

Mapping Adaptive Processes in Football: A Scoping Review of Research Approaches

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Abstract

The adaptive response to football is a complex physiological process that occurs across various levels of biological organisation as a system attempts to adapt to training and match stimuli both acutely and chronically. Despite extensive research on football training adaptations, no systematic mapping exists of the measurement approaches used across different biological levels, creating gaps in our understanding of how researchers operationalise and study adaptive processes in this complex sport. A scoping review per PRISMA-ScR was conducted. Eligible studies included peer-reviewed articles assessing acute and chronic physiological, neuromuscular, biomechanical, or physical performance responses to training interventions and match play in healthy, uninjured male football players (professional, semi-professional, youth, university levels) using pre-post measurements. SportDiscus, PubMed, Web of Science Core Collection, and Scopus were searched to June 19, 2025. Three reviewers independently screened titles, abstracts, and full texts against eligibility criteria. 472 studies met inclusion criteria. Study outcome measures were extracted and categorised by biological level. Of 472 studies, 217 (46%) measured at a single level, 146 (31%) at two levels, 84 (18%) at three levels, and 25 (5%) at four levels. Organism-level measurement was most common, appearing in 336 studies (71%). The most frequently used outcome measures at each level were countermovement jump (organism level, n = 148), lactate (cellular level, n = 75), maximal heart rate (tissue/organ level, n = 65), and VO₂max (organ system level, n = 42). This review represents the first attempt to systematically map measurement approaches across cellular through organism biological levels in football adaptation research, revealing concentrated effort towards organism-level assessments with limited multi-level integration. The findings reveal where football adaptation research has focused but not yet how well those approaches capture adaptive mechanisms.

Keywords: Training, Performance, Response, Systems, Complexity

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Abstract

The adaptive response to football is a complex physiological process that occurs across various levels of biological organisation as a system attempts to adapt to training and match stimuli both acutely and chronically. Despite extensive research on football training adaptations, no systematic mapping exists of the measurement approaches used across different biological levels, creating gaps in our understanding of how researchers operationalise and study adaptive processes in this complex sport. A scoping review per PRISMA-ScR was conducted. Eligible studies included peer-reviewed articles assessing acute and chronic physiological, neuromuscular, biomechanical, or physical performance responses to training interventions and match play in healthy, uninjured male football players (professional, semi-professional, youth, university levels) using pre-post measurements. SportDiscus, PubMed, Web of Science Core Collection, and Scopus were searched to June 19, 2025. Three reviewers independently screened titles, abstracts, and full texts against eligibility criteria. 472 studies met inclusion criteria. Study outcome measures were extracted and categorised by biological level. Of 472 studies, 217 (46%) measured at a single level, 146 (31%) at two levels, 84 (18%) at three levels, and 25 (5%) at four levels. Organism-level measurement was most common, appearing in 336 studies (71%). The most frequently used outcome measures at each level were countermovement jump (organism level, $n = 148$), lactate (cellular level, $n = 75$), maximal heart rate (tissue/organ level, $n = 65$), and VO₂max (organ system level, $n = 42$). This review represents the first attempt to systematically map measurement approaches across cellular through organism biological levels in football adaptation research, revealing concentrated effort towards organism-level assessments with limited multi-level integration. The findings reveal where football adaptation research has focused but not yet how well those approaches capture adaptive mechanisms.

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Introduction

Exercise causes adaptive responses in the body's tissues and systems to support and improve whole-body exercise efficiency (Hughes et al., 2018). Understanding how the body responds and adapts to an intermittent high-intensity sport such as football can impact football training and performance in several ways. This includes gaining insights into the physical requirements of these activities, how responses to training and matchplay can be monitored and helping design tailored training interventions for individual players (Reilly, 2005). Knowledge of adaptive responses is therefore crucial for those working in the game, as well as those who are interested in the scientific study of football. For the purposes of this review, adaptive responses are defined as measurable physiological, neuromuscular, biomechanical, or physical performance changes observed in response to a relevant stimulus (i.e., football-specific training, physical conditioning, or match play), captured through pre-and post-stimulus assessment. This definition encompasses both acute responses occurring immediately following a single session or match, and chronic adaptations resulting from repeated exposures. We acknowledge the distinction between acute responses and chronic adaptations. However, the same outcome measure, such as CMJ height, can be used to assess an acute fatigue response or a chronic

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4 adaptation to training. Consequently, we use 'adaptive responses' as an umbrella term for this
5 scoping review.
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8 Determining these adaptive responses for team sports such as football is difficult. This is a
9 function of several intricacies in both the sport and the underpinning biological processes
10 related to adaptation. Football is complex from a physiological and biomechanical perspective
11 primarily due to the intermittent and unpredictable activities that underpin the physical demands
12 e.g. accelerations, decelerations, running, sprinting, changes of direction and jumping
13 (Bangsbo, 1994; Drust et al., 2000; Hagman et al., 2018; Nicholas et al., 2000; Paul and Nassis,
14 2015, Reilly, 1997). These activities lead to a change in the status of many physiological
15 systems and promote a range of signalling cascades in multiple tissues within the body. These
16 different tissues will respond uniquely to these exercise stimuli to ensure the body can manage
17 the stress placed upon it and ultimately improve the body's functional capacity and physical
18 performance (Vanrenterghem et al, 2017, Kalkhoven et al., 2021).
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23 These adaptive responses are complex and involve a cascade of interlinked processes that
24 begin at the molecular level and propagate through multiple levels ranging from cellular, tissue,
25 organ, organ system, and organism levels (Carmichael and Hadzikadi, 2019; Walleczek, 2000)
26 then ultimately modifying function at a whole-body level if repeated (Wisdom et al., 2015).
27 Consequently, there are numerous potential indicators of the adaptive process that can be
28 measured on and across numerous levels in the body. These different indicators can also be
29 operationalised and measured using a variety of different approaches (Robling and Turner,
30 2009; Turner et al., 1995; Manolagas, 2000; Parfitt, 1994; Wisdom et al., 2015; Bohm et al.,
31 2015; Rio and Docking, 2017). The specific insight around the adaptive process is probably
32 dependent on the level at which the researcher chooses to measure the adaptation. For
33 example, measuring whole-body performance on an identified test (i.e. 1 rep max strength test)
34 at the organism level will only give a "snapshot" of the overall performance change. This means
35 that it will overlook the specific adaptive mechanisms that occur at lower levels of organisation
36 (e.g. changes in fibre size). Measuring at the cellular, tissue, and organ levels has the potential
37 therefore to provide a more detailed framework for understanding adaptation that can guide
38 better training, injury prevention, recovery strategies, and long-term performance.
39 Understanding tissue-specific adaptations has been advanced by recent reviews examining
40 recovery timelines and loading strategies across different biological tissues and systems, which
41 highlight the complexity of the response to training and the value of considering adaptive
42 responses across multiple biological levels when examining training effects (Gabbett & Oetter,
43 2024). However, it remains unclear how football research has approached the problem of
44 studying the adaptive process. Do approaches focus primarily on performance insights using
45 organism-level outcomes? Or do approaches at cellular and tissue levels also exist in the
46 literature? Moreover, have attempts been made to integrate across different biological levels,
47 and if so, how? These knowledge gaps are the primary motivation for this review.
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57 To date, no research has attempted to systematically map the approaches used to assess
58 adaptation in football research. This review focuses specifically on male football players
59 (professional, semi-professional, university and youth academy) examining training and match
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4 adaptations through pre-post measurement designs. By examining the levels at which adaptive
5 responses are measured, and the outcome measures used at each level, we can gain insight
6 into the research approaches used within football and offer a summary of what has or has not
7 yet been explored across various system levels. Consequently, this scoping review aimed to
8 examine the measurement approaches at different levels of biological organisation in football
9 research, to identify how these approaches contribute to understanding adaptation and
10 performance.
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15 **Materials & Methods**

