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# Safety implications of mask use: a systematic review and evidence map

Wigdan Farah <sup>1,2</sup> Mohamed F Abusalih,<sup>1,3</sup>  
Bashar Hasan <sup>1,3</sup> Elizabeth H Lees,<sup>3</sup> Farah Fleti,<sup>1,3</sup>  
Wiaam Y Elkhatib,<sup>3</sup> Bruce D Johnson,<sup>4</sup> Gary Toups,<sup>3</sup>  
Michael Wolf,<sup>3</sup> M Hassan Murad <sup>1,3</sup>

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<sup>1</sup>Evidence-Based Practice Center, Mayo Clinic, Rochester, Minnesota, USA

<sup>2</sup>Division of Pulmonary and Critical Care Medicine, Mayo Clinic, Rochester, Minnesota, USA

<sup>3</sup>Division of Public Health, Infectious Diseases, and Occupational Medicine, Mayo Clinic, Rochester, Minnesota, USA

<sup>4</sup>Division of Preventive Cardiology, Mayo Clinic, Rochester, Minnesota, USA

Correspondence to:  
**Dr Wigdan Farah**; Farah.wigdan@mayo.edu



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## Abstract

**Background** Widespread use of respiratory protection masks has become a critical component of public health response.

**Objectives** This systematic review synthesises the evidence on the acute physiological, cognitive and psychological impacts associated with different types of masks and provides an evidence map of research gaps.

**Methods** A comprehensive search from 2000 to 2023 was conducted across multiple databases (MEDLINE, EMBASE, Cochrane databases, Scopus and PubMed). An umbrella systematic overview was conducted for physiological outcomes using existing systematic reviews. We conducted de novo systematic reviews for cognitive and psychological outcomes. Pairs of independent reviewers determined eligibility, extracted data and assessed risk of bias. Certainty at an outcome level was appraised using the Grading of Recommendations Assessment, Development and Evaluation approach.

**Results** The search resulted in 13 370 potential citations, leading to the inclusion of nine systematic reviews for physiological outcomes (87 primary studies) and 10 primary studies for cognitive and psychological outcomes (3815 participants), with the majority of participants being healthy adults. Studies evaluating physiological outcomes demonstrated that various types of masks have little to no significant difference in heart rate (surgical mask (mean difference (MD): 0.96 (−1.01 to 2.93)), N95 mask (MD: 1.63 (−2.79 to 6.05)) and cloth mask (MD: −0.94 (−6.39 to 4.52))) or respiratory rate during rest or exercise (surgical mask (MD: −1.35 (−3.00 to 0.29)), N95 mask (MD: 0.10 (−3.10 to 3.29)) and cloth mask (MD: −2.57 (−6.44 to 1.29)) (low certainty for most outcomes)). Mask use may be associated with very small changes in minute ventilation (surgical mask (MD: −13.9 (−20.30 to −7.53)) and N95 mask (MD: −16.3 (−28.7 to −3.9))), tidal volume (surgical mask (MD: −0.14 (−0.23 to −0.05)) and N95 mask (MD: −0.10 (−0.33 to 0.13))), oxygen saturation (surgical mask (MD: −0.59% (−0.87 to −0.30)), N95 mask (MD: −0.35% (−0.75 to 0.05)) and cloth mask (MD: −0.50% (−1.23; 0.24))), carbon dioxide partial pressure (surgical mask (standardised MD (SMD): 1.17 (0.70 to 1.64)) and N95 mask (SMD:

## WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Prior research on the effects of face masks on physiological, cognitive and psychological outcomes during rest and exercise across different mask types and participant populations to date has been inconclusive.

## WHAT THIS STUDY ADDS

⇒ The current evidence showed a slight change in minute ventilation, tidal volume, oxygen saturation, maximal oxygen consumption ( $VO_{2max}$ ), carbon dioxide partial pressure, lactate levels and exercise performance with mask use. There was a little to no significant difference in heart rate, stroke volume, cardiac output, blood pressure or respiratory rate. Studies evaluating cognitive and psychological outcomes showed mixed results. The study fills a crucial knowledge gap by systematically synthesising and analysing the current evidence on the acute physiological, cognitive and psychological impacts of face mask use during rest and exercise while providing a comprehensive understanding of the current knowledge regarding the effects of mask wearing on various health outcomes across different mask types and populations and highlighting areas of evidence gap to help guide future investigations in respiratory protection and public health.

## HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ More research is needed on the effects of mask wearing during physical activity to inform tailored recommendations for individuals and public health policies.

0.43 (0.08 to 0.79)) and exercise performance (surgical mask (SMD: −0.12 (−0.39 to 0.15)), N95 mask (SMD: −0.42 (−0.76 to −0.08)) and

cloth mask (SMD:  $-0.26$  ( $-0.54$  to  $0.02$ )) (low certainty for most outcomes). Studies evaluating cognitive outcomes showed mixed results. Some studies reported reduced mental workload, and others showed no significant effect or decreased performance. The impact on attention, errors and reaction time was variable. These studies were small and at moderate to high risk of bias. Evidence was insufficient to estimate the effect of mask use on psychological outcomes (claustrophobia, depression and anxiety) as these studies were small, non-longitudinal and at high risk of bias.

**Conclusion** This evidence map provides a comprehensive insight into the multifaceted impact of respiratory protection mask use, and highlights the limited certainty in the available body of evidence. This evidence map supports the development of future research agenda.

## Introduction

In recent years, face masks became a crucial strategy to mitigate the transmission of infectious diseases, particularly respiratory viruses, causing a paradigm shift in the global public health landscape.<sup>1-3</sup> This shift extends across diverse settings, including public transport, workplaces and recreational activities. During the early stages of the COVID-19 pandemic when vaccines were not widely available, wearing masks became one of the primary methods for protection against the disease.<sup>1</sup> During this period, the selection of mask types has received considerable attention, driven by evidence suggesting that surgical masks and FFP2/N95 respirators offer superior particle filtration compared with cloth masks.<sup>4</sup> While the efficacy of masks in reducing infection transmission is widely recognised,<sup>5</sup> the surge in mask usage has raised concerns regarding their impact on health outcomes.<sup>6</sup> Particularly, questions have arisen regarding their potential effects on respiratory and physiological parameters, especially during physical activity.<sup>7,8</sup>

Notably, numerous studies have examined the respiratory implications of prolonged mask use, revealing diverse findings.<sup>7</sup> This is significant, especially given concerns regarding the increased breathing resistance and potential rebreathing of exhaled air associated with certain mask types, such as FFP2/N95 respirators and surgical masks. This effect may impact gas exchange dynamics leading to decreased oxygen intake ( $VO_2$  max), oxygen saturation ( $SpO_2$ ) and increased carbon dioxide levels ( $PetCO_2$ ) especially during physical activity.<sup>9-12</sup> However, existing literature presents conflicting data on the overall physiological effects of mask wearing during physical exertion.<sup>12-14</sup> While some systematic reviews suggest modest impacts on physiological parameters like gas exchange and pulmonary function,<sup>12</sup> others report minimal effect on physiological outcomes,<sup>15</sup> with similar results noted for exercise performance.<sup>12,15</sup>

Mask use may also have an effect on various cognitive aspects, such as obscuring facial expressions, creating challenges with communication and increasing cognitive load.<sup>16</sup> Few observational studies have touched on this, demonstrating increasing incidence of headache, attention deficit and difficulty in concentrating.<sup>17</sup> Overall data about the impact of face mask use on cognitive function remain limited. Furthermore, the psychological impact of face mask use is another issue that warrants thorough exploration. Facial expressions provide visible cues and play a vital role in human connection and emotional communication. Alterations induced by masks in these cues may contribute to

social and emotional challenges,<sup>18</sup> potentially affecting mental well-being.

Considering the heightened focus on mask usage and its implications amid the COVID-19 pandemic, there has been an exponential rise in both individual studies and systematic reviews addressing this topic. However, the sheer volume of literature, coupled with the variability in findings and methodological quality among systematic reviews, poses a significant challenge for decision-makers. This abundance of information, often with conflicting results and varying levels of rigour, can obscure the actual state of evidence and potentially mislead those responsible for crafting public health guidelines and policies. Therefore, the objectives of our systematic review are to (1) synthesise the evidence on the acute physiological, cognitive and psychological impacts associated with different types of masks and (2) produce an evidence map<sup>19</sup> that identifies evidence gaps and inform future research.

