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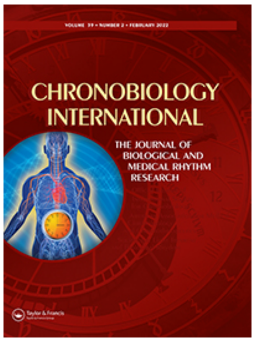

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REVIEW ARTICLE

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Daily variation in performance measures related to anaerobic power and capacity: A systematic review

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ABSTRACT

Numerous functional measures related to anaerobic performance display daily variation. The diversity of tests and protocols used to assess anaerobic performance related to diurnal effects and the lack of a standardized approach have hindered agreement in the literature. Therefore, the aim of the present study was to investigate and systematically review the evidence relating to time-of-day differences in anaerobic performance measures. The entire content of PubMed (MEDLINE), Scopus, SPORTDiscus® (*via* EBSCOhost) and Web of Science and multiple electronic libraries were searched. Only experimental research studies conducted in male adult participants aged ≥ 18 yrs before May 2021 were included. Studies assessing tests related to anaerobic capacity or anaerobic power between a minimum of two time-points during the day (morning *vs* evening) were deemed eligible. The primary search revealed that a total of 55 out of 145 articles were considered eligible and subsequently included. Thirty-nine studies assessed anaerobic power and twenty-five anaerobic capacity using different modes of exercise and test protocols. Forty-eight studies found several of their performance variables to display time-of-day effects, with higher values in the evening than the morning, while seven studies did not find any time-of-day significance in any variables which were assessed. The magnitude of difference is dependent on the modality and the exercise protocol used. Performance measures for anaerobic power found jump tests displayed 2.7 to 12.3% differences, force velocity tests ~8% differences, sprint tests 2.7 to 11.3% differences and 5-m multiple shuttle run tests 3.7 to 13.1% differences in favour of the evening. Performance measures for anaerobic capacity found Wingate test to display 1.8 to 11.7% differences and repeated sprint tests to display 3.4 to 10.2% differences. The only test not to display time-of-day differences was the running based anaerobic sprint test (RAST). Time-of-day variations in anaerobic performance has previously been partially explained by higher core-body and/or muscle temperature and better muscle contractile properties in the afternoon, although recent findings suggest that differences in methodology, motivation/arousal, habitual training times and chronotypes could provide additional explanations. There is a clear demand for a rigorous, standardised approach to be adopted by future investigations which control factors that specifically relate to investigations of time-of-day.

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Time-of-day; circadian rhythms; diurnal variation; anaerobic capacity; anaerobic power; review

Introduction

A large body of research has shown that physical and physiological variables display a diurnal variation in a temperate environment (around 17–22°C) in males (Atkinson and Reilly 1996; Drust et al. 2005). In the absence of external cues, cortisol levels, melatonin levels and core/muscle temperature levels are believed to play a role in the circadian regulation through signals directed by the suprachiasmatic nucleus (Reilly and Waterhouse 2009a, b). It has long been established that both cortisol levels (Reilly and Waterhouse 2009b) and body temperature (Atkinson and Reilly 1996, Pullinger et al. 2019) are higher in the mid-afternoon/evening, while levels of melatonin display higher values during the nocturnal period (Edwards et al. 2000). Muscle force production and power output also display an evening superiority, regardless of the muscle group measured (Atkinson and Reilly 1996; Drust et al. 2005). Anaerobic performance, such as anaerobic power in activities lasting less than 6 seconds (short-term, maximal power output) have previously shown to peak between 17:00 to 19:00 h (Bernard et al. 1998; Racinais

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et al. 2004). Similarly, anaerobic capacity, further defined as activities lasting between 30-s to 2-min in duration show a parallel peak in performance with greater values detected during evening hours between 16:00 to 19:00 h (Chtourou et al. 2012b; Souissi et al. 2013 c). The diurnal variation in peak power has previously shown to have an amplitude of ~7% and an acrophase around 17:00 h, while average power has displayed a higher amplitude of ~11% with an acrophase occurring slightly later at 18:00 h (Dergaa et al. 2019).

Time-of-day differences in anaerobic performance have previously been investigated using an array of tests and equipment (Aloui et al. 2013; Kin-Isler 2006; Melhim 1993; Souissi et al. 2010, 2002). Research concerning diurnal variation in anaerobic power has involved using sprint tests on a cycle ergometer (Souissi et al. 2010, 2004), swimming (Zarrouk et al. 2012b) or overground running (Chtourou et al. 2018), jump tests (Bernard et al. 1998; Heishman et al. 2017), force-velocity tests (Falgairette et al. 2003). In order to assess anaerobic capacity, many tests ranging from the Wingate test (Hill and Chtourou 2020), repeated sprint performance/ability (Chtourou et al. 2018; Pullinger et al. 2018a, 2018b), running based anaerobic sprint test (RAST; Dergaa et al. 2019) have previously been used in the literature to assess time-of-day variation. Classical Wingate tests have shown differences in mean and peak power by 11% and 14% during evening time (Drust et al. 2005). Variables related to repeated sprint performance have shown to peak between 17:00 h and 19:00 h with differences ranging from 3.4% to 10.2%. Ranges observed in daily variation of performance are dependent on numerous characteristics related to the performance variable measured, the mode of exercise (running *vs*. cycling) and the protocol used (duration of sprint, duration of recovery, the number of sprints), the fitness level of the athlete and the motivation of the subject (Giacomoni et al. 2006; Pullinger et al. 2014). Although most variables related to anaerobic performance have been thoroughly investigated, with diurnal variation evident; a diurnal variation in the variable "fatigue index" is not always reported in the literature and this inconsistency is attributed to the mode of exercise used and the type of protocol. Bishop et al. (2011), found that fatigue index was a valid measure of performance, however, fatigue index did not display time-of-day differences in repeated sprint performance (Pullinger et al. 2018a, 2018b).

The observation of notable changes in diurnal variation are still unknown but involve several potential contributing factors (Edwards et al. 2013; Pullinger et al. 2018a, 2018b). The evening superiority in muscle force production and power output has been attributed to a causal link between core body/muscle temperatures and performance and has previously at least partially been linked to diurnal changes in core and muscle temperatures (Robinson et al. 2013), although the exact mechanism(s) between performance and central temperature require additional research. Further, peripheral or muscle-related variables (contractibility, metabolism, and morphology of muscle fibres) influenced by hormonal and ionic muscle process variations (Reilly and Waterhouse 2009; Tamm et al. 2009), central/neurological factors (central nervous system command, alertness, motivation, and mood: Castaingts et al. 2004; Giacomoni et al. 2005; Racinais 2010; Racinais et al. 2005a) and/or greater phosphorylation of M-band-associated proteins (Ab Malik et al., 2020) have also been put forward as potential explanations that affect diurnal variation in muscle performance. Finally, aspects related to research design deemed specifically important for studies of a chronobiological (time-of-day) nature can influence potential findings. The lack of standardisation of these methods and adherence to these aspects hinder agreement on time-of-day effects and performance. Therefore, considering the large differences between findings and methodologies currently used to assess time-of-day and anaerobic performance measures, providing a clear and comprehensive review on this topic will help identify the current research gaps in our understanding within the area. In addition, highlighting the methodological concerns and other findings will help improve future studies related to anaerobic performance measures and time-of-day.

Given the amount of research and the equivocal evidence presented in the literature, the aim of the present paper was to examine the following research question: "In healthy adolescent males, what is the magnitude of time-of-day differences in performance variables related to anaerobic power and capacity?" In addition, information will be provided in relation to aspects related to research design deemed specifically important for studies of a chronobiological (time-of-day) nature.

Methods

Reporting standard

This systematic review conforms to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al. 2021). The PRISMA checklist is presented in Appendix 1, indicating the page numbers where items of information are present in the current manuscript.

Eligibility criteria

The inclusion criteria were based on the Cochrane guidelines for conducting systematic reviews (Higgins et al. 2021). The criteria for inclusion and exclusion were set and agreed by all six authors. Following the initial selection process of studies, three authors (AR, SP & TB) independently completed the eligibility assessment in a blinded standardized way by screening the titles and abstracts. To be considered eligible, the manuscript had to meet the following inclusion criteria:

(1) Population – healthy males and adult participants (18+ years of age) only. Females were excluded due to the impact of hormonal fluctuations on performance parameters thereby rendering it difficult to interpret findings. Female sex hormones have displayed substantial physiological effects related to altering fluid regulation, and modifications in thermoregulatory, muscular and metabolic responses all of which have been shown to affect anaerobic performance (Meignié et al. 2021).
(2) Time-of-day – compared the effects of morning versus evening in performance variables related to anaerobic power and/or anaerobic capacity (a minimum of two time-points).
(3) Anaerobic power – force-velocity test, crictical power test, jump tests (e.g. squat jump, counter movement jump test), Margaria Kalamen test, sprint test (cycling, running or swimming) and multiple shuttle run test

and/or

Anaerobic capacity – Repeated sprint testing, Running Based Anaerobic Sprint Test (RAST), 60 to 800-meter run, Cunningham Faulkner test and Wingate test

