Do environmental temperatures and altitudes affect physical outputs of elite football athletes in match conditions? A systematic review of the 'real world' studies

Running Head: Effect of Temperature and Altitude on Elite Team Sport Physical Performance

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ABSTRACT

Players involved in the various football codes compete throughout the calendar year around the world. Therefore, environmental stressors such as temperature and altitude should be considered in preparation for, and during, matches. We aimed to systematically review the observational and quasi-experimental studies that have been specifically designed to quantify the effects of temperature (hot or cold) high altitude on in-match physical performance indicators. A search of electronic databases (Web of Science, Scopus, SPORTDiscus, PubMed/MEDLINE) was conducted, resulting in 19,424 papers being identified as relevant. Following sifting in relation to the eligibility criteria, 12 papers were deemed directly relevant. The reviewed studies scored 6-9 (on a 0-9 scale) for quality assessment using a previously used scale. The major outcome variables relevant to the current review were total distance (m), high speed running (m) and high-speed runs (count) measured during matches. Standardized effect sizes (ES) were heterogeneous across studies for total distance (ES: -0.96 to -0.14) and high-speed running (ES: -0.69 to 0.12) for >1000 m vs sea-level, time spent at the given altitude being a putative factor for this heterogeneity. Heat had mainly detrimental effects on performance, but ES were, again, heterogeneous across studies (ES: -1.25 to 0.26), dependent on temperature. Given the small number of studies that only involved mostly male athletes, and large heterogeneity across studies, more research needs be conducted on physical performance in these environmental conditions, with attention paid to standardizing outcomes and broadening the approaches of studies to guide future decision making in professional sporting environments.

Keywords: weather, environmental, physical, high-speed running, sprint, football

INTRODUCTION

Environmental factors, such as temperature and altitude, are widely considered to affect the performance of players in the various codes of football (McSharry, 2007; Aldous *et al.*, 2016). The effects of hot and cold temperatures on performance are explained predominantly by physiological mechanisms. The effects of high altitude are also mainly physiological in nature, although there are also physical mechanisms at play in some sports, e.g. decreased air resistance. Laboratory-based research has focused extensively on the physiology of acute and chronic environmental challenges and shown the potential for decrements in these conditions (Levine, Stray-Gunderson and Mehta, 2008; Cheung, 2010; Girard, Brocherie and Bishop, 2015). Findings from these studies have led governing bodies such as the Federation of International Football Associations (FIFA) and the International Football Association Board (IFAB), to make amendments to their rules and regulations to allow for situational decisions based on these conditions. These guidelines include “cooling” breaks or “drinks” breaks and restricted kickoff times due to mid-day heat. Similarly, official competition is banned above a specific altitude, in the interest of player health and safety (Sato, 2007). These topics are of particular interest in competitions where these environmental constraints are commonly encountered, e.g., the FIFA World Cups in Qatar in Winter 2022 and USA/Mexico/Canada in Summer 2026.

Broadly, studies on environmental exercise physiology encompass five overarching themes: 1) acute exposure responses, 2). chronic exposures responses, 3). effects on performance, 4). individual variation in responses, and 5). counter measures to the environmental challenge (Cheung, 2010). Mitigation approaches seem to be a popular topic, especially in testing the effectiveness of commercial products. Therefore, there have been more studies of this nature published recently (Rodríguez *et al.*, 2020). The effects of chronic exposures to an environmental challenge are also commonly investigated, where studies typically focus on acclimatization or habituation, to understand the time required for performance outcomes to normalize in a specific environment. This particular topic tends to be especially studied leading into Olympic competition or World Cup competitions such as the recent Tokyo Olympics in ~~2020~~ 2021 (McSharry, 2007; Levine *et al.*, 2008; Périard, Racinais and Sawka, 2015). Markedly less research work has been conducted on acute exposure responses in the sporting environment itself during actual competitions and matches, i.e., in "real world" conditions. In football competitions, there is not always time to acclimatize, often as a result of the high frequency of competitions, "fixture congestion being defined as greater than one game per week (Bengtsson, Ekstrand and Hägglund, 2013; Carling *et al.*, 2015).

Many reviews have been written to synthesize the research on acclimatization to an environmental stressor (McSharry, 2007; Levine *et al.*, 2008; Girard and Chalabi, 2013; Périard, Racinais and Sawka, 2015; Gibson *et al.*, 2020), but there are gaps in the literature on acute changes in football performance when these athletes compete in difficult 'real world' environments. Therefore, the purpose of this systematic review was to synthesize and summarize the current evidence in relation to physical performances in football codes during short stays (<14days) in which athletes are exposed to two different environmental factors (temperature and altitude).

MATERIALS AND METHODS

This systematic review was written in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Panic *et al.*, 2013). The original protocol was posted on TU PURE, an online university repository and also at OSF Registries, osf.io/6ya5w. The PROSPERO database does not accommodate reviews focused purely on sports performance topics.

Search Strategy

All studies were identified through a search of the following databases: Web of Science, Scopus, SPORTDiscus, PubMed/MEDLINE. Searches for articles were conducted over a 3-4 month period, concluding in Summer 2021. Following the identification of articles meeting the search parameter criteria, a secondary search through reference lists was conducted. The following restrictions were applied to the search: 1. Full text articles must be written in, or already translated into, English; 2. The study was published in a peer-reviewed journal or book.

Eligibility Criteria

The inclusion criteria for this systematic review, along with the search parameters, are reported in Table (1)

TABLE 1 ABOUT HERE

To address issues surrounding the reliability and validity of some of the technologies adopted in football environments over the past 20 years, we did not include studies in which outdated time motion techniques, such as notation of manual video analysis, or technologies with reduced capabilities, were used. This exclusion is consistent with other published research, which was determined by author's review of methodology and company websites (Jennings *et al.*, 2010; Jennings *et al.*, 2010; Scott, Scott and Kelly, 2015; Trewin *et al.*, 2017). Studies were also excluded if they were completed on "youth" athletes (under 18 years of age OR completely amateur populations), if the paper was not available in full text, the outcome measure were not related to physical performance (e.g., technical, or psychological), or if the study sought to evaluate an intervention other than the fundamental response to heat or altitude (example: cooling vests). Other exclusion criteria are displayed in Table 1.