## Methods

### Study design

Due to the availability of multiple systematic reviews that addressed physiological outcomes, an umbrella systematic review (ie, an overview of systematic review) was conducted to identify and synthesise data from published systematic reviews. For the cognitive and psychological outcomes, no systematic reviews were identified and therefore de novo reviews were conducted. We followed a predefined published protocol without any upfront deviations<sup>20</sup> and reported the methodology and findings in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.<sup>21,22</sup> The detailed PICO (Population, Intervention, Comparison, Outcome) questions addressed in this comprehensive systematic review are outlined in table 1.

As our study followed a systematic review design and did not involve original research on human participants or direct patient involvement, we did not seek Institutional Review Board approval. However, we have rigorously maintained ethical standards in selecting, analysing and presenting existing literature.

### Data sources and search strategy

A comprehensive search of several databases from 2000 to 28 July 2023 in any language was conducted. Databases included MEDLINE, EMBASE, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, Scopus and PubMed. The search strategy was designed and conducted by a medical librarian with input from the study investigators. A controlled vocabulary supplemented with keywords was used to search various outcomes from wearing medical masks or air-purifying respirators (APR). The complete search strategies are available in online supplemental appendix A.

### Eligibility criteria

We included studies that (1) enrolled adults (aged 18 years and older), (2) evaluated surgical/medical masks, N95 masks/filtering facepiece respirators, military, and fire service APRs, and cloth masks, with no mask use, and (3) included at least one outcome of interest. (4) The study designs available include systematic review and meta-analysis for acute physiological outcomes (Q1), and comparative individual studies for cognitive (Q2) and psychological (Q3) outcomes. Factors such as duration of masking, activity level (at rest or with exercise) and altitude level (when relevant) were considered for subgroup analyses.

**Table 1** Key questions (three questions addressing acute physiological, cognitive and psychological outcomes associated with mask use)

|   |   |
|---|---|
| Population of interest  | ▶ Adults 18 years and older   |
| Intervention  | ▶ Surgical/medical masks<br>▶ N95 masks/filtering facepiece respirator<br>▶ Military and fire service air-purifying respirators (APR)<br>▶ Cloth mask   |
| Comparison  | ▶ No mask   |
| Outcomes  | <p>Q1. Acute physiological outcomes</p> <ul style="list-style-type: none"> <li>▶ Cardiovascular responses <ul style="list-style-type: none"> <li>– Heart rate</li> <li>– Cardiac output/stroke volume</li> <li>– Blood pressure</li> </ul> </li> <li>▶ Ventilatory responses <ul style="list-style-type: none"> <li>– Respiratory rate</li> <li>– Minute ventilation</li> <li>– Tidal volume</li> <li>– VE/VCO<sub>2</sub></li> <li>– Ventilation equivalent</li> </ul> </li> <li>▶ Metabolic response <ul style="list-style-type: none"> <li>– Arterial oxygen saturation</li> <li>– Oxygen extraction/muscle oxygenation</li> <li>– Carbon dioxide/end-tidal CO<sub>2</sub></li> <li>– Arterial partial pressure of carbon dioxide</li> <li>– Blood lactate</li> </ul> </li> <li>▶ Exercise performance <ul style="list-style-type: none"> <li>– Rating of perceived exertion (RPE)</li> <li>– Time to exhaustion and perceived exertion</li> <li>– Thermal sensation and facial skin temperature</li> </ul> </li> </ul> <p>Q2. Cognitive outcomes</p> <ul style="list-style-type: none"> <li>▶ Mini-Mental State Examination</li> <li>▶ Standardized Mini-Mental State Examination</li> <li>▶ Montreal Cognitive Assessment (MOCA)</li> <li>▶ Mini-Cog</li> <li>▶ Functional Cognitive Assessment Scale</li> <li>▶ Functional Activities Questionnaire</li> <li>▶ Abbreviated Mental Test</li> <li>▶ Six-item Cognitive Impairment Test <ul style="list-style-type: none"> <li>– Distraction, total number of errors, correct responses, response time, self-perceived arousal and ability to concentrate</li> </ul> </li> </ul> <p>Q3. Psychological outcomes</p> <ul style="list-style-type: none"> <li>▶ Anxiety</li> <li>▶ Depression</li> <li>▶ Claustrophobia</li> </ul> |
| Study designs   | ▶ Systematic review and meta-analysis for Q1<br>▶ Comparative individual studies for Q2 and Q3  |
| Timing  | From 2000 to 2023   |
| Subgroup analyses   | ▶ People working in a field with a position description that expects them to wear a face mask (pilots or qualified aircrew including flight attendants, military and public safety professionals)<br>▶ Duration of masking<br>▶ Activity level <ul style="list-style-type: none"> <li>– At rest</li> <li>– With exercise (progressive intensity protocol applied the exercise test until exhaustion vs steady exercise state)</li> </ul> <p>Altitude level (when relevant)</p>  |
| CO <sub>2</sub> , carbon dioxide; Q1,2,3, Question 1,2,3; VE/VCO <sub>2</sub> , minute ventilation/carbon dioxide production. |   |

### Study selection

Pairs of independent reviewers identified eligible studies by screening titles, abstracts and then full texts. Disagreements were resolved by consensus or arbitrated by a third reviewer, if necessary. For the systematic review addressing physiological outcomes, we only included reviews that had explicit inclusion and exclusion criteria and searched at least two databases. Inclusion was restricted to publications in the English language. In cases where

multiple systematic reviews existed for a particular outcome, to avoid risk of overlapping evidence, studies were prioritised based on their methodological rigour, determined by the quality of included evidence and the overall methodological quality of the systematic review, followed by the highest number of included studies and then publication year. Notably, at least one systematic review was included for each intervention under investigation.

### Data extraction and risk of bias assessment

Pairs of reviewers extracted data using a standardised, piloted, electronic form. We extracted data on patient characteristics, type of interventions and outcomes. Methodological quality of the systematic reviews was assessed using the AMSTAR instrument (a measurement tool to assess the methodological quality of systematic reviews). Pairs of reviewers working independently assessed the risk of bias using the modified Cochrane Collaboration tool for randomised clinical trials<sup>23</sup> and the modified Newcastle-Ottawa Quality Assessment tool for observational studies<sup>24</sup> for Q2 and Q3. Data regarding the risk of bias for Q1 were extracted from the systematic reviews. Disagreements were resolved by discussion or arbitrated by a third reviewer. We summarised the risk of bias for all domains to produce an overall risk of bias for every study.

### Data synthesis and analysis

For continuous outcomes, we estimated the effect of interventions using the weighted mean difference or the standardised mean difference. For dichotomous outcomes, we estimated the relative risk. We used the I<sup>2</sup> statistic and the Q statistic to assess heterogeneity. Evaluation for publication bias was not possible because of large heterogeneity that makes statistical tests for funnel plot symmetry unreliable.<sup>25</sup> The certainty in evidence was rated using the approach of Grading of Recommendations Assessment, Development and Evaluation and narrative adaptations.<sup>26–28</sup> Certainty from randomised controlled trials (RCT) was considered high but may be rated down for bias, indirectness, imprecision, inconsistency and publication bias. We rated down for inconsistency when we visually observed an important lack of overlap of CIs of individual studies. For imprecision, we rated down if sample size was <500 or the number of events was <100, or when CIs crossed the null effect with appreciable harm or benefit (<30 fewer outcomes or >30 more outcomes per 1000). For continuous outcome, we rated down for imprecision when the CI for the effect size crossed the null, except when the sample size was >800. We created a visual representation of all study outcomes (quantitative and qualitative) in the form of an evidence map. An evidence map shows the overall effects of mask use along with the risk of bias and certainty in these effects, helping decision-makers understand the possible benefits and gaps in research.<sup>19 29</sup>

