

## Future Perspectives for Warm-Up Strategies in Sport

by

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*Warm-up is a universal practice in sport, yet many aspects of its prescription remain unresolved. A recent international Delphi consensus reached agreement on only 60% of 122 statements, highlighting that, despite decades of research, several practically relevant questions remain open. Rather than continuing to ask whether the warm-up improves performance, future research should focus on addressing problems faced by athletes and practitioners in real training and competition settings. In this opinion paper, we highlight five areas that may be particularly relevant to advancing warm-up research and practice: (1) optimization of duration in relation to warm-up comprehensiveness; (2) individualization of the warm-up design; (3) reproducibility of individual responses; (4) integration of daily monitoring into warm-up routines; and (5) greater use of non-exercise strategies to achieve readiness with minimal additional physical load. We argue that future warm-up research and practice should move beyond universal prescriptions toward adaptive strategies that tailor warm-up content and dose, including non-exercise approaches, while accounting for the reproducibility and day-to-day variability of individual responses to optimize the balance between readiness and fatigue.*

**Keywords:** athletic performance; fatigue; monitoring; post-activation performance enhancement; readiness; thermoregulation

### Introduction

Warm-up is one of the most widespread practices in sport. Athletes routinely perform a warm-up before training and competition with the expectation that it will improve physiological and psychological readiness, thus enhancing subsequent performance while also contributing to other training-related objectives. However, the apparent simplicity and universality of the warm-up contrast with the complexity of determining what constitutes an optimal warm-up for a given athlete and a particular context.

The recently published *International Expert Consensus on Warm-Up Protocols for Athletes* provides an opportunity to reconsider this problem (Boulosa et al., 2026). Twenty-three international experts evaluated 122 statements addressing definitions and nomenclature, objectives and structure, exercises and mechanisms, along with health and injury

prevention aspects of warm-up protocols. Consensus was achieved on 72 statements, corresponding to 60% of those evaluated. Thus, perhaps one of the most informative outcomes of the consensus process was not only what experts agreed upon, but also what could not be generalized.

Several rejected statements attempted to establish universal recommendations regarding warm-up duration, exercise selection, or standardization across populations. Rather than interpreting these disagreements simply as limitations of current knowledge, they may indicate that some questions in warm-up research and practice have been formulated too broadly. For example, searching for “optimal warm-up duration” may be of limited value if the answer depends on the athlete, the subsequent task, environmental conditions, the content of the warm-up, and the time available between the warm-up and performance.

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Consequently, we propose that the next phase of warm-up research should be increasingly directed toward addressing practical problems rather than identifying universally optimal protocols. In this opinion paper, we highlight five areas that we consider particularly relevant for translating current warm-up knowledge into better solutions for athletes and practitioners: duration and comprehensiveness, individualization, reproducibility, daily monitoring, and non-exercise warm-up strategies.

### ***Duration and Comprehensiveness: How Much Warm-Up Is Enough?***

Warm-up duration is one of the most easily quantifiable characteristics of a warm-up protocol, yet its practical interpretation cannot be separated from the content and demands of the protocol itself. In our recent consensus, experts agreed that short ( $\leq 5$  min) and long ( $\geq 20$  min) warm-ups may both comprise different work-to-rest ratios and levels of comprehensiveness, while warm-up duration was considered dependent on the intensity and density of the exercises performed, sport-specific demands, athlete characteristics, and contextual factors (Boullosa et al., 2026). Collectively, these statements challenge the usefulness of prescribing or investigating warm-up duration in isolation and suggest that duration should instead be considered in relation to how comprehensive the protocol needs to be for a given athlete, task, and context. Thus, rather than continuing to search for “optimal” warm-up duration (Tomaras and Macintosh, 2011; Yanci et al., 2019), a more practically relevant question may be how much time is required to deliver the necessary warm-up content while achieving the desired readiness with the lowest possible cost in terms of time and fatigue.

For instance, a 10-min warm-up comprising only continuous low-intensity exercise represents a fundamentally different stimulus from a 10-min warm-up incorporating low-intensity exercise, dynamic stretching, technical drills, and high-intensity conditioning activities. Similar duration may therefore impose markedly different physiological demands and provide different levels of preparedness. Consequently, duration alone provides limited information regarding the cost and effectiveness of a warm-up. The more relevant issue should be the interaction

between duration, comprehensiveness, and the resulting readiness-fatigue balance.