Study Selection

Articles identified by the search were initially reviewed by a single author for eligibility, leaving any "borderline" studies in the sample for secondary review by two other authors in the research group. Discrepancies were decided via discussion and the voting of eligibility by the three reviewing authors. There were two studies which were debated in selection, one structure the data in a way which would not allow for direct comparisons or appropriate extraction (Zhou *et al.*, 2019) and the other as it was decided did not contain or have the potential to contain "professional" athletes (Bohner *et al.*, 2015), though future studies may look to include based on the input from other studies (Mckay *et al.*, 2022). Data were extracted during the initial reviewing process and agreed upon by the authors during the eligibility review, see Figure 1 for further detail of the selection process. The following data were collected via a self-designed spreadsheet: bibliographic information, sport type, study design, sample size, population characteristics, environmental conditions, time in conditions, outcome measures, reference material and discussion materials. Due to their documented practical relevance (Jennings *et al.*, 2010; Trewin *et al.*, 2017, 2018), our main study outcomes were total distance (m/min, TD), high speed running (m, HSR), high speed run count (count, HSRuns). In the absence of information about how much of a change in these match-related outcomes relates to real-world football code performance, we focused upon standardized effect sizes (Cook *et al.*, 2018). Standardized effect sizes (Cohen's d) were calculated following data collection and are presented within Tables 4 and 5. For interpretation, the following thresholds were selected for the effect sizes measures; 0.00-0.20= Minimal, 0.21-0.50= Small, 0.51-0.80= Medium, >0.81= Large (Cohen, 1977)

FIGURE 1 ABOUT HERE

Quality Assessment

To quantify the quality of studies in the current systematic review, a study quality scale that has been used in other football focused systematic reviews, was selected (Castellano, Alvarez-Pastor and Bradley, 2014). The authors made some small revisions to the previously-used scale to relate more to the current topic. The scale included nine "yes or no" questions, which were adapted from the original scale in Castellano et al (2014). A detailed display of the scale is presented in Table (2). The authors also used the Risk of Bias Assessment Tool for Nonrandomized Studies (RoBANS) to assess potential biases within eligible studies (Kim *et al.*, 2013) (Appendix A)

TABLE 2 ABOUT HERE*

Results

Studies Included

A total of 19,424 articles were initially retrieved in the search. After deduplication, time frame filtering, full text availability, English language only and subject matter relevance were levelled at the studies, 4,127 articles were to be reviewed. Following the title and abstract review of these remaining articles, 37 articles remained to be reviewed further for methodological and outcome consistency. After the third level of criteria-based selection, only 12 met all eligibility criteria for inclusion. The item-by-item responses on the quality assessment tool are reported in Table (3). Of the 12 studies, there was one study which had 2 or less factors for high risk of bias, two studies had three factors contributing to high risk of bias. Nine studies had 4 or more factors contributing to high risk of bias. See Appendix A for more detailed information

****TABLE 3 ABOUT HERE****

Participant Characteristics

All population and environmental descriptors are presented in Table (4). The reported sample sizes ranged from 9 (Carling, Dupont and Le Gall, 2011) to 340 participants (Konefał *et al.*, 2020). All studies recruited males (Özgünen *et al.*, 2010; Carling, Dupont and Le Gall, 2011; Mohr *et al.*, 2012; Nassis, 2012; Aughey *et al.*, 2013; Aughey, Goodman and McKenna, 2014; Garvican *et al.*, 2014; Link and Weber, 2015; Chmura *et al.*, 2017; Loxston, Lawson and Unnithan, 2019; Konefał *et al.*, 2020) in their analysis, except for one (Trewin *et al.*, 2018). All eligible studies were focused on soccer, except for Aughey et al. (2014) who focused on Australian Rules Football (AFL) (Aughey, Goodman and McKenna, 2014).

TABLE 4 ABOUT HERE

Study Characteristics

All studies were designed to compare the acute effects of temperature or altitude to neutral conditions in football performance. The effects of altitude on performance were investigated in four studies (Nassis, 2012; Aughey *et al.*, 2013; Garvican *et al.*, 2014; Trewin *et al.*, 2018) while nine other studies focused on the effects of high or low temperatures on performance (Özgünen *et al.*, 2010; Carling, Dupont and Le Gall, 2011; Mohr *et al.*, 2012; Aughey, Goodman and McKenna, 2014; Link and Weber, 2015; Chmura *et al.*, 2017; Trewin *et al.*, 2018; Loxston, Lawson and Unnithan, 2019; Konefał *et al.*, 2020). One of the twelve studies included data from both altitude and temperature conditions (Trewin *et al.*, 2018).

For the altitude-related studies, (Tables 4&5), there was a wide range in reported altitude; from >500m (Trewin *et al.*, 2018) to 3600m (Aughey *et al.*, 2013). Time spent at altitude, was not consistently reported or not made apparent in the research methods of three studies. Time in the environment ranged from 24-120hrs, when reported. (Aughey *et al.*, 2013; Garvican *et al.*, 2014)

TABLE 5 ABOUT HERE

In the studies which focused on performance in different temperature conditions, (Tables 4 & 6), the range of environmental temperatures was from <5°C (Carling, Dupont and Le Gall, 2011) to 43°C (Mohr *et al.*, 2012). The time that participants spent in the temperature conditions was not always disclosed, but of those studies in which it was reported, it ranged from <24 h (Mohr *et al.*, 2012; Trewin *et al.*, 2018) and >72 h (Özgünen *et al.*, 2010; Loxston, Lawson and Unnithan, 2019).

TABLE 6 ABOUT HERE

Outcome Measures

All reviewed study authors reported Total Distance Covered (m/min) (Özgünen *et al.*, 2010; Carling, Dupont and Le Gall, 2011; Mohr *et al.*, 2012; Nassis, 2012; Garvican *et al.*, 2014; Aughey, Goodman and McKenna, 2014; Link and Weber, 2015; Chmura *et al.*, 2017; Trewin *et al.*, 2018; Loxston, Lawson and Unnithan, 2019; Konefał *et al.*, 2020). Ten of the articles included high speed running (HSR) distance (m) (Özgünen *et al.*, 2010; Carling, Dupont and Le Gall, 2011; Mohr *et al.*, 2012; Aughey *et al.*, 2013; Garvican *et al.*, 2014; Aughey, Goodman and McKenna, 2014; Chmura *et al.*, 2017; Trewin *et al.*, 2018; Loxston, Lawson and Unnithan, 2019; Konefał *et al.*, 2020), while four of the studies included HSRuns as an outcome measure (Chmura *et al.*, 2017; Trewin *et al.*, 2018; Loxston, Lawson and Unnithan, 2019; Konefał *et al.*, 2020). The definitions for both HSR and HSRuns included ranges starting between 5 and 7m/s in the eligible studies

Eight articles included other pertinent metrics, which were deemed important to practitioners, which were also included when available. These metrics included maximal acceleration count (#) (Aughey *et al.*, 2013; Garvican *et al.*, 2014; Aughey, Goodman and McKenna, 2014; Trewin *et al.*, 2018) and maximal or peak speed (m/s) (Mohr *et al.*, 2012; Nassis, 2012; Chmura *et al.*, 2017; Loxston, Lawson and Unnithan, 2019).

Because of the heterogeneity between studies in terms of methods, study quality, severity of environmental stressors, and selected outcomes, it was not feasible to undertake a meta-analysis to arrive at appropriately meaningful and precise effect sizes.

