Guidelines to Classify Subject Groups in Sport-Science Research

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Purpose: The aim of this systematic literature review was to outline the various preexperimental maximal cycle-test protocols, terminology, and performance indicators currently used to classify subject groups in sport-science research and to construct a classification system for cycling-related research. Methods: A database of 130 subject-group descriptions contains information on preexperimental maximal cycle-protocol designs, terminology of the subject groups, biometrical and physiological data, cycling experience, and parameters. Kolmogorov-Smirnov test, 1-way ANOVA, post hoc Bonferroni (P < .05), and trend lines were calculated on height, body mass, relative and absolute maximal oxygen consumption (VO2max), and peak power output (PPO). Results: During preexperimental testing, an initial workload of 100 W and a workload increase of 25 W are most frequently used. Three-minute stages provide the most reliable and valid measures of endurance performance. After obtaining data on a subject group, researchers apply various terms to define the group. To solve this complexity, the authors introduced the neutral term performance levels 1 to 5, representing untrained, recreationally trained, trained, well-trained, and professional subject groups, respectively. The most cited parameter in literature to define subject groups is relative VO2max, and therefore no overlap between different performance levels may occur for this principal parameter. Another significant cycling parameter is the absolute PPO. The description of additional physiological information and current and past cycling data is advised. Conclusion: This review clearly shows the need to standardize the procedure for classifying subject groups. Recommendations are formulated concerning preexperimental testing, terminology, and performance indicators. Keywords: male road cycling, subject-group description, preexperimental testing, performance indicators, terminology

Experiments in the field of sport science often focus on cycling performance because it is practical to simulate the actual competition in a laboratory environment. However, due to the lack of uniformity of preexperimental protocols and the use of various performance indicators and criteria to classify subject groups, it is difficult to translate scientific results into practice and to interpret and extrapolate research data. In the past, several research groups have mentioned the discrepancy in methodology to classify subject groups and attempted to unify the classification. Unfortunately, these efforts are not adequately applied in sport science.

In many studies, a maximal incremental cycle test precedes an experiment to demographically describe and categorize the fitness of the subject group. These physiological variables may include peak power output (PPO), maximal aerobic capacity (VO2max), and submaximal characteristics such as anaerobic and ventilatory threshold. However, these variables are affected by the initial workload, the workload increase, and step duration. Therefore, it is of utmost importance to standardize data collection to classify the subject group. Currently, a variety of biometric, physiological, and training criteria are used to define subject groups. Three main factors appear to play key roles in endurance performance: VO2max, lactate threshold, and efficiency. In the field of cycling, PPO is another significant performance parameter that provides a direct and immediate measure of work rate, as opposed to an athlete’s perceptual or cardiovascular response to that exercise intensity. The question thus arises as to which parameters and criteria should be used to define a subject group.

The literature contains a variety of qualitative terms to classify subject groups, such as sedentary, untrained, physically fit/active, (habitually) active, recreational, (endurance) trained, amateur, well-trained, highly trained, (highly) competitive, club-level, elite, world-class, and professional. Misclassification from these qualitative terms is a problem from a scientific perspective, because comparing research data from one study group to another may be confusing. Examples of discrepancies in terminology in the current literature are numerous. Hansen et al describe a male subject group with a VO2max...
of 61.6 (± 2.0) mL · min⁻¹ · kg⁻¹ as “healthy,” whereas Halson et al⁴ presented endurance-trained cyclists with a VO₂max of 58.0 (± 1.7) mL · min⁻¹ · kg⁻¹ and Burnley et al⁸ named 12 cyclists with a VO₂peak of 58 (± 4) mL · min⁻¹ · kg⁻¹ as “well trained.” VO₂max values of 71.2 (± 6.8), 69 (± 5), and 65.6 (± 1.3) mL · min⁻¹ · kg⁻¹ were also noted for, respectively, endurance-trained male cyclists,⁹ trained male cyclists,¹⁰ and highly trained athletes.¹¹