16 **Protocol and Registration**

17 A scoping review of the available literature was conducted as per the PRISMA Extension for
18 Scoping Reviews (PRISMA-ScR) Checklist and Explanation (Tricco et al., 2018). No protocol
19 was pre-registered given the exploratory nature of this review, where the full scope of the
20 literature and appropriate mapping approach could not be determined in advance. Scoping
21 reviews have developed due to evolving research objectives and questions, leading to new
22 approaches to synthesising evidence. Although these reviews are systematic, they lend
23 themselves to being more suitable for less precise research questions, thus making them more
24 ideal for exploring the extent of the literature, mapping concepts, or informing future practice in a
25 research field (Tricco et al., 2016; Arksey and O'Malley, 2005). To mitigate transparency
26 concerns, we have reported all eligibility criteria, search strategies, and included studies in full,
27 and our data extraction spreadsheet is available upon request. Ethical approval was not sought
28 as the data collected for this study is available in the public domain.
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35 **Eligibility Criteria**

36 Peer-reviewed articles in the English language that assessed responses to training and match
37 stimuli in uninjured, male professional, semi-professional, youth academy, and university-level
38 football players were eligible for analysis. Recreational and amateur football players were
39 excluded as a scoping decision to focus on competitive contexts where training environments
40 are likely to be more structured and systematically documented. The review was purposefully
41 scoped to male players to align with the broader research programme from which this work
42 emerged, and future reviews should seek to address female populations to provide a more
43 complete picture of adaptive responses in football. Eligible outcomes included any physiological,
44 neuromuscular, biomechanical, or physical performance measure obtained in response to a
45 defined stimulus. A stimulus was defined as any structured football-specific or physical training
46 session or competitive match, with studies required to include a minimum of one pre- and one
47 post-measurement regardless of stimulus duration, thus capturing both acute and chronic
48 adaptive responses. Studies measuring adaptations exclusively in upper body musculature or
49 upper limb performance were excluded. Eligible study designs included pre-post studies (single-
50 group or multi-group, randomised or non-randomised). Cross-sectional studies, conference
51 proceedings, book chapters, letters to the editor, comments, and reviews were excluded.
52 Detailed inclusion and exclusion criteria are presented in Table 1.
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Information Sources & Search Terms

SportDiscus, PubMed, Web of Science Core Collection and Scopus were searched for relevant publications before 19/06/2025. These databases were deemed to represent most of the relevant literature. Searches were conducted across title, abstract, and keyword fields within each database. The search terms involved using the keywords Soccer OR Football and each associated with the terms: Mechanical OR Physiological OR Muscle OR Tendon OR Bone AND Change* OR Inceas* OR Improve* OR Adapt* OR Respons* OR Decreas*. The search strategy was designed to capture studies measuring biological and performance adaptations across multiple levels of organisation. The terms Mechanical, Physiological, Muscle, Tendon, and Bone were selected to encompass structural, functional, and tissue-specific adaptations commonly assessed in football research. The complete search strategy for PubMed is presented below as an example:

PubMed Search Strategy (via NCBI interface):

(Soccer [Title/Abstract] OR Football[Title/Abstract])

AND

(Mechanical[Title/Abstract] OR Physiological[Title/Abstract] OR Muscle[Title/Abstract] OR Tendon[Title/Abstract] OR Bone[Title/Abstract])

AND

(Change*[Title/Abstract] OR Inceas*[Title/Abstract] OR Improve*[Title/Abstract] OR Adapt*[Title/Abstract] OR Respons*[Title/Abstract] OR Decreas*[Title/Abstract])

The search strategy was adapted for Scopus, Web of Science Core Collection, and SPORTDiscus using equivalent field tags for title, abstract, and keywords in each database. Complete search strategies for all databases are provided in supplementary material.

Screening & Data Extraction

Results from all databases were combined and downloaded to Mendeley (Elsevier, Amsterdam, Netherlands), and any duplicate studies were removed. Studies were initially screened by title and abstract by three authors against the eligibility criteria (Table 1). Where disagreement occurred between reviewers during screening, consensus was reached through discussion, with a fourth reviewer consulted if agreement could not be reached. When eligibility could not be determined from title/abstract alone, full-text review was conducted. The included studies were then examined by full text.