DISCUSSION

Competing in football codes at moderate-to-high altitudes or in extreme temperatures is a multifactorial challenge which requires planning to ensure athletes can compete optimally. Most of this planning has been guided by information derived from laboratory-based simulations. It is interesting to study whether the detrimental effects reported in these experiments are also present in “real world” competitions, for which amelioration strategies can be implemented by athlete support staff, e.g. pre-cooling approaches or acclimatization. Therefore, the purpose of this systematic review was to summarize the current ‘real world’ evidence in relation to elite football physical performances during short stays (<14 days) in two differing environmental conditions (heat and altitude), which are commonly dealt with in elite sporting calendars.

Not surprisingly, all the reviewed studies showed a high risk of bias (using formal appraisal tools) for components of their study, due to the “real world” nature of the studies. We found that the effects of moderate altitudes (<1500m) on physical performance measures were very variable compared with sea level measurements. As altitude increased, there were more consistently moderate-to-large negative changes in physical performance outcomes. The detrimental effects of hot environmental temperatures on performance outcomes were generally more consistently across the studies. At the lower environmental temperatures (<11°C), there were also reported detrimental effects on performance.

Altitude

Between 1000 m and 1500m, data from controlled experiments indicate negative effects on the physiological responses to exercise, and note significant changes with changes of as low as 100m (Armstrong, 2000), and note the potential for up to ~3% change in aerobic power (Armstrong, 2000; Cheung, 2010). In sport, even a small magnitude changes can have large impacts on the outcome (Abt *et al.*, 2021). Studies which looked at competition at altitudes <1400m had inconsistencies in reported outcomes. Trewin (2018) reported very likely declines in TD (-4%; 95%CI: -5.9 to -2.1%) at >500m as compared to sea level, while Nassis (2012) reported negligible effects on TD at 660 m, but moderate negative effects on TD between 1200m and 1400m when compared to sea level (Nassis, 2012; Trewin *et al.*, 2018). Trewin et al. (2018) reported small effects on HSR and HSRuns in this altitude zone. Trewin (2018) reported their experimental condition as >500m, which encompasses a wide range of altitudes, though the data reported seems to align with other data collected at altitudes less than 1400m. These reported differences at lower altitudes may also be due to other factors, gender, level of competition or fitness level, which are discussed within other sections of this paper.

At more moderate altitudes, 1400-1800m, there were consistent moderate to large negative effects reported for TD when compared to sea level in Nassis et al. and Garvican et al. (Nassis, 2012; Garvican *et al.*, 2014). Garvican et al (2014) examined performance within this range of altitudes, with the addition of acclimatization effects, which was a central purpose of their examination. Within the acute phases (<4 days at altitude) of their study, there were large negative effects on TD and moderate negative effects on HSR. As the Garvican et al. (2014) study extended their time at altitude, TD continued to be reported as negatively affected, though with less effects, and HSR was reported as negligibly different, which will be discussed further in the paper. With hematologic and cardiovascular factors being the most greatly effected in initial arrival and throughout an acute stay at altitude (Armstrong, 2000; Cheung, 2010), these alterations in TD and reductions in metrics which require the aerobic system to replenish fuel stores, such as HSR, seem to agree with the physiologic models previously discussed (Armstrong, 2000; Cheung, 2010). There did not appear to be a consistent effect on performance based solely on the change of altitude reported by eligible studies, as even the study reporting the lowest altitudes showed “very likely negative” effects on TD (Trewin *et al.*, 2018) and performance at the highest altitudes (Aughey *et al.*, 2013) was not always reported as being negatively affected..

A major component of altitude performance research is centered around understanding the process and timeline to acclimatization (Girard and Chalabi, 2013; Girard and Pluim, 2013). Typically, a professional team’s calendar will not allow for optimal acclimatization due to fixture congestion, defined by Carling (2015) as one game per four or less calendar days (Carling *et al.*, 2015). This will cause teams to select sub optimal approaches to altitude, given performance at altitude may not stabilize until after

14 days (Cheung, 2010). Between 0-96hrs at altitude, moderate to large negative effects were reported in TD with some studies reporting ~9% decrements (Aughey *et al.*, 2013; Garvican *et al.*, 2014; Trewin *et al.*, 2018). HSR was reported as not significantly affected in one study (Trewin *et al.*, 2018) while other study authors reported significant moderate changes in performance outcomes when athletes spent less than 96hrs in altitude prior to competition (Aughey *et al.*, 2013; Garvican *et al.*, 2014). For studies where athletes spent 100-150hrs in altitude conditions prior to competition, there were still reported changes in TD outputs in athletes, though the overall effects appeared to be less than in the 0-96hr time frame (-5.1%, ES: -0.42 ± 0.36 vs. -9.1, ES: -0.76 ± 0.37, respectively) (Garvican *et al.*, 2014). Similarly, Aughey et al. (2013) also reported a reduction in the effects on TD and HSR following a stay at altitude longer than 96hr, as compared to less than 96 hours, though their study reported more consistently significant effects (Aughey *et al.*, 2013). One research group examined performances 312 hours after arriving at altitude, and reported physical outputs were not significantly different from their sea level comparisons (Aughey *et al.*, 2013). In elite sport, ultimately, the decision on arrival time at altitude comes down to "return on investment" and the challenging decision making around "how much is a win worth?".

Metrics such as Maximal Velocity and Maximal Accelerations, which are pertinent to the applied practitioner, were reported in most eligible studies. Girard (2013) discussed the potential the benefits of reduced air resistance at altitude (Girard *et al.*, 2013), giving weight to potential improvements in metrics such as maximal velocity, though no included studies found significant differences (Nassis, 2012; Garvican *et al.*, 2014). Maximal Accelerations also have the potential of being impacted at altitude, with up to ~10% reduction per 1000m of altitude (Girard *et al.*, 2013). Acceleration count was also reported in some altitude studies, these studies found either a maintenance or improvement in these measures, though like TD and HSR, it may be impacted by both altitude and time at altitude, further investigation is recommended (Aughey *et al.*, 2013; Garvican *et al.*, 2014; Trewin *et al.*, 2018).

Temperature

Within eligible studies, there was a wide range of studied environmental temperatures (<5°C to 43°C). As noted by Cheung (2010), the physiological response to heat and cold can be heterogeneous between athletes, and thus may result in different management by practitioners and athletes. The coldest reported temperatures, <5°C and 6-11°C, were associated with no reported changes in TD or HSR (Carling, Dupont and Le Gall, 2011) when compared to thermal neutral 11-20°C. Studies showed inconsistent results at 21-27°C, four studies reported small to moderate effects on TD when compared to <24°C conditions (Carling, Dupont and Le Gall, 2011; Link and Weber, 2015; Trewin *et al.*, 2018; Loxston, Lawson and Unnithan, 2019) while one research group reported no significant differences with temperatures <22°C (Chmura *et al.*, 2017). Within this temperature range, HSR was consistently reported as being negatively affected (Chmura *et al.*, 2017; Trewin *et al.*, 2018; Loxston, Lawson and Unnithan, 2019), though one research group reported no significant impact (Carling, Dupont and Le Gall, 2011). Reported control conditions ranged from 11-26°C within eligible studies (Mohr *et al.*, 2012; Link and Weber, 2015; Loxston, Lawson and Unnithan, 2019; Konefał *et al.*, 2020). .