(1) Design – Randomised and/or counterbalanced trials

Literature search strategy and information sources

A computerised English-language literature search of the grey literature (TB & SP): Liverpool John Moores University electronic library, Manipal Academy of Higher Education electronic library, Qatar National Library; and electronic databases: PubMed (MEDLINE), Scopus, SPORTDiscus® (*via* EBSCOhost) and Web of Science were conducted (October 2020 – April 2021). A search for relevant content related to anaerobic power and/or anaerobic capacity and time-of-day variation using the following search syntax using Boolean operators in titles, abstracts, and keywords of indexed documents: ("circadian variation" OR "diurnal variation" OR "time-of-day" OR "circadian fluctuation") AND ("anaerobic capacity" OR "anaerobic power" OR "short-term power output" OR "anaerobic performance") was conducted (Appendix 2). Additional advanced search techniques using wildcards, truncation and proximity searching were incorporated. Secondary

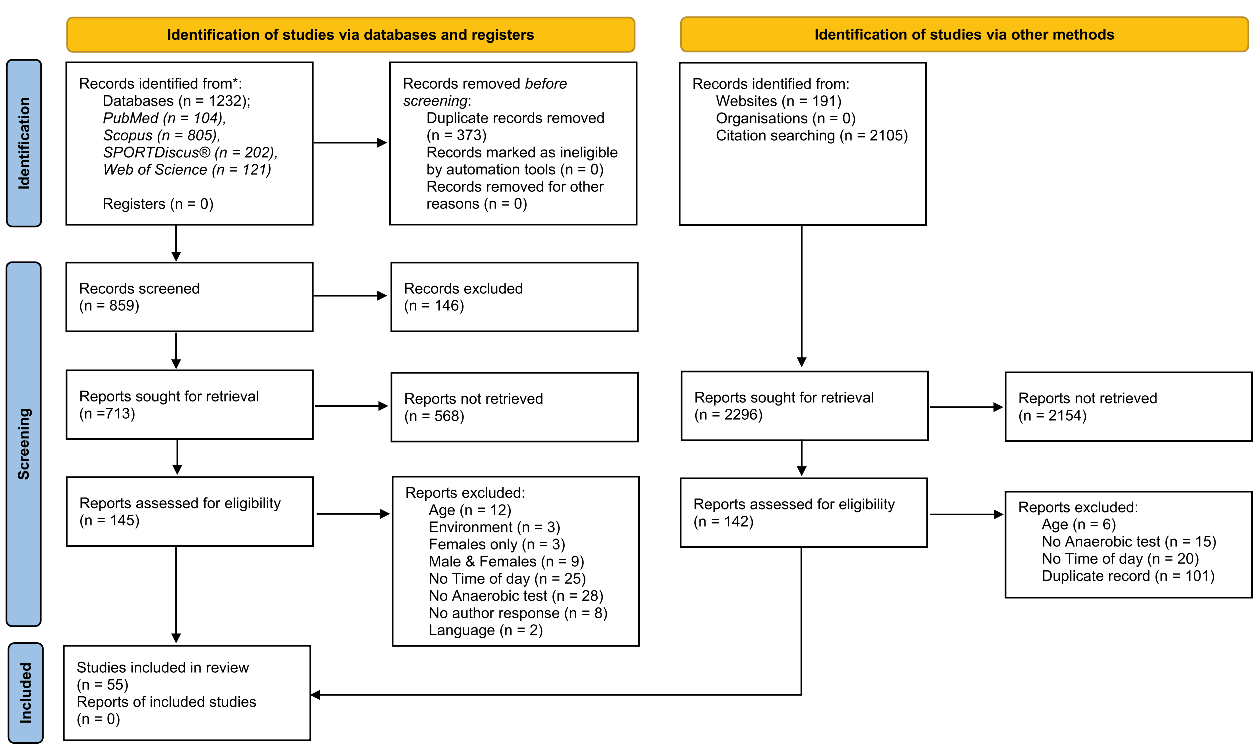

Figure 1. PRISMA 2020 flow diagram (Page et al. 2021) of the study selection process.

searches consisting of the reference lists of all papers included were screened manually for additional relevant papers, as part of the secondary search (AR & TB). In addition, forward reference searching was conducted to explore potential follow-up studies through citations and authors. One author (SP) independently carried out the searches for study selection to minimise potential selection bias. Figure 1 presents the flow of papers through the study selection process using the PRISMA 2020 flow diagram (Page et al. 2021).

Study selection

Where both male and female participants took part in a research study, the article was included if the data from male participants could be independently identified. In instances where the title and abstract did not contain enough detail to indicate whether an article was relevant to the review, the complete article was obtained and read. This enabled the authors to determine whether the paper met the primary inclusion criteria. In instances where the primary purpose of the article was not an investigation looking at the effects of time-of-day, meaning a minimum of two time-points were not assessed (morning and evening), the papers were excluded from the review. Letters to the editor, conference abstracts and literature reviews were excluded as these studies were not found to be methodologically-quality-assessable and/or critically appraisable.

Data extraction

Data extraction was performed by two authors (AR & TB) independently and a data check performed by a third author (SP) with the following data extracted from the included studies: (1) the study authors and date; (2) the number of participants and participant's characteristics (e.g. age, body mass, stature); (3) the circadian chronotype questionnaire used to assess the participants (and their scores); (4) the time-of-day testing sessions took place (e.g. morning, afternoon, evening); (5) anaerobic power or anaerobic capacity test used; (6) equipment used (e.g. cycle ergometer, non-motorised treadmill, Ergojump); (7) performance variables assessed (e.g. jump height, peak power, fatigue index, time); (8) the significance established with *P* values; and (9) % difference between testing time-points (if results were provided) and information as to whether diurnal variation was established. In addition, analysis regarding aspects relating to research design and factors deemed specifically important in investigations of chronobiological nature were quantified; randomisation, counterbalancing, record of light intensity, control of meals, control of room temperature, control of sleep and fitness of participants, as previously used by Pullinger et al. (2019). In most instances, a simple 'yes' or 'no' was recorded against each of the included studies, other than 'fitness' (when the studies were classified as having 'trained' or 'untrained' participants). All articles that made no specific reference to any of these primary areas were considered to indicate a negative response and 'no' was marked against the area in question.

Quality assessment

A modified 26-item methodological quality assessment checklist on each included article using the Downs and Black scale (Downs and Black 1998). was conducted. The checklist consisted of 26 "yes"-or- "no" questions which were scored totalling up to a possible 27 points. The questions were categorized under 4 sections: Reporting (10 items; 1–10), External validity (3 items; 11–13), Internal validity study bias (7 items; 14–20) and internal validity confounding selection bias (7 items; 21–26). The quality assessment of the articles was conducted by two reviewers (AR and TB) independently with disagreement on 5 manuscripts (9.1%). The observed differences were resolved by a third reviewer (SP).

Results

Search results

The literature search ended on April 2021 and the primary database search revealed 1232 articles and 2296 articles via other methods. Figure 1 presents the number of articles found in each electronic database and a detailed flow chart of the literature search, including all the steps performed. Once duplicates were removed, 859 titles remained in the reference manager (Mendeley, Elsevier, Amsterdam, The Netherlands). Following the examination of titles, abstracts and keywords of all these manuscripts, 145 academic studies were deemed eligible and retained for full text-analysis. After additional full-text analysis, 55 studies were deemed eligible and included in the systematic review. Reasons for exclusion can be found in Figure 1. Upon further inspection of all articles in their bibliographical references, none of these studies met the inclusion criteria and hence were deemed ineligible.

Study characteristics

The detailed participant characteristics are shown in Tables 1, 2, 3. A total of 813 participants were included across the 55 studies (average number of participants per

Table 1. Summary of the articles reviewed for anaerobic power (n = 16) with an overview of the participants, the experimental protocols with the time-of-day, exercise mode, performance test, the variables examined, and the main findings related to time-of-day in relation to each variable.

Author and Date	Participants	Chronotype assessment and distribution	Testing time-of-day	Test	Mode of exercise	Performance variables examined	Significance of main effects between condition	Main findings
Belkhir et al. (2019)	12 soccer players	Morningness-eveningness questionnaire (Horne and Ostberg, 1976)	M = 07:00 h	5-m multiple shuttle run test	Overground	Total Distance	P < .01	Total distance was significantly higher in both A and E compared to M; 3.7%
	21.8 ± 2.5 yrs, 1.78 ± 0.04 m, 71.3 ± 4.2 kg	12-M types	E = 18:00 h			Highest Distance	P < .001	Highest distance was significantly higher in both A and E compared to M; 13.1%
						Fatigue Index	P > .05	No significant difference between M, A, E
Belkhir et al. (2020)	16 highly trained physical education students	Morningness-eveningness questionnaire (Horne and Ostberg, 1976)	M = 07:00 h	30-s continuous jump	Optojump™ photoelectric cells Microgate	Maximal Height	P < .01	Maximal height was significantly higher in both A and E compared to M; 11.4%
	20.9 ± 1.5 yrs, 1.76 ± 0.05 m, 74.6 ± 8.6 kg	16-M types	E = 18:00 h			Mean Height	*P < .05*	Mean height was significantly higher in both A and E compared to M; 10.6%
						Fatigue Index	P > .05	No significant difference between M, A, E
Bernard et al. (1998)	23 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg, 1976)	M = 09:00 h	Force velocity test	Cycle ergometer	Cycling Power	*P < .05*	Cycling Power was significantly higher in both A and E compared to M.
	23 ± 3 yrs, 1.80 ± 0.07 m, and 72 ± 7 kg	7-M types, 4-E types, 10-N types	A = 14:00 h		Monark, 14E	Absolute power cycling	P < .01	Absolute power cycling was significantly higher in both A and E compared to M.
			E = 18:00 h			Optimal Force	P > .05	No significant difference between M, A, E
						Optimal Velocity	P > .05	No significant difference between M, A, E
				50-m sprint	Overground	Peak Velocity	P = .0544	Statistical "trend" between time-points.
				Multi-jump test	Ergojump, Globus Inc.	Jump Power	*P < .05*	Jump power was significantly higher in both A and E compared to M.
						Ground contact time	P > .05	No significant difference between M, A, E
						Flight time	*P < .05*	Flight time was significantly higher in both A and E compared to M.
Bougard and Davenne (2012)	8 healthy motorcyclists	Morningness-eveningness questionnaire (Horne and Ostberg, 1976)	M = 06:00 h	Abalakov jump test	Takaï Scientific Instrument®	Jump Height	*P < .05*	Jump height was significantly higher in both A and E compared to M; 6.9%
	21 ± 3 yrs, 1.76 ± 0.07 m, and 69 ± 6 kg	8-N types	E = 18:00 h	Long jump riding test	n/a	Jump distance	*P < .05*	Significantly higher in the E vs. M; 3.6%
Chtourou et el. (2013)	20 soccer players	Morningness-eveningness questionnaire (Horne and Ostberg, 1976)	M = 07:00 h	Squat Jump (without arm-swing)	Optojump, Microgate	Height	F = 34.6, P < .001	Significantly higher in the E vs. M
	18.6 ± 1.3 yrs, 1.75 ± 0.04 m, and 71.1 ± 8.6 kg	20-MM types	E = 18:00 h	CMJ (without arm-swing)		Height	F = 24.4, P < .001	Significantly higher in the E vs. M