Recent studies further illustrate the complexity and the context-dependent nature of this relationship. Different warm-up duration has been shown to alter internal and external loads during subsequent soccer small-sided games, with distinct trade-offs among 8-, 15-, and 25-min protocols (Yilmaz et al., 2025). In contrast, another recent study examining different combinations of warm-up intensity and duration before incremental cardiopulmonary exercise testing reported no meaningful effects on maximal physiological responses of physically active young adults (Pedrosa et al., 2025). These apparently different findings reinforce the notion that the value of extending or shortening a warm-up depends primarily on the demands of the subsequent task and on what is intended to be achieved with the warm-up.

We therefore suggest that future studies should move away from identifying optimal duration *per se* and instead investigate the minimum effective warm-up dose across different levels of comprehensiveness and sporting contexts. This concept should not be interpreted simply as advocating the shortest possible warm-up. The objective should be to identify the shortest protocol that remains sufficiently comprehensive to achieve the required physiological, technical, and psychological readiness without producing unnecessary fatigue. Future studies should therefore manipulate duration and comprehensiveness simultaneously, ideally while quantifying both preparedness and fatigue-related outcomes. Such designs will inevitably be more complex, but they are also more likely to provide answers that are transferable to real training and competition settings.

### ***Individualization: From Group Responses to the Individual Athlete***

Perhaps the most important conceptual shift required in warm-up research is a move from average group responses toward individual optimization. This problem is well illustrated by research on post-activation performance enhancement (PAPE) (Xu et al., 2025a). We previously proposed that PAPE responses should be described according to the conditioning activity, the subsequent verification test, and the

population studied, rather than assuming that a given conditioning activity would elicit a universally reproducible response (Boullosa et al., 2020). This framework was expanded to consider moderators related to the conditioning activity (the exercise type, loading, and timing), the verification test (the recovery interval, the exercise type, and the performance variable), and the athlete (sport, training background, age, and sex) (Boullosa, 2021). More recent evidence appears to confirm these previous suggestions (Zheng et al., 2026).

This logic can be extended beyond PAPE to the warm-up. An appropriate warm-up should emerge from the interaction among the athlete's characteristics, training background, the design and content of the warm-up, and the demands of the subsequent task (e.g., the verification test), with the sporting context providing an additional layer of constraints and opportunities for adaptation. Recent evidence supports this perspective. A study examining a basketball pre-game warm-up reported considerable interindividual variability in performance responses, reinforcing the difficulty of assuming that a team-level warm-up produces equivalent readiness in every player (Papagiannis et al., 2024). Moreover, recent PAPE research showed that elite volleyball athletes could self-select recovery intervals after a conditioning activity and achieve performance enhancements comparable to those obtained using the best fixed recovery interval (Fontanetti et al., 2025). This finding is practically relevant because it suggests that athletes' perceived readiness may provide useful information for regulating warm-up prescription. However, subjective information should ideally be integrated with objective measures within a fine-tuning approach to better inform individualized decisions (Boullosa et al., 2023; Xu et al., 2025b).

Individualization should therefore not simply mean allowing athletes to select their preferred exercises. Instead, practitioners may use evidence-informed recommendations to establish an initial framework and subsequently adjust the exercise type, load, volume, recovery, and timing according to the athlete's characteristics and systematically observed responses. Our previous proposal that practitioners should verify whether the expected responses derived from the literature actually occur in the individual athlete remains particularly relevant (Boullosa, 2021). In this

regard, future warm-up research should increasingly focus on identifying which athlete-, task-, and context-specific factors meaningfully modify responses, and on developing practical methods to translate this information into individualized warm-up prescriptions.

### ***Reproducibility: Is an Individual Response Really Individual?***

Individualization assumes that an athlete's response to a warm-up can be characterized, as discussed above. However, this also requires establishing how reproducible that response is. If an athlete demonstrates enhanced sprint or jump performance after a specific warm-up before a training session, it cannot automatically be assumed that the same response will occur one week later, at another point in the season, or under competitive conditions.

An important distinction should therefore be made between interindividual variability and intraindividual reproducibility. The former refers to differences in the responses of different athletes exposed to the same stimulus and can be addressed through the individualization approaches discussed in the previous section. The latter refers to the stability of an athlete's response when the same or a similar stimulus is repeatedly applied. This distinction is critical because an apparently individual response observed on a single occasion may reflect normal day-to-day variability rather than a stable athlete-specific characteristic.

