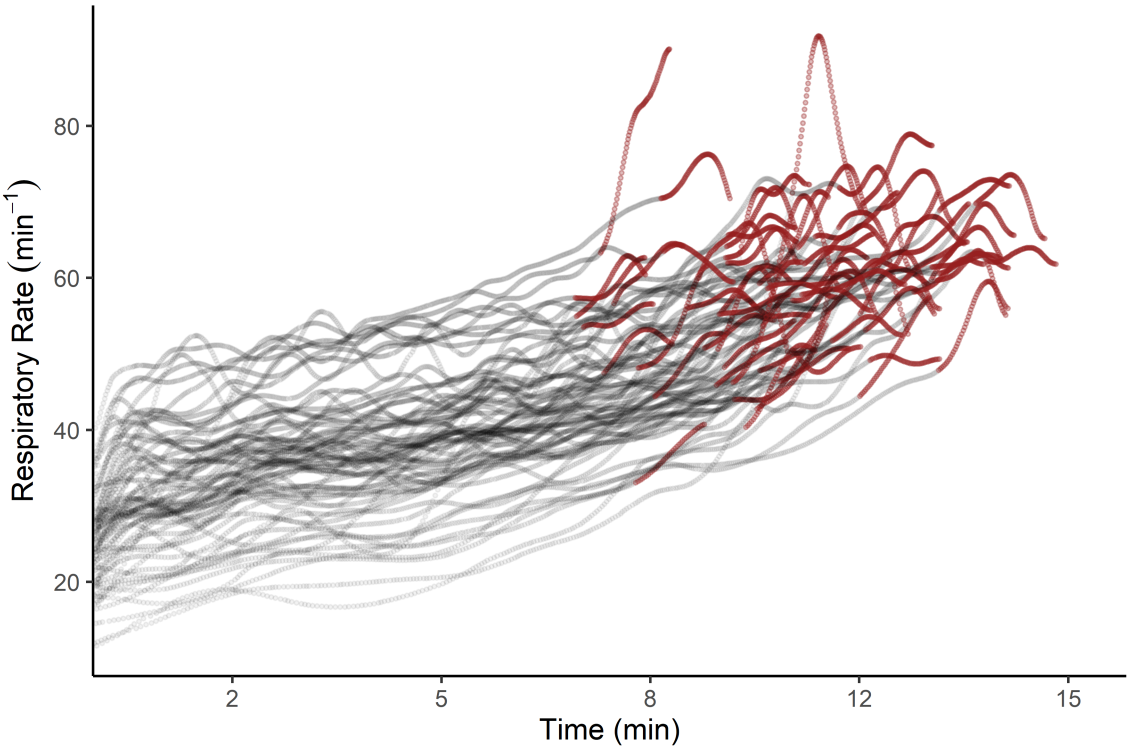

Figure 5: Respiratory Rates peak around 60min^{-1} in the ramp tests. The red segments correspond to the last minute before exhaustion of each individual (n = 72). .

4 Discussion

5 Conclusion

6 Bibliography

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7 Appendix