(*Continued*)

Table 1. (Continued).

Author and Date	Participants	Chronotype assessment and distribution	Testing time-of-day	Test	Mode of exercise	Performance variables examined	Significance of main effects between condition	Main findings
Falgairette et al. (2003)	9 sport science students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 09:00 h	Force velocity test		Peak Power	P > .05	No significant difference between M, A, E
	23 ± 2 yrs, 180 ± 4 cm, weight: 74.8 ± 7.8 kg	9-N types	A = 14:00 h			Total Work	P > .05	No significant difference between M, A, E
			E = 18:00 h					
Heishman et al. (2017)	10 elite level division 1 basketball players	Not assessed	M = 07:00 h – 09:00 h	CMJ	Just Jump System (Probiotics, Huntsville, Al)	Jump height	P = .008	Significantly higher in the E vs. M; 4.8%
	20.9 ± 1.2 yrs, 1.88 ± 0.08 m, and 100.8 ± 9.2 kg		E = 13:45 h – 16:00 h			Peak Power	P = .004	Significantly higher in the E vs. M; 3.4%
López-Samanes et al. (2017)	13 highly competitive tennis players	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 08:00–09:30 h	10-m sprint	Overground (Smartspeed, Fusion Sport)	Sprint Time	P = .021	Significantly faster in the E vs. M; 2.7%
	22.5 ± 3.7 yrs, 1.82 ± 0.08 m, and 78.6 ± 10.0 kg	9-N types, 3-ME types, 1-MM type	E = 18:00–19:30 h	CMJ	Optojump, Microgate	Height	P = .018	Significantly higher in the E vs. M; 4.5%
Nikolaidis et al. (2018)	13 healthy swimmers	Not assessed	M = 09:30–10:30 h	25 m swim time	Indoor 25 m swimming pool	Time	P > .05	No significant difference between M and E
	24.7 ± 5.1 yrs, 1.80 ± 0.09 m, and 80.6 ± 10.6 kg		E = 16:00–18:00 h					
Otani et al. (2018)	8 healthy individuals	Not assessed	M = 08:00 h	10-second bicycle sprint at 5kp load	Cycle ergometer,	Maximal sprint power	P = 0 .787	No significant difference between M and E
	21.9 ± 0.4 yrs, 1.74 ± 0.06 m, and 67 ± 12 kg		E = 17:00 h		Monark 828E			
Pavlović et al. (2018)	16 elite handball players	Not assessed	M = 08:00–09:30 h	5-m sprint	Overground (Witty, Microgate)	Sprint Time	P < .001	Significantly faster in the E vs. M; 10.9%
	25.4 ± 5.8 yrs 1.94 ± 0.08 m, and 94.0 ± 7.4 kg		E = 18:00–19:30 h	10-m sprint		Sprint Time	P < .001	Significantly faster in the E vs. M; 11.3%
				20-m sprint Squat Jump CMJ (with arm-swing	Optojump, Microgate	Sprint Time Height Height	P < .001 P < .001 P < .001	Significantly faster in the E vs. M; 10.8% Significantly higher in the E vs. M; 9.6% Significantly higher in the E vs. M; 12.3%
				CMJ (without arm-swing)		Height	P < .001	Significantly higher in the E vs. M; 11.3%
Racinais et al. (2004)	12 physical education students	Not assessed	M = 07:00–09:00 h	5 to 6-s maximal sprint	Cycle ergometer,	Power Output full pedal	P > .05	No significant difference between M and E

(*Continued*)

Table 1. (Continued).

Author and Date	Participants	Chronotype assessment and distribution	Testing time-of-day	Test	Mode of exercise	Performance variables examined	Significance of main effects between condition	Main findings
	27 ± 4 yrs, 1.76 ± 0.01 m, and 70.3 ± 11 kg		E = 17:00–19:00 h		Monark 824E	Power Output half pedal	*P < .05*	Significantly higher in the E vs. M; 3.7%
				Squat Jump	Takei Kiki Kogyo vertical jump meter (T.K.K.5106)	Jump power	**P < .05**	Significantly higher in the E vs. M
				CMJ		Jump power	**P < .05**	Significantly higher in the E vs. M; ~5%
Racinais et al. (2005a)	8 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg, 1976)	M = 07:00–09:00 h	7-s maximal sprint	Cycle ergometer,	Maximal Power	**P < .05**	Significantly higher in the E vs. M; 4.5%
	27 ± 8 yrs, 1.76 ± 0.06 m, and 68.3 ± 10 kg	8-N types	E = 17:00–19:00 h		Monark 824E	Maximal Force	**P < .05**	Significantly higher in the E vs. M; 3.8%
						Maximal Velocity	P > .05	No significant difference between M and E
Souissi et al. (2019b)	15 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg, 1976)	M1 = 07:00 h	5-m multiple shuttle run test	Indoor gymnasium	Peak Distance	F = 153.38; **P < .05**	Significantly higher M2, M3, A1, A2 E vs. M1, and M3, A1, A2 E vs. M2 and A1, A2 E vs. M3 and A2 E vs. A1; 4.4%
	20 ± 1 yrs, 1.74 ± 0.09 m, and 70.8 ± 3.5 kg	15-N types	M2 = 09:00 h			Total Distance	F = 87.82; **P < .05**	Significantly higher M2, M3, A1, A2 E vs. M1, and M3, A1, A2 E vs. M2 and A1, A2 E vs. M3 and A2 E vs. A1; 4.4%
			M3 = 11:00 h			Fatigue Index	F = 33.09; **P < .05**	Significantly higher M2, M3, A1, A2 E vs. M1, and M3, A1, A2 E vs. M2 and A1, A2 E vs. M3 and A2 E vs. A1; 62.2%
			A1 = 13:00 h A2 = 15:00 h E = 17:00 h					
Unver and Atan (2015)	25 students	Not assessed	M = 09:00 h	Static Jump	Newtest Powertimer 300 equipment	Flight Time	P < .01	Significantly higher in the E vs. M, A
	23.0 ± 2.4 yrs, 1.74 ± 0.05 m, and 70.7 ± 8.4 kg		A = 14:00 h	(without arm-swing)		Height	P < .01	Significantly higher in the E vs. M, A
			E = 19:00 h					
Zarrouk et al. (2012b)	15 swimmers and physical education students	Morningness-eveningness questionnaire (Horne and Ostberg, 1976)	M = 07:00 h	25 m swim time	Indoor 25 m swimming pool	10-m sprint crawl	F1, 13 = 10.40, P < .01	Significantly faster in the E vs. M
	24.7 ± 5.1 yrs, 1.80 ± 0.09 m, and 80.6 ± 10.6 kg	10-N types, 5-MM types	E = 17:00 h			25-m sprint crawl	F1, 13 = 11.15, P < .01	Significantly faster in the E vs. M

M = Morning, EM = Early morning, A = Afternoon, E = Evening, N = Night, h = hours, s = seconds, yrs = years, m = metres, kg = kilogram, min = minute, M types = morning types, MM = moderately morning, ME = moderately evening, E types = evening types, N = neither, CMJ = counter movement jump.
Statistical significance ($P < 0.05$) is indicated in bold. Statistical "trend" or "marginal significance" in italic ($0.10 > P > 0.05$).

study = 15), ranging from a total of 8 to 31 participants. Forty-three studies (78%) assessed circadian chronotype of participants using the morningness-eveningness questionnaire (Horne and Ostberg 1976). The majority of participants belonged to the intermediate chronotype (73.0%), 12.8% to the moderately morning chronotype and 3.1% to the moderately evening chronotype. A further 6.4% of participants belonged to either the "extreme" morning (5.4%) or "extreme" evening (0.6%) chronotype. Two studies did not provide detailed information in regard to circadian chronotype of its participants, stating that they belonged to either moderately morning or intermediate chronotypes (5.1%; see Tables 1, 2, 3). A total of twelve studies failed to report any information related to chronotype for their participants.