### Patient and public involvement

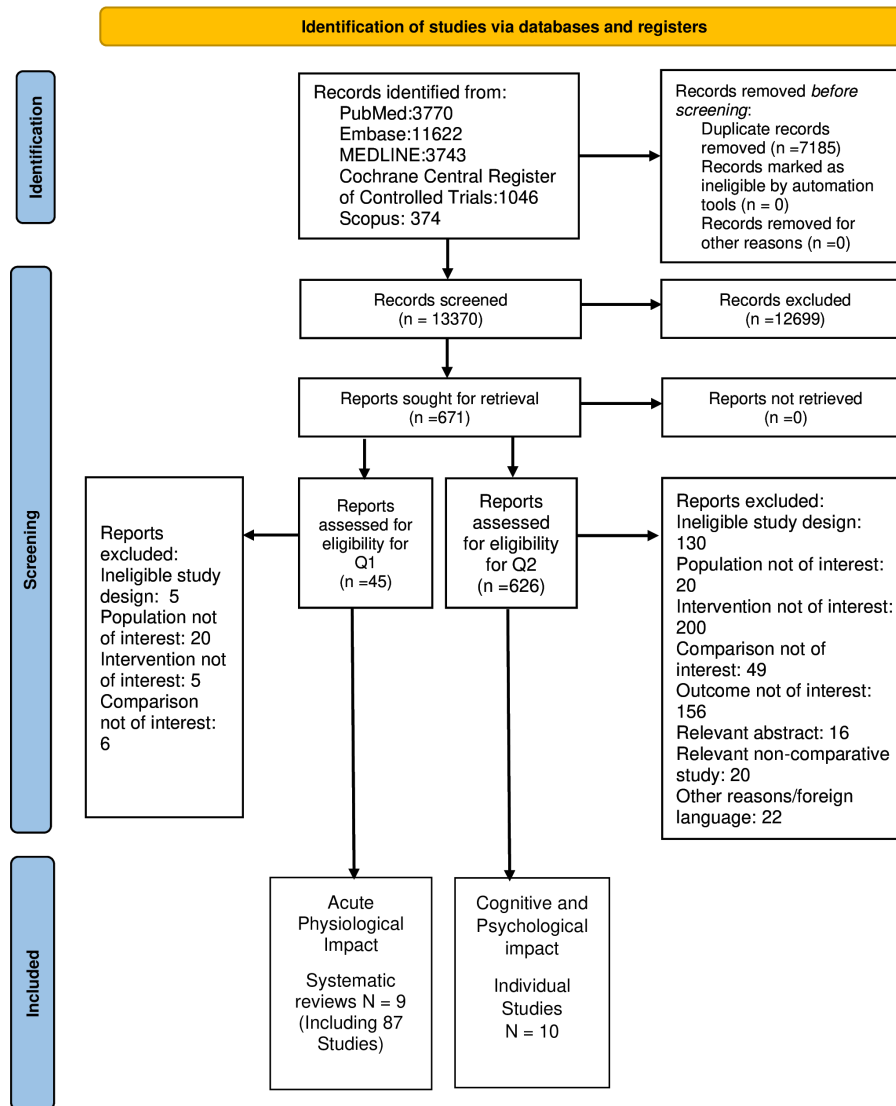
We did not involve patients or the public in the design, conduct, reporting and dissemination plans of this study.

## Results

### Literature search results

The electronic search yielded 13 370 potentially relevant citations, of which nine systematic reviews<sup>6 7 12 15 30–34</sup> including 87 primary individual studies (74 RCTs, 9 non-RCTs and 4 observational studies) enrolling 3404 participants were included to assess the impact of respiratory protection mask use on acute physiological outcomes, with the majority of participants being healthy adults (86.6%), followed by adults with chronic obstructive pulmonary

PRISMA 2020 flow diagram



**Figure 1** Flow chart. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

disease (COPD; 9.2%), and healthy children (3.1%). Additionally, one systematic review included 42 pregnant women. Additionally, 10 primary individual studies (2 RCTs,<sup>35 36</sup> 1 non-randomised controlled study<sup>37</sup> and 7 observational studies<sup>17 38–43</sup>) involving 411 healthy participants were included to assess the impact of respiratory protection mask use on cognitive and psychological outcomes. The screening process is illustrated in [figure 1](#), and the key characteristics of the selected studies are summarised in online supplemental tables 1 and 2, while the methodological qualities of the included studies are summarised in online supplemental table 3 (comparative observational studies) and online supplemental table 4 (randomised clinical trials).

## Outcomes

### *Acute physiological impact of respiratory protection mask use*

The impact of respiratory protection mask use on acute physiological responses was extensively assessed across numerous systematic reviews and studies with low to very low certainty evidence.

### *Cardiovascular responses*

#### Heart rate

Seven reviews reported on the impact of mask use on heart rate,<sup>6 12 15 30–33</sup> out of which we prioritised two systematic reviews based on their methodological rigour, number of included studies and recent publication time.<sup>12 32</sup> Wearing masks may cause little to no difference in heart rate compared with no mask in healthy adults or patients with COPD. In a subgroup analysis by exercise state, no significant difference was noted with mask wearing in healthy adults during the progressive exercise state; however, a slight increase in heart rate was noted during steady exercise state. Meta-analysis results are presented in [table 2](#).

#### Cardiac output

An analysis from one systematic review<sup>15</sup> showed no significant difference on stroke volume or cardiac output with mask use compared with no mask in healthy adults. Meta-analysis results are presented in [table 2](#).



**Table 2** Effect of respiratory protection mask use on cardiovascular responses and certainty of evidence

| Outcome (measurement unit)   | Systematic review                | Population         | Comparison   | Participants (included studies)                                     | Effect size MD (95% CI) | Risk of bias | Certainty of evidence |
|--|----------------------------------|--------------------|--|---|-------------------------|--------------|-----------------------|
| Heart rate (measured in beats per minute (bpm))                      | Zheng <i>et al</i> <sup>12</sup> | Healthy adults     | Surgical mask versus no mask                             | 692 (28 RCTs/randomised crossover trials)                           | 0.96 (−1.01 to 2.93)    | Moderate     | ⊕⊕○○*<br>Low          |
|  |                                  |                    | N95 respirator versus no mask                            | 391 (18 RCTs/randomised crossover trials)                           | 1.63 (−2.79 to 6.05)    | Moderate     | ⊕⊕○○*<br>Low          |
|  |                                  |                    | Cloth mask versus no mask                                | 115 (5 crossover trials)  | −0.94 (−6.39 to 4.52)   | Moderate     | ⊕⊕○○*<br>Low          |
|  |                                  |                    | Mask versus no mask (progressive exercise state)         | 803 (31 RCTs/randomised crossover trials)                           | −0.74 (−4.48 to 2.99)   | Moderate     | ⊕⊕○○*<br>Low          |
|  |                                  |                    | Mask versus no mask (steady-state exercise)              | 685 (25 RCTs/randomised crossover trials)                           | 2.69 (1.10 to 4.28)     | Moderate     | ⊕⊕○○*<br>Low          |
|  | Chen <i>et al</i> <sup>32</sup>  | Patients with COPD | Face mask versus no mask                                 | 97 (1 non-RCT)  | 4.70 (−0.30 to 9.70)    | Moderate     | ⊕⊕○○†<br>Low          |
| Maximum heart rate   | Chen <i>et al</i> <sup>32</sup>  | Patients with COPD | Face mask versus no mask                                 | 27 (1 randomised crossover trial)                                   | −1.90 (−10.84 to 7.04)  | Moderate     | ⊕○○○†<br>Very low     |
| Stroke volume (measured in millilitres (mL) per beat)                | Shaw <i>et al</i> <sup>15</sup>  | Healthy adults     | Face mask versus no mask                                 | 26 (2 crossover trials)   | 12.33 (−4.09 to 28.75)  | Moderate     | ⊕⊕○○‡<br>Low          |
|  |                                  |                    | N95 respirator versus no mask                            | 14 (1 crossover trial)  | 13.0 (−6.97 to 32.97)   | Moderate     | ⊕○○○†<br>Very low     |
| Cardiac output (measured in mL/min)                                  | Shaw <i>et al</i> <sup>15</sup>  | Healthy adults     | Face mask versus no mask                                 | 26 (2 crossover trials)   | 2.26 (−0.15 to 4.67)    | Moderate     | ⊕⊕○○‡<br>Low          |
|  |                                  |                    | N95 respirator versus no mask                            | 14 (1 crossover trial)  | 1.20 (−2.19 to 4.59)    | Moderate     | ⊕○○○†<br>Very low     |
| Systolic blood pressure (measured in millimetres of mercury (mm Hg)) | Shaw <i>et al</i> <sup>15</sup>  | Healthy adults     | Face mask versus no mask                                 | 1088 (4 crossover trials and 2 retrospective observational studies) | −2.23 (−5.28 to 0.82)   | High         | ⊕○○○§<br>Very low     |
|  |                                  |                    | N95 respirator versus no mask                            | 130 (3 randomised crossover trials and 1 RCT)                       | −0.12 (−4.22 to 3.97)   | Moderate     | ⊕⊕○○‡<br>Low          |
|  | Chen <i>et al</i> <sup>32</sup>  | Patients with COPD | Face mask versus no mask following 6MWT                  | 97 (1 non-RCT)  | 0.40 (−4.36 to 5.16)    | Moderate     | ⊕⊕○○†<br>Low          |
|  |                                  |                    | Face mask versus no mask following maximum exercise test | 27 (1 crossover trial)  | −6.80 (−24.37 to 10.77) | Moderate     | ⊕⊕○○†<br>Low          |
| Diastolic blood pressure (measured in mm Hg)                         | Shaw <i>et al</i> <sup>15</sup>  | Healthy adults     | Face mask versus no mask                                 | 38 (3 crossover trials)   | −0.96 (−5.32 to 3.40)   | Moderate     | ⊕⊕○○‡<br>Low          |
|  |                                  |                    | N95 respirator versus no mask                            | 114 (2 crossover trials and 1 non-RCT)                              | −0.23 (−3.06 to 2.60)   | Moderate     | ⊕⊕○○‡<br>Low          |
|  | Chen <i>et al</i> <sup>32</sup>  | Patients with COPD | Face mask versus no mask at rest                         | 97 (1 non-RCT)  | 2.70 (−0.34 to 5.74)    | Moderate     | ⊕⊕○○‡<br>Low          |
|  |                                  |                    | Face mask versus no mask following 6MWT                  | 97 (1 non-RCT)  | −0.80 (−4.13 to 2.53)   | Moderate     | ⊕⊕○○‡<br>Low          |
| Mean arterial blood pressure (measured in mm Hg)                     | Lima <i>et al</i> <sup>31</sup>  | Adult patients     | Face mask versus no mask                                 | 116 (6 crossover trials)  | −0.07 (−0.32 to 0.17)   | High         | ⊕○○○§<br>Very low     |