Jeukendrup et al² and Ansley and Cangley¹ combined biometric, physiological, and training data in an attempt to unify the classification system. Jeukendrup et al² presented 4 different subject classifications (trained, well-trained, elite, and world-class) and took into account training and race status (training frequency, duration and background, race days per year and UCI ranking) and physiological variables (absolute and relative PPO, VO₂max, and cycling economy). Ansley and Cangley¹ categorized subject groups on a scale of 1 to 6, whereby 1 represents a group of professional cyclists; 2, national-level competitors; 3, club competitors; 4, recreational cyclists; 5, athletic noncyclists; and 6, noncyclists. According to Ansley and Cangley,¹ the relative VO₂max (mL · min⁻¹ · kg⁻¹), PPO, annual training distance, and typical 16-km and 40-km time-trial times are the most important cycling parameters worth mentioning in the description of a subject group. These classification systems have some drawbacks, however. No data are provided on training or competition status and metabolic efficiency, because Ansley and Cangley¹ indicated that these data can be misleading indicators of performance. Although subjects can be genetically predisposed, history and current training and race data provide significant supplementary information to describe a subject group. Jeukendrup et al² did not include criteria for untrained and recreationally trained subjects. However, research including less-trained subject groups needs a classification for lower-performance-level subjects.

From the preceding, it appears that we need a unified classification system concerning the protocol of a preexperimental test, along with the terminology and performance indicators to classify the subject group to avoid misinterpretation of scientific outcomes. Therefore, this study aims at standardizing the definition of subject groups in cycling research by creating a database containing preexperimental protocols and biometric, physiological, and training data per performance level in the field of male cycling research, which will finally lead to bottom-up recommendations on preexperimental testing, terminology, and classification of subject groups.

Method

Search Strategy

The key databases for exercise and sports science PubMed, Web of Science, SPORTDiscus, and ScienceDirect were consulted and screened for literature containing sufficient data on terminology and performance indicators of the subject group. The research screening combined the following keywords: cycling aerodynamics, bicycle design, body position, cooling, hyperthermia, hyperoxia, hypoxia, training types, detraining, tapering, warm-up, recovery, bike-specific injury, sport nutrition, pacing, physiology, and testing. An initial raw screening resulted in the selection of 259 articles.

Inclusion and Exclusion Criteria

A more profound screening of subject-group descriptions using predetermined inclusion and exclusion criteria resulted in the selection of 108 articles.⁶⁻⁸,¹⁰,¹²⁻¹¹⁵ Studies were included when the subject group contained healthy, male subjects and included at least 6 adult subjects. The topics of the studies are sport-science related, containing information on cycling or including a cycle test. The studies were published from 1999 to 2012. Studies were excluded when they included female or mixed-sex subjects (n = 21), students and volunteers, non-road cyclists (n = 16), and trained elderly subjects (n = 1). Other exclusion criteria were subject descriptions containing insufficient information such as male/road cyclists (n = 9) or males (n = 2) or mixed information such as “male cyclists, ranging from recreational to professional status.”¹¹⁶ Reviews, leading articles, letters to the editor (n = 46), and single-case studies (n = 2) were also excluded. Figure 1 shows the progress of the literature screening. Some articles presented data for more than 1 subject group, and in total 130 subject groups were included for further analysis of the subject-description data. Data about the number of subjects per group, biometric and physiological data analysis, cycling experience, and parameters were included in the database.

Nomenclature: Performance Levels 1–5

After the selection of the articles, subject groups were divided in distinct classifications according to the nomenclature. Related terms were combined, and this qualitative approach resulted in 5 distinct performance levels. A database per performance level was constructed to obtain a clear overview of the currently used parameters and criteria to describe subject groups. Based on this classification, further analysis was performed before we formulated recommendations on criteria per performance parameter per performance level.