The National Weather Service (NWS) classifies 27-39°C as potentially risky for healthy individuals. Negative symptoms can include heat cramps, heat illness or heat stroke if not managed appropriately, and the NWS recommends extreme caution with any physical activity (Central, 2019). The NWS utilizes Heat Index; a more complex measurement of the ambient environment, which utilizes ambient temperature and relative humidity to calculate a perceptive temperature (National Oceanic and Atmospheric Administration, No date). Other methods such as Wet-bulb Globe Temperature (WBGT) may be useful. Risk ranges from the NWS are utilized with heat index, though for the purposes of this study they were applied to temperature. One research group reported no significant differences in TD or HSR, though their control group competed at 20°C, in which they reported decrements in performance (Özgünen *et al.*, 2010). Of the other eligible studies, there were reported reductions in TD, HSR or both (Aughey, Goodman and McKenna, 2014; Chmura *et al.*, 2017; Loxston, Lawson and Unnithan, 2019). For Aughey et al (2014) there was a large increase in HSR in their study, though participants were at the high end of the 27-39°C range. Effects on HSRuns were inconsistent, with one research group reporting no significant difference (Loxston, Lawson and Unnithan, 2019) and another reporting a significant reduction at >28°C (Chmura *et al.*, 2017).

The final range of temperatures falls within the NWS' third highest risk range (40°C to 50°C), which may be classified as "Danger Days" (National Oceanic and Atmospheric Administration, No date). Extreme caution is recommended during physical activity at this temperature, even in healthy individuals, as participants are likely to experience heat cramps, heat exhaustion or heat stroke (Central, 2019). Mohr et al. (2012) studied this extreme temperature, and reported a large reduction in TD of 7% and a 26%-drop in HSR compared with performances at 21°C (Mohr *et al.*, 2012).

Unlike the literature on altitude, heat-related studies tended to not focus on time-course factors when discussing systematic preparation of athletes. Of the studies which reported time in the experimental condition, there was very minimal time spent in the environments to evaluate (from 0 to 72hrs) (Özgünen *et al.*, 2010; Mohr *et al.*, 2012; Loxston, Lawson and Unnithan, 2019). The study in which participants spent the longest time (72hrs) in heat reported no significant changes in TD or HSR (Özgünen *et al.*, 2010), though both the experimental and control outcome measures were reported as lower than in other eligible studies (TD: 84 m/min vs. 101.4 to 125.3m/min; HSR: 442 ± 211m vs. 506m to >1000m). In the studies which reported or alluded to shorter times in the environment (Mohr et al., 2012; Loxston, Lawson and Unnithan, 2019) there were consistent reports of significant decreases in TD and HSR, alluding to a potential acclimatization effect in heat conditions.

Concurrent exposure to Altitude Heat

Information about the oxyhemoglobin dissociation curve has been used by previous researchers to indicate some potential physiologic interactions in responses to heat and altitude (Armstrong, 2000; Cheung, 2010; Buchheit *et al.*, 2013). Laboratory and controlled studies have contrasted heat training and altitude training for its potential benefits in performance (Buchheit *et al.*, 2013; Carr *et al.*, 2020; McLean *et al.*, 2020). Very few have researchers investigated concurrent effects on performance. Within the eligible studies, there are some consistent observations as we explore varying ranges of each environmental factor. As altitude increased (> 1400m), and temperatures increased into higher risk ranges (>27°C), there were consistently reported reductions in performance on most of the key outcome measures (Özgünen *et al.*, 2010; Mohr *et al.*, 2010; Nassis, 2012; Aughey *et al.*, 2013; Garvican *et al.*, 2014; Aughey, Goodman and McKenna, 2014; Chmura *et al.*, 2017; Loxston, Lawson and Unnithan, 2019). These effects reduced when participants spent significant time in the environment. Aughey et al (2013) studied for 312 hrs at altitude, which is the longest reported time in the altitude section; Ozgunen et al. (2010) spent >72hrs in heat, which is the longest of any other study in the temperature section) (Özgünen *et al.*, 2010; Aughey *et al.*, 2013). The alignment of these reported changes gives reason for the authors to suggest that deeper analysis of data understanding concurrent mechanistic responses to these environments should be utilized, to compare the physiologic and performance responses of athletes, to guide practitioner knowledge and applications.

Limitations

Within the current sample of eligible studies, there was a large array of technology used. In a previous systematic review, which investigated heat and altitude performance in football, there were studies, which would have been included by us were it not for use of poor or inaccurate technologies (Trewin *et al.*, 2017). Within the current study, measurement approached included optical tracking (by several manufacturers), commercial GPS (Varley, Fairweather and Aughey, 2012; Beato *et al.*, 2018) and GPS watches intended for personal use. The use of "gold standard" technologies in future research should help decrease the heterogeneity in findings in future research. The selection of relevant metrics should also be consistently evaluated to enhance the understanding of the environmental responses. Altitude and heat have been shown repeatedly to have profound effects on internal load measures, though internal load measures were rarely reported within the eligible studies (Armstrong, 2000; Cheung, 2010)

Within the eligible studies, only two sports were focused upon by the various authors; soccer and AFL (only 1 study). Our systematic review focused specifically on professional athletes in the various codes of football, though only one relevant study focused on a football code other than association football (soccer). Findings may be different if our inclusion criteria were more liberal for more sports, especially those involving individual athletes. Also of major concern, which must be addressed in future work, is the lack of studies (only 1 study) on female professional athletes.

A final limitation was a lack of standardized reporting of data for extraction. There is an excess of literature on key contributing factors to changes in performance, this literature should be considered when developing methodology and reporting structures. Work such as the ISA3600 is of great benefit to the field thanks to the study author's thoughtful consideration of all potential aspects of performance in their selected environmental conditions, and potential implications which may affect athletes and practitioners (Gore *et al.*, 2013) A unique aspect of these applied studies was that practitioners/researchers naturally sought to systematically mitigate effects through their normal practice, as many of these studies were performed during competition windows. A consistently high risk of bias was found throughout eligible studies (Appendix A), showing potential for increased error in reported effects. A recommendation for all future research on performance in challenging environmental conditions is to observe key factors and potential limiting factors in the experimental conditions, and ensure the reported data aligns with key physiologic components of the environmental condition that is studied.