\*Low quality of evidence is due to unexplained inconsistency and imprecise results due to small magnitude of change and wide CI.  
†Low quality of evidence is due to imprecise results due to small magnitude of change and wide CI and some concern with risk of bias.  
‡Low quality of evidence is due to imprecise results due to small magnitude of change and wide CI.  
§Low quality of evidence is due to unexplained inconsistency and imprecise results due to small magnitude of change and wide CI and some concern with risk of bias.  
COPD, chronic obstructive pulmonary disease; MD, mean difference; 6MWT, 6 min walk test; RCT, randomised controlled trial.

### Blood pressure

Four systematic reviews examined the impact of mask use on blood pressure,<sup>6 15 31 32</sup> out of which we prioritised three systematic reviews based on their methodological rigour and number of included studies.<sup>15 31 32</sup> Wearing masks was associated with little to no difference in systolic, diastolic and mean arterial blood pressure compared with no mask in healthy adults or patients with COPD. In a subgroup analysis by exercise state, no significant difference was noted in systolic or diastolic blood pressure in patients with COPD. Meta-analysis results are presented in table 2.

### Ventilatory responses

#### Respiratory rate

Seven reviews reported the impact of mask use on respiratory rate (RR),<sup>6 12 15 30–33</sup> out of which we prioritised two systematic reviews based on their methodological rigour, number of included studies and recent publication time.<sup>12 32</sup> Wearing masks may cause little to no difference in RR compared with no mask in healthy adults or patients with COPD. In a subgroup analysis by exercise state, no significant difference was noted in RR in healthy adults during the different exercise states. Meta-analysis results are presented in table 3.

**Table 3** Effect of respiratory protection mask use on ventilatory responses and certainty of evidence

| Outcome (measurement unit)                        | Systematic review                | Population     | Comparison                                       | Participants (included studies)           | Effect size MD (95% CI)    | Risk of bias | Certainty of evidence |
|---|----------------------------------|----------------|--|---|----------------------------|--------------|-----------------------|
| Respiratory rate (measured in breaths per minute) | Zheng <i>et al</i> <sup>12</sup> | Healthy adults | Surgical mask versus no mask                     | 358 (13 crossover trials)                 | -1.35 (-3.00 to 0.29)      | Moderate     | ⊕⊕○○*<br>Low          |
|   |                                  |                | N95 respirator versus no mask                    | 248 (11 crossover trials)                 | 0.10 (-3.10 to 3.29)       | Moderate     | ⊕⊕○○*<br>Low          |
|   |                                  |                | Cloth mask versus no mask                        | 81 (3 crossover trials)                   | -2.57 (-6.44 to 1.29)      | High         | ⊕○○○†<br>Very low     |
|   |                                  |                | Mask versus no mask (progressive exercise state) | 540 (20 RCTs/randomised crossover trials) | -1.40 (-4.02 to 1.23)      | Moderate     | ⊕⊕○○*<br>Low          |
|   |                                  |                | Mask versus no mask (steady-state exercise)      | 386 (13 RCTs/randomised crossover trials) | -0.26 (-1.83 to 1.30)      | Moderate     | ⊕⊕○○*<br>Low          |
| Minute ventilation (measured in mL/min)           | Zheng <i>et al</i> <sup>12</sup> | Healthy adults | Surgical mask versus no mask                     | 212 (11 crossover trials)                 | -13.9 (-20.30 to -7.53)    | High         | ⊕○○○†<br>Very low     |
|   |                                  |                | N95 respirator versus no mask                    | 62 (5 crossover trials)                   | -16.3 (-28.7 to -3.9)      | Moderate     | ⊕○○○‡<br>Very low     |
|   |                                  |                | Mask versus no mask (progressive exercise state) | 217 (16 RCTs/randomised crossover trials) | -18.11 (-24.63 to -11.58)  | High         | ⊕○○○†<br>Very low     |
|   |                                  |                | Mask versus no mask (steady-state exercise)      | 62 (3 RCTs/randomised crossover trials)   | -0.07 (-4.47 to 4.33)      | High         | ⊕○○○†<br>Very low     |
| Tidal volume (measured in millilitres)            | Zheng <i>et al</i> <sup>12</sup> | Healthy adults | Surgical mask versus no mask                     | 151 (6 crossover trials)                  | MD: -0.14 (-0.23 to -0.05) | Moderate     | ⊕⊕○○§<br>Low          |
|   |                                  |                | N95 respirator versus no mask                    | 46 (4 crossover trials)                   | -0.10 (-0.33 to 0.13)      | Moderate     | ⊕⊕○○§<br>Low          |
|   |                                  |                | Mask versus no mask (progressive exercise state) | 168 (9 RCTs/randomised crossover trials)  | -0.21 (-0.31 to -0.10)     | Moderate     | ⊕⊕○○*<br>Low          |
|   |                                  |                | Mask versus no mask (steady-state exercise)      | 80 (5 RCTs/randomised crossover trials)   | -0.00 (-0.12 to 0.12)      | Moderate     | ⊕⊕○○*<br>Low          |
| Carbon dioxide ventilation equivalent             | Zheng <i>et al</i> <sup>12</sup> | Healthy adults | Surgical mask versus no mask                     | 139 (5 crossover trials)                  | -1.69 (-3.10 to -0.27)     | Moderate     | ⊕○○○‡<br>Very low     |
|   |                                  |                | Mask versus no mask (progressive exercise state) | 125 (4 RCTs/randomised crossover trials)  | -1.18 (-2.42 to 0.06)      | Moderate     | ⊕○○○‡<br>Very low     |
|   |                                  |                | Mask versus no mask (steady-state exercise)      | 58 (3 RCTs/randomised crossover trials)   | -2.39 (-4.97 to 0.19)      | Moderate     | ⊕○○○‡<br>Very low     |

\*Low quality of evidence is due to unexplained inconsistency and imprecise results due to small magnitude of change and wide CI.  
†Low quality of evidence is due to unexplained inconsistency and imprecise results due to small magnitude of change and wide CI and some concern with risk of bias.  
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§Low quality of evidence is due to imprecise results due to small magnitude of change and wide CI.  
COPD, chronic obstructive pulmonary disease; MD, mean difference; RCT, randomised controlled trial.

### Minute ventilation

Six systematic reviews<sup>6 12 15 30 32 33</sup> reported this outcome, out of which we prioritised two systematic reviews based on their methodological rigour, number of included studies and recent publication time.<sup>12 32</sup> Wearing masks was associated with a reduction in minute ventilation (VE) in healthy adults, with little to no difference in VE noted with mask use in patients with COPD. In a subgroup analysis by exercise state, wearing masks was associated with a reduction in VE in healthy adults during progressive exercise states with little to no difference noted during the steady exercise state. Meta-analysis results are presented in [table 3](#).