The time-of-day during which morning sessions took place ranged from 05:30 to 11:00 h and evening sessions between 16:00 and 19:30 h, in 51 studies. A total of 2 studies used different time-points to assess diurnal variation (Heishman et al. 2017; Hill and Smith 1991). In addition, 9 studies used additional time-points to assess diurnal variation; Aziz et al. (2012) (21:00 h); Bernard et al. (1998) (14:00 h); Falgairette et al. (2003) (14:00 h); Heishman et al. (2017) (13:45 h); Hill and Smith (1991) (03:00 h and 21:00 h); Kin-Isler (2006) (13:00 h); Souissi et al. (2003) (02:00 h; 14:00 h and 22:00 h); Souissi et al. (2019b) (13:00 h; 15:00 h), Unver and Atan (2015) (14:00 h).

The total number of studies which performed an anaerobic capacity test was 39, while 25 performed an anaerobic power test. From these, 9 (16.4%) had a combination of both an anaerobic capacity and anaerobic power test, with 16 (29.1%) only conducting anaerobic power tests and 30 (54.5%) only anaerobic capacity tests. The mode of exercise varied across studies, with 37 studies using cycling, 14 using jumping, 10 using running and 2 using swimming. From these, 9 studies a combination of testing modes, such as: cycling, running and jumping (Aloui et al. 2017; Bernard et al. 1998); cycling and jumping (Chtourou et al. 2012a; Chtourou et al. 2012 c; Racinais et al. 2004; Souissi et al. 2013b; Souissi et al. 2019a); and running and jumping (López-Samanes et al. 2017; Pavlović et al. 2018). The type of anaerobic tests varied from Wingate tests, force velocity tests, sprint tests, repeated sprint tests, and multiple shuttle run tests using cycling, running or swimming as the mode of exercise. Different jump tests were also used ranging from squat jump, countermovement jump, static jump, continuous jump and long jump (Tables 1, 2, 3).

Forty-eight studies found several of their performance variables to display time-of-day effects, with higher values in the evening than the morning, while seven studies (Aziz et al. 2012; Chtourou et al. 2018; Falgairette et al. 2003; Gholamhasan et al. 2013; Giacomoni et al. 2006; Nikolaidis et al. 2018; Unver and Atan 2015) did not find any time-of-day significance in any variables which were assessed. A further 18 studies also found at least one of their variables not displaying time-of-day variation (excluding the studies mentioned above). Variables assessed during the Wingate test (n = 28), found all measures of peak power (maximal power) and mean power to always be significantly in favour of evening performance compared to the morning with ranges from 3.4 to 7.5% and 1.6 to 11.7%, respectively. Only one study used a RAST protocol and found all variables to be significantly better in the evening compared to the morning session. Repeated sprint performance found 8 of the 10 studies to report time-of-day significance, with higher values in the evening, with ranges from 3.5 to 9.0% dependant on the mode of exercise, the protocol used, and the variable assessed (see Pullinger et al. 2019b). A total of 6 studies performed a force velocity test and found significant differences to be present in measures of maximal power (7.8%), cycling power, absolute power cycling, and peak velocity in favour of the evening. However, one study (Souissi et al. 2008) showed no significant difference in peak velocity, while one other study (Falgairette et al. 2003) showed no significant difference in peak power and total work. Most studies found measures of jump height or distance to be significantly higher in the evening compared to the morning in the squat jump (3.3 to 9.6%), counter movement jump (2.7 to 12.3%), Sargeant jump, static jump, long jump (3.6%), Abalakov jump test (6.9%), and 30-s continuous jump (11.4%). Singular sprints also showed a tendency for significant better performance in the afternoon compared to the morning, with overground running sprint times decreasing by 10.9% for 5-m sprint, 2.7 to 11.3% for a 10-m sprint, and 10.8% for a 20-m sprint. The 50-m sprint did not show any significance. Cycling sprint performance was also significantly higher for power output at half-pedal (3.7%) for a 5 to 6-s maximal sprint, and maximal power (4.5%) and maximal force (3.8%) for a 7-s maximal sprint. A 10-s sprint showed no significant difference for maximal sprint power, while variables of power output full pedal and maximal velocity showed no significant differences for a 5 to 6-s, and a 7-s sprint respectively. Swim times over 10-m and 25-m showed significantly better times in the evening up to 1.5% in two studies. The multiple shuttle run test found performance variables to be significantly different in both studies, with total distance (3.7 to 4.4%), and highest distance (4.4 to 13.1%) better in the afternoon. Fatigue index was assessed in a total of 21 studies, with

Table 2. Summary of the articles reviewed for anaerobic capacity (n = 30) with an overview of the participants, the experimental protocols with the time-of-day, exercise mode, performance test, the variables examined, and the main findings related to time-of-day in relation to each variable.

Author and Date	Participants	Chronotype assessment and distribution	Testing time-of-day	Test	Mode of exercise	Performance variables examined	Significance of main effects between condition	Main findings
Abedelmalek et al. (2013)	12 football players	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 08:00 h	30-s Wingate test	Cycle ergometer	Peak Power	$F_{4, 32}$ = 45.89, P < .05	Significantly higher in the E vs. M; 9.4%
	21.2 ± 1.2 yrs, 1.74 ± 0.01 m, and 73.5 ± 1.7 kg	12-N types	E = 18:00 h		N/a	Mean Power	$F_{1, 8}$ = 10.57, P < .05	Significantly higher in the E vs. M; 6.3%
Aloui et al. (2013)	12 amateur soccer players	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00–09:00 h	5 x 6-s sprints	Cycle ergometer	Peak Power	F = 5.1, P = .045	Significantly higher in the E vs. M for sprint 1 only
	20 ± 2 yrs, 1.74 ± 0.05 m, 72.5 ± 6.4 kg	8-MM types and 4-N types	E = 17:00–19:00 h	24-s passive recovery	Monark 894E	% Peak Decrement	P = .012	% peak decrement was significantly higher in the E than in the M
						Total Work	P > .05	No significant difference between M and E
Aziz et al. (2012)	9 trained athletes	Not assessed	M = 08:00 h	30-s Wingate test	Cycle ergometer	Total work	P = .15	No significant difference between M and E
	18.9 ± 1.1 yrs, 1.71 ± 0.04 m, 71 ± 10 kg		E = 18:00 h N = 21:00 h		Monark 834 C			
Bousetta et al. (2017)	24 physically active individuals	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 08:00 h	30-s Wingate test	Cycle ergometer	Peak Power	P < .01	Significantly higher in the E vs. M
	21.1 ± 1.5 years, 1.78 ± 0.08 m, 73.9 ± 8.92 kg (control group, n = 8)	24-N types	E = 18:00 h		Monark 894E	Mean Power	P < .01	Significantly higher in the E vs. M
Chaari et al. (2014a)	11 handball players	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00–09:00 h	30-s Wingate test	Cycle ergometer	Peak Power	$F_{1, 10}$ = 161.56; P < .001	Significantly higher in the E vs. M; 5.2 to 8.1%
	22.6 ± 2.6 yrs, 1.80 ± 0.04 m, and 82.5 ± 10.1 kg	9-N types, 2-ME types	E = 17:00–19:00 h		Monark 894E	Mean Power	$F_{1, 10}$ = 27.3; P < .001	Significantly higher in the E vs. M; 3.5 to 4.8%
						Fatigue Index	P > .05	No significant difference between M and E
Chaari et al. (2014b)	11 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00–09:00 h	30-s Wingate test	Cycle ergometer	Peak Power	$F_{1, 10}$ = 105.57; P < .001	Significantly higher in the E vs. M
	22.6 ± 2.7 yrs; 1.79 ± 0.05 m, and 82.8 ± 10.5 kg	8-N types, 3-ME types	E = 17:00–19:00 h		Monark 894E	Mean Power	$F_{1, 10}$ = 41.59; P < .001	Significantly higher in the E vs. M
						Fatigue Index	$F_{3, 30}$ = 5.9; P < .01	Significantly higher in the E vs. M
Chaari et al. (2011)	11 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 08:00 h	30-s Wingate test	Cycle ergometer	Peak Power	$F_{1, 10}$ = 51.71; P < .001	Significantly higher in the E vs. M
	22.6 ± 2.5 yrs, 1.79 ± 0.06 m, and 82.6 ± 9.6 kg	8-N types, 3-ME types	E = 18:00 h		Monark 894E	Mean Power	$F_{1, 10}$ = 13.61; P < .001	Significantly higher in the E vs. M
						Fatigue Index	P > .05	No significant difference between M and E

(*Continued*)

Table 2. (Continued).