Conclusion

On-field performance is a multi-factorial construct in football codes. In the current review, we found that altitude and temperature can detrimentally affect certain physical performance outcomes, though the effects are inconsistent, and should be studied more systematically to understand components pertinent to performance. Specific focus should be given to consistent data collection and reporting in these conditions to enhance future practitioner decision making. Noted challenges to practitioners stem from very limited resources, with limited studies, and only one study outside of association football (soccer). There is also a glaring sparsity of data on female professional athletes.

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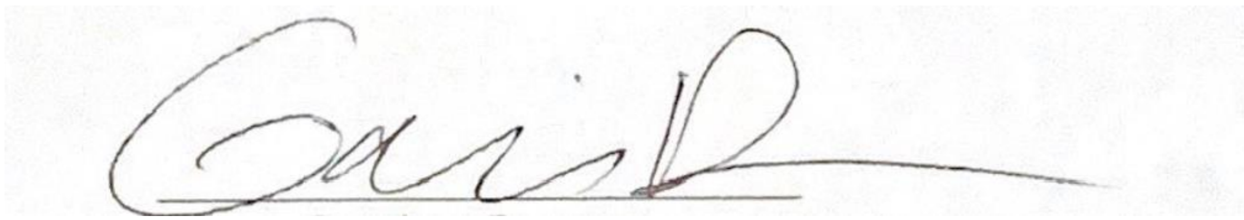
☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.



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Tables

Table (1). Inclusion, exclusion and search terms following the PICO principles

	Inclusion criteria	*Exclusion*	*Boolean search terms*
Population	Elite professional team sport athletes, Field Players	a.) Youth b.) Average age is <18 years old	“Team Sport athlete” OR “footballer” OR “football player” OR “Rugby Player” OR “Rugby” OR “Soccer athlete” OR “Soccer player” OR “Soccer” AND “Elite” OR “Professional” OR “Olympic”
Intervention	Competed in matches (competitive or friendly) at a.) >500m above sea level b.) >26°C OR <~11°C	a.) Time Spent in environment was >14days (336hrs)	“weather” OR “heat” OR “hot” OR “climate” OR humid* OR “temperature” OR “ambient” OR “High” OR “extreme” OR “Temperature Change” OR “altitude” OR hypobari*

Control	Competed in matches (friendly or competitive) at a neutral environment a.) <500m above sea level b.) ~11-~20°C (slight variations were allowed for)	a.) Control condition was deemed "challenging" b.) No Control condition used	
Outcomes	Studies that report in-match external load variables: Total distance, High speed running distances and / or counts.	a.) External load derived via Notation of manual video analysis b.) Reported GPS frequency of <3hz	"performance" OR "GPS" OR "External Loading" OR "workload" OR "loading" OR "Distance" OR "High Speed Running" OR "Sprinting" OR "workrate" OR "Self Report" OR "Questionnaire" OR "Survey" OR "self-evaluation" OR "self rating" OR "perceptual" OR "RPE" OR "Perceived Exertion"

Table (2) Quality criteria used to analyze publications

Question #	*Question*	*No*	*Yes*
1	The study is published in a peer-reviewed journal or book	X=0	•=1
2	The study is published in an indexed journal	x=0	•=1
3	The study objective(s) is/are clearly set out	X=0	•=1
4	Either the number of recordings is specified or the distribution of players/recordings used is known	X=0	•=1
5	The duration of player recordings is clearly indicated	X=0	•=1
6	A distinction is made according to player positions	X=0	•=1
7	The reliability/validity of the instrument is mentioned or is measured	X=0	•=1
8	Some contextual variables (e.g. Weather Conditions, Humidity,) are taken into account	X=0	•=1
9	The results are clearly presented	X=0	•=1

Table (3): Eligible Study Quality Assessment

Study	1	2	3	4	5	6	7	8	9	*Total*
(Özgünen et al., 2010)	•	•	•	•	•	**X**	**X**	•	•	**7**
(Carling, Dupont and Le Gall, 2011)	•	•	•	•	**X**	•	•	•	•	**8**
(Mohr et al., 2012)	•	•	•	**X**	•	**X**	**X**	•	•	**6**
(Aughey, Goodman and McKenna, 2014)	•	•	•	•	**X**	**X**	•	•	•	**7**
(Link and Weber, 2015)	•	•	•	•	•	**X**	**X**	•	•	**7**
(Chmura *et al.*, 2017)	•	•	•	•	**X**	**X**	**X**	•	•	**6**
(Loxston, Lawson and Unnithan, 2019)	•	•	•	•	•	•	•	•	•	**9**
(Konefał et al., 2020)	•	•	•	•	**X**	**X**	•	•	•	**7**
(Nassis, 2012)	•	•	•	•	•	**X**	**X**	•	•	**7**

(Aughey *et al.*, 2013)	•	•	•	•	**X**	**X**	**X**	•	•	**6**
(Garvican et al., 2014)	•	•	•	•	**X**	**X**	•	•	•	**7**
(Trewin et al., 2018)	•	•	•	•	•	•	•	•	•	**9**

Peer Reviewed Journal 2. Indexed Journal 3. Objectives 4. Recordings Specified 5. Duration 6. Player Position 7. Reliability/Validity of Instrument 8. Contextual Variables 9. Results; •= Yes/"1", -= No/"0"

Table 4: Study participant characteristics, environmental condition and technology

In-Text Citation	**Level** **Sex**	**Data Collection Time Frame**	***Age*** ***Stature*** ***Body mass*** (mean ± SD)	**Participants (File Count)**	**Environmental Condition**	**Technology (System)**
Özgünen *et al.* (2010)	Professional Soccer Players ♂	2007	20.4 ± 2.1 years 176.8 ± 4.8 cm 68.5 ± 5.3 kg	11	Temperature	GPS (Forerunner 305)
Carling, Dupont and Le Gall (2011)	French Professional Soccer Players ♂	2007-2011		9 (339)	Temperature	Optical Tracking (AMISCO Pro)
Mohr *et al.* (2012)	Scandinavian Professional Soccer Players ♂	n/a	26.6 ± 1.2 years 184.0 ± 1.0 cm 80.1 ± 1.6 kg	20	Temperature	Optical Tracking (AMISCO Pro)
Aughey, Goodman and McKenna (2014)	Professional Australian Rules Football Players ♂	n/a	25.9 ± 3.5 years 188.4 ± 7.8 cm 90.6 ± 8.8 kg	35	Temperature	GPS (Catapult MinimaxX)

