Exercise Monitoring Defined

Appropriate exercise prescriptions will presuppose beneficial skeletal muscle and peripheral tissue adaptations for health and performance. Exercise prescription is knowing how and when to adjust the multitude of programming variables (i.e. mode, frequency, intensity, volume, density, rest intervals) to achieve a certain physiological objective. In the past 20 years, considerable attention has been paid to the monitoring and quantification of exercise training "load" to optimize exercise prescriptions. The primary goal of exercise load monitoring is to quantify the prescribed exercise stressor to more appropriately match the prescription to the stimulus needed to reach the desired physiological outcome (1). Load monitoring data also provides helpful insights into the fatigue/recovery status of an individual to give exercise prescribers and sports practitioners quantitative data to reduce the risk of injury, illness, or overtraining resulting from excessive exercise load (2). Ultimately, load monitoring should provide practitioners with actionable insights to acutely manipulate exercise prescriptions to reach a desired physiological outcome. As a result of an ever increasing number of biotech sensors in recent years, numerous commercial products also exist that purport to offer load monitoring, physical activity monitoring, or exercise movement monitoring (3). Furthermore, multiple research and commercial products can monitor the levels of various metabolites that are secreted during exercise such as glucose and lactate in bodily fluids which may give insights into both the stress of acute exercise, and the physiological response to chronic exercise (4). Given the irrefutable benefits of regular exercise, it is the position of the author that the increased interest and accessibility to tools and techniques that help individuals engage in, and effectively monitor exercise training is extremely positive. However, an overlooked area pertaining to the research investigating methods to quantify exercise stress has been an exact definition of what constitutes "exercise monitoring." Therefore, the aim of this paper is to provide a basic definition of exercise monitoring providing a foundation for future enquiries into this extremely relevant and rapidly growing field.

Within a clinical setting, disease monitoring is defined as the "periodic measurement that guides the management of a chronic or recurrent condition" (5). Using this definition as a starting point, it is proposed that exercise monitoring be defined as *any measurement(s) that are taken to quantify the stress imposed by an exercise intervention, and to assess the efficacy of an exercise intervention in inducing a desired physiological outcome* (outcome is used to refer to both acute exercise responses and longitudinal exercise adaptations). Therefore, exercise monitoring consists of two distinct, but non mutually exclusive components: workload and efficacy. The monitoring of exercise stress is a measure of *workload* and is synonymous with a "periodic measurement that guides management." Workload monitoring entails measurements that help exercise prescribers to manage and tailor their prescriptions to induce a desired physiological outcome. Load monitoring can be external (e.g., distance run or load lifted), internal (e.g., heart rate), objective (i.e., biochemical measure) or subjective (i.e., ratings of perceived effort) (2). The second component of exercise monitoring is in regards to the *efficacy* of the exercise intervention (i.e., did the exercise intervention accomplish what was intended). Indeed, the "chronic or recurrent condition" from the original definition of clinical monitoring is synonymous with a health and/or performance outcome in an exercise context. Both health and performance outcomes are underpinned by physiological changes to exercise interventions. For example, in a health context, hemoglobin A1c (HbA1c) levels are a physiological outcome that is a good indicator of diabetes management (7). Aerobic, resistance, and combined aerobic and resistance exercise all significantly reduce HbA1c levels following 6 months of prescribed training in type 2 diabetes patients (8). In a performance context, improvement in muscular strength is a physiological outcome that is significantly influential in sport success and athletic performance (9). A recent meta-analysis concluded that strength performance in resistance trained men is improved in the back squat and bench press following 6-12 weeks of strength training consisting of 1-3 sets of 6-12 reps at 70-85% of 1RM 2-3 times per week (10). The monitoring of these physiological changes before, during, and/or after an exercise intervention are measures of *efficacy*. Therefore, the proposed definition of exercise monitoring helps provide a framework by which periodically measured desirable physiological outcomes are connected to the measurements of preceding exercise stressors. It also highlights the importance of both workload *and* efficacy measure to an effective exercise monitoring process.

