# **Validity of estimating the maximal oxygen consumption by consumer wearables: A systematic review with meta-analysis and expert statement of the INTERLIVE network**

**Journal name:** Sports Medicine

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| **Supplementary Material 1.** Search terms used in Scopus, PubMed, and Web of Science databases excluding study design. | | |
| **Scopus** | **Web of Science** | **Pubmed** |
| **Index device**  TITLE-ABS-KEY ( wearable\* OR smartwatch\* OR "smart watch" OR "smart watches" OR watch\* OR smartband\* OR "smart band" OR "smart bands" OR smartbracelet\* OR "smart bracelet" OR "smart bracelet" OR "smart bracelets" OR “tracker” OR “trackers” OR "fitness tracker" OR "fitness trackers" OR “monitor”) | **Index device**  ALL=( wearable\* OR smartwatch\* OR "smart watch" OR "smart watches" OR watch\* OR smartband\* OR "smart band" OR "smart bands" OR smartbracelet\* OR "smart bracelet" OR "smart bracelet" OR "smart bracelets" OR “tracker” OR “trackers” OR "fitness tracker" OR "fitness trackers" OR “monitor”) | **Index device**  ( wearable\* OR smartwatch\* OR "smart watch" OR "smart watches" OR watch\* OR smartband\* OR "smart band" OR "smart bands" OR smartbracelet\* OR "smart bracelet" OR "smart bracelet" OR "smart bracelets" OR “tracker” OR “trackers” OR "fitness tracker" OR "fitness trackers" OR “monitor”) |
| **Outcome**  TITLE-ABS-KEY ("VO2max" OR "VO2 max" OR "VO2maximum" OR "VO2 maximum" OR "VO2peak" OR "VO2 peak" OR "oxygen uptake" OR "O2 uptake" OR "oxygen consumption" OR "O2 consumption" OR "aerobic capacity" OR “cardiorespiratory”) | **Outcome**  ALL=("VO2max" OR "VO2 max" OR "VO2maximum" OR "VO2 maximum" OR "VO2peak" OR "VO2 peak" OR "oxygen uptake" OR "O2 uptake" OR "oxygen consumption" OR "O2 consumption" OR "aerobic capacity" OR “cardiorespiratory”) | **Outcome**  ("VO2max" OR "VO2 max" OR "VO2maximum" OR "VO2 maximum" OR "VO2peak" OR "VO2 peak" OR "oxygen uptake" OR "O2 uptake" OR "oxygen consumption" OR "O2 consumption" OR "aerobic capacity" OR “cardiorespiratory”) |
| **Study Design**  TITLE-ABS-KEY (Valid\* OR accura\*) | **Study Design**  ALL=(Valid\* OR accura\*) | **Study Design**  (Valid\* OR accura\*) |
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| **N studies included:** 706 | **N studies included:** 525 | **N studies included:** 433 |

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| **Supplementary Material 2.** Criteria for the risk of bias assessment | |
| Criteria items | Number and percentage of studies meeting criterion out of 14 studies included. N (%) |
| **DOMAIN 1: Participants** |  |
| 1. Were participants selected appropriately to represent the desired target population defined by study authors? | 11 (78.6) |
| 1. Did all or nearly all participants sampled for the study, contribute with data to be included in the analysis of criterion validity? | 11 (78.6) |
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| **DOMAIN 2: Index Measure** |  |
| 1. Was the wearable device administered during sampling of data according to manufacturer’s instructions? | 10 (71.4) |
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| **DOMAIN 3: Reference Standard** |  |
| 1. Was the criterion measure instrument to assess VO2 appropriate and administered appropriately during the test? | 10 (71.4) |
| 1. Was the test protocol (including criteria for a valid test) for VO2-max assessment appropriate? | 9 (64.3) |
| 1. Did the professional(s) administer the VO2-max test (reference) without knowledge of values from the wearable device? | 4 (28.6) |
| 1. Was the time interval between reference and index measurements appropriate? | 9 (64.3) |
|  |  |
| **DOMAIN 4: Statistical Analysis** |  |
| 1. Was the statistical approach to estimate agreement appropriate? | 8 (57.1) |
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**Supplementary Material 3.** Risk of bias assessment of each article using the COSMIN tool and the Risk of Bias 2 (RoB 2) criteria.