INSERT TABLE 1 HERE

The design of studies can exhibit different variations depending on the aim of the research question. The decisions made regarding study design will impact the data collection process and the depth of insights that can be gained. Firstly, study designs may differ based on whether responses are measured on a single level or multiple levels, which has implications for the complexity of the data collection process and analysis. Single-level approaches may be easier to operationalise, whereas multi-level approaches may require more sophisticated approaches. Secondly, decisions must be made regarding which levels to measure responses on. Careful consideration must be given to the specific aspects of the adaptive process one wishes to

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4 examine. These decisions also have implications for the complexity of the data collection
5 process and analysis as measures taken at the organism level may be less complex to
6 operationalise than measures taken at the cellular level. Lastly, there are choices to be made
7 regarding the outcome measure used at each level, which will be dictated by the aim of the
8 research question and the stimulus being implemented. Each of these decisions carries
9 implications for the types of insights that can be obtained into the adaptive responses to football
10 activities. With this in mind, a two-step approach was adopted for the extraction and
11 organisation of data.
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16 1. An excel spreadsheet (Microsoft Corporation, Redmond, WA) was used to collect and
17 organise the extracted data from each study under the following headings: title, stimulus,
18 outcome measure, and any additional relevant details.
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21 2. Outcome measures were then categorised by level, and measurement category. Two
22 reviewers met throughout this process to independently categorise outcome measures by level
23 and outcome measure category, with refinements conducted following any uncertainty or
24 differences. While inter-rater reliability statistics were not calculated, consensus was reached on
25 all categorisations through discussion and refinements to the categorisation framework were
26 made collaboratively as required.
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30 Details of how the outcome measures were categorised can be found further on in the methods
31 section. Outcome measures were extracted from the methods and results section of each
32 paper. In some cases, variables may not have been mentioned in the methods section as they
33 are sub-variables of the primary outcome measure (i.e. peak power during a countermovement
34 jump); these sub-variables were included as an outcome measure, provided it was clear how
35 they have been measured. Outcome measures mentioned in the results with no indication of
36 how they have been measured were disregarded. However, in the rare case that a reference
37 was made to a paper from which the method was replicated, this paper was subsequently
38 reviewed, and the methods were extracted and attributed to the paper the initial paper
39 screened. Finally, the following assumptions and simplifications were made to organise the
40 extracted data under the following headings: Level and Outcome Measures.
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45 **Level**

46 The study of anatomy categorises the body into multiple levels; subatomic particles, atoms,
47 molecules, macromolecules, cells, tissue, organ, organ system and organism (Shier et al.,
48 2019). In this study we focused on the cellular, tissue, organ, organ system, and organism
49 levels. The tissue and organ levels were combined due to the relative scarcity of studies
50 measuring exclusively at one level or the other, we therefore merged for practical purposes (see
51 limitation section). We did not create a separate molecular-level category because relatively few
52 studies in our dataset reported molecular outcomes (e.g., gene expression, protein synthesis,
53 signalling cascades) as primary measures. We acknowledge that this approach may have
54 underrepresented the extent of molecular-level measurement in the included studies, and that
55 molecular-level adaptation warrants dedicated examination in future reviews with search
56 strategies specifically optimised for molecular biology terminology.
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4 A decision tree (Figure 1) demonstrates the process for categorising an outcome measure by
5 level. If a measure can be obtained without using the whole body, then it was categorised by the
6 outcome measure's level, not the test's level. For example, if bicep femoris activity is measured
7 during a running test, the outcome measure is biceps femoris activity, which occurs at the tissue
8 level.
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14 **Outcome Measure**

15 Outcome measures were categorised by the outcome measure only. For example, if lactate was
16 taken during a running test, the outcome measure was simply referred to as lactate. Sprinting
17 speed or agility measures were categorised by the distance or type of test (e.g. 10m sprint time
18 or agility t-test time). Jump performance measures were categorised by the type of jump and the
19 measurement variable (e.g. drop jump height or drop jump RSI). Outcome measures for muscle
20 force or torque measured with an isokinetic dynamometer were categorised based on the
21 muscle group's role in joint movement (e.g. hamstring peak force as knee flexor peak force).
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25 **Outcome Measure Category**

26 Outcome measures were grouped under broad descriptive categories to highlight their
27 functional relevance to performance for illustration purpose only (Table 2 and Figure 4). This
28 classification system prioritised functional relevance to football practitioners while maintaining
29 alignment with biological levels, with categories developed iteratively during data extraction to
30 accommodate the diversity of measurement approaches encountered. Molecules and
31 metabolites that were unfamiliar to the authors were referenced against the open chemistry
32 database PubChem (Kim et al., 2021) or The Human Metabolome Database (HMDB) (Wishart
33 et al., 2018), which guided the categorisation.
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38 At organism and organ system levels, categories reflect performance categories familiar to
39 practitioners (agility, power, strength, fitness) rather than strict physiological constructs. For
40 example, "fitness" at the organism level includes whole-body performance tests (e.g., YOYO
41 tests), while at the organ system level it captures physiological system capacities (e.g., VO₂). At
42 the cellular level, categories reflect biological processes and biomarker families (muscle
43 damage & metabolism or hormonal function) commonly assessed in football research. Some
44 measures could conceivably fit across multiple categories. However, this approach prioritises
45 operational clarity over theoretical accuracy. Category definitions provided in table 2 reflect this
46 approach
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4 **Results**
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9 Searches were conducted on June 19, 2025, across all available database fields. Database
10 records identified: PubMed (n = 6,316), Scopus (n = 7,508), Web of Science Core Collection (n
11 = 6,556), SPORTDiscus (n = 2,457), for a combined total of 22,837 records before duplicates
12 were removed. 6855 records were identified through database searching after duplicates were
13 removed. Following screening, 765 full-text articles were assessed for eligibility, and 472 studies
14 were included.
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18 **Level**
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23 From the 472 studies reviewed in this study, it was found that as the complexity of study design
24 increased (based on the number of levels used to measure responses on) the number of
25 studies identified decreased progressively. This is demonstrated as the most adopted approach
26 was to measure responses at 1 level (n = 217, 46%), followed by 2 levels (n = 146, 31%), 3
27 levels (n = 84, 18%) and 4 levels (n = 25, 5%) (Figure 3). Organism-level measurement
28 dominated across all study designs. Among single-level studies (n = 217), organism was most
29 common (n = 111, 51%), followed by organ system (n = 59, 27%), with tissue/organ (n = 25,
30 12%) and cellular (n = 22, 10%) less frequently used alone. This organism-level trend continued
31 in multi-level studies. In two-level studies (n = 146), the most frequent combinations included
32 organism paired with either organ system (n = 51, 35%) or cellular (n = 48, 33%). Similarly, in
33 three-level studies (n = 84), the three most common combinations all included organism-level
34 measurement (n = 28, 25, and 25 respectively), with only 6 studies (7%) excluding organism.
35 Overall, 336 of 472 studies (71%) included organism-level measurement, demonstrating
36 consistent preference for this level regardless of study design complexity.
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42 **Outcome Measures**
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47 The results of this study demonstrate a trend towards using a small number of dominant
48 outcome measures to assess adaptive responses, despite considerable overall variability. At the
49 organism level, of the 336 studies that measured responses at this level, CMJ height was the
50 most used outcome measure (n = 148, 44% of organism-level studies), yet 492 unique outcome
51 measures were identified at this level. At the organ system level, of the 178 studies that
52 measured responses at this level, VO₂max was the most used outcome measure (n = 42,
53 24%), with 304 unique measures employed. At the tissue/organ level, of the 154 studies that
54 measured response at this level, Max HR was the most used outcome measure (n = 65, 42%),
55 alongside 193 unique measures. Finally, at the cellular level, of the 193 studies measuring
56 responses at this level, lactate was the most used outcome measure (n = 75, 39%), with 295
57 unique measures identified. Overall, 1284 unique outcome measures were identified.
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Discussion