### Tidal volume

Four systematic reviews<sup>6 12 15 33</sup> reported data regarding the impact of mask use on tidal volume (VT), out of which we prioritised one systematic review based on methodological rigour, number of included studies and recent publication time.<sup>12</sup> Wearing surgical masks was associated with a reduction in VT in healthy adults compared with no mask. However, little to no difference was observed with N95 mask use. In a subgroup analysis by exercise state, wearing masks was associated with a reduction in VT in

healthy adults during progressive exercise states with little to no difference noted during the steady exercise state. Meta-analysis results are presented in [table 3](#).

### Carbon dioxide ventilation equivalent (VE/VCO<sub>2</sub>)

An analysis from one systematic review<sup>12</sup> showed a reduction in VE/VCO<sub>2</sub> with surgical mask use compared with no mask in healthy adults. In a subgroup analysis by exercise state, little to no difference was noted in VE/VCO<sub>2</sub> in healthy adults during the different exercise states. Meta-analysis results are presented in [table 3](#).

### Metabolic responses

#### Oxygen saturation

Eight systematic reviews<sup>6 7 12 15 30-33</sup> reported this outcome, out of which we prioritised two systematic reviews based on their methodological rigour, number of included studies and recent publication time.<sup>12 32</sup> Wearing surgical masks was associated with a small reduction in oxygen saturation in healthy adults and patients with COPD, with little to no difference noted in oxygen saturation with N95 or cloth mask use. In a subgroup analysis by exercise

**Table 4** Effect of respiratory protection mask use on metabolic responses and certainty of evidence

| Outcome (measurement unit)   | Systematic review                 | Population                      | Comparison   | Participants (included studies)              | Effect size (95% CI)                      | Risk of bias              | Certainty of evidence |
|--|-----------------------------------|---------------------------------|--|--|---|---------------------------|-----------------------|
| Oxygen saturation (measured in %)  | Zheng <i>et al</i> <sup>12</sup>  | Healthy adults                  | Surgical mask versus no mask   | 589 (20 RCTs/crossover trials and 1 non-RCT) | MD -0.59% (-0.87% to -0.30%)              | Moderate                  | ⊕⊕○○*<br>Low          |
|  |                                   |                                 | N95 respirator versus no mask  | 232 (10 RCTs/crossover trials and 1 non-RCT) | MD -0.35% (-0.75% to 0.05%)               | Moderate                  | ⊕⊕○○*<br>Low          |
|  |                                   |                                 | Cloth mask versus no mask  | 164 (6 RCTs/crossover trials and 1 non-RCT)  | MD -0.50% (-1.23%; 0.24%)                 | Moderate                  | ⊕⊕○○*<br>Low          |
|  |                                   |                                 | Mask versus no mask (progressive exercise state)                             | 821 (27 RCTs/crossover trials and 1 non-RCT) | MD -0.60 (-1.02 to -0.18)                 | Moderate                  | ⊕⊕○○*<br>Low          |
|  |                                   |                                 | Mask versus no mask (steady-state exercise)                                  | 660 (19 RCTs/crossover trials and 1 non-RCT) | MD -0.41 (-0.73 to -0.10)                 | Moderate                  | ⊕⊕○○*<br>Low          |
|  | Chen <i>et al</i> <sup>32</sup>   | Patients with COPD              | Face mask versus no mask   | 97 (1 non-RCT)                               | MD -0.80 (-1.56 to -0.04)                 | High                      | ⊕○○○†<br>Very low     |
| End-tidal oxygen partial pressure (measured in mm Hg)                      | Zheng <i>et al</i> <sup>12</sup>  | Healthy adults                  | Surgical mask versus no mask   | 132 (6 RCTs/crossover trials)                | MD -3.17 mm Hg (-4.87 to -1.47)           | Moderate                  | ⊕⊕○○‡<br>Low          |
|  |                                   |                                 | N95 respirator versus no mask  | 42 (4 RCTs/crossover trials)                 | MD -5.10 mm Hg (-9.27 to -0.94)           | Moderate                  | ⊕⊕○○‡<br>Low          |
| Oxygen uptake (measured in mL/kg/min)                                      | Zheng <i>et al</i> <sup>12</sup>  | Healthy adults                  | Surgical mask versus no mask   | 202 (9 RCTs/crossover trials and 1 non-RCT)  | MD -0.64 (-0.86 to -0.42)                 | High                      | ⊕○○○†<br>Very low     |
|  |                                   |                                 | N95 respirator versus no mask  | 72 (5 RCTs/crossover trials)                 | MD -0.66 (-1.16 to -0.16)                 | Moderate                  | ⊕⊕○○‡<br>Low          |
|  |                                   |                                 | Cloth mask versus no mask  | 51 (2 RCTs/crossover trials)                 | MD -0.73 (-1.96 to 0.51)                  | Moderate                  | ⊕⊕○○*<br>Low          |
|  |                                   |                                 | Mask versus no mask (progressive exercise state)                             | 265 (16 RCTs/crossover trials)               | MD -0.68 (-0.93 to -0.43)                 | High                      | ⊕○○○†<br>Very low     |
|  |                                   |                                 | Mask versus no mask (steady-state exercise)                                  | 62 (3 RCTs/crossover trials)                 | MD -0.57 (-0.94 to -0.21)                 | High                      | ⊕○○○†<br>Very low     |
| Muscle oxygenation (measured in %)   | Shaw <i>et al</i> <sup>15</sup>   | Adults                          | Surgical mask versus no mask   | 40 (3 RCTs/crossover trials)                 | MD -0.41 (-0.86 to 0.05)                  | Moderate                  | ⊕⊕○○*<br>Low          |
| VCO <sub>2</sub> (measured in mL/min)                                      | Zheng <i>et al</i> <sup>12</sup>  | Healthy adults                  | Surgical mask versus no mask   | 127 (4 RCTs/crossover trials, 1 non-RCT)     | SMD -0.74 (-1.19 to -0.28)                | Moderate                  | ⊕⊕○○*<br>Low          |
|  |                                   |                                 | N95 respirator versus no mask  | 28 (2 RCTs/crossover trials)                 | SMD -0.87 (-1.82 to 0.07)                 | Moderate                  | ⊕⊕○○*<br>Low          |
| Carbon dioxide partial pressure (measured in mm Hg)                        | Wangsan <i>et al</i> <sup>7</sup> | Healthy adults                  | N95 respirator versus no mask (high-intensity exercise)                      | 51 (4 RCTs/crossover trials)                 | SMD 1.17 (0.70 to 1.64)                   | Moderate                  | ⊕⊕○○*<br>Low          |
|  |                                   |                                 | N95 respirator versus no mask (low-intensity to moderate-intensity exercise) | 54 (4 RCTs/crossover trials)                 | SMD 0.43 (0.08 to 0.79)                   | Moderate                  | ⊕⊕○○*<br>Low          |
| Arterial CO <sub>2</sub> (measured in milliequivalents per litre (mmol/L)) | Shaw <i>et al</i> <sup>15</sup>   | Adults                          | Surgical mask versus no mask   | 62 (1 RCT/crossover trial and 1 non-RCT)     | MD 0.41 (-2.15 to 1.33)                   | High                      | ⊕○○○†<br>Very low     |
|  |                                   |                                 | N95 respirator versus no mask  | 54 (3 RCTs/crossover trials, 1 non-RCT)      | MD 1.33 (0.02; 2.64)                      | High                      | ⊕○○○†<br>Very low     |
| End-tidal CO <sub>2</sub> (measured in mm Hg)                              | Zheng <i>et al</i> <sup>12</sup>  | Healthy adults                  | Surgical mask versus no mask   | 269 (9 RCTs/crossover trials)                | MD 2.32 (1.38; 3.26)                      | High                      | ⊕○○○†<br>Very low     |
|  |                                   |                                 | N95 respirator versus no mask  | 213 (9 RCTs/crossover trials)                | MD 2.93 (2.01; 3.86)                      | High                      | ⊕○○○§<br>Very low     |
|  |                                   |                                 | Mask versus no mask (progressive exercise state)                             | 369 (10 RCTs/crossover trials)               | MD 4.15 (2.77 to 5.53)                    | High                      | ⊕○○○†<br>Very low     |
|  |                                   |                                 | Mask versus no mask (steady-state exercise)                                  | 387 (10 RCTs/crossover trials)               | MD 2.09 (0.93 to 3.25)                    | High                      | ⊕○○○§<br>Very low     |
|  |                                   | Chen <i>et al</i> <sup>32</sup> | Patients with COPD   | Face mask versus no mask                     | 112 (1 RCT/crossover trial and 1 non-RCT) | MD 0.10 (-1.57 to 1.78)   | Moderate              |
| Lactate level (measured in mmol/L)   | Zheng <i>et al</i> <sup>12</sup>  | Healthy adults                  | Surgical mask versus no mask   | 160 (7 RCTs/crossover trials)                | MD -0.10 (-1.11; 1.31)                    | Moderate                  | ⊕⊕○○*<br>Low          |
|  |                                   |                                 | N95 respirator versus no mask  | 28 (2 RCTs/crossover trials)                 | MD -1.02 (-2.09; 0.05)                    | Moderate                  | ⊕⊕○○*<br>Low          |
|  |                                   |                                 | Mask versus no mask (progressive exercise state)                             | 147 (6 RCTs/crossover trials)                | MD -1.06 (-1.69 to -0.44)                 | Moderate                  | ⊕⊕○○*<br>Low          |
|  |                                   |                                 | Mask versus no mask (steady-state exercise)                                  | 127 (4 RCTs/crossover trials)                | MD -1.23 (-0.40 to 2.86)                  | Moderate                  | ⊕⊕○○*<br>Low          |
|  |                                   | Chen <i>et al</i> <sup>32</sup> | Patients with COPD   | Face mask versus no mask                     | 27 (1 RCT/crossover trial)                | MD -0.90 (-1.73 to -0.07) | Moderate              |