Statistics

Values are presented as mean ± SD. SPSS 20.0 was used and the level of significance was set at P < .05. Before further analyses, data were tested for normality using histograms, normal probability plots, and Kolmogorov-Smirnov test. As all data were normally distributed, 1-way ANOVA was used to observe significant differences between the different groups according to the classification. Thereafter, a post hoc Bonferroni test was used to detect significant differences. In addition, a trend line and the corresponding determination coefficient (R²) were analyzed.
Results

This section will be divided in 3 parts. The first part deals with preexperimental testing, the second defines the terminology of the subject groups, and the third focuses on the required criteria to allocate a subject group to a certain classification.

Preexperimental Testing

Different preexperimental protocols are observed in literature. Test protocols were accurately described in 41 of the collected articles. The initial workload ranged from 0 to 200 W, the step length ranged from 0.5 to 8 minutes, and the workload increase ranged from 10 to 50 W. An initial workload of 100 W (n = 10), a workload increase of 20 to 25 W (n = 22), and a step duration of 1 minute (n = 24) are most frequently used in the current literature.

Terminology

The literature is saturated with various qualitative subject-group descriptions. To solve this complexity we applied the following neutral terms for performance levels 1 to 5. Ten articles (7.7%) defined their subject group as untrained or sedentary: this group will be referred to as performance level 1. The terms healthy,* habitually active,26 physically fit,46 physically active,45,63 active,74 and habitually physically active94 are clustered in the recreationally trained group referred to as performance level 2. Based on this terminology, 25 articles (19.2%) are included in this classification. Performance level 3 includes a collection of terms referring to trained subject groups: trained,† trained competitive,78 endurance-trained,‡ and competitive.** Forty-five articles (34.6%) were found to describe performance level 3. Thirty-six articles (27.7%) were selected for performance level 4. They contain the terms highly trained,58,56,102,105 well-trained,†† well-trained competitive,67,78 highly trained competitive,14 and national cycling league.‡‡ Fourteen articles (10.8%) included professional cyclists (performance level 5).

Required Criteria per Classification

A 1-way ANOVA showed significant differences between the different performance levels for all included parameters (P < .001) except for height (P = .752). Some data are derived from available information; for example, the relative PPO was derived from the absolute PPO and body mass of the subjects.

Biometric Parameters. Body-mass data were provided for 95.4% of the subject groups (n = 124). The post hoc test showed significantly lower body-mass values for performance level 5 than for performance levels 1, 2, and 4 (P < .044) and between performance levels 2 to 3 and 2 to 4 (P < .036). A strong inverse association (r = .92) was observed between body mass and performance level. Other biometric parameters of height and percent body fat were cited in 101 (77.7%) and 18 (13.9%) articles, respectively. No significant differences were observed for height (P > .05), and insufficient data were available concerning percent body fat.

Physiological Parameters. Day et al117 stated that the VO2peak attained on a maximum-effort incremental test in subjects exercising to the limit of tolerance is likely to be a valid index of VO2max, despite no evidence of an actual VO2 plateau. From a practical point of view, we will use the term VO2max for VO2peak.

Relative and absolute VO2max were cited in 60.8% and 32.3% of the collected articles, respectively. Significant differences were clearly shown between performance

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†References 10, 18, 20, 27, 32, 33, 41, 62, 76, 79, 81, 115.
‡References 9, 12, 30, 31, 42, 49–51, 57, 60, 82, 87, 110, 111.
**References 13, 16, 17, 52, 61, 75, 85, 91, 101.
††References 8, 21, 28, 37, 39, 54, 66, 72, 92, 95, 96, 99, 100, 106, 109.
‡‡References 33, 38, 39, 43, 48, 85, 92, 100–102, 107.
levels 1 to 5 for relative ($P < .014$) and absolute $\text{VO}_{2\text{max}}$ ($P < .006$), except between performance levels 3 and 4 to 5. Very high $R^2$ values (.97) were observed (Figure 2).

The PPO, sometimes called maximum work rate, is obtained by measuring the highest, fully completed stage during an incremental maximal test. If the last stage is not fully completed, PPO needs to be calculated according to the following formula:

$$\text{PO1} + \left( \frac{(\text{PO2} - \text{PO1})T2}{T1} \right)$$

where $\text{PO1}$ = power output during the previous stage, $\text{PO2}$ = power output during the highest stage, $T1$ = predetermined step duration (min), and $T2$ = amount of time spent in the last stage (min).