This scoping review aimed to examine the measurement approaches at different levels of biological organisation in football research. This was done to identify how these approaches contribute to understanding adaptation and performance. Results revealed a trend towards study designs that evaluated outcomes using measures at the organism level. Furthermore, as the complexity of study design increased (based on the number of levels used to measure responses), the number of studies identified decreased progressively. Moreover, despite some clear outcome measures being consistently favoured at each level, it is demonstrated that there is considerable variability in how similar outcomes are measured. This may reflect appropriate variation in response to different research and applied questions or may indicate lack of methodological standardisation. The limited multi-level integration observed means that performance changes are documented without characterizing their underlying biological mechanisms. Consequently, common approaches to football research may be limited in its ability to capture the complexity of the adaptive process. This insight may make it important to consider where future efforts could be directed to enhance our understanding of the complexity of the adaptive process.

Key Observations from the research studies

The most widely adopted approach in the included studies was to measure responses at a single level ($n = 217$). There were examples of studies that measured response across 4 levels ($N = 25$), with the number decreasing progressively from 1 level to 4 levels. This may suggest a preference for either very focused study designs that clearly understand how they want to operationalise adaptation, or simple study designs that may have ease of delivery as their basis. It may also reflect the availability of resources to support relevant research designs and measurement outcomes in football research, as practitioners do not frequently have the opportunity to employ measurement tools that extend beyond field-based tools. Our mapping approach cannot distinguish among these explanations; thus, future research may be warranted to understand researcher and practitioner perspectives.

Beyond the number of levels measured, patterns also emerged in which specific outcome measures were selected. Whilst certain outcome measures are more frequently observed, significant variability exists in how adaptive response are assessed across levels, with 1284 unique outcome measures mapped (Figure 4). CMJ height was the most commonly used organism-level measure ($n = 148$). At the organ system level, $VO_2\text{max}$ was the most frequent outcome measure ($n = 42$), while at the tissue/organ level, Max HR was the most commonly used ($n = 65$). At the cellular level, lactate was the most prevalent outcome measure ($n = 75$). These outcome measures, alongside some of the other prevalent measures outlined in Figure 4, are likely preferred as they are reliable and accessible indicators of performance and fitness changes in response to training stimuli (Bok and Foster, 2014).

However, substantial variation exists in how researchers assess responses within each biological level. The results of this review found many unique outcome measures within each category and at each level. This review identified 492 unique outcome measures at the organism level, 304 at the organ system level, 193 at the tissue/organ level, and 295 at the

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4 cellular level. At the cellular level, this variation may reflect the array of biological processes that
5 can be assessed; muscle damage markers, metabolic markers, hormonal responses, and
6 immune function markers each capture different aspects of cellular adaptation (Castiglione et
7 al., 2014). However, the diversity observed at the organism level may reflect appropriate
8 variation in response to different research questions and applied contexts, or it may indicate
9 methodological inconsistency across the field.
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12 **Critical challenges for future research**

14 Overall, the design preference for fewer levels and the common outcome measures selected
15 may reflect the generally applied nature of football research. In these situations, practical
16 concerns, such as ease of data collection, access to resources and facilities, and relevance to
17 training and performance, may be prioritised over more conceptual explorations of adaptive
18 processes during the study design process. A recent study mapping the data analytical
19 approaches of football clubs found that practitioners were more influenced by accepted norms
20 and perceived importance and validity when selecting metrics to analyse and inform practice
21 (Dello Lacono et al., 2025). This pattern could conceivably extend to applied research. While the
22 pragmatic approach allows for quick and performance-related measurements (e.g., running
23 tests, agility tests, jump tests), there may be limited insights into the mechanisms behind
24 performance changes with these approaches. Understanding the mechanisms behind any
25 performance is essential as training should address the fundamental cause of any performance
26 limitations. A practitioner who can discern whether a player's jump performance is compromised
27 due to inadequate muscle fiber recruitment, incomplete tissue recovery, or systemic fatigue can
28 prescribe more appropriate training interventions, leading to better overall improvement in
29 performance. These ideas are evidenced by literature referring to the need to refine our
30 approaches to important practical and theoretical issues such as training load monitoring when
31 the complexities of the adaptive response are considered (Vanrenterghem et al, 2017;
32 Kalkhoven et al., 2021; Gabbett & Oeter, 2024; Montull et al., 2022).
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40 Aside from the pattern of organism level dominance, the variability in outcome measures found
41 may reflect appropriate variation in response to different research questions or may indicate
42 methodological inconsistency. Methodological inconsistency can complicate the development of
43 frameworks to better understand the complexity of adaptation (Barabási & Oltvai, 2004; West &
44 Goldberger, 2006; Gunderson & Holling, 2002; Kozlowski & Swiderski, 2015). However, this
45 variation could also reflect the natural evolution of approaches over time both through
46 knowledge development and technological advancements. Nevertheless, the development in
47 the available technology will not necessarily equate to significant progress in our understanding
48 of the underlying mechanisms of adaptation (Montull et al., 2022), and as such does not in itself
49 impact the limitations considered here.
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54 **Potential Solutions for those completing future studies in the area**

