

# Current Gaps and Future Directions in Recovery Research

*Wissenslücken und Perspektiven in der Regenerationsforschung*

**E**nsuring high training quality to achieve optimal effectiveness has always been a primary focus in sports science and practice. In recent years, especially in high-performance sports, this focus has expanded to include additional measures for enhancing performance. A key aspect is the growing emphasis on optimizing recovery to balance stress and recovery, thereby preventing overload. The long-term goal is to foster positive performance development by strategically planning and executing training or competition loads in alignment with the athlete's level of fatigue or performance readiness, while facilitating performance recovery through various interventions (1).

In the context of recovery interventions, athletes, coaches and therapists are increasingly faced with a growing number of methods and trends, many of which lack clear scientific evidence. Despite the absence of proven efficacy, certain purported recovery-enhancing products and technologies have become part of athletes' routines, often driven by persuasive (social media) marketing, numerous unsubstantiated or exaggerated claims, and widespread pseudoscience.

While Tiller et al. (2) propose various strategies to counteract the spread of unfounded claims and pseudoscience in the sports and fitness sector, one of the most crucial objectives remains the continued planning and execution of high-quality research. This issue of the German Journal of Sports Medicine, with its diverse scientific contributions on various aspects of performance and recovery, aims to support these efforts.

In addition to nutrition and sleep as fundamental and perhaps the most relevant components of effective recovery, numerous dietary supplements, pharmaceuticals, cosmetics, as well as cold and heat applications, psychological measures, compression garments, self- and externally administered massage therapies, and various device-based recovery methods such as massage guns, compression massage devices, or light therapy devices are currently among the most widely used complementary recovery methods.

## Research Gaps and Challenges

Although numerous original studies, reviews and meta-analyses on the effects of recovery inter-

ventions have been published over the past two decades, their overall impact remains unclear or uncertain, with notable individual differences in efficacy. Despite the extensive studies already conducted, many research gaps and challenges remain. These include, in particular:

### There Are Open Questions About the Underlying Cellular-Molecular Mechanisms of Recovery Interventions

While convincing and sometimes highly detailed theories of the effectiveness of various recovery interventions exist, such as the framework proposed by Ihsan et al. (3) for cold water immersion (CWI), there is a lack of basic research that directly observes and validates these assumed effects with appropriate measurement tools. The overwhelming majority of published data focuses exclusively on the indirect effects of recovery interventions, such as the restoration of sport-specific performance and neuromuscular function, heart rate and heart rate variability, subjective fatigue and and/or sleep.

### For Most Complementary Recovery Interventions, the Optimal Recovery Dose Remains Unclear and Is Largely Based on Theoretical and Practical Considerations

While some exceptions exist, such as the systematic review by Machado et al. (4), which finds that 11-15 minutes of cold water immersion at 11-15°C is most effective in reducing muscle soreness, overall understanding is still limited. Specifically, there is an urgent need to determine the optimal recovery dose for various outcomes across all recovery interventions. In addition, it is crucial to understand the effectiveness and potential interactions of recovery effects when several recovery measures are combined, as is often the case in sports (e.g. the combination of cold and heat applications).

### The Extent to Which the Effectiveness of Recovery Interventions Depends on the Timing of Application Remains Inconclusive for Many Scenarios

For example, Kwiecien and McHugh (5) describe that cryotherapy is only effective in reducing secondary muscle damage and, consequently, the severity of muscle soreness if cryotherapy is applied as soon as possible after the initial injury response, particularly within the first 24 hours >

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after intense physical activity. However, the optimal timing for heat therapies or massages remains completely unclear.

### Investigating the Role of the Placebo Effect in Recovery Research Remains an Important Area of Research

The remarkable success of certain recovery interventions is largely attributed to subjectively perceived effects, which are often much more pronounced than the objectively measured effects. Many supplementary recovery measures lead, at least temporarily, to pain reduction, improvement in well-being or body perception. However, with few exceptions, such as the study by Wilson et al. (6) (where a placebo intervention was conducted alongside two recovery interventions, with the placebo group receiving cornstarch pills but was informed that they were amino acid pills that could accelerate recovery), it remains largely unclear to what extent the effects of recovery interventions are attributable to actual or placebo effects.

### Outlook

Future research should focus on individual responses to specific recovery interventions (7). By considering evidence-based recommendations, preferences of the athlete, and practical feasibility, various recovery measures can be selected to support optimal performance progression. Technological advancements, such as the development of new sensors and mobile health applications, could help in the future to tailor recovery strategies even more precisely to an athlete's psychophysiological profile and optimize adherence to recovery protocols, for example by reminding athletes about food/fluid intake or other recovery measures, and enabling direct biofeedback (8). ■

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