Link and Weber (2015)	1n and 2n Division German Soccer Players ♂	2011-2013		(~24,220)	Temperature	Optical Tracking (VisTrack)
Chmura *et al.* (2017)	International Soccer Players ♂	2014	27.22 ± 3.75 years 181.16 ± 6.72 cm 76.95 ± 7.22 kg	304 (905)	Temperature/ Humidity	Castrol Performance Index (Optical Tracking)
Loxston, Lawson and Unnithan (2019)	United Arab Emirates Professional Soccer Players ♂	n/a	26.4 ± 3.1 years 177.0 ± 6.0 cm 73 ± 6.6 kg	20 (315)	Temperature	GPS (STATSports APEX)
Konefał *et al.* (2020)	International Soccer Players ♂	2018	27.1 ± 3.55 years 182.03 ± 6.90 cm 77.11 ± 6.99 kg	340 (945)	Temperature	Optical Tracking (STATS®)
Nassis (2012)	International Soccer Players ♂	2010		105 *team data not individual data	Altitude	Optical Tracking (not listed)
Aughey *et al.* (2013)	Soccer Players ♂	2012	18.1 ± 1.0 years 171.11 ± 6.3 cm 63.6 ± 7.2 kg	39	Altitude	GPS (Catapult MinimaxX S4)

Garvican *et al.* (2014)	Soccer Players ♂	2011	18.8 ± 1.0 years 180.8 ± 6.1 cm 77.4 ± 6.2 kg	20	Altitude	GPS (Catapult MinimaxX S4)
Trewin *et al.* (2018)	International Soccer Players ♁	n/a	15 - 34 years*	45	Altitude/Temperature	GPS (Catapult MinimaxX S4)

Env. Condition: Environmental Condition, Tech.: Technology, ♂: Male, ♁: Female
*Age range

Table (5) Results of the included Altitude based studies

Study	*Pop (#)* *Sport* *Gender*	***Altitude (m)*** *CON* *EXP*	***Time in EXP (hrs)***	***CON Condition*** a.)TD(m/min) b.) HSRD (m) c.) HSRuns(#)	***Experimental Condition*** a.)TD(m/min) b.) HSRD (m) c.)HSRuns (#)	***Effects (Standardized Effect Size)*** a.)TD(m/min) b.) HSRD (m) c.) HSRuns(#)	***Other Metrics of Interest***
(Nassis, 2012)	47 Soccer ♂	0 660	Not reported	a.) 111.35 ± 4.48	a.) 110.31 ±10.94	a.) → (-0.13)	a.) Max Velocity→ (27.74 ± 2.12 vs. 27.91 ± 2.41)
(Nassis, 2012)	64 Soccer ♂	0 1200-1400	Not reported	a.) 111.35 ± 4.48	a.) 107.81 ± 5.63	a.) ↓(-0.70)	a.) Max Velocity → (27.74 ± 2.12 vs. 27.91 ± 2.41)
(Nassis, 2012)	72 Soccer ♂	0 1401-1753	Not reported	a.) 111.35 ± 4.48	a.) 107.29 ± 5.42	a.) ↓ (-0.82)	a.) Max Velocity → (27.74 ± 2.12 vs. 28.4 ± 2.21)
(Aughey et al., 2013)	14 Soccer ♂	430 3600	24	a.) 96 ± 9 b.) 1344 ± 960	a.) 85 ± 14 b.) 912 ± 288	a.) ↓ (-0.96) b.) ↓ (-0.69)	a.) Max Accel →
(Aughey et al., 2013)	14 Soccer ♂	430 3600	144	a.) 96 ± 9 b.) 1344 ± 960	a.) 95 ± 6 b.) 1056 ± 192	a.) ↓ (-0.14) b.) ↓ (-0.46)	a.) Maximal accelerations →
(Aughey et al., 2013)	14 Soccer ♂	430 3600	312	a.) 96 ± 9 b.) 1344 ± 960	a.) 97 ± 5 b.) 1056 ± 288	a. → (0.13) b. → (-0.41)	a.) Maximal accelerations →

Study	Pop (#) Sport Gender	Altitude (m) CON EXP	Time in EXP (hrs)	CON Condition a.)TD(m/min) b.) HSRD (m) c.) HSRuns(#)	Experimental Condition a.)TD(m/min) b.) HSRD (m) c.)HSRuns (#)	Effects (Standardized Effect Size) a.)TD(m/min) b.) HSRD (m) c.) HSRuns(#)	Other Metrics of Interest
(Garvican et al., 2014)	20 Soccer ♂	0 1600	96	a.) 114.25 ± 13 b.) 1440 ± 450	a.) 102 ± 16 b.) 1170 ± 360	a.) ↓ (-0.84) b.) ↓ (-0.67)	a.) Max Accelerations → (ES= -0.08 ± 0.44)
(Garvican et al., 2014)	20 Soccer ♂	0 1600	144	a.) 114.25 ± 13 b.) 1440 ± 450	a.) 107 ± 11 b.) 1488 ± 336	a.) ↓ (-0.60) b.) → (0.12)	a.) Maximal accel↑ (9.4%) (ES=-0.23± 0.31)
(Trewin et al., 2018)	45 Soccer ♁	<500 >500	36-48	a.) 108 ± 9.8 b.) 882 ± 297 c.) 76.5 ± 26.1	a.) 104 ± 7.8 b.) 837 ± 261 c.) 72.9 ± 22.5	a.) ↓ (-0.45) b.) → (-0.16) c.) → (-0.15)	a.) Max Accel ↑ (6.8%, CI: 2.0-12%)

Key: Pop: Population, CON: Control Condition, EXP: Experimental Condition, TD(m/min): Total Distance (m/min), HSRD: High Speed Running Distance, HSRuns (#): Count of High Speed Runs, →: no significant difference, ↑: Significant Increase, ↓: Significant Decrease, ♂: Male, ♁: Female