55 Understanding adaptive processes requires comprehensive insights into responses at multiple
56 levels (Wackerhage, 2014; Gomes et al., 2019). The emergence of complex systems-based
57 approaches and fields such as network physiology arises from the recognition that adaptation is
58 not a linear process but rather a network of interconnected events (Balagué et al., 2020;
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4 Gersherson & Fernández, 2012; Tzafestas, 2018). Conceptual and methodological approaches
5 that focus on understanding the dynamic interactions within biological systems may provide
6 more comprehensive and impactful explanations behind organism-level functionality or
7 performance (Paul and Nassis, 2015). However, adopting more complex research designs may
8 not automatically lead to better insights, as increased complexity comes with practical
9 challenges as they often require multidisciplinary expertise, large datasets, network analyses
10 and computational challenges (Zierath and Wallberg-Henriksson, 2015). This creates a
11 significant barrier to implementation in applied settings. This tension highlights the need for a
12 more strategic solution that combines both pragmatic and conceptual approaches in football
13 research. After all, a proxy measure of adaptation that can be applied consistently and reliably
14 in the field will hold more value than complex insights that can't impact the applied world.
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20 Designing studies with both practical considerations and novel conceptual frameworks may
21 create research that generates deeper insights that can directly translate into practical
22 applications. This approach could lead to more robust methods that seamlessly coordinate
23 responses across multiple levels, which may help guide the monitoring of a stimulus-response
24 relationships over time through constant triangulation (Kiely, 2012). However, this process is
25 difficult as the balance between the two drivers (insight and application) must be carefully
26 considered. The solution isn't to design multi-level studies as a default approach, but to consider
27 the depth of the problem, design studies strategically and acknowledge the limitations to help
28 create less blurry pictures of adaptation complexity over time. Such conceptual
29 thoughts/frameworks have been presented by various research groups (Vanrenterghem et al,
30 2017; Kalkhoven et al., 2021; Gabbett & Oeter, 2024; Montull et al., 2022; Buchheit & Hader,
31 2025) and may inform research in the future.
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36 **Implications for Applied Practitioners**

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38 The organism-level measurement bias revealed in this review has implications for how
39 practitioners should interpret football research. This indicates that football research has
40 demonstrated various ways to measure performance at the organism level but has not
41 adequately captured the complexity of the adaptive process at underlying levels. Without
42 mechanistic insight into underlying adaptive processes, the evidence base cannot guide
43 practitioners toward targeted solutions. However, rather than attempting multi-level
44 measurement for all athletes as a next step forward, practitioners might use unpredictable
45 training responses or persistent performance plateaus as opportunities for deeper investigation
46 through research partnerships or targeted investment in accessible technologies (portable
47 ultrasound, blood biomarkers). Until research better characterises the relationships between
48 organism-level changes and their underlying mechanisms in football-specific contexts,
49 practitioners should approach the evidence base with the understanding of the limitations that
50 come with performance measures at the organism level. This perspective should inform not just
51 training decisions, but also critical appraisal and identification of when existing research cannot
52 inform practice meaningfully.
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58 Whilst this review is comprehensive, there are some notable limitations. No protocol was
59 preregistered prior to commencing this scoping review. However, the exploratory nature of
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4 scoping reviews, where the optimal mapping and categorisation framework cannot always be
5 determined until engagement with the literature, meant that some decisions regarding how to
6 present the results found were refined iteratively during the review process. To mitigate
7 transparency concerns, we have reported all eligibility criteria, search strategies, included and
8 excluded studies in full, and our data extraction spreadsheet is available upon request. Our
9 search strategy likely underrepresented molecular-level measurement approaches. This means
10 our mapping is incomplete. Consequently, molecular-level adaptation research warrants
11 dedicated examination in future reviews. We merged tissue and organ levels as a pragmatic
12 methodological decision. These intermediate biological levels proved difficult to consistently
13 distinguish when categorizing outcome measures from included studies, as many
14 measurements (e.g., muscle architecture via ultrasound, whole-muscle cross-sectional area via
15 imaging) could reasonably be assigned to either category depending on how the distinction is
16 operationalised. Rather than develop arbitrary classification rules, we merged these levels for
17 mapping purposes. This decision simplifies the biological hierarchy and may obscure potential
18 distinctions in how researchers approach tissue-level versus organ-level measurement.
19 However, given the relatively low frequency of measurement at these intermediate levels in our
20 dataset, separating them would have resulted in even smaller subcategories without
21 substantially changing the primary pattern of organism-level predominance. Additionally, the
22 classification of outcome measurement categories is inherently simplistic. We have categorised
23 measures using "football terminology" in some instances to prioritise practical relevance to the
24 field over physiological precision. However, it should be noted that this was primarily for
25 illustrative purposes in Figure 4. Finally, this review only accounted for male football players, as
26 it was purposefully scoped to align with the broader research program from which it emerged.
27 Future scoping reviews should address female populations to provide a more complete picture
28 of adaptive processes in football.
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37 **Conclusion**

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39 This scoping review systematically mapped measurement approaches in football adaptation
40 research across 472 studies. The mapping reveals concentrated measurement effort at the
41 organism level with limited multi-level integration. Practical considerations may influence
42 methodological choices in applied football settings, though our descriptive mapping cannot
43 establish causation. While such approaches offer feasibility and immediate performance
44 insights, they provide incomplete mechanistic understanding of adaptive responses.
45 For researchers, this review helps signpost potential opportunities for multi-level designs to
46 answer specific questions about adaptive processes. For practitioners, it reveals that football
47 research has demonstrated various ways to measure performance at the organism level but has
48 not adequately captured the complexity of the adaptive process at underlying biological levels.
49 Without mechanistic insight, the evidence base cannot explain why adaptations occur or guide
50 practitioners toward targeted solutions when organism-level measures show unexpected
51 responses
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57 This review demonstrates where football adaptation research has concentrated measurement
58 effort, but not yet how well those approaches capture adaptive mechanisms. Overall, the pursuit
59 of understanding adaptation demands further exploration across multiple levels. While systems-
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based approaches offer promise, their implementation poses significant practical challenges in the applied world. Future research would benefit from incorporating multi-level measurement strategies where practically feasible. This requires a strategic approach to answer specific questions rather than pursuing multi-level study designs as a default approach. Such integration would advance understanding while maintaining practical applicability, shifting the field toward explaining how and why adaptations occur.

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Appendices

Tables

Table 1. Eligibility and exclusion criteria

Category	Inclusion	Exclusion
Population	Healthy, uninjured male football players (professional, semi-professional, youth, university)	Female players; mixed-sport athletes; injured/rehabilitation studies
Intervention	Training stimulus (football training, physical conditioning, or match play) with pre-post measurements	Recovery/nutritional interventions; acute environmental responses only
Outcomes	Physiological, neuromuscular, biomechanical, or physical performance measures	Upper body only; GPS/load profiles without adaptive outcomes; cognitive/tactical only
Study Design	Pre-post intervention designs (any group structure)	Cross-sectional; observational without intervention; insufficient methodological detail
Publication Type	Peer-reviewed journal articles with full text in English	Conference abstracts; letters; comments; book chapters; reviews; non-English full text

Table 2. Outcome measure categories used in Figure 4 for each level.