Author and Date	Participants	Chronotype assessment and distribution	Testing time-of-day	Test	Mode of exercise	Performance variables examined	Significance of main effects between condition	Main findings
Chtourou et al. (2011)	22 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00 h	30-s Wingate test	Cycle ergometer	Peak Power	P < .05	Significantly higher in the E vs. M; 2.6%
	23.2 ± 1.9 yrs, 1.75 ± 0.05 m, and 72.4 ± 5.7 kg	22-N types	E = 17:00 h		Monark 894E	Mean Power	P < .05	Significantly higher in the E vs. M; 2.3%
						Fatigue Index	P < .05	Significantly higher in the E vs. M; 4.1%
Chtourou et al. (2012b)	12 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00–09:00 h	30-s Wingate test	Cycle ergometer	Peak Power	P < .001	Significantly higher in the E vs. M
	22.4 ± 1.7 yrs, 1.77 ± 0.06 m, and 72.5 ± 6.5 kg	8-N types, 4-MM types	E = 17:00–19:00 h		Monark 894E	Mean Power	P < .05	Significantly higher in the E vs. M
Chtourou et al. (2018)	14 judokas	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00 h	6 x ~ 5-s sprints	Overground Indoor	Mean Sprint Time	P > .05	No significant difference between M and E
	21 ± 1 yrs, 1.72 ± 0.07 m, and 70.0 ± 8.1 kg	22-N types	E = 17:00 h	~ 20s active rest	PVC running Surface	Ideal Sprint Time	P = .609	No significant difference between M and E
						Fatigue Index	P = .570	No significant difference between M and E
Dergaa et al. (2019)	20 healthy active individuals	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 7:30 h	RAST	Overground	Peak Power	$F_{1,76} = 14.70$; $P = .006$	Significantly higher in the E vs. M
	25.9 ± 2.0 yrs, 1.78 ± 0.07 m, 80.2 ± 7.0 kg,	11-N types, 9-MM types	E = 17:30 h			Average power	$F_{1,76} = 8.12$; $P = .006$	Significantly higher in the E vs. M
						Minimal Power	$F_{1,76} = 11.62$; $P = .001$	Significantly higher in the E vs. M
Frikha et al. (2015)	22 (12 trained & 10 un-trained) physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 08:00 h	30-s Wingate test	Cycle ergometer	Peak Power	$F = 120.12$; $P < .001$	Significantly higher in the E vs. M; 3.5 to 9.5%
	Trained: 21.5 ± 1.3 yrs, 1.82 ± 0.04 m, and 82.9 ± 11.2 kg	18-N types, 4-ME types	E = 18:00 h		Monark 894E	Mean Power	$F = 54.32$; $P < .001$	Significantly higher in the E vs. M; 2.1 to 8.9%
	Untrained: 23.9 ± 3.2 yrs, 1.77 ± 0.02 m, and 82.2 ± 8.4 kg					Fatigue Index	$F = 1.71$; $P > .05$	No significant difference between M and E.
Gholamhasan et al. (2013)	30 students	Not assessed	M = 09:00 h	Wingate test		Anaerobic power	P < .131	No significant difference between M and E.
	19 ± 1.5 yrs, 68 ± 4.38 kg, 170.5 ± 5.67 cm		E = 17:00 h					
Giacomoni et al. (2006)	12 active individuals	Not assessed	M = 08:00–10:00 h	10 x 6-s sprints	Cycle ergometer	Peak Power Output	$F_{2,\ 22} = 16.8$, $P > .05$	No significant difference between M and E
	23 ± 2 yrs, 1.80 ± 0.06 m, and 76.4 ± 4.2 kg		E = 17:00–19:00 h	30-s recovery	SRM	Total Mechanical Work	$F_{2,\ 22} = 5.9$, $P > .05$	No significant difference between M and E
						Pedalling rate	$F_{2,\ 22} = 21.2$, $P > .05$	No significant difference between M and E
Hill and Smith (1991)	6 healthy individuals	Not assessed	EM = 03:00 h	Modified Wingate test	Cycle ergometer	Peak Power	P = .02	Significantly higher in the A vs. M, with highest values at 21:00 h

(*Continued*)

Table 2. (Continued).

Author and Date	Participants	Chronotype assessment and distribution	Testing time-of-day	Test	Mode of exercise	Performance variables examined	Significance of main effects between condition	Main findings
	22 ± 3 yrs, 1.78 ± 0.07 m, and 74.6 ± 4.9 kg.		M = 09:00 h A = 15:00 h N = 21:00 h		Monark 864	Anaerobic Capacity	P = .02	Significantly higher in the A vs. M, with highest values at 21:00 h
Kin-Isler (2006)	14 Sport Science Students	Not assessed	M = 09:00 h	30-s Wingate test	Cycle ergometer	Peak Power	F = 4.137, *P* = .028	Significantly higher in the A vs. M; 4.7%
	22.6 ± 1.1 yrs,1.77 ± 0.06 m, 72.1 ± 5.4 kg		A = 13.00 h E = 17.00 h		Monark 834E	Mean Power	F = 3.421, *P* = .048	Significantly higher in the A vs. M; 2.5%
Lericollais et al. (2009)	16 healthy competitive cyclists	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 06:00 h	60-s Wingate test	Cycle ergometer	Peak Power	P < .01	Significantly higher in the E vs. M; 8.2%
	23.5 ± 1.1 yrs, 1.77 ± 0.01 m, and 70.2 ± 1.7 kg	3-MM types, 12-N types, 1-ME types	E = 18:00 h		Ergomeca™	Mean Power 30-s	P < .05	Significantly higher in the E vs. M; 7.8%
						Mean Power 60-s	P < .01	Significantly higher in the E vs. M; 7.8%
Lericollais et al. (2011)	20 active individuals	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 05:30 h – 06:00 h	60-s Wingate test	Cycle ergometer	Peak Power	P < .01	Significantly higher in the E vs. M; 6.6%
	21.2 ± 1.4 yrs, 1.78 ± 0.08 m, and 70.3 ± 10.1 kg	20-N types	E = 17:30 h – 18:00		Monark 874E	Mean Power 30-s	P < .01	Significantly higher in the E vs. M; 3.3%
						Mean Power 60-s	P < .01	Significantly higher in the E vs. M; 2.7%
						Fatigue Index	P < .05	Significantly higher in the E vs. M; 2.2%
Lopes-Silva et al. (2019)	13 physically active individuals	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 08:00 h	10 x 6-s sprints	Cycle ergometer	Total Work Done	$F_{1,\ 22}$ = 21.35, *P* = .001	Significantly higher in the E vs. M; 8%
	26 ± 4 yrs, 1.77 ± 0.07 m, 77.0 ± 12.6 kg and VO2 peak 43.2 ± 6.9 ml.kg.min-1	4-MM types, 4-ME types and 5-N types	E = 18:00 h	30-s recovery	Lode Excalibur	Relative Peak Power	$F_{1,\ 23}$ = 4.40, *P* = .04	Significantly higher in the E vs. M; 6%
						Anaerobic Power Reserve	$F_{1,\ 22}$ = 13.67, *P* = .001	Significantly higher in the E vs. M; 9%
						Total Anaerobic Power Reserve	$F_{1,\ 23}$ = 4.40, *P* = .04	Significantly higher in the E vs. M
Pullinger et al. (2014)	20 well-trained field-based team-sport players	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:30 h	10 x 3-s sprints	NMT	Distance Covered	$F_{1,\ 19}$ = 43.973, *P* < .0005	Significantly higher in the E vs. M; 8.2%
	21 ± 2 yrs, 1.79 ± 0.07 m, 77.2 ± 10.5 kg and VO2 max 60.8 ± 4.8 ml.kg.min-1	20-N types	E = 17:30 h	30-s passive recovery	Woodway Force 3.0	Peak Power	*$F_{1,\ 19}$ = 4.067, P = .058*	"Trend" for higher values in the E vs. M; 4.5%
						Average Power	$F_{1,\ 19}$ = 14.926, *P*= .001	Significantly higher in the E vs. M; 7.8%

(*Continued*)

Table 2. (Continued).

Author and Date	Participants	Chronotype assessment and distribution	Testing time-of-day	Test	Mode of exercise	Performance variables examined	Significance of main effects between condition	Main findings
						Peak Velocity	$F_{1, 19} = 8.161$, $P = .010$	Significantly higher in the E vs. M; 3.3%
						Average Velocity	$F_{1, 19} = 44.065$, $P < .0005$	Significantly higher in the E vs. M; 8.3%
						% Decrement Peak Power	$F_{1, 19} = 0.831$, $P = .373$	No significant difference between M and E
						% Decrement Peak Velocity	$F_{1, 19} = 0.235$, $P = .633$	No significant difference between M and E
Pullinger et al. (2018a)	12 well-trained field-based team-sport players	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:30 h	10 x 3-s sprints	NMT	Distance Covered	$P < .0005$	Significantly higher in the E vs. M; 8.2%
	21.0 ± 2.3 yrs, 1.79 ± 0.06 m, 78.2 ± 11.8 kg and VO_2 max 60.0 ± 4.4 ml.kg.min^{-1}	12-N types	E = 17:30 h	30-s passive recovery	Woodway Force 3.0	Peak Power	$P = .004$	Significantly higher in the E vs. M; 6.7%
						Average Power	$P < .0005$	Significantly higher in the E vs. M; 8.3%
						Peak Velocity	$P = .031$	Significantly higher in the E vs. M; 3.4%
						Average Velocity	$P < .0005$	Significantly higher in the E vs. M; 7.8%
						% Decrement Peak Power	$P = .823$	No significant difference between M and E
						% Decrement Peak Velocity	$P = .101$	No significant difference between M and E
Pullinger et al. (2018b)	12 well-trained field-based team-sport players	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:30 h	10 x 3-s sprints	NMT	Distance Covered	$P < .0005$	Significantly higher in the E vs. M; 9%
	21.8 ± 2.6 yrs, 1.78 ± 0.07 m, 76.0 ± 6.3 kg and VO_2 max 60.6 ± 4.6 ml.kg.min^{-1}	12-N types	E = 17:30 h	30-s passive recovery	Woodway Force 3.0	Peak Power	$P = .006$	Significantly higher in the E vs. M; 4.9%
						Average Power	$P < .0005$	Significantly higher in the E vs. M; 10.2%
						Peak Velocity	$P < .0005$	Significantly higher in the E vs. M; 3.7%
						% Decrement Peak Power	$P = .765$	No significant difference between M and E
						% Decrement Peak Velocity	$P = .343$	No significant difference between M and E
Racinais et al. (2005b)	9 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00–09:00 h	5 x 6-s sprints	Cycle ergometer	Peak Power Output	$F_{4, 32} = 45.89$, $P < .05$	Significantly higher in the E vs. M for sprint 1 only; 5.3%
	22 ± 4 yrs, 1.78 ± 0.07 m, and 73.5 ± 10.5 kg	2-MM types, 1-ME type and 6-N types	E = 17:00–19:00 h	24-s passive recovery	Monark 824E	Power Decrement	$F_{1, 8} = 10.57$, $P < .05$	Significantly higher in the E vs. M; 4%
						Total Work	$F_{1, 8} = 0.01$, $P = .93$	No significant difference between M and E

(*Continued*)

Table 2. (Continued).