The absolute and relative PPO were mentioned in 31.5% and 8.5% of the selected articles, respectively. Although the available data for the relative PPO were few, we calculated extra data using the absolute PPO and body mass of the subject group, thereby enabling statistical analysis on this specific parameter. ANOVA showed significant differences ($P < .001$) between groups. The post hoc test revealed significant differences for the absolute ($P < .018$) and relative ($P < .044$) PPOS between the performance levels (1–3, 1–4, 1–5, 2–4, 2–5, 3–5). However, no significant differences were found between performance levels 1 to 2, 2 to 3, and 4 to 5 for the absolute ($P = 1.00$; $P = .449$ and $P = .27$) and relative ($P = 1.00$; $P = .232$ and $P = .051$) PPO (Figure 3). A high $R^2$ of .99 for both parameters has been found.

**Training Status.** Training and competition data are lacking in performance levels 1 and 2. Del Coso et al,31 Hug et al,58 and Bergman and Brook15 stated that their subject groups participated in physical activity less than 2 to 3 h/wk in the previous year. Only 2 articles from performance level 2 included the training status of the subject groups. Hansen et al6 noted that the subject groups had already trained for several years, and Fujita et al16 specified in detail that their subjects had trained regularly for approximately 2 h/d, at least 3 d/wk for the previous 4 years. More training and competition information is provided in performance levels 3 (47%), 4 (46%), and 5. Subject groups from performance level 3 already have cycling experience of 3 to 10 years20,50,62; train frequently, meaning at least 3 times and 5 h/wk27,91,115; and cover 3000 to 15,000 km/y.62

The training and competition experience of subject groups from performance level 4 is more than 3 years.67,92,95 Subjects train at least 10 h/wk,78,92 in which a minimal distance of 250 km is covered.95 Professional cyclists (performance level 5) complete about 25,000 to 35,000 km/y.59,112,118,119

**Literature-Based Recommendations**

Taking into account the section on physiological parameters, we suggest the following recommendations to classify subject groups (Table 1). The most-cited parameter in sport-science research is relative $\text{VO}_{2\text{max}}$, so no overlap...
can occur for this principal parameter. Another significant cycling parameter is absolute PPO. We first take into account the relative VO$_{2\text{max}}$ and second the absolute PPO to classify the subject group. The description of additional physiological information (absolute VO$_{2\text{max}}$ and relative PPO) is advised.

**Discussion**

Different preexperimental test protocols, a methodological diversity of terminology, and various biometric and physiological criteria currently contribute to the misleading description of subject groups in cycling research. This yields the necessity to apply a unified classification system to avoid misinterpretation of the results and difficulties comparing results of different studies. Therefore, the goals of this systematic review were to unify the test protocol preceding the experiment to obtain performance-related data of the subject group, to propose a unified terminology to describe the subject group, and to select performance parameters and outline criteria per parameter for each performance level. Finally, we merge our findings to formulate a classification system that is based on the available data. To achieve our goals we first composed a database to provide an overall picture of the currently used information to describe subject groups. Three main findings emerged. First, a variety of test protocols...
are selected by researchers engaging in cycling science, but our database outlined that an initial workload of 100 W and a workload increase of 20 to 25 W are most frequently used. Second, various terms are cited to clarify the performance level of the subject group, and, third, relative VO$_{2\text{max}}$ and absolute PPO are the most important endurance-performance indicators.

During preexperimental testing, time until volitional exhaustion is shortened as the length of the stages decreases or the workload per step increases. This, however, does not seem to affect VO$_{2\text{max}}$ values.\textsuperscript{120–122} The reliability of the absolute PPO obtained from an incremental test comprising 60-second stages has been shown to be high (coefficient of variation = 2%),\textsuperscript{123} and most studies used 1-minute stages. Bentley et al,\textsuperscript{124} on the other hand, stated that incremental exercise protocols comprising 3-minute stages provide the most reliable and valid measures of endurance performance, and therefore we suggest applying 3-minute steps during preexperimental testing. Our database showed that an initial workload of 100 W and a step increase of 20 to 25 W are most frequently applied. After obtaining the physiological data of a subject group, researchers select various terms to define the group. In our database, we combined data per performance level according to interdependent terms. We suggest applying the neutral term \textit{performance levels 1–5}, representing an untrained, a recreationally trained, a trained, a well-trained, and a professional\textsuperscript{5} subject group, respectively.