Level	Category	Definition
Organism	Agility	Measures assessing change of direction performance.
	Anatomical	Measures related to fat, lean tissue, and bone mass of the full body.
	Balance	Measures using tests designed to examine lower limb balance, such as a Y balance test.
	Fitness	Measures used to assess running performance, such as a YOYO IR1 test.
	Power	Measures used to assess the ability to produce force rapidly, such as countermovement jump height.
	Reactions	Measures used to assess reaction time performance.
	ROM	Measures used to assess whole body flexibility or range of motion.
	Speed	Measures used to assess acceleration and top speeds, such as 5m or 30m speed.
	Strength	Measures used to assess the ability to produce or absorb force, such as a 1RM Squat.
	Subjective	Measures used to assess participants' feelings or opinions on a task, such as RPE.
Temperature	Measures used to assess whole body temperature.	
Organ System	Anatomical	Measures related to fat, lean tissue, and bone mass at specific sites in the body.
	Contractile Properties	Measures used to assess the ability of a group of muscles to contract, such as hamstring muscle activity.
	Fitness	Measures used to assess the performance of systems in the body related to fitness, such as VO2 max.
	ROM	Measures used to assess muscle flexibility or joint range of motion, such as a Thomas test.
	Strength	Measures used to assess the ability of an isolated muscle group to produce force, such as concentric knee flexor peak torque.
	Subjective	Measures used to assess participants' feelings or opinions related to specific body systems.
Temperature	Measures used to assess the temperature of systems in the body, such as core temperature.	
Tissue/ Organ	Anatomical	Measures related to fat, lean tissue, and bone mass at specific tissues in the body, such as bone mineral density.
	Cardiovascular	Measures used to assess the function and performance of the heart, such as Max HR.
	Contractile Properties	Measures used to assess a specific muscle's ability to contract and produce force, such as vastus lateralis muscle activity.
Cellular	Bone & Connective Tissue Metabolism	Markers that reflect the status of bone/collagen turnover.
	Cardiovascular	Markers reflecting the status of cardiovascular cell structure and function.
	Hematology & Blood Chemistry	Markers of blood acid balance/blood cell status, such as red blood cell count.
	Hormonal & Endocrine Function	Markers that reflect hormone levels, such as testosterone or cortisol.
	Immune Function & Inflammation	Markers related to immune responses/inflammation, such as Immunoglobulin G levels.
	Metabolic & Nutritional Biomarkers	Markers related to macro (fats & carbs) and micronutrient metabolism, such as Iron levels.
	Muscle Damage & Metabolism	Markers related to muscle structure, function, and muscle damage, such as muscle fiber type, creatine kinase or lactate.
Oxidative Stress & Antioxidants	Measures of damaging species, such as reactive oxygen, nitrogen, and chlorine species.	

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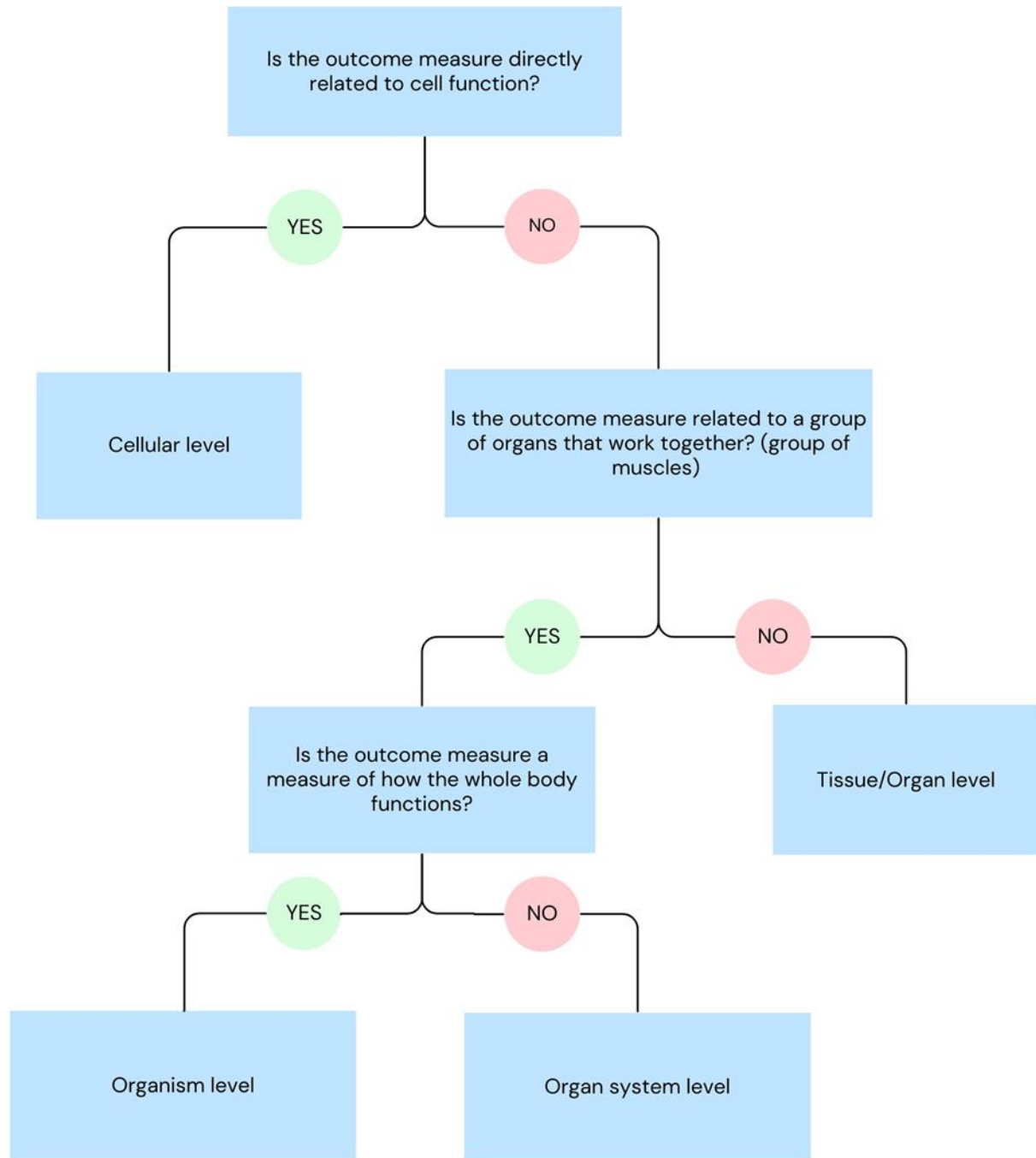


Figure 1 Decision tree used to categorise outcome measures into levels.