Table (6) Results of the included Temperature based studies

Study	*Pop (#)* *Sport* *Gender*	*Temp (°C)* *CON* *EXP*	*Time in EXP (hrs)*	*CON Condition* *a.) TD(m/min)* *b.) HSRD (m)* *c.) HSRuns(#)*	*Experimental Condition* *a.) TD(m/min)* *b.) HSRD (m)* *c.) HSRuns (#)*	*Effects (Standardized Effect Size)* *a.) TD(m/min)* *b.) HSRD (m)* *c.) HSRuns(#)*	*Other Metrics of Interest*
(*K. T. Özgünen* et al., *2010)*	11 Soccer, ♂	20 28	72	*a.) 89 ± 6.08* b.) 484 ± 143	a.) 84.95 ± 7.61 b.) 442 ± 211	a.) → (-0.59) b.) → (-0.23)	
(C. Carling, Dupont and Le Gall, 2011)	166 Soccer ♂	11-20 >21	n/a	a.) 123.4 ± 5.4 b.) 787.2 ± 220	a.) 118.7 ± 6.9 b.) 720 ± 230.4	*a.) ↓ (-0.76)* b.) → (-0.31)	
(C. Carling, Dupont and Le Gall, 2011)	166 Soccer ♂	11-20 6-11	n/a	a.) 123.4 ± 5.4 b.) 787.2 ± 220.8	a.) 123.6 ± 6.8 b.) 777.6 ± 211.2	*a.) → (0.03)* b.) *→ (-0.04)*	
(C. Carling, Dupont and Le Gall, 2011)	166 Soccer ♂	11-20 <5	n/a	a.) 123.4 ± 5.4 b.) 787.2 ± 220.8	a.) 124.2 ± 7.1 b.) 777.6 ± 230.4	*a.) → (0.13)* b.) *→ (-0.04)*	
(Mohr et al.*, 2012)*	*20* *Soccer* ♂	*21* *43*	*<24*	*a.) 116.67 ± 12.3* *b.) 1000 ± 85*	*a.) 102.77 ± 8.3* *b.) 647 ± 65*	*a.) ↓ (-1.35)* *b.) ↓ (-4.71)*	*a.) Peak running speed ↑4% in Hot (p<0.05)*
(Robert J. Aughey, Goodman and McKenna, 2014)	*35* *AFL* ♂	*18* *28*	*n/a*	*a) 125 ± 15* *b) 2565 ± 720*	*a.) 114 ± 11* *b.) 3150 ± 180*	*a.) ↓(-0.85)* *b.) ↑(1.30)*	*b. Max accel → but ↑95%, 0.87 ± 0.87) in 3rd quarter* *c. RPE ↓ in hot matches*

(Link and Weber, 2015)	24220 Soccer ♂	<21 >21	n/a	a.) 120.5 ± 2.5	a.) 119 ± 2.25	a.) ↓ (-0.63)	
(Link and Weber, 2015)	24220 Soccer ♂	<21 >21	n/a	a.) 125.25 ± 2.25	a.) 123.5 ± 2.5	a.) ↓ (-0.74)	
(Chmura *et al.*, 2017)	304 Soccer ♂	<22 22-28	n/a	a.) 117.11 ± 10.11 b.) 2960 ± 580 c.) 40.5 ± 11.20	a.) 104.5 ± 10 b.) 2580 ± 590 c.) 34.75 ± 1.25	a.) → (-1.25) b.) → (-0.65) c.) ↓ (-0.92)	→ Peak Running speeds.
(Chmura *et al.*, 2017)	304 Soccer ♂	<22 >28	n/a	a.) 117.11 ± 10.11 b.) 2960 ± 580 c.) 40.5 ± 11.20	a.) 113.11 ± 9.78 b.) 2400 ± 560 c.) 30.72 ± 9.4	a.) ↓ (-0.40) b.) ↓ (-0.98) c.) ↓ (-0.95)	→ in Peak Running speeds.
(Trewin et al., 2018)	48 Soccer ♁	<21 >21	n/a	a.) 108 ± 9.5 b.) 940 ± 326.4 c.) 62.4 ± 18.24	a.) 106 ± 9.9 b.) 912 ± 278.4 c.) 57.6 ± 16.32	a.) ↓ (-0.21) b.) ↓ (-0.09) c.) ↓ (-0.28)	a.) Acceleration Count ↓
(Loxston, Lawson and Unnithan, 2019)	20 Soccer ♂	<24 33	12-36	a.) 106.8 ± 7.98 b.) 577.4 ± 157.1 c.) 7.7 ± 3.2	a.) 104 ± 8.07 b.) 506.6 ± 165.5 c.) 7.3 ± 3.6	a.) ↓ (-0.35) b.) ↓ (-0.08) c.) → (-0.12)	b.) → Maximum Speed
(Loxston, Lawson and Unnithan, 2019)	20 Soccer ♂	<24 28-33	12-36	a.) 106.8 ± 7.98 b.) 577.4 ± 157.1 c.) 7.7 ± 3.2	a.) 105.46 ± 7.0 b.) 562.8 ± 192.7 c.) 8.4 ± 4.4	a.) ↓ (-0.18) b.) ↓ (-0.08) c.) →(0.18)	a.) → Maximum Speed
(Loxston, Lawson and Unnithan, 2019)	20 Soccer ♂	<24 24-27	12-36	a.) 106.8 ± 7.98 b.) 577.4 ± 157.1 c.) 7.7 ± 3.2	a.) 105.61 ± 7.90 b.) 570.0 ± 181.1 c.) 8.6 ± 3.6	a.) ↓ (-0.15) b.) ↓ (0.04) c.) → (0.26)	a.) → Maximum Speed

(Konefał et al.*, 2020)*	340 Soccer ♂	9-26 >26	n/a	a.) 109.9 ± 15 b.) 563.73 ± 188.34 c.) 33.42 ± 12.17	a.) 101.35 ± 9.9 b.) 509 ± 166.61 c.) 30.77 ± 11.13	a.) ↓ (-0.69) b.) ↓ (-0.31) c.) ↓ (-0.23)

Key: Pop: Population, CON: Control Condition, EXP: Experimental Condition, TD(m/min): Total Distance (m/min), HSRD: High Speed Running Distance, HSRuns (#): Count of High Speed Runs, →: no significant difference, ↑: Significant Increase, ↓: Significant Decrease, ♂: Male, ♀: Female

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Figures

Figure (1).