In the past, Jeukendrup et al\textsuperscript{2} and Ansley and Cangley\textsuperscript{1} provided guidelines for classifying subject groups. Ansley and Cangley\textsuperscript{1} categorized groups on a scale of 1 to 6, from professional to noncyclist. According to this classification system, the most important parameters in defining the subject group are relative VO$_{2\text{max}}$ (mL · min$^{-1}$ · kg$^{-1}$), PPO (W), annual training distance, and typical 16-km and 40-km time-trial time (min). This implies at least 2 additional preexperimental tests. Furthermore, data on training and competition status are lacking. On the other hand, Jeukendrup et al\textsuperscript{2} presented training and race data (training frequency, duration and background, race days per year, and UCI ranking) and physiological variables (absolute and relative PPO and VO$_{2\text{max}}$ and cycling economy) to classify subject groups in 4 classifications. This classification system focuses more on better-trained subject groups, and no data are provided on lower-performance-level subject groups. Jeukendrup et al\textsuperscript{2} divided professional cyclists into elite and world-class cyclists, according to their UCI ranking. Professional cyclists are rarely assigned to an experimental setup, so researchers can recruit subjects with similar physiological parameters to better understand how research outcomes can be translated to competitive athletes.

Over 60% of the articles present relative VO$_{2\text{max}}$ values, and over 30% mention absolute PPO to define the subject group. Although interdependent terms were combined to build our database, we still observed a wide range of relative and absolute VO$_{2\text{max}}$ values to classify subject groups at certain performance levels. This caused the lack of significant differences between performance levels 3 to 4 and 4 to 5 for, respectively, relative and absolute VO$_{2\text{max}}$. Our recommended criteria per performance level on relative VO$_{2\text{max}}$ are comparable to the recommendations of Ansley and Cangley,\textsuperscript{1} who suggested that subject groups from performance level 1 had an average relative VO$_{2\text{max}}$ of less than 45 mL · min$^{-1}$ · kg$^{-1}$. There appears to be a slight difference for performance levels 2 and 3. Ansley and Cangley\textsuperscript{1} defined subject groups with an average of 45 to 50 and 50 to 60 mL · min$^{-1}$ · kg$^{-1}$ as performance levels 2 and 3, compared with our recommendations for performance level 2, 45 to 54.9 mL · min$^{-1}$ · kg$^{-1}$, and performance level 3, 55 to 64.9 mL · min$^{-1}$ · kg$^{-1}$. Several studies\textsuperscript{118,125,126} indicate very high relative VO$_{2\text{max}}$ values of over 70 mL · min$^{-1}$ · kg$^{-1}$ for professional cyclists. Our absolute VO$_{2\text{max}}$ recommendations (level 3, 4.2–4.9; level 4, 4.5–5.3 L/min) are similar to the classification system of Jeukendrup et al\textsuperscript{2} (performance level 3, 4.5–5.0; level 4, 5–5.3 L/min). An absolute VO$_{2\text{max}}$ of over 5.0 L/min is typical for professional cyclists. Most research found no differences in relative VO$_{2\text{max}}$ between well-trained cyclists and elite professional performers. The major difference between professional and well-trained is the power produced at VO$_{2\text{max}}$.\textsuperscript{118} Therefore, it is more common for researchers to refer to the aerobic power of cyclists in terms of absolute PPO from an incremental protocol. Such absolute PPO typically ranges from 350 to more than 500 W for professional cyclists.\textsuperscript{118,127} The range of absolute PPO per performance level differs between the classification proposals of Jeukendrup et al\textsuperscript{2} and ours. On the other hand, the relative PPO recommendations between the classification system of Jeukendrup et al\textsuperscript{2} and ours showed similar results for performance levels 3 and 4 (level 3, 4–5; level 4, 5–6 W/kg and level 3, 4.6–5.5; level 4, 4.9–6.4 W/kg, respectively). A relative PPO of over 5.5 W/kg is considered a prerequisite for professional cyclists.\textsuperscript{125} The question remains whether researchers have to consider relative VO$_{2\text{max}}$ and/or absolute PPO before classifying the subject group. As the relative VO$_{2\text{max}}$ is the most important indicator of endurance performance and seems to be less affected by the preexperimental protocol than is absolute PPO,\textsuperscript{124} relative VO$_{2\text{max}}$ should be the first parameter to consider before classifying a subject group. Therefore, overlap of the relative VO$_{2\text{max}}$ ranges between performance levels needs to be prevented.