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| **Supplementary Material 4.** Leave-one-out method to test the robustness of the meta-analysis. | | | |
| **Methodology** | **Study** | **Bias (95% IC)** | **Z (p)** |
| **Resting test** | **All Studies included** | **2.17 [0.28, 4.07]** | **2.25 (0.020)** |
| Cooper et al. (2019) | 2.50 [0.48, 4.52] | 2.42 (0.020) |
| Crouter et al. (2004). Men | 2.42 [0.42, 4.42] | 2.38 (0.020) |
| Crouter et al. (2004). Women | 1.49 [-0.13, 3.31] | 1.80 (0.070)\* |
| Esco et al. (2011) | 2.66 [0.81, 4.51] | 2.82 (0.005) |
| Esco et al. (2014) | 1.96 [-0.16, 4.09] | 1.81 (0.070)\* |
| Kraft and Dow (2019) | 2.10 [0.03, 4.16] | 1.99 (0.050) |
| Lowe et al. (2010) | 2.14 [-0.12, 4.39] | 1.86 (0.060)\* |
| Passler et al. (2019) | 2.09 [-0.01, 4.19] | 1.95 (0.050)\* |
| Snyder et al. (2019). Men | 1.92 [-0.11, 3.94] | 1.86 (0.060)\* |
| Snyder et al. (2019). Women | 2.55 [0.58, 4.52] | 2.54 (0.010) |
|  |  |  |  |
| **Exercise test** | **All Studies included** | **-0.09 [-1.66, 1.48]** | **0.11 (0.910)** |
| Anderson et al. (2019) | 0.17 [-1.54, 1.88] | 0.20 (0.850) |
| Carrier et al. (2020) | -0.38 [-2.00, 1.25] | 0.46 (0.650) |
| Freeberg et al. (2019) | -0.45 [-2.02, 1.12] | 0.57 (0.570) |
| Klepin et al. (2019) | -0.06 [-1.86, 1.74] | 0.07 (0.950) |
| Kraft and Dow (2019) | -0.14 [-1.84, 1.56] | 0.16 (0.870) |
| Passler et al. (2019) | 0.17 [-1.55, 1.89] | 0.19 (0.850) |
| Snyder et al. (2019). Men | -0.28 [-1.98, 1.42] | 0.33 (0.740) |
| Snyder et al. (2019). Women | -0.19 [-1.96, 1.58] | 0.21 (0.830) |
|  | Wagner et al. (2020) | 0.38 [-0.86, 1.61] | 0.60 (0.550) |
| \* : When leaving out this study, the overall effect changes significantly in comparisson with the overall effect including all the studies. | | | |



**Supplementary Material 5.** Funnel plots and Egger’s tests to assess the publication bias in both the orthostatic-test and exercise-test studies.

**Supplementary Material 6.** Pooled bias and standard error (SE) for wearables VO2max using photoplethysmography (PPG) for heart rate recording (panel A) versus wearables using chest strap (panel B) in the resting conditions. A negative bias represents an underestimation and a positive an overestimation of the VO2max by the wearables in comparison to the reference standard.



**Supplementary Material 7.** Pooled bias and standard error (SE) for wearables VO2max using photoplethysmography (PPG) for heart rate recording (panel A) versus wearables suing chest strap (panel B) in the exercise tests. A negative bias represents an underestimation and a positive an overestimation of the VO2max by the wearables in comparison to the reference standard.

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| **Supplementary Material 8.** Consumer wearable devices identified in the market providing VO2max estimations and their main characteristics. | | | | | | |
| **Manufactor** | **Devices** | **Sensors used** | **Additional measures included** | **Constraints** | **Protocol** | **Source** |
| Apple | Watch 6,  WatchOS 7 | HR | Age, gender, weight |  | 6-minute walk test 20 min workout | [Link](https://www.apple.com/healthcare/docs/site/Using_Apple_Watch_to_Estimate_Cardio_Fitness_with_VO2_max.pdf) |
| Garmin | All Forerunner All Fenix All Instinct | HR and GPS | Age, gender, weight | Need GPS for walking and running Cycling needs power meter | Running 10 minutes (15 minutes with vivosport) Cycling: Minimum of 20 minutes and HR must be at least 70% of HRmax Walking: Minimum 10 minutes and HR must be at least 70% of HRmax Cycling – Minimum of 20 minutes | [Link](https://support.garmin.com/en-US/?faq=lWqSVlq3w76z5WoihLy5f8) |
| TomTom | Spark Cadio | HR and GPS | Age, gender, weight | Steady HR | min 15 minutes of running, trail running or treadmill | [Link](https://help.tomtom.com/hc/en-us/articles/360013899420-VO2max-and-Fitness-Age-calculation) |
| Polar | V800 | HRV | Age, gender, weight |  | During resting conditions | [Link](https://support.polar.com/e_manuals/V800/Polar_V800_user_manual_English/Content/Fitness_Test.htm) |
| Polar | Polar Vantage V2 Polar Unite Polar Grit X Polar H10 and OH1 (chest strap) | HR and GPS | Age, gender, weight |  | 5 min fitness test | [Link](https://www.polar.com/blog/lets-talk-polar-polar-fitness-test/) |
| Huawei | GT2 and GT3 | HR and GPS | Age |  | Running of at least 2.4 km within 20 min | [Link](https://consumer.huawei.com/us/wearables/watch-gt/) |
| Suunto | Suunto 3, 5, 7 and 9 | HR and GPS | Age, gender and weight |  | At least 15 minutes of outdoor walking or running | [Link](https://www.suunto.com/da-dk/Support/Product-support/suunto_5/suunto_5/funktioner/fitnessniveau/) |
| Withings | Steel HR sport | HR and GPS | Age, gender, weight |  |  | [Link](https://support.withings.com/hc/en-us/articles/360009326614-Steel-HR-Sport-What-is-VO2-max-and-does-the-watch-measure-it-) |
| Coros | APEX | HR and GPS |  |  |  | [Link](https://coros.com/apex.php) |
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Note: The brands and models might be subject to constant changes and, therefore, this table should be used as a set of examples identified in the market at the moment of doing this review article, but there might be other wearables estimating VO2max and that were missed during the search