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Commentary

# Could near infrared spectroscopy be the new weapon in our understanding of the cerebral and muscle microvascular oxygen demand during exercise?

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Near-infrared spectroscopy (NIRS) has been increasingly utilized in both sport and health sciences to assess various physiological parameters related to exercise performance.<sup>1</sup> NIRS methods coupled with the recent development of portable and wearable devices suitable for field-based measurements have revolutionized the study of exercise physiology and the determinants of exercise performance by providing real-time, non-invasive, and spatially localized measurements of tissue oxygenation dynamics.<sup>2</sup> NIRS is a non-invasive optical technique that measures changes in the concentration of oxygenated and deoxygenated hemoglobin in tissue, providing insights into tissue oxygenation, blood flow, and metabolism during exercise.<sup>3</sup> In particular, the integration of NIRS technology has enhanced our ability to concurrently measure cerebral and skeletal muscle oxygenation while exercising, i.e., the dynamic interplay between oxygen delivery, utilization, and distribution to different tissues.<sup>4</sup>

In this issue, the systematic review by Orcioli-Silva et al.<sup>5</sup> represents a significant endeavor to synthesize the burgeoning evidence from the available literature on concomitant changes in cerebral and muscle hemodynamics during exercise performance as revealed by NIRS technology. By analyzing a sample of 20 studies involving 290 young or middle-aged adults during various forms of exercise, this review provides valuable new insights into the physiological responses underlying exercise and their implications for both sports performance and health sciences. One of the central findings elucidated by this review<sup>5</sup> is the consistent pattern of muscle deoxygenation increases during incremental exercise, ultimately reaching a plateau upon voluntary exhaustion. This observation underscores the intricate relationship between oxygen utilization and muscle performance, offering valuable insights into the physiological mechanisms governing exercise tolerance. Secondly, the review highlights the compelling evidence for increased cerebral oxygenation with exercise

intensity, indicating a critical cerebral mechanism for sustaining exercise performance.<sup>6</sup> Taken together, the findings shed light on the physiological brain–muscle responses underlying exercise performance by taking advantage of the continuous measurements of cerebral and muscle oxygenation.

What these studies suggest is that the link between cerebral and muscle oxygenation during exercise is primarily mediated by the cardiovascular system. As cardiac output increases in response to exercise, blood is redistributed from non-essential organs and tissues to the working muscles and brain. This redistribution of blood flow ensures that both the muscles and the brain receive sufficient oxygen and nutrients to sustain their metabolic activities during exercise.<sup>7</sup> Obviously there are some differences between whole body (endurance) and localized (strength) exercises. In their review (Fig. 2),<sup>5</sup> the authors underlined that factors such as exercise intensity, duration, and mode can influence the magnitude and timing of concomitant changes in cerebral and muscle oxygenation. Interestingly, besides regular exercise modes (cycling and running) simulated in the laboratory, unique muscle and brain oxygenation responses (e.g., diving reflex prioritizing blood delivery to the brain) have been documented in elite level synchronized swimmers presenting apneic periods.<sup>8</sup> Therefore, further studies are required to monitor brain–muscle oxygenation responses with wearable NIRS devices in demanding sports under real-life conditions to elucidate their cardiovascular responses. Some studies (not included in the review) have shown that important changes in cardiac output, cerebral perfusion pressure during exercise caused by environmental factors (e.g., altitude,<sup>9</sup> g-forces<sup>10</sup>), can affect both cerebral and muscle oxygenation. Coupled with blood flow assessment, NIRS technology can facilitate the understanding of the coordinated regulation of blood flow and oxygen delivery to both the brain and working muscles to meet the increased metabolic demands of any exercise.

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Authors in their review<sup>5</sup> highlighted well that simultaneous measurement of oxygen availability and utilization in both the brain and muscles enables the identification of potential limiting factors in exercise performance, or provides valuable insights into the mechanisms underlying exercise-induced fatigue.<sup>4,9</sup> This may have implications for optimizing training interventions and enhancing athletic performance. Additionally, this multidimensional approach enhances our understanding of the complex interaction between the brain and muscles during physical activity, ultimately contributing to improved physical and cognitive health. Cognitive and motor functions are not so separated systems, and the interactions between them could be profoundly detected with muscle–brain oxygenation patterns. This can allow for a deeper understanding of how the cardiovascular, respiratory, and neurological systems interact and adapt to meet the demands of physical activity. For instance, studying oxygenation patterns in individuals with cardiovascular diseases, respiratory disorders, or neurological impairments can clarify the impact of these conditions on exercise tolerance and functional capacity.<sup>11</sup> In aging, the interaction between brain and musculoskeletal activity is the cause of sarcopenia, which affects muscle metabolism and cognitive function.<sup>12</sup> Given that higher cardiorespiratory fitness is associated with increased cerebral oxygenation,<sup>13</sup> NIRS measures on muscle and brain can complement the existing literature on the mechanisms involved in exercise and improved cognition.<sup>14</sup>

Although measuring cerebral and muscle oxygenation simultaneously during exercise has several advantages, it also presents potential pitfalls that researchers should consider. Simultaneously measuring cerebral and muscle oxygenation can increase the complexity of data interpretation. Researchers must carefully analyze the relationships between these variables and consider various physiological factors that may influence oxygenation patterns, such as skin blood flow and mean arterial pressure.<sup>15</sup> Obtaining accurate and reliable measurements of cerebral and muscle oxygenation during exercise can be technically challenging.<sup>16</sup> Motion artifacts, signal interference, and device placement can affect the validity of collected data. The current commercially available NIRS technology used for measuring oxygenation has limited spatial resolution, which may restrict the ability to localize changes in oxygenation within specific brain regions or muscle groups. Addressing these challenges requires careful attention to study design, methodological rigor, and technological advancements in the field.

The NIRS methods advancements provide researchers with powerful tools to investigate the physiological responses to exercise, optimize training interventions, and enhance performance outcomes across diverse populations and contexts. However, the review of Orcioli-Silva et al.<sup>5</sup> indicates that a few scarce studies have conducted joint measurements of muscular and cerebral oxygenation during exercise, compared to a large number of studies that have used either muscular

NIRS or cerebral NIRS in isolation. Exercise physiology would benefit from additional studies like those proposed in the literature review<sup>5</sup> to offer new valuable insights into exercise physiology and performance, fatigue mechanisms, training optimization, and clinical management.

### Competing interests

The author declares that he has no competing interests.

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