Author and Date	Participants	Chronotype assessment and distribution	Testing time-of-day	Test	Mode of exercise	Performance variables examined	Significance of main effects between condition	Main findings
Racinais et al. (2010)	8 active individuals	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 08:00–10:00 h	10 x 6-s sprints	Cycle ergometer	Power Output	$F_{1,7}$ = 12.15, *P* < .05	Significantly higher in the E vs. M for sprints 1, 2, 3 and 5 only
	25 ± 1 yrs, 1.77 ± 0.02 m, and 68.7 ± 3.2 kg	2-MM types, 1-ME type and 5-N types	E = 17:00–19:00 h	30-s recovery	Monark 818E	Power Decrement	$F_{9,63}$ = 4.53, *P* < .05	Significantly higher in the E vs. M
Souissi et al. (2002)	14 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00–08:00 h	30-s Wingate test	Cycle ergometer	Peak Anaerobic Power	$F_{1,12}$ = 16.8, *P* = .001	Significantly higher in the E vs. M; 8.4%
	19 ± 1.2 yrs, 1.77 ± 0.02 m, and 68.7 ± 3.2 kg	Either MM types, or N types	E = 17:00–18:00 h		n/a			
Souissi et al. (2007a)	11 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00 h	30-s Wingate test	Cycle ergometer	Peak Power	P < .001	Significantly higher in the E vs. M; 8.4%
	21.8 ± 2.4 yrs, 1.81 ± 0.02 m, and 67.7 ± 3.4 kg	3-MM types and 8-N types	E = 18:00 h		Ergomeca	Mean Power	P < .001	Significantly higher in the E vs. M; 9.0%
						Total Work Output	P < .001	Significantly higher in the E vs. M; 14.0%
						% decrease in Power	P < .001	Significantly higher in the E vs. M; 13.9%
Souissi et al. (2010)	12 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00 h	30-s Wingate test	Cycle ergometer	Peak Power	$F_{1,11}$ = 55.36; *P* < .001	Significantly higher in the E vs. M; 3.7%
	23.5 ± 3.1 yrs, 1.79 ± 0.06 m, and 74.1 ± 6.5 kg	4-MM types, and 8-N types	E = 18:00 h		Monark 864E	Mean Power	$F_{1,10}$ = 7.28; *P* < .001	Significantly higher in the E vs. M; 1.6 to 3.6%
						Fatigue Index	P > .05	Significantly higher in the E vs. M for sprints 1, 2, 3 and 5 only
Souissi et al. (2013a)	12 elite judoists	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00 h	30-s Wingate test	Cycle ergometer	Peak Power	F = 12.72; *P* < .05	Significantly higher in the E vs. M
	21.2 ± 1.2 yrs, 1.80 ± 0.06 m, and 79.4 ± 10.8 kg	12-N types	E = 17:00 h		Monark 818E	Mean Power	F = 7.28; *P* < .05	Significantly higher in the E vs. M
						Fatigue Index	P > .05	No significant difference between M and E
Souisi et al. (2013 c)	12 judokas	Not assessed	M = 09:00–10:00 h	30-s Wingate test	Cycle ergometer	Peak Power	$F_{1,11}$ = 0.29, *P* < .05	Significantly higher in the E vs. M; 2.4%
	18.6 ± 2.4 yrs, 1.78 ± 0.06 m, 77.1 ± 10.7 kg		E = 16:00–17:00 h		Monark 894E	Mean Power	$F_{1,11}$ = 4.19, *P* < .05	Significantly higher in the E vs. M; 2.7%
Zarrouk et al. (2012a)	12 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00 h	5 x 6-s sprints	Cycle ergometer	Power Output	P < .05	Significantly higher in the E vs. M for sprints 1, 2 and 3 only
	21 ± 2 yrs, 1.78 ± 0.02 m, and 76.8 ± 3.7 kg	12-N types	E = 17:00 h	24-s recovery	Monark 894E	Power Decrement	t = 2.32, *P* = .041	Significantly higher in the E vs. M
						Total Work	t = 4.15, *P* = .002	Significantly higher in the E vs. M

M = Morning, EM = Early morning, A = Afternoon, E = Evening, N = Night, h = hours, s = seconds, yrs = years, m = metres, kg = kilogram, ml = millilitre, min = minute, MM = moderately morning, ME = moderately evening, N = neither, NMT = Non-motorised treadmill.
Statistical significance ($p < 0.05$) is indicated in bold. *Statistical "trend" or "marginal significance" in italic (0.10 > p > 0.05).*

the majority of studies displaying no significant difference. However, 7 of these studies did display a significant difference between morning and evening, with ranges from 2.2 to 62.2%, using multiple shuttle run test, repeated sprint ability test or Wingate test as their testing protocol. The majority of studies which used multiple time-points found majority of majority of measures in the late afternoon or evening (15:00–22:00 h) to be significantly higher than measures in the early morning (02:00–03:00 h), morning (07:00–10:00 h), or mid-afternoon (13:00–14:00 h).

The substantial differences in methodological and clinical heterogeneity among studies meant we were unable to conduct a meta-analysis and pool the observed data-sets to evaluate the evidence related to findings in anaerobic performance and therefore provided in-depth information related to unweighted results. Missing data information, differences in populations, metrics, outcomes and designs were the main reasons for a meta-analysis not to be pursued. Conducting a meta-analysis will simply compound the errors and produce an inappropriate set of results and summary.

Quality of work

Table 5 provides detailed information related to randomisation, counterbalancing, record of light intensity, control of meals, control of room temperature, control of sleep and fitness, to quantify for the control of aspects relating to research design deemed specifically important in investigations of a chronobiological nature. None of the studies met all 7 criteria required for an investigation of chronobiological nature. Only one study failed to provide any information related to fitness of participants. A total of 27 counterbalanced the order of administration to minimise learning effects and 39 studies performed the time-of-day session in a randomised order. From these, 17 used counterbalancing and randomisation within their protocol. The majority of studies controlled for meals (n = 39) and sleep (n = 48) of their participants and controlled for room temperature (n = 32), but very few recorded light intensity (n = 7). Only 4 studies quantified all four of the 4 aforementioned criteria (Bougard and Davenne 2012; Pullinger et al. 2014, 2018a, 2018b).

Methodological quality control and publication bias

Based on a modified 26-item Downs and Black (1998) checklist, the results of the methodological quality assessment of the included studies ranged from 19 to 26. Reporting (10 items; items 1–10) showed 6 items to be fully met by all studies (Items 1–4, 6 and 9), with 10 studies meeting full criteria for reporting. External validity (3 items; items 11–13) displayed all three items to be met by only 28 studies. Internal validity study bias (7 items; items 14–20) reported 5 items out of 7 items (items 16–20) to be fully met, with one study fully meeting all criteria for internal validity study bias (Souissi et al. 2019b). Confounding selection bias (6 items; items 21–26) reported 2 studies to meet all criteria (Chtourou et al. 2012a, 2012 c), with item 21 met by all studies. Detailed methodological quality assessment scores can be found in Table 5.

Discussion

The present study analysed data from studies that compared the effects of diurnal variation on anaerobic performance measures and determined the quality of evidence that reports a "peak" time for performance. The main finding of this review was that most research papers (n = 49; 89.1%) established time-of-day differences related to anaerobic performances, with significantly greater values observed in the afternoon (16:00 to 19:30 h) compared to the morning (05:30 to 11:00 h) dependent on the variable assessed.

Anaerobic power

Twenty-five papers were found to have investigated time-of-day effects on a measure of anaerobic power (Tables 1, 3). The majority of studies established found a diurnal variation in anaerobic power performance measures, consistently peaking in the afternoon or early evening (16:00 h – 19:30 h) compared to the morning (06:00 h – 10:00 h), in agreement with previously established research related to human performance. Only three studies (Falgairette et al. 2003; Nikolaidis et al. 2018; Unver and Atan 2015) failed to establish time-of-day variation (12%) in any of their measures.