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§Low quality of evidence is due to unexplained inconsistency and imprecise results due to small magnitude of change and wide CI and some concern with risk of bias.

CO<sub>2</sub>, carbon dioxide; COPD, chronic obstructive pulmonary disease; MD, mean difference; RCT, randomised controlled trial; SMD, standardised mean difference; VCO<sub>2</sub>, carbon dioxide production.

**Table 5** Effect of respiratory protection mask use on exercise performance and certainty of evidence

| Outcome                              | Systematic review                     | Population         | Comparison                                       | Participants (included studies) | Effect size (95% CI)       | Risk of bias | Certainty of evidence |
|--------------------------------------|---------------------------------------|--------------------|--|---------------------------------|----------------------------|--------------|-----------------------|
| Exercise performance                 | Zheng <i>et al</i> <sup>12</sup>      | Healthy adults     | Surgical mask versus no mask                     | 541 (20 RCTs/crossover trials)  | SMD -0.12 (-0.39 to 0.15)  | Moderate     | ⊕⊕○○*<br>Low          |
|                                      |                                       |                    | N95 respirator versus no mask                    | 232 (11 RCTs/crossover trials)  | SMD -0.42 (-0.76 to -0.08) | Moderate     | ⊕⊕○○*<br>Low          |
|                                      |                                       |                    | Cloth mask versus no mask                        | 114 (5 RCTs/crossover trials)   | SMD -0.26 (-0.54 to 0.02)  | Moderate     | ⊕⊕○○*<br>Low          |
|                                      |                                       |                    | Mask versus no mask (progressive exercise state) | 917 (34 RCTs/crossover trials)  | SMD -0.34 (-0.52 to -0.15) | Moderate     | ⊕⊕○○*<br>Low          |
|                                      |                                       |                    | Mask versus no mask (steady-state exercise)      | 283 (7 RCTs/crossover trials)   | SMD 0.16 (-0.32 to 0.65)   | Moderate     | ⊕⊕○○*<br>Low          |
|                                      | Chen <i>et al</i> <sup>32</sup>       | Patients with COPD | Face mask versus no mask                         | 27 (1 crossover trial)          | MD -9.90 (-28.20 to 8.40)  | Moderate     | ⊕⊕○○†<br>Low          |
| Rating of perceived exertion         | Zheng <i>et al</i> <sup>12</sup>      | Healthy adults     | Surgical mask versus no mask                     | 424 (20 crossover trials/RCTs)  | SMD 0.36 (0.21 to 0.52)    | Moderate     | ⊕⊕○○†<br>Low          |
|                                      |                                       |                    | N95 respirator versus no mask                    | 174 (10 crossover trials/RCTs)  | SMD 0.17 (-0.01 to 0.35)   | Moderate     | ⊕⊕○○†<br>Low          |
|                                      |                                       |                    | Cloth mask versus no mask                        | 161 (7 crossover trials/RCTs)   | SMD 0.22 (-0.13 to 0.57)   | Moderate     | ⊕⊕○○*<br>Low          |
| Time to exhaustion                   | Glänzel <i>et al</i> <sup>34</sup>    | Healthy adults     | Face mask versus no mask                         | 210 (9 crossover trials/RCTs)   | MD -0.29 (-0.48 to -0.10)  | Moderate     | ⊕⊕○○†<br>Low          |
| Thermal sensation                    | Zheng <i>et al</i> <sup>12</sup>      | Healthy adults     | Surgical mask versus no mask                     | 56 (4 RCTs/crossover trials)    | SMD 0.46 (0.06 to 0.85)    | Moderate     | ⊕⊕○○†<br>Low          |
|                                      |                                       |                    | N95 respirator versus no mask                    | 36 (3 RCTs/crossover trials)    | SMD 0.97 (-0.05 to 2.00)   | Moderate     | ⊕⊕○○†<br>Low          |
|                                      |                                       |                    | Mask versus no mask (progressive exercise state) | 24 (2 RCTs/crossover trials)    | SMD 1.59 (0.55 to 2.64)    | Moderate     | ⊕⊕○○*<br>Low          |
|                                      |                                       |                    | Mask versus no mask (steady-state exercise)      | 68 (5 RCTs/crossover trials)    | SMD 0.35 (0.01 to 0.69)    | Moderate     | ⊕⊕○○*<br>Low          |
| Facial skin temperature              | Litwinowicz <i>et al</i> <sup>6</sup> | Healthy adults     | N95 respirator versus no mask                    | 86 (5 RCTs/crossover trials)    | SMD 1.05 (0.48 to 1.63)    | Moderate     | ⊕⊕○○†<br>Low          |
| Subjective rating of heat perception | Litwinowicz <i>et al</i> <sup>6</sup> | Healthy adults     | N95 respirator versus no mask                    | 54 (4 RCTs/crossover trials)    | SMD 1.04 (-0.12 to 2.19)   | Moderate     | ⊕⊕○○†<br>Low          |

\*Low quality of evidence is due to unexplained inconsistency and imprecise results due to small magnitude of change and wide CI.  
†Low quality of evidence is due to imprecise results due to small magnitude of change and wide CI.  
COPD, chronic obstructive pulmonary disease; MD, mean difference; RCT, randomised controlled trial; SMD, standardised mean difference.

state, a small reduction in oxygen saturation was noted in healthy adults during the different exercise states. Meta-analysis results are presented in [table 4](#).

#### End-tidal oxygen partial pressure

An analysis from one systematic review<sup>12</sup> showed a reduction in end-tidal oxygen partial pressure (PetO<sub>2</sub>) with mask use. Meta-analysis results are presented in [table 4](#).

#### Oxygen uptake

Three systematic reviews<sup>6 12 30</sup> reported data regarding the impact of mask use on oxygen uptake, out of which we prioritised two systematic reviews based on their methodological rigour, number of included studies and recent publication time.<sup>12 32</sup> Wearing masks was associated with a decrease in oxygen uptake (VO<sub>2</sub>) compared with no mask in healthy adults. In a subgroup analysis by exercise state, a small reduction in oxygen uptake was noted in healthy adults during the different exercise states. Meta-analysis results are presented in [table 4](#).

#### Muscle oxygenation

An analysis from one systematic review<sup>15</sup> showed wearing face masks was associated with little to no significant difference in muscle oxygenation during exercise compared with no mask

use in adult participants. Meta-analysis results are presented in [table 4](#).

#### Carbon dioxide

Three systematic reviews<sup>6 7 30</sup> reported this outcome, out of which we prioritised two systematic reviews based on the methodological rigour, number of included studies and publication time.<sup>7 12</sup> Wearing surgical masks was associated with a small reduction in VCO<sub>2</sub> in healthy adults, with little to no significant difference noted with N95 mask use. In a subgroup analysis by exercise state, wearing an N95 mask was associated with a slight increase in carbon dioxide in healthy adults during the different exercise states. Meta-analysis results are presented in [table 4](#).