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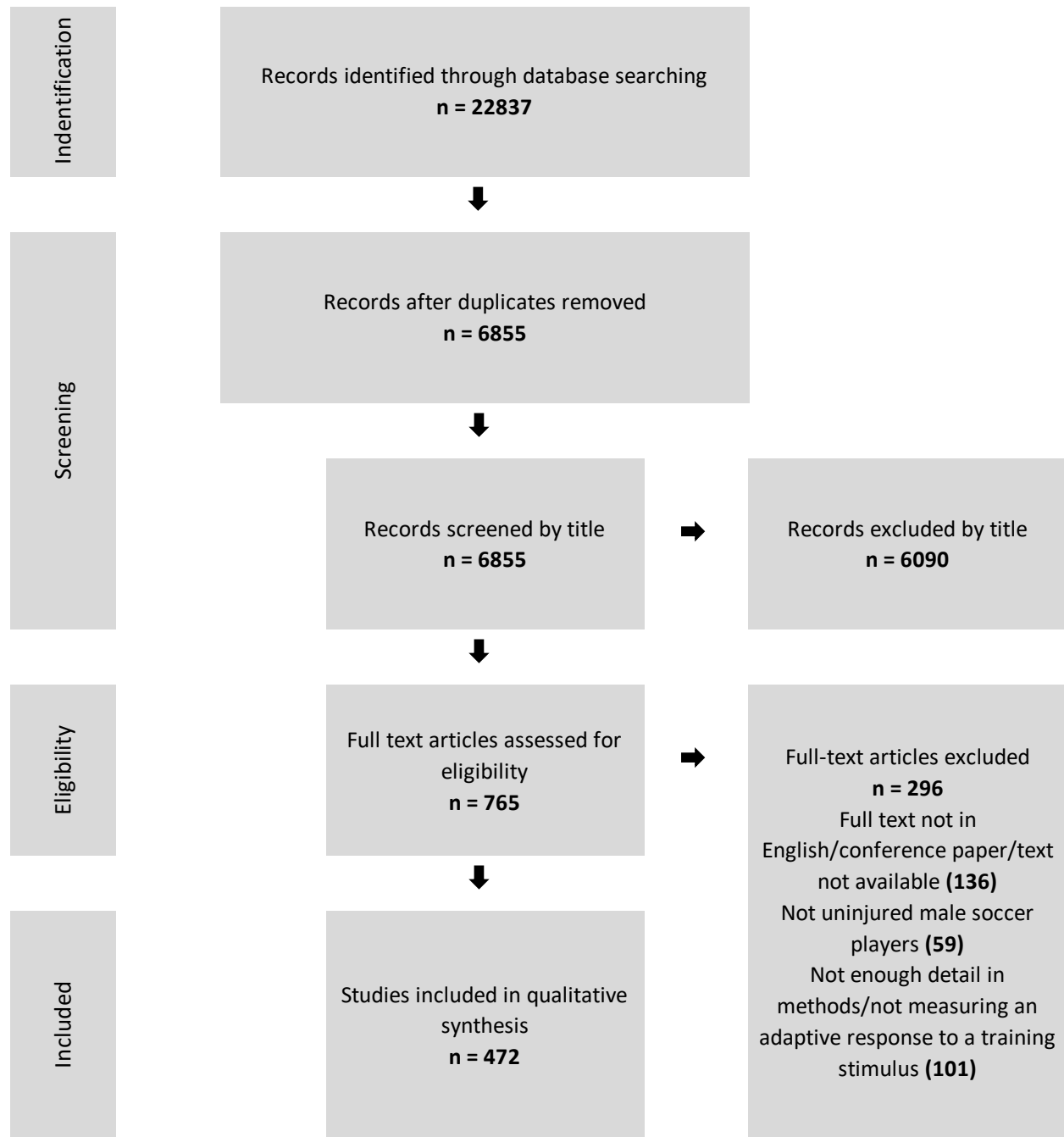


Figure 2 Prisma diagram of the study selection process

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





























No. of Levels	Levels Measured	No. of Studies
1 Level	 Cellular	45
	 Tissue/Organ	29
	 Organ System	32
	 Organism	111
2 Levels	 Cellular  Tissue/Organ	13
	 Cellular  Organ System	6
	 Cellular  Organism	48
	 Tissue/Organ  Organ System	6
	 Tissue/Organ  Organism	22
	 Tissue/Organ  Organ System  Organism	51
3 Levels	 Cellular  Tissue/Organ  Organ System	5
	 Cellular  Tissue/Organ  Organism	26
	 Cellular  Organ System  Organism	25
	 Tissue/Organ  Organ System  Organism	28
4 Levels	 Cellular  Tissue/Organ  Organ System  Organism	25

Figure 3. Number of studies measuring responses at single and multiple levels (n=472). Illustrations on the row represent the levels that were used in combination (i.e. in the 5th row 13 studies took outcome measures at the cellular and tissue/organ level, whereas on the 7th row 48 studies took outcome measures at the cellular and organism level). The size of the circle corresponds to the number of studies. 4 Levels (n = 25), 3 Levels (n = 84), 2 Levels (n = 146), 1 Level (n = 217)