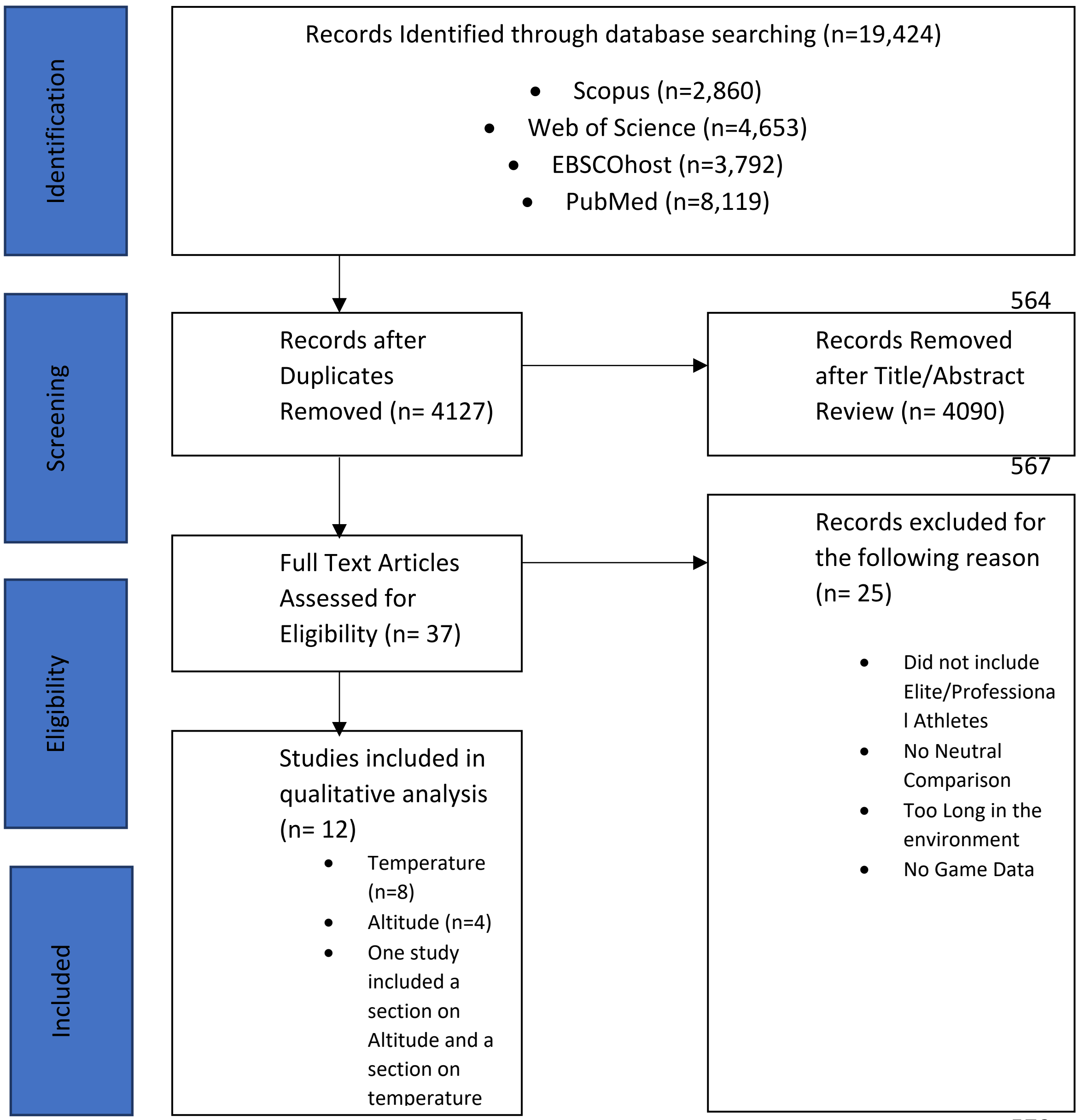

Figure Captions

Figure (1). Flow Diagram of study selection process

Appendix (A): The risk of bias assessment tool for nonrandomized studies. Adapted from Kim et al, 2013 and assessed risk of bias for eligible studies

#	Question	Details	Definition of LOW Risk of Bias Example	Definition of HIGH Risk of Bias Example
1	Selection of Participants	Selection bias caused by inadequate selection of participants	Comparable population (identical institution and period)	Different population groups make up the intervention and control groups
2	Confounding Variables	Selection bias caused by the inadequate confirmation and consideration of confounding variables	Major confounding variables were confirmed and adjusted for in analysis	Confounding variables were confirmed but not adjusted for
3	Measurement of Exposure	Performance bias caused by the inadequate measurement of exposure	Data was obtained from medical records or structured interview	Data obtained from un-reliable sources
4	Blinding of Outcome Assessment	Detection bias caused by the inadequate blinding of outcome assessments	Although blinding was not present, its absence was judged to have no effect on the outcome measurements	Blinding was not performed or incomplete, and has a likely effect on outcome measures
5	Incomplete Outcome Data	Attrition bias caused by the inadequate handling of incomplete outcome data	Causes of missing data are considered to be relevant to the study out come	Missing data could affect the study outcome
6	Selective outcome Reporting	Reporting bias caused by the selective reporting of outcomes	All expected outcomes are included in the study descriptions	Pre defined outcomes not reported OR outcomes not reported in accordance with previously defined standards

Study	1	2	3	4	5	6
(Özgünen et al., 2010)	**LOW**	**HIGH**	**HIGH**	**LOW**	**HIGH**	**HIGH**
(Carling, Dupont and Le Gall, 2011)	**HIGH**	**HIGH**	**HIGH**	**LOW**	**LOW**	**LOW**
(Mohr et al., 2012)	**LOW**	**HIGH**	**HIGH**	**LOW**	**HIGH**	**LOW**
(Aughey, Goodman and McKenna, 2014)	**HIGH**	**HIGH**	**HIGH**	**LOW**	**HIGH**	**HIGH**
(Link and Weber, 2015)	**HIGH**	**HIGH**	**HIGH**	**LOW**	**HIGH**	**HIGH**
(Chmura *et al.*, 2017)	**HIGH**	**HIGH**	**HIGH**	**LOW**	**HIGH**	**LOW**
(Loxston, Lawson and Unnithan, 2019)	**HIGH**	**HIGH**	**HIGH**	**LOW**	**LOW**	**LOW**
(Konefał et al., 2020)	**HIGH**	**HIGH**	**HIGH**	**LOW**	**HIGH**	**HIGH**
(Nassis, 2012)	**HIGH**	**HIGH**	**HIGH**	**LOW**	**HIGH**	**HIGH**
(Aughey *et al.*, 2013)	**LOW**	**LOW**	**HIGH**	**LOW**	**HIGH**	**LOW**

(Garvican et al., 2014)	**HIGH**	**HIGH**	**HIGH**	**LOW**	**HIGH**	**HIGH**
(Trewin et al., 2018)	**HIGH**	**HIGH**	**HIGH**	**LOW**	**HIGH**	**HIGH**

1. *Selection of Participants, 2. Confounding Variables, 3. Measurement Exposure, 4. Blinding of Outcome Assessments, 5. Incomplete outcome Data, 6. Selective Outcome Reporting;*
2. *Low= Low Risk of Bias, High= High Risk of Bias, Unclear= Unclear Risk of Bias*

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Appendix (B): The PRISMA 2020 Checklist with all pertinent information for the current study.

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	L 60-61
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	L:61-63
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Line 74
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Lines 71-73
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Table 1
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Line 94-95
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Line 97-101
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Line 101-106
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Table 4
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Appendix A
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Table 5 & 6
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Line 71-76; Table 1
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Lines 101-108
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Tables 4-6

Section and Topic	Item #	Checklist item	Location where item is reported
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Line 105-108
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	n/a
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	n/a
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Appendix a
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	n/a
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Figure 1
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Line 97-100
Study characteristics	17	Cite each included study and present its characteristics.	Table 4
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Appendix A
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Table 5 & 6
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Line 131-132
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Table 5 & 6
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	n/a
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	n/a
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Appendix A
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	n/a
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Line 187-205

Section and Topic	Item #	Checklist item	Location where item is reported
	23b	Discuss any limitations of the evidence included in the review.	Line 326-359
	23c	Discuss any limitations of the review processes used.	Line 326-359
	23d	Discuss implications of the results for practice, policy, and future research.	Line 361-365
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Line 68
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Line 68
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	n/a
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Publication version
Competing interests	26	Declare any competing interests of review authors.	n/a
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	n/a

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

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