Benefits of an Established Exercise Monitoring Definition

A definition that clearly delineates these two components, workload and efficacy, can help practitioners and individuals reflect on the information they are collecting and highlight the complex, heterogeneous, but ultimately causal relationship between exercise stress, and exercise outcome. Clearly, the two elements of exercise monitoring, workload and efficacy, are not independent. Clear dose-response relationships exist between training workload and various physiological outcomes including but not limited to VO_2 max (11), muscle hypertrophy (12), and metabolic function (13). However, it is also apparent that despite these relationships, physiological outcomes to the same exercise intervention are not homogenous or necessarily follow a predictable time course (14, 15). As such, it is recommended to individualize exercise prescriptions to better manage the complex environment of variables that may influence outcomes to exercise interventions. Despite initially reductionist beliefs, it is now accepted that in order for exercise prescription to induce optimal exercise outcomes continuous monitoring of the exercise intervention is necessary (15). Therefore, a clear and agreeable exercise monitoring definition is necessary to facilitate optimal exercise outcomes. Workload information (i.e. internal, external, objective, subjective) that communicates and quantifies the exercise stress contextualizes the different programming variables that lead to physiological outcomes which are selected in accordance with strategically planned exercise goals. For example, the collection of testosterone following acute exercise represents a method of quantifying the internal stress of the exercise intervention while the measurement of strength represents a physiological outcome that testosterone levels influence (16). The monitoring of testosterone responses to acute exercise sessions can inform the practitioner of appropriate workloads to induce hormonal responses that cumulatively lead to strength increases (16). Multiple elements contribute to the selection of a valid and reliable workload monitoring tool, as reviewed elsewhere (2). As part of an effective exercise monitoring program, workload monitoring cannot be divorced from the outcome measure/s, and vice versa. Though this may sound intuitively obvious, the influx of technological advancements and substantial focus within scientific literature on methods to quantify and monitor workload have perhaps overshadowed the fundamental focus of an exercise intervention; did the desired physiological outcome occur? The hope is that a definition of exercise monitoring will tether and focus future investigations to consider what is actually being monitored and how the information helps propel desirable health and performance outcomes.

What Exercise Monitoring is Not

Readers well versed in sport and exercise literature may notice a few elements not discussed by the above definition. Namely, and perhaps most noticeably, is the absence of any mention of fatigue or readiness monitoring. Monitoring fatigue status is a critical element of overall athlete/individual wellness and can help in the prevention of injury, illness, burnout, and overtraining (2). Fatigue monitoring is therefore a critical component of overall wellness. However, fatigue monitoring does not equate to exercise monitoring. Prior to any further discussion it is important to differentiate between post-exercise fatigue, and pre-exercise fatigue status (henceforth referred to as readiness). Both fatigue and readiness monitoring focus on the status of the individual performing the exercise. Conversely, exercise monitoring is focused on communicating the magnitude of stress imposed by the exercise prescription and relating the workload to the efficacy in inducing a physiological outcome. Clearly, the two concepts overlap, it is clear that greater exercise workloads relate to greater fatigue and neither exercise nor fatigue occurs in a vacuum. Therefore, like workload and efficacy, fatigue and exercise monitoring are distinct but not entirely divorced from each other. Consider an exaggerated example: two individuals complete a relatively easy exercise protocol but one has not slept or eaten for 24 hours and trains alongside a partner who is well rested and well fed. Despite identical exercise prescriptions, there are highly divergent physiological responses to the exercise prescription between the two individuals. These divergences could not be considered an indicator of greater workload, nor would they indicate a more efficacious exercise intervention. In applied practice, inclusion of post exercise fatigue and readiness monitoring enhances exercise monitoring and *vice versa*. Attempting to monitor exercise without consideration of the significant roles social, emotional, and psychological variables play in anchoring perceptions of stress and influencing some physiological responses (i.e. increased heart rate under periods of increased emotional stress) is neglectful. Similarly, fatigue and readiness monitoring to optimize exercise in the absence of workload or efficacy monitoring does not have any functional significance. An individual may achieve high readiness scores and never be fatigued simply because they are executing extremely light workloads that are not effective at inducing any outcome, or perhaps not exercising at all.