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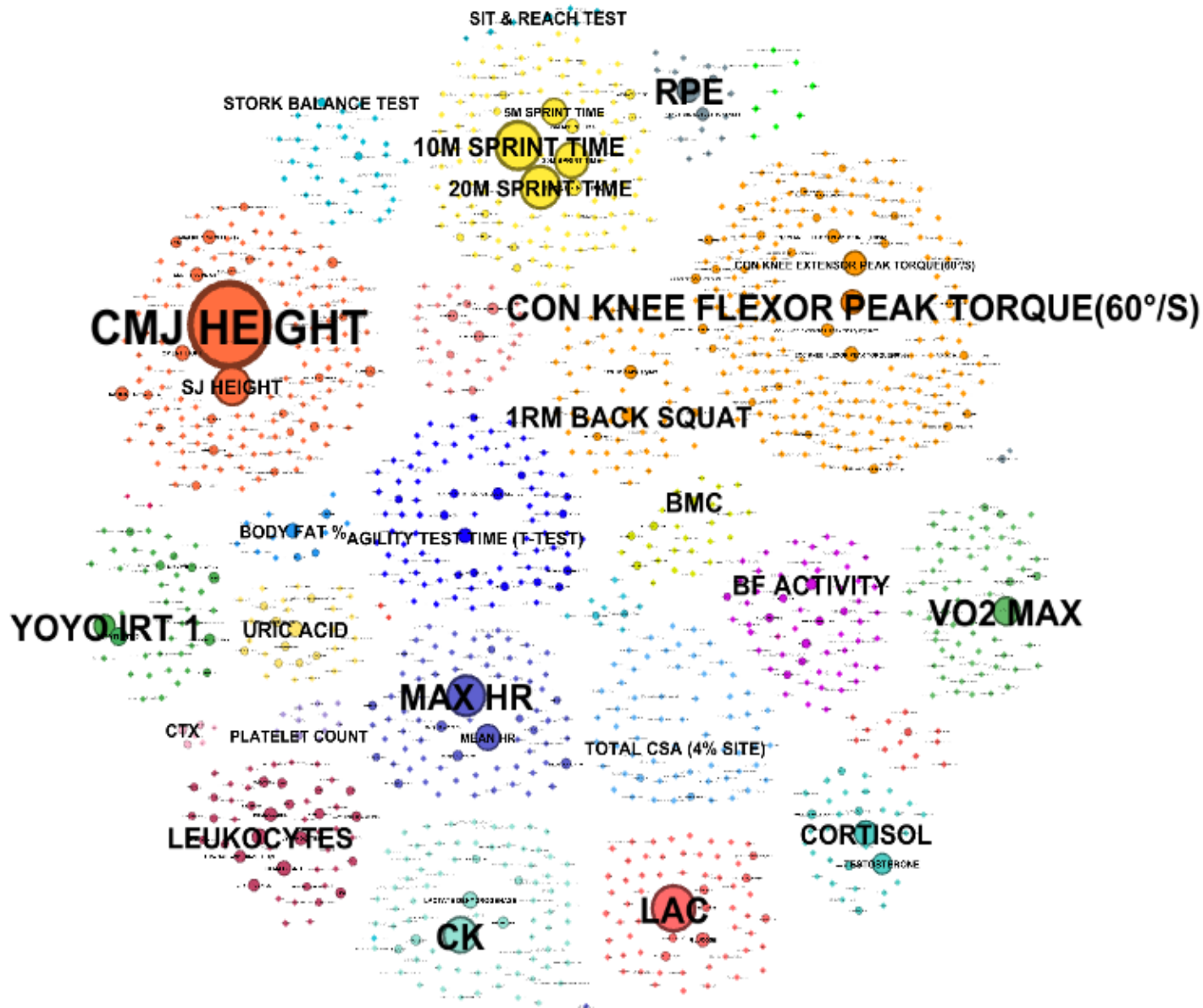


Figure 4 Outcome measures across all 4 levels of organisation in the body, specific measures labels have been enlarged for illustrative purposes only. Full interactive network data is provided as supplementary material (FootballAdaptation.json) and can be visualised using Gephi Lite. The size of the nodes indicates the number of studies an outcome measure has appeared in. The nodes are scaled based on each level. At the organism level, CMJ height was the most frequently used measure (n = 148); however, 492 unique outcome measures were identified at this level. At the organ system level, VO2max was most frequent (n = 42), with 304 unique measures employed. At the tissue/organ level, Max HR was most commonly used (n = 65), alongside 193 unique measures. At the cellular level, lactate was the most prevalent outcome measure (n = 75), with 295 unique measures identified. Outcome measure categories are colour coded based on categories (See Figure 5).

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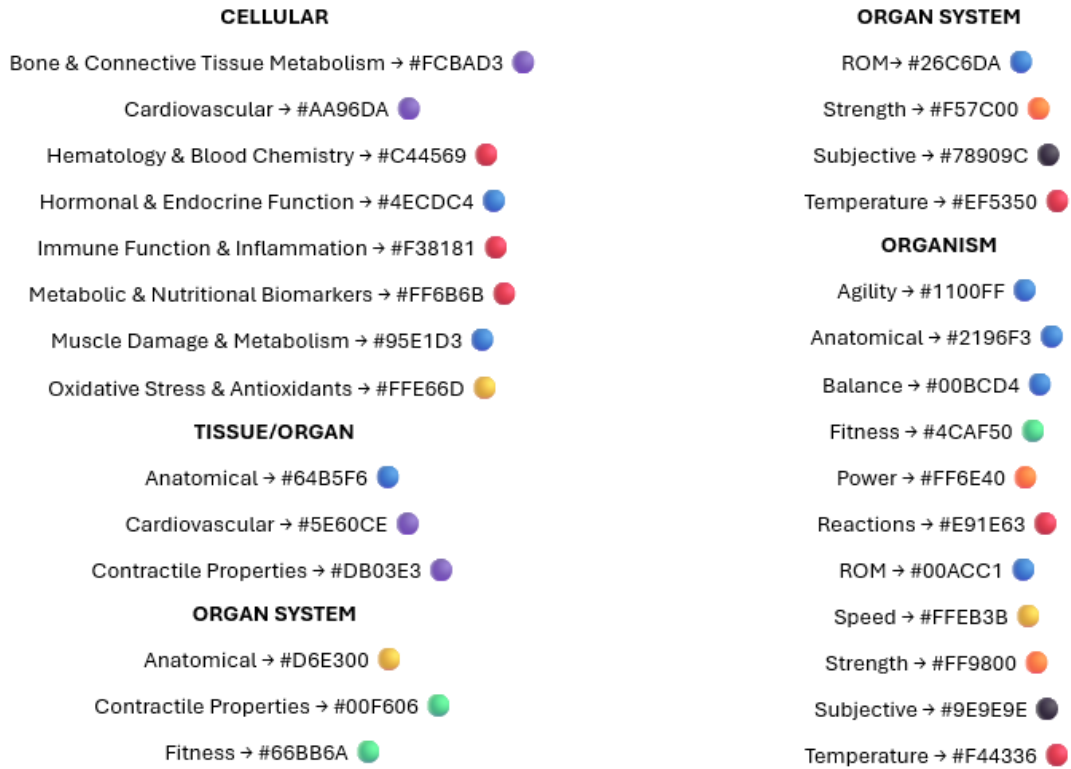


Figure 5. Outcome measure category colour codes