#### End-tidal CO<sub>2</sub>

Three systematic reviews<sup>12 15 32</sup> reported the impact of mask use on end-tidal carbon dioxide, out of which we prioritised two systematic reviews based on their methodological rigour, number of included studies and recent publication time.<sup>12 32</sup> Wearing masks was associated with an increase in end-tidal CO<sub>2</sub> in healthy adults with little to no significant difference noted in patients with COPD. In a subgroup analysis by exercise state, a slight increase in end-tidal CO<sub>2</sub> was noted in healthy adults during the different exercise states. Meta-analysis results are presented in [table 4](#).



**Table 6** A narrative review of the available evidence on the effect of mask use on cognitive performance and psychological outcomes

| Author, year of publication   | Participants (study design)  | Outcome  | Risk of bias | Certainty of evidence |
|---|------------------------------|--|--------------|-----------------------|
| <b>Cognitive performance</b>  |                              |  |              |                       |
| Braun-Trocchio <i>et al</i> , <sup>37</sup> 2022  | 54 (non-randomised study)    | Wearing masks was associated with an increase in the internal focus score during the stepping exercise task compared with no mask.   | High         | ⊕○○○*<br>Very low     |
| Deng <i>et al</i> , <sup>35</sup> 2022  | 20 (RCT)                     | Wearing a mask was associated with reduced mental workload compared with no mask; however, mask use was associated with worse performance scores and fewer correct numbers or rates. | Moderate     | ⊕⊕○○†<br>Low          |
| Grimm <i>et al</i> , <sup>36</sup> 2022   | 23 (RCT)                     | Mask use was associated with little to no significant difference in cognitive performance, self-perceived arousal or ability to concentrate ratings during rest or exercise.         | Moderate     | ⊕⊕○○*<br>Low          |
| Ipek <i>et al</i> , <sup>17</sup> 2021  | 34 (cross-sectional study)   | Wearing N95 masks was associated with higher attention deficit rates and difficulty in concentrating compared with the face mask group.  | High         | ⊕○○○*<br>Very low     |
| Jahangiri <i>et al</i> , <sup>39</sup> 2023   | 40 (quasiexperimental study) | No significant difference was noted between face mask and N95 respirator groups in cognitive performance, number of correct responses or response time.                              | High         | ⊕○○○*<br>Very low     |
| Slimani <i>et al</i> , <sup>41</sup> 2021   | 17 (cross-sectional study)   | Wearing face masks was associated with improved cognitive function, resulting in fewer errors compared with no mask group.   | High         | ⊕○○○*<br>Very low     |
| Tornero-Aguilera and Clemente-Suarez, <sup>43</sup> 2021  | 50 (cross-sectional study)   | Wearing a face mask was associated with little to no difference in mental fatigue perception or reaction time compared with no mask.   | High         | ⊕○○○*<br>Very low     |
| <b>Psychological outcomes</b>   |                              |  |              |                       |
| Chong <i>et al</i> , <sup>38</sup> 2022   | 93 (cross-sectional study)   | Claustrophobia was noted in 3% of the participants while wearing face masks. Comparable results were noted while wearing an N95 respirator or surgical mask.                         | High         | ⊕○○○*<br>Very low     |
| Khalid <i>et al</i> , <sup>40</sup> 2021  | 12 (cross-sectional study)   | Higher rate of claustrophobia among the N95 respirator group when compared with the face mask group.   | High         | ⊕○○○*<br>Very low     |
| Su <i>et al</i> , <sup>42</sup> 2021  | 68 (cross-sectional study)   | No significant difference was noted in depression or anxiety rate among the surgical mask or N95 respiratory group.  | High         | ⊕○○○*<br>Very low     |
| *Low quality of evidence is due to unexplained inconsistency and imprecise results due to small magnitude of change and wide CI and some concern with risk of bias. |                              |  |              |                       |
| †Low quality of evidence is due to imprecise results due to small magnitude of change and wide CI.  |                              |  |              |                       |
| RCT, randomised controlled trial.   |                              |  |              |                       |

### Lactate

Three systematic reviews<sup>12 15 32</sup> reported this outcome, out of which we prioritised two systematic reviews based on their methodological rigour, number of included studies and recent publication time.<sup>12 32</sup> Wearing masks was associated with little to no significant difference in lactate levels in healthy adults; however, a small reduction in lactate level was noted in patients with COPD. In a subgroup analysis by exercise type, a small decrease in lactate level was noted in healthy adults during the progressive exercise state with little to no significant difference noted during steady exercise state. Meta-analysis results are presented in [table 4](#).

### Exercise performance

Exercise performance  
Four systematic reviews<sup>12 15 30 32</sup> assessed the impact of mask use on exercise performance, out of which we prioritised two systematic reviews based on their methodological rigour, number of included studies and recent publication time.<sup>12 32</sup> N95 mask use was associated with a slight reduction in exercise performance in healthy adult's rate compared with no mask, with little to no significant difference noted with surgical and cloth mask use in healthy adults and patients with COPD. In a subgroup analysis by exercise type, a small decrease in exercise performance was noted with mask use in healthy adults during the progressive exercise state with little to no significant difference noted during the steady exercise state. Meta-analysis results are presented in [table 5](#).

### Time to exhaustion and perceived exertion

Three systematic reviews<sup>12 15 34</sup> reported this outcome. We prioritised two systematic reviews based on their methodological rigour, number of included studies and publication time.<sup>12 34</sup> Wearing surgical masks was associated with higher perceived exertion (rating of perceived exertion) scores in healthy adults compared with no mask use; however, little to no significant difference was noted with N95 or cloth mask use. Additionally, a slight reduction in time to exhaustion was noted with the use of face masks compared with the no mask. Meta-analysis results are presented in [table 5](#).

### Thermal sensation and facial skin temperature

Two systematic reviews<sup>6 12</sup> reported this outcome. Wearing masks was associated with an increase in thermal sensation compared with no mask use in healthy adults. In a subgroup analysis by exercise type, an increase in thermal sensation was noted with mask use in healthy adults during different exercise states. Additionally, facial skin temperature significantly increased with mask use; however, no significant difference was observed in subjective ratings of heat perception between mask and no mask groups. Meta-analysis results are presented in [table 5](#).

### Cognitive influence of respiratory protection mask use

Studies examining the impact of face mask use on cognitive function during exercise have produced mixed results