In the previous scenario, neither post exercise fatigue scores or readiness scores would adequately reflect the workload of the exercise protocol or its efficacy, however, this may not always be the case. Assuming maximal effort and adequate readiness, as is usually done in a laboratory setting, post exercise fatigue status can function as a measure of exercise workload. Within these contexts, fatigue status is a function of exercise workload and only exercise workload, though the reality is more nuanced in applied practice. Fatigue status may function as an efficacy outcome if the goal is in fact improvements in maintaining work/power outputs (21) or improvements in overall energy levels (29). A plethora of non-exercise factors influence readiness to train including social, emotional, and psychological stressors (17) which cannot be accounted for by the exercise prescription but may ultimately influence the physiological outcome to an exercise prescription. Partitioning the physiological influence of non-exercise factors from exercise prescription factors improves the translational potential of exercise prescriptions for specific physiological outcomes (i.e. in disease treatment) and also furthers our understanding of how non-exercise stressors influence physiological outcomes following exercise training. Clarification and agreement on the associated terms and definitions will facilitate more robust insights and allow for superior management, exercise intervention design, and better health and performance outcomes.

Related to fatigue status and the multitude of variables that may contribute to it, readers may also have noticed that assessment of efficacy is related to the ability of an exercise intervention to induce a *physiological* outcome, not a performance outcome. Physiological changes underpin and influence performance, however performance in contexts like multidimensional team-sports are influenced by a multitude of variables such as technical skill, strategy, and opponents. Even in sports in which the physiological outcome directly relates to sport performance, (i.e. strength in powerlifting, VO_2 max in marathon runners), variables like pre-competition anxiety can negatively or positively influence performance (18). As such, performance in a competition may be the ultimate goal of an athlete, but it is not the ultimate product of an exercise intervention, and as such cannot be used to assess the efficacy of the preceding exercise intervention. Ideally, to assess efficacy, physiological outcome measurements are taken under identical controlled circumstances at different timepoints preceding, throughout, and following the exercise intervention. When the ultimate goal of an exercise intervention is a health outcome, prescribers usually have specific physiological outcomes that the exercise intervention is aimed at improving (i.e. decreased HbA1c in diabetes management). However efficacy measurements may be confounded by additional interventions, such as diet, that contribute to the magnitude of change in physiological outcome. In these cases, workload monitoring is important to contextualize and connect the magnitude of exercise stress to the physiological change and inform subsequent exercise prescriptions. Concerningly, there is a paucity of evidence based information regarding exercise prescriptions and appropriate workloads to induce positive physiological outcomes in clinical populations (19, 20) and therefore represents a critical area of future research**.**

Another area of growing interest is the use of biosensors to assess exercise quality and the movement execution of exercise prescriptions. Exercise requires a certain level of technical competency to perform dynamic movements with confidence in a manner that minimizes risk of injury and maximizes beneficial outcomes (21). In many circumstances, individuals who have never engaged with an exercise program are directed by clinicians, trainers, or coaches to execute exercise movements or even comprehensive exercise interventions with little or no guidance. In these cases, technical oversight is valuable to enhance the adherence with an exercise program, personal accountability, and self-efficacy (22). Exercise *quality assessment* is a critical component of an exercise intervention that can be fulfilled by a physiotherapist, personal trainer, strength and conditioning coach, or even a camera and appropriate software. However, the assessment of exercise quality does not constitute exercise monitoring as it is not an indicator of the workload of an exercise intervention or a measure of the efficacy of the intervention in inducing a physiological outcome. Movement quality could in theory be used to determine the stress of an exercise intervention, but this would require advanced equipment such as force plates and EMG to quantify the relative stress imposed by movements performed with differing technical proficiency and at certain ranges of motion. However, in the absence of this equipment and appropriate analytical tools, movement quality cannot effectively communicate the stress imposed by an exercise intervention. In some circumstances, the goal of an exercise intervention may be to improve movement competency in hopes of reducing injury risk. In this case, it may be tempting to use the assessment of movement quality as an outcome measure. However, there is currently no evidence to suggest that movement quality as determined by conventional movement screens underpins injury risk (23) or sport performance (24). A recent study in a large cohort of older individuals demonstrated that better performance on a movement screening is positively associated with health markers (lower blood glucose, HbA1c, and HDL) in older individuals (25). However, individuals with better movement also had higher overall levels of exercise volume and frequency, therefore it cannot be claimed that the association between movement quality and health outcomes constitutes a physiological underpinning. In addition, subjective assessment of movement quality is problematic (23) and may introduce bias into interpretations of efficacy if movement quality is used as an outcome measure. Machine learning models may be used to mitigate this potential bias, though to date the assessment of movement quality by machine learning is not ubiquitous and requires further validation. If improvement in movement variables (e.g. flexibility, mobility) are the desired physiological outcomes then they should be assessed objectively by validated tests (e.g. sit and reach for hamstring flexibility) in controlled environments (26). However, for individuals that aim to select flexibility as a physiological outcome measure, it should be highlighted that there is a recent push to retire flexibility as a component of physical fitness due to its lack of predictive ability and validity with relevant health and performance outcomes (27). As such, though assessment of movement quality is an important element of exercise to ensure appropriate execution of exercise prescriptions, the assessment of movement quality does not constitute exercise monitoring as movement quality cannot be used as a measure of workload or efficacy.