Time-of-day differences in jump tests ranged from 2.7 to 12.3%, with the magnitude of difference highly dependent on the jump test used and performance variable measured. All seven different jump tests used to assess anaerobic power in the literature; counter movement jump, squat jump, static jump, Abalakov jump, long jump, 30-s continuous jump and the Sargent jump found jump height and/or flight time and/or distance and/or power to be significantly higher in the afternoon. The only measures which failed to establish any diurnal variation were fatigue index in a 30-s continuous jump test. It has been suggested that jump performance is closely related to peripheral mechanisms of muscular

Table 3. Summary of the articles reviewed which conducted an anaerobic power and anaerobic capacity test (n = 9) with an overview of the participants, the experimental protocols with the time-of-day, exercise mode, performance test, the variables examined, and the main findings related to time-of-day in relation to each variable.

Author and Date	Participants	Chronotype assessment and distribution	Testing time-of-day	Test	Mode of exercise	Performance variables examined	Significance of main effects between condition	Main findings
Aloui et al. (2017)	22 healthy physically active subjects	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00 h	30-s Wingate Test	Cycle ergometer	Peak Power	P < .01	
	20.9 ± 1.2 yrs, 1.82 ± 0.08 m, and 73.1 ± 1.9 kg	22-N types	E = 17:00 h			Mean Power	P < .01	Significantly higher in the E vs. M
						Fatigue Index	P > .05	No significant difference between M and E
				10-m sprint	Infrared photoelectric system	Time	P > .05	No significant difference between M and E
				Sargent Jump		Jump height	P < .05	Significantly higher in the E vs. M
Chtourou et al. (2012a)	31 healthy physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00 h	30-s Wingate test	Cycle ergometer	Peak Power	$F_{1,9} = 23.06$, $P < .001$	Significantly higher in the E vs. M; 3.5%
	23.1 ± 2.0 yrs, 1.76 ± 0.06 m, and 74.9 ± 10.9 kg	10-MM types, and 21-N types	E = 18:00 h		Monark 894E	Mean power	$F_{1,9} = 15.05$, $P < .01$	Significantly higher in the E vs. M; 3.2%
						Fatigue Index	$F_{1,9} = 1.67$, $P > .05$	No significant difference between M and E
				Squat Jump	Takei Kiki Kogyo vertical jump meter (T.K. K.5406)	Jump height	$F_{1,9} = 9.62$, $P < .05$	Significantly higher in the E vs. M; 9.1%
				CMJ	Takei Kiki Kogyo vertical jump meter (T.K. K.5406)	Jump height	$F_{1,9} = 10.41$, $P < .05$	Significantly higher in the E vs. M; 7.4%
Chtourou et al. (2012 c)	30 healthy physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00 h	30-s Wingate test	Cycle ergometer	Peak Power	$F_{1,27} = 64.33$, $P < .001$	Significantly higher in the E vs. M
	22.9 ± 1.3 yrs, 1.80 ± 0.05 m, and 72.0 ± 8.8 kg	8-MM types, and 22-N types	E = 18:00 h		Monark 894E	Mean power	$F_{1,27} = 55.81$, $P < .001$	Significantly higher in the E vs. M
				Squat Jump	Takei Kiki Kogyo vertical jump meter (T.K. K.5406)	Jump height	$F_{1,27} = 1{,}453.18$, $P < .001$	Significantly higher in the E vs. M
				CMJ		Jump height	$F_{1,27} = 1146.69$, $P < .001$	Significantly higher in the E vs. M
Souissi et al. (2003)	13 healthy physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 06:00 h	Force velocity test	Cycle ergometer	Maximal Power	P < .001	Significantly higher in the E vs. M; 7.8%
	22.4 ± 2.4 yrs, 1.80 ± 0.10 m, and 67.7 ± 6.6 kg	13-N types	E = 18:00 h	30-s Wingate test	Ergomeca	Peak Power	P < .001	Significantly higher in the E vs. M; 9.3%

(*Continued*)

Table 3. (Continued).

Author and Date	Participants	Chronotype assessment and distribution	Testing time-of-day	Test	Mode of exercise	Performance variables examined	Significance of main effects between condition	Main findings
						Mean Power	P < .001	Significantly higher in the E vs. M; 7.7%
Souissi et al. (2004)	19 healthy physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	EM = 02:00 h	Force velocity test	Cycle ergometer	Maximal Power	$F_{5,\ 90}$ = 8.61, P < .001	Significantly higher in the E vs all time-points
	21.6 ± 5.1 yrs, 1.80 ± 0.09 m, and 80.6 ± 10.6 kg	MM or N types	M_1 = 06:00 h	30-s Wingate test	Ergomeca	Peak Power	$F_{5,\ 90}$ = 12.95, P < .001	Significantly higher in the E vs all time-points
			M_2 = 10:00 h			Mean Power	$F_{5,\ 90}$ = 11.49, P < .001	Significantly higher in the E vs all time-points
			A = 14:00 h E = 18:00 h N = 22:00 h					
Souissi et al. (2007b)	12 healthy physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00 h	Force velocity test	Cycle ergometer	Maximal Power	$F_{2,\ 22}$ = 29.75, P < .001	Significantly higher in the E vs. M
	22.6 ± 1.3 yrs, 1.78 ± 0.07 m, and 71.7 ± 7.2 kg	12-N types	E = 17:00 h		Monark 818E	Peak Velocity	$F_{2,\ 12}$ = 15.65, P < .001	Significantly higher in the E vs. M
			N = 21:00 h	30-s Wingate test		Peak Power	$F_{2,\ 22}$ = 5.9, P < .01	Significantly higher in the E vs. M
						Mean Power	$F_{2,\ 22}$ = 6.9, P < .01	Significantly higher in the E vs. M
						Power Decrease Index		
Souissi et al. (2008)	11 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 07:00 h	Force velocity test	Cycle ergometer	Maximal Power	$F_{1,.10}$ = 59.92, P < .001	Significantly higher in the E vs. M; 7.5%
	21.7 ± 1.3 yrs, 1.78 ± 0.06 cm, and 79.0 ± 10.7 kg	11-N types	E = 18:00 h		Monark 894E	Peak Velocity	P > .05	No significant difference between M and E
				30-s Wingate test		Peak Power	$F_{1,.10}$ = 52.99, P < .001	Significantly higher in the E vs. M; 3.8%
						Mean Power	$F_{1,.10}$ = 73.13, P < .001	Significantly higher in the E vs. M; 5.2%
Souissi et al. (2013b)	12 physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 08:00 h	Wingate test	Cycle ergometer	Peak Power	$F_{1,\ 7}$ = 23.0, P < .001	Significantly higher in the E vs. M; 3.8%
	22.2 ± 2.2 yrs, 1.76 ± 0.06 m, 79.4 ± 10.8 kg	12-N types	E = 17:00 h		Monark 894E	Mean power	$F_{1,\ 7}$ = 9.9, P < .05	Significantly higher in the E vs. M; 1.8%
						Fatigue Index	$F_{1.7}$ = 2.6, P > .05	No significant difference between M and E
				Squat Jump	Optojump, Microgate	Jump height	$F_{1,\ 7}$ = 4.0, P < .05	Significantly higher in the E vs. M; 5%

(*Continued*)

Table 3. (Continued).

Author and Date	Participants	Chronotype assessment and distribution	Testing time-of-day	Test	Mode of exercise	Performance variables examined	Significance of main effects between condition	Main findings
				CMJ	Optojump, Microgate	Jump height	$F_{1,7} = 5.7$, $P < .05$	Significantly higher in the E vs. M; 2.7%
Souissi et al. (2019a)	13 healthy physical education students	Morningness-eveningness questionnaire (Horne and Ostberg 1976)	M = 08:00 h	30-s Wingate test	Cycle ergometer	Peak Power	P < .05	Significantly higher in the E vs. M; 7.5%
	21.1 ± 1.1 yrs, 1.77 ± 0.06 m 77.1 ± 7.2 kg,	13-N types	E = 18:00 h			Mean power	P < .05	Significantly higher in the E vs. M; 11.7%
						Fatigue Index	P > .05	No significant difference between M and E
				Squat Jump	Optojump, Microgate	Jump height	F = 13.76; $P < .05$	Significantly higher in the E vs. M; ~3.3%

M = Morning, EM = Early morning, A = Afternoon, E = Evening, N = Night, h = hours, s = seconds, yrs = years, m = metres, kg = kilogram, min = minute, MM = moderately morning, N = neither, CMJ = counter movement jump.
Statistical significance ($P < 0.05$) is indicated in bold. *Statistical "trend" or "marginal significance" in italic (0.10 > P > 0.05).*

contraction (Castaingts et al. 2004). Findings suggest that the higher core temperature present in the afternoon ameliorates the peripheral mechanisms of the muscular contraction thus increasing short term maximal performance (Belkhir et al. 2020). The increase in body temperature could enhance the extensibility of connective tissue as well as the viscosity and conduction velocity of connective tissue (Racinais and Oksa 2010). Previous studies have also reported, a significant diurnal change in tendon stiffness (Pearson and Onambele 2005) and muscle architecture (pennation angle: fibre arrangement relative to the force generation axis; Pearson et al. 2004). The authors reported higher tendon stiffness and pennation angle in the morning compared to the afternoon. Onambele-Pearson and Pearson (2007) reported that the tendon stiffness increased by 20% in the morning when compared to the afternoon and this suggest that the tendon is more compliant in the afternoon. Further, it has been suggested that increased body temperatures reduce muscle viscosity and increase the extensibility of connective tissues (Waterhouse et al. 2005), thus facilitating both neuromuscular and metabolic systems (Racinais and Oksa 2010), ultimately increasing jump performance.