Recent PAPE research provides a useful illustration of this problem. Stuart et al. (2025) examined elite speed skaters across six repeated sessions using high-velocity and high-force conditioning activities. Although PAPE could be identified across sessions, individual athletes did not consistently achieve their best countermovement jump performance at the same post-conditioning recovery interval, raising questions about the stability of an individually "optimal" recovery window. In contrast, Fontanetti et al. (2026) recently reported that a self-selected rest interval method was reliable for eliciting PAPE in strength-trained athletes, suggesting that allowing athletes to regulate recovery according to their perceived readiness may provide a reproducible alternative to prescribing a fixed individualized time interval.

Jarosz et al. (2025) further showed that a small PAPE effect following a maximal isometric squat could be maintained at the group level across four weekly assessments, although the reproducibility of individual PAPE responses was poor to moderate ( $ICC = 0.56$ ) and the distribution of individual responses varied across sessions. Collectively, these findings highlight an important distinction: the effectiveness of a conditioning activity may be reproducible at the group level, and even achievable through a reliable self-regulated approach, while the magnitude and precise timing of the individual response may remain considerably less stable. However, the available evidence remains too limited to draw firm conclusions.

This issue has important methodological implications for warm-up research and practice. Studies aiming to inform individualized prescription should incorporate repeated-measures designs that characterize within-athlete variability rather than relying predominantly on group means obtained from different experimental conditions. Repeated assessments could establish an athlete-specific response distribution and help determine whether an apparent improvement following a particular warm-up exceeds normal day-to-day variability. Importantly, adequate familiarization with the conditioning activities and other warm-up components is essential for this purpose.

Reproducibility should also be considered within the realities of training and competition. Sleep, accumulated fatigue, preceding training loads, environmental conditions, psychological state, and competition schedules may modify the response to an otherwise identical warm-up. Therefore, variability should not necessarily be considered merely experimental noise. Meaningful deviations from an athlete's expected response may provide information about changes in readiness because of the influence of individual and contextual factors. Future studies, using appropriate designs, should consequently explore not only whether warm-up responses are reproducible, but also which factors explain meaningful within-athlete variation across days and throughout the training and competitive season.

Hence, before claiming that a warm-up has been successfully individualized, practitioners and

researchers should establish whether the observed response is sufficiently reproducible to support that prescription. At the same time, deviations from an athlete's expected response may be informative rather than problematic. This perspective provides a direct rationale for another promising application of warm-up routines: their systematic use as an opportunity for daily athlete monitoring.

### ***Warm-Up as an Opportunity for Daily Monitoring***

The reproducibility issue leads directly to another promising perspective: using the warm-up itself as an opportunity for daily monitoring. Athlete monitoring often requires additional tests, questionnaires, or equipment outside the regular training routine, potentially increasing the burden on athletes and practitioners. The warm-up offers an attractive alternative because athletes already perform it routinely. If selected components are sufficiently standardized and their responses are reliable, information collected during the warm-up could provide a rapid and practically meaningful indication of current readiness and training adaptations.

The concept involves performing a standardized component of the warm-up, assessing the athlete's responses, and using this information to adjust the subsequent training session when appropriate. For example, a countermovement jump (Claudino et al., 2017), submaximal aerobic bout (Capostagno et al., 2016; Shushan et al., 2023; Vesterinen et al., 2014), resistance exercise (Suchomel et al., 2021), or the rating of perceived exertion (Rodriguez-Marroyo et al., 2017) could be embedded within the normal warm-up routine for this purpose. Importantly, the athlete's response could be compared with their own expected range, established through repeated observations, rather than with population-based reference values. An athlete displaying responses within their usual range could proceed with the planned training session, whereas meaningful deviations could inform modifications to the session's content or loading variables.

Previous and recent research on athletes' monitoring provides a foundation for developing increasingly sophisticated applications of this approach. In this context, the fine-tuning framework may provide a more comprehensive

assessment of an athlete's readiness and adaptation by integrating complementary objective and subjective measures rather than relying on a single indicator (Boullosa et al., 2023; Brandão et al., 2026). Such measures should nevertheless be selected according to their validity, reliability, sensitivity, practicality, and relevance to the specific sport and training context. Considerable research is still required before warm-up-based monitoring can be systematically recommended. In this regard, it is necessary to establish which warm-up-derived variables are sufficiently reliable, sensitive to meaningful changes in readiness and training status, minimally affected by learning effects, and practical to obtain and interpret. More importantly, future studies should determine whether decisions informed by warm-up responses actually improve subsequent adaptation and performance. In this manner, the warm-up could evolve from being exclusively a preparatory procedure into an integrated preparation-and-monitoring system.