Finally exercise monitoring does not equate to physical activity monitoring. The Center for Disease Control defines exercise as a subset of physical activity that is "planned, structured, repetitive, and performed with the intent to improve health or fitness" (28). Physical activity in contrast is any bodily movement produced by skeletal muscles that result in energy expenditure (29). Physical activity includes structured exercise, sports training, occupational labor, and other activities (30). The distinction may appear semantic in nature but is important to highlight given that adherence to recommended exercise requirements by the World Health Organization provides significant protection against non-communicable disease and premature death (30). Physical activities such as walking or hiking may constitute exercise if in fact the activities are planned, structured, repetitive and done with purposeful intent to improve a physiological outcome. In contrast, social activities such as sporadic weekend trail hikes, walks on the beach, or at the shopping mall are not deemed exercise. The distinction between physical activity and exercise is critical as it can help individuals more clearly understand the directions and expectations of exercise prescribers. In the same manner, a definition of exercise monitoring helps differentiate between exercise monitoring, fatigue/readiness monitoring, exercise quality assessment, and physical activity monitoring. For a more comprehensive breakdown between exercise and physical activity the reader is referred elsewhere (30).

Increased popularity of wearable technologies that contain pedometers and accelerometers have allowed improved insights into activity variables such as the number of daily steps performed and the total calories burned. These devices can help individuals reach daily activity goals and may facilitate exercise monitoring if the physical activity in fact constitutes exercise and the workload measures are related to specific physiological outcomes. For example, individuals who track total calories burnt after daily aerobic exercise sessions in an effort to lose weight or body fat (31) would satisfy the criteria for exercise monitoring. Similarly, individuals who assess the effectiveness of specific types of aerobic training (i.e. HIIT vs moderate intensity continuous exercise) to burn calories would also constitute exercise monitoring. These examples highlight the flexibility of the proposed exercise monitoring definition, it is both acute and longitudinal. In the first example, caloric expenditure after every aerobic exercise session is recorded and exercise induced caloric expenditure is related to longitudinal weight loss. In the second example, exercise variables are manipulated and related to acute exercise induced caloric expenditure. Both are examples of exercise monitoring and are certainly not mutually exclusive. As previously discussed, the selection of an appropriate workload monitoring tool is critical (2) and must be considerate of the desired physiological outcome. Selecting caloric expenditure as a workload monitoring tool for a powerlifter whose goal is maximal muscle hypertrophy is inappropriate and would therefore not be an effective application of exercise monitoring (33).

Conclusions

To date, an exact definition of exercise monitoring has not been developed. The importance of a clear definition is well established by governing bodies such as the Center for Disease Control and the World

Health Organization and can help guide exercise research and exercise prescribers. Using an established definition of disease monitoring as a framework, it is proposed that exercise monitoring be defined as *any measurement(s) that are taken to quantify the stress imposed by an exercise intervention and to assess the efficacy of an exercise intervention in inducing a physiological outcome.* This definition establishes two distinct, yet inherently linked components to exercise monitoring: workload and efficacy. Measurements of both workload and efficacy are required to contextualize the magnitude and direction of exercise intervention outcomes to specific exercise prescriptions. As such, a clear definition that explicitly contains and relates both elements is necessary to further elucidate the causal relationship between exercise and physiological changes. Workload monitoring tools should relate to and significantly contribute to the physiological outcome selected as an efficacy measure. A definition of exercise monitoring will help guide the increasing influx of technological advancements in workload monitoring and tether them to the ultimate goal of an exercise intervention: a change in a physiological outcome that underpins health or performance. Though exercise monitoring is distinct from fatigue/readiness monitoring, exercise quality assessment, and physical activity monitoring; that does not detract from their importance within the health and performance sphere. Unfortunately there is currently not a single test or strategy that can completely elucidate the complex and heterogeneous relationship between exercise stress and exercise outcome. It is therefore recommended that exercise prescribers use a variety of monitoring techniques to explore and document the exercise process.

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