| Comparisons                           | FFP/N95 respirator vs. No mask | Surgical mask vs. No mask | Cloth mask vs. No mask | All facemask vs. No mask | Face mask vs. No mask following low to moderate intensity exercise | Facemask vs. No mask following high intensity exercise |
|---------------------------------------|--------------------------------|---------------------------|------------------------|--------------------------|--|--|
| <b>Cardiovascular Responses</b>       |                                |                           |                        |                          |  |  |
| Heart Rate                            | –                              | –                         | –                      | –*                       |  |  |
| Maximum Heart Rate                    |                                |                           |                        | –*                       |  |  |
| Stroke Volume                         | –                              |                           |                        | –                        |  |  |
| Cardiac Output                        | –                              |                           |                        | –                        |  |  |
| Systolic Blood Pressure               | –                              |                           |                        | –                        | –*   | –*   |
| Diastolic Blood Pressure              | –                              |                           |                        | –                        | –*   |  |
| Mean Arterial Blood Pressure          |                                |                           |                        | –                        |  |  |
| <b>Ventilatory Responses</b>          |                                |                           |                        |                          |  |  |
| Respiratory Rate                      | –                              | –                         | –                      | ↑*                       |  |  |
| Minute Ventilation                    | ↓                              | ↓                         |                        | –*                       |  |  |
| Tidal Volume                          | –                              | ↓                         |                        |                          |  |  |
| Carbon Dioxide Ventilation Equivalent |                                | ↓                         |                        |                          |  |  |
| <b>Metabolic Responses</b>            |                                |                           |                        |                          |  |  |
| Oxygen Saturation                     | –                              | ↓                         | –                      | ↓*                       |  |  |
| End Tidal Oxygen Partial Pressure     | ↓                              | ↓                         |                        |                          |  |  |
| Oxygen Uptake                         | ↓                              | ↓                         | –                      |                          |  |  |
| Muscle Oxygenation                    |                                | –                         |                        |                          |  |  |
| Carbon Dioxide Partial Pressure       |                                |                           |                        |                          | ↑¥   | ↑¥   |
| VCO2                                  | –                              | ↓                         |                        |                          |  |  |
| Arterial CO2                          | ↑                              | –                         |                        |                          |  |  |
| End Tidal CO2                         | ↑                              | ↑                         |                        | –*                       |  |  |
| Lactate Level                         | –                              | –                         |                        | ↓*                       |  |  |
| <b>Exercise Performance</b>           |                                |                           |                        |                          |  |  |
| Exercise Performance                  | ↓                              | –                         | –                      | –*                       |  |  |
| Rating of Perceived Exertion          | –                              | ↑                         | –                      |                          |  |  |
| Time to Exhaustion                    |                                |                           |                        | ↓                        |  |  |
| Thermal Sensation                     | –                              | ↑                         |                        |                          |  |  |
| Facial Skin Temperature               | –                              |                           |                        |                          |  |  |
| Subjective Rating of Heat Perception  | –                              |                           |                        |                          |  |  |
| <b>Cognitive Impact</b>               |                                |                           |                        |                          |  |  |
| Focus/concentration                   |                                |                           |                        | ↑–                       |  |  |
| Mental Workload                       |                                |                           |                        | ↓                        |  |  |
| Performance                           | –                              |                           |                        | ↓↑                       |  |  |
| Mental Fatigue Perception             |                                | –                         |                        |                          |  |  |
| Attention Deficit                     | ↑                              |                           |                        |                          |  |  |
| Reaction Time                         |                                | –                         |                        |                          |  |  |
| <b>Psychological Impact</b>           |                                |                           |                        |                          |  |  |
| Anxiety                               | –                              | –                         |                        |                          |  |  |
| Depression                            | –                              | –                         |                        |                          |  |  |
| Claustrophobia                        | ↑↑                             | ↑                         |                        | ↑–                       |  |  |

Statistically significant Effect: increase ↑, Statistically significant Effect: decrease ↓, Non statistically significant Effect/no effect: –  
 Type of mask N95: ¥, COPD patients: \*

**Certainty of evidence:**

|          |     |          |      |                      |
|----------|-----|----------|------|----------------------|
| Very Low | Low | Moderate | High | No available studies |
|----------|-----|----------|------|----------------------|

**Figure 2** Evidence map demonstrating the availability of evidence and its quality for the various physiological, cognitive and psychological outcomes associated with mask use. COPD, chronic obstructive pulmonary disease.

with low to very low certainty of evidence. Some studies, such as Braun-Trocchio *et al*<sup>37</sup> and Slimani *et al*,<sup>41</sup> suggest potential benefits, including improved cognitive function and increased internal focus among mask wearers. However, other research, like that by Deng *et al*,<sup>35</sup> indicates a reduction in mental workload but lower performance in terms of accuracy. Contrary findings were reported by Jahangiri *et al*<sup>39</sup> and Grimm *et al*,<sup>36</sup> no significant differences in cognitive performance were observed between mask types or during exercise. Additionally, Tornero-Aguilera and Clemente-Suárez<sup>43</sup> found

no effects on mental fatigue or reaction time with surgical face mask use. Notably, Ipek *et al*<sup>17</sup> identified a higher rate of attention deficit among N95 respirator wearers compared with face mask wearers, suggesting potential drawbacks associated with certain mask types. Overall, while some studies suggest potential cognitive benefits, others report no significant effects or even adverse outcomes, highlighting the complexity of the relationship between mask use and cognitive function during exercise. Results are presented in table 6.

### Psychological impact associated with respiratory protection mask use

The psychological impact of respiratory protection mask use, particularly regarding claustrophobia and mental health outcomes, has been investigated in several studies with varying results and limited certainty of evidence. A study conducted by Chong *et al*<sup>38</sup> revealed that 3% of healthcare workers experienced claustrophobia while wearing face masks. This percentage was found to be similar for both N95 respirators and surgical masks. However, Khalid *et al*<sup>40</sup> discovered higher rates of claustrophobia in the N95 group. On the other hand, Su *et al*<sup>42</sup> observed no significant difference in depression or anxiety rates between healthcare workers wearing surgical masks and those using N95 respirators. Results are presented in [table 6](#).

### Evidence map

[Figure 2](#) provides an evidence map illustrating the main findings on various respiratory protection mask use. The map suggests a lack of comprehensive assessment regarding the acute physiological, cognitive and psychological impacts of different mask types. Physiological effects showed minimal changes, particularly in ventilation and oxygen levels. However, evidence on cognitive and psychological outcomes varied and was constrained by study limitations and various biases. Overall, the certainty of evidence ranged from very low to low for most interventions, with no high-certainty evidence available. Furthermore, there is insufficient evidence regarding the impact of mask use on different work groups, duration of masking or the effects of mask use at high altitude levels.

### Discussion

To our knowledge, this is the first evidence map to examine the acute physiological, cognitive and psychological impacts of different mask types during rest and exercise. Similar to previously reported studies,<sup>12 15 30</sup> our study revealed modest impacts on variables such as ventilation and oxygen levels; however, the overall evidence remains inconclusive, with majority of studies indicating minimal changes in cardiovascular, ventilatory and metabolic responses, and exercise performance associated with mask use during both rest and physical activity. We noted variations in findings across different mask types and participant populations. For instance, while surgical masks and cloth masks showed no significant impact on physiological parameters, N95 respirators were associated with modest changes in VE, VT, oxygen saturation, carbon dioxide levels and exercise performance. While some of these parameters revealed statistical differences between those wearing and not wearing face masks, the level of change was small, and most values remained in the normal range.

Studies examining the cognitive effects of mask use during exercise yielded heterogeneous results, reflecting the multifaceted nature of cognitive function. While some studies suggested potential benefits in terms of improved cognitive function and increased internal focus among mask wearers, others reported no significant effects or even adverse outcomes. Communication challenges and perceptual shifts induced by mask wearing may contribute to variations in cognitive performance during physical activity. However, methodological limitations and inconsistencies across studies warrant cautious interpretation of these findings. Future research should aim to clarify the relationship between mask use and cognitive function, considering factors such as mask type, duration of use and activity level.

Similarly, the psychological impact of mask use remains a complex and understudied area. While some studies report elevated levels of claustrophobia among mask wearers, others find no significant differences in depression or anxiety rates compared with non-mask wearers. These conflicting findings highlight the need for more rigorous studies assessing the psychological effects of mask use over time, considering individual factors such as personality traits, coping mechanisms and pre-existing mental health conditions.

### Strengths and limitations

The strengths of this systematic review relate to the comprehensive search and rigorous methodological approach in addition to the inclusion of diverse study designs and populations. Moreover, by synthesising evidence from multiple systematic reviews and primary studies, we provided a comprehensive overview of the current state of knowledge on mask-related health outcomes.

Despite our efforts to include high-quality studies across various settings and populations, the increased heterogeneity across studies and the methodological quality of the current available studies have led to lower certainty of evidence. The exclusion of non-English language studies and limiting our search strategies only to studies published after 2000 and the focus on acute rather than long-term effects may have limited the generalisability of the findings, although the inclusion of systematic review that included studies published before 2000 may have limited the impact of this. Additionally, most of the data regarding the psychological and cognitive outcomes were driven from studies performed on healthcare workers which may limit its generalisability to the public.

### Research implications

Additionally, the predominance of observational studies and the limited number of high-quality RCTs underscore the need for more robust research in this area. Studies need to have a longer follow-up to address the short- and long-term effects of different types of face mask, fit and duration of use on different physiological, cognitive and psychological parameters. Future studies should leverage previously validated and standardised assessment tools to assess the cognitive and psychological outcomes. Qualitative research is critical to better understand barriers to face mask use and perceptions of individuals in different contexts, cultural backgrounds and professional roles.

### Conclusion

This evidence map provides a comprehensive insight into the multifaceted impact of respiratory protection mask use in addition to the limited certainty in the currently available body of evidence. The evidence map approach is intended to facilitate the development of future research agenda.

X Bashar Hasan @BasharHasanMD

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#### ORCID iDs

Wigdan Farah <http://orcid.org/0000-0002-2886-341X>

Bashar Hasan <http://orcid.org/0000-0001-9531-4990>

M Hassan Murad <http://orcid.org/0000-0001-5502-5975>

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