### ***Non-Exercise Strategies: Achieving Readiness with Less Fatigue***

The final perspective concerns a fundamental assumption underlying the warm-up: that physiological preparation necessarily requires additional exercise. Active exercise is highly effective for increasing muscle and core temperature and eliciting neuromuscular and metabolic responses. However, these benefits come with an energetic cost and, depending on the volume and intensity, may also induce different forms of fatigue. Consequently, there may be situations in which specific warm-up effects can be achieved or maintained more efficiently through non-exercise strategies that impose no additional physical load.

Passive heating can reproduce several acute responses associated with exercise, including increased body temperature and blood flow, as well as neuromuscular and cardiovascular responses (Li et al., 2026; Menzies et al., 2025; Rodrigues et al., 2022). This may be particularly relevant when there is a delay between the completion of the warm-up and competition. Rather than repeatedly performing additional exercise to maintain readiness, heated garments or other passive thermal strategies may preserve temperature-related benefits without adding

meaningful physiological load.

Psychological and acute ergogenic strategies may provide another low-cost avenue for enhancing readiness without additional physical work. Motor imagery (Rumeau et al., 2024), preferred music (Jebabli et al., 2022), and other cognitive strategies (Diaz-Garcia et al., 2025; Mortimer et al., 2026) may influence arousal, motivation, attentional focus, perceived readiness, and, potentially, subsequent performance. Similarly, acute ergogenic aids, such as ammonia inhalants, may transiently influence performance (Bender and Popkin, 2024). Moreover, combining caffeine ingestion with a PAPE-inducing conditioning activity may also enhance subsequent anaerobic performance, particularly peak power along with participants' subjective perception of power (Zhang et al., 2024). Other substances or sensory stimuli with potential acute ergogenic effects could also be considered within this framework. However, their effectiveness, mechanisms, timing, safety, and applicability are likely to differ substantially across athletes, tasks, and competitive contexts. Future studies should therefore investigate whether psychological and acute ergogenic strategies can complement active warm-up and contribute to achieving the desired readiness while limiting additional physical and metabolic demands.

The relevant future question is therefore which components of readiness require active exercise, and which can be achieved or maintained without additional physical work. This could lead to hybrid strategies in which active exercise is selectively used to elicit task-specific neuromuscular and metabolic responses, while passive thermal, psychological, and acute ergogenic methods complement these effects at minimal additional physiological cost. Such an approach may be particularly valuable when maximizing readiness while minimizing fatigue is critical.

### ***Conclusions: Toward an Adaptive and Efficient Warm-Up***

Taken together, these perspectives suggest that the future of warm-up research may lie less in identifying universally optimal protocols and more in improving the decision-making process underlying warm-up prescription. Rather than searching for optimal duration, research should

identify a minimum effective dose that remains sufficiently comprehensive to achieve the intended purposes of the warm-up. Such a dose should be individualized according to the athlete, the subsequent task, and the context. However, meaningful individualization requires establishing the reproducibility of individual responses and distinguishing consistent response patterns from normal variability. Once characterized, standardized components of the warm-up may also provide an opportunity to monitor readiness and training adaptations and inform subsequent training decisions.

Warm-up efficiency may also be improved by combining active exercise with non-exercise strategies that enhance or maintain readiness without substantially increasing metabolic cost. Passive thermal methods may help increase or preserve muscle temperature and other acute responses, while psychological strategies such as motor imagery, preferred music, or cognitive

exercises may contribute to neuromuscular and psychological readiness. The potential role of acute ergogenic substances also warrants further investigation. Future research should determine which components of readiness require active exercise and which can be achieved or maintained through these complementary approaches.

Overall, these perspectives support a transition from standardized protocols toward an adaptive warm-up, in which sufficiently standardized components allow individual responses to be characterized and monitored, while other components are adjusted according to current readiness and contextual demands. Accordingly, the optimal warm-up may not be a fixed protocol, but rather an adaptive process aimed at providing the minimum necessary yet sufficiently comprehensive stimulus to maximize readiness and minimizing unnecessary fatigue, time, and metabolic cost.

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