Current and past training data complete the subject-group profile. Training and competition data are lacking for performance levels 1 and 2. Del Coso et al,\textsuperscript{31} Hug et al,\textsuperscript{59} and Bergman and Brook\textsuperscript{15} provided some training information for subject groups in performance level 1. Subjects defined as performing at level 1 participated in physical activity for less than 2 to 3 h/wk in the previous year.\textsuperscript{15,31,58} Subject groups from performance level 2 had already practiced for several years\textsuperscript{6} on a regular basis of approximately 2 h/d. At least 3 d/wk.\textsuperscript{16} Performance level 3 subject groups had already cycled for 3
to 10 years and trained frequently and at least 5 h/wk. Thereby, an annual cycle distance of about 3000 to 15,000 km/y is covered. The major difference between subject groups from performance levels 3 and 4 is that higher-performance-level subject groups train more and cover greater distances. Professional cyclists typically cycle 25,000 to 35,000 km in a season. This cycling distance differentiates professional cyclists from less genetically endowed, albeit well-trained, individuals.

This systematic review presents guidelines to classify male subject groups. Female subject groups were not included since there are significantly fewer data available on them in the scientific literature. Nevertheless, future work should also provide guidelines for the classification of female subject groups. An element we must consider in terms of the applicability of the classification system for master athlete groups (>40 y) is that these subjects are often characterized by a higher percentage of body fat. Therefore, it will be more suitable for researchers to focus first on absolute PPO to classify the subject group in this specific target population.

## Conclusion

We present a unified classification system including biometric measurements (body mass, height), physiological performance indicators and criteria, and current and past training data. Physiological parameters (relative and absolute VO2max and PPO) are obtained via a preexperimental test. We recommend performing a unified cycle test comprising 3-minute stages, an initial workload of 100 W, and a workload increase of 25 W.

According to the literature, relative VO2max (mL · min⁻¹ · kg⁻¹) is the most important performance predictor, so we suggest classifying the subject group according to this principal parameter. The second parameter to take into account is absolute PPO (W). Additional information on absolute VO2max, relative PPO, and cycling status completes the subject-group profile (Figure 4). To avoid contamination of terminology we recommend the following terms for performance levels 1 to 5: untrained, recreationally trained, trained, well-trained, and professional subject groups, respectively. Each performance level is defined by different criteria for each parameter (Table 2).

### Table 2: Recommendations for Criteria per Performance Level (PL)

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<tr>
<th>Physiological performance indicators</th>
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<th>PL 2</th>
<th>PL 3</th>
<th>PL 4</th>
<th>PL 5</th>
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<tr>
<td>1° relative VO2max, mL · min⁻¹ · kg⁻¹</td>
<td>&lt;45</td>
<td>45–54.9</td>
<td>55–64.9</td>
<td>65–71</td>
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<td>absolute VO2max, L/min</td>
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<td>relative PPO, W/kg</td>
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<td>4.6–5.5</td>
<td>4.9–6.4</td>
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<td>—</td>
<td>—</td>
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<td>≥5</td>
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Abbreviations: VO2max indicates maximal oxygen consumption; PPO, peak power output.
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