Performance variables related to the force velocity test displayed contradictory findings. Mean power displayed time-of-day variation with values of maximal power showing an increase of ~ 8% in the evening compared to the morning. Falgairette et al. (2003) however, failed to establish any diurnal variation in peak power. Peak velocity established time-of-day difference in one of the three studies which assessed this variable, while total force and total work found no significance between morning and evening measures (Tables 1, 3). Several factors have been put forward to explain the diurnal variation observed in maximal power in the force velocity test. As power is the product of force multiplied by velocity, fluctuations in power is dependent on diurnal fluctuations in force or velocity (Souissi et al. 2007b; Souissi et al. 2008). As velocity fails to establish time-of-day variation as opposed to (maximal) force, it has been suggested that force, which has previously shown to have a significant correlation with maximal isometric voluntary force and peak torques in isokinetic knee extensions (Driss et al. 2002), plays a significant role in time-of-day variation observations in maximal power. Diurnal fluctuations in maximal force have been attributed to variations in muscle contractile properties (Davenne and Gauthier 1997; Racinais et al. 2005a), which are affected by the intracellular variation present within the muscle (Martin et al. 1999), and to the circadian rhythm in central temperature (Racinais et al. 2005a).

Sprint tests also showed significant time-of-day differences between morning and evening, with faster sprint times in 5-m to 20-m overground running distance (range: 2.7–11.3%), in 25-m swim distance and for mean power output (half pedal) during a 5-s to 6-s cycling sprint (3.7%), and maximal power and maximal force during a 7-s cycling sprint (3.8–4.5%) observed in the evening condition. Overground sprints of 50-m only found a trend for significance, while a longer duration cycling sprint of 10-s found no differences in mean power between morning and evening. One study also established no differences in 25-m swim sprint between conditions. It has been suggested that both neuromuscular changes and fluctuations in core temperature present from morning to evening result in observed differences in overground running performance (Pavlović et al. 2018). The authors also mention that physical attributes, such as leg muscle qualities play a role in elucidating sprint performance (Young et al. 2015), and that sleeping patterns play a role in the presence of short-term maximal performance (Drust et al. 2005). The significant findings related to swim performance minimise the observation of diurnal variation solely related to fluctuations in core temperature and suggest that observed differences are due to a combination of both central and peripheral factors (Zarrouk et al. 2012b). Nikolaidis et al. (2018) suggested that the lack of diurnal variation in 25-m swim performance was due to the use of a different exercise protocol and methodology compared to other studies. The observed differences in power output during cycling sprints is thought to be due to the simultaneous increases in local temperature, as opposed to solely core temperature, which has previously been suggested (Racinais et al. 2004). In addition, the diurnal rhythm of muscle contractile processes was responsible for the diurnal variation in muscular short-term cycling performance (Racinais et al. 2005a, 2004).

Both studies which performed a 5-m multiple shuttle run test found peak distance and total distance to display time-of-day variations, with higher values observed in the afternoon for total distance and peak distance (range: 3.7 to 13.1%). However, only one study found fatigue index to differ significantly. Belkhir et al. (2019) hypothesised that the total duration of the 5-m shuttle run test is about 6 min and this duration needs a high contribution of the aerobic pathway to maintain the maximal performance. Thus, it is possible that the better total distance during the 5-m shuttle run test observed in the afternoon was related to better energy production from the aerobic pathway. However, Souissi et al. (2019b) suggested that the observed differences were due a possible link between the diurnal fluctuation of

Table 4. Detailed information related to randomization, counterbalancing, record of light intensity, control of meals, control of room temperature, control of sleep and fitness for articles related to chronobiology (time-of-day).

Date	Author	Randomization	Counterbalancing	Record of light intensity	Control of meals	Control of room temperature	Control of sleep	Fitness
2013	Abedelmalek et al.	Yes	No	No	Yes	No	Yes	Football Players
2013	Aloui et al.	No	No	No	Yes	No	Yes	Amateur Soccer
2017	Aloui et al.	No	No	No	Yes	Yes	Yes	Healthy Physically Active
2012	Aziz et al.	No	Yes	No	Yes	No	Yes	Trained Athletes
2019	Belkhir et al.	Yes	No	No	Yes	No	Yes	Soccer players
2020	Belkhir et al.	Yes	No	No	No	No	Yes	Highly Trained Physical Education Students
1998	Bernard et al.	No	Yes	No	Yes	No	No	Physical Education Students
2012	Bougard and Davenne	No	Yes	Yes	Yes	Yes	Yes	Healthy Motorcyclists
2017	Bousetta et al.	No	No	No	Yes	Yes	Yes	Physically Active Individuals
2014a	Chaari et al.	Yes	Yes	No	No	Yes	No	Handball Players
2014b	Chaari et al.	Yes	No	No	No	Yes	Yes	Physical Education Students
2015	Chaari et al.	Yes	Yes	No	Yes	Yes	Yes	Physical Education Students
2011	Chtourou et al.	Yes	No	No	Yes	Yes	Yes	Physical Education Students
2012a	Chtourou et al.	Yes	No	No	Yes	Yes	Yes	Physical Education Students
2012b	Chtourou et al.	Yes	No	No	Yes	No	Yes	Physical Education Students
2012c	Chtourou et al.	Yes	No	No	Yes	Yes	Yes	Physical Education Students
2013	Chtourou et al.	Yes	No	No	Yes	No	Yes	Soccer players
2018	Chtourou et al.	Yes	Yes	No	Yes	No	Yes	Judokas
2019	Dergaa et al.	No	No	Yes	No	Yes	Yes	Healthy Active
2003	Falgairette et al.	Yes	No	No	No	Yes	No	Sport Science Students
2015	Frikha et al.	Yes	Yes	No	No	No	Yes	Trained and Untrained Physical Education Students
2013	Gholamhasan et al.	No	No	No	Yes	No	Yes	Students
2006	Giacomoni et al.	No	Yes	No	No	No	Yes	Active Individuals
2017	Heishman et al.	No	No	No	Yes	No	Yes	Elite Level Basketball Players
1991	Hill and Smith	Yes	Yes	No	No	No	No	Healthy Individuals
2006	Kin-Isler	Yes	Yes	No	Yes	No	Yes	Sport Science Students
2017	López-Samanes et al.	Yes	Yes	Yes	Yes	Yes	No	Tennis Players
2019	Lopes-Silva et al.	Yes	No	No	Yes	No	No	Physically Active
2009	Lericollais et al.	No	Yes	No	Yes	Yes	Yes	Competitive Cyclists
2011	Lericollais et al.	No	Yes	No	Yes	Yes	Yes	Active Individual
2018	Nikolaidis et al.	Yes	No	No	Yes	Yes	Yes	Healthy Swimmers
2018	Otani et al.	Yes	Yes	No	Yes	Yes	Yes	Healthy Individuals
2018	Pavlović et al.	No	Yes	No	No	No	Yes	Elite Handball Players
2014	Pullinger et al.	No	Yes	Yes	Yes	Yes	Yes	Well Trained Field-Based Team-Sports
2018a	Pullinger et al.	No	Yes	Yes	Yes	Yes	Yes	Well Trained Field-Based Team-Sports
2018b	Pullinger et al.	No	Yes	Yes	Yes	Yes	Yes	Well Trained Field-Based Team-Sports
2004	Racinais et al.	Yes	No	No	No	Yes	Yes	Physical Education Students
2005a	Racinais et al.	Yes	No	No	No	Yes	Yes	Physical Education Students
2005b	Racinais et al.	Yes	Yes	No	No	Yes	Yes	Physically Education Students
2010	Racinais et al.	Yes	Yes	No	No	No	Yes	Active Individuals
2002	Souissi et al.	Yes	Yes	No	Yes	Yes	Yes	Physical Education Students
2003	Souissi et al.	Yes	Yes	No	Yes	Yes	Yes	Healthy Physical Education Students
2004	Souissi et al.	Yes	Yes	No	No	Yes	Yes	Healthy Physical Education Students
2007a	Souissi et al.	Yes	No	No	No	Yes	Yes	Physical Education Students
2007b	Souissi et al.	Yes	Yes	No	Yes	No	Yes	Healthy Physical Education Students
2008	Souissi et al.	Yes	No	Yes	Yes	No	Yes	Physical Education Students
2010	Souissi et al.	Yes	Yes	No	Yes	Yes	Yes	Active Individuals
2013a	Souissi et al.	Yes	No	No	Yes	Yes	Yes	Elite Judoists
2013b	Souissi et al.	Yes	Yes	No	Yes	No	Yes	Physical Education Students
2013c	Souissi et al.	Yes	No	No	Yes	No	Yes	Judokas
2019a	Souissi et al.	Yes	No	No	Yes	Yes	Yes	Healthy Physical Education Students
2019b	Souissi et al.	Yes	Yes	No	Yes	Yes	Yes	Physical Education Students
2015	Unver and Atan	Yes	Yes	No	No	No	No	Students
2012a	Zarrouk et al.	Yes	No	No	Yes	Yes	Yes	Physical Education Students
2012b	Zarrouk et al.	Yes	No	No	No	No	Yes	Swimmers and Physical Education Students

short-term maximal performance and the daily variation of core temperature, and daily fluctuations of attention and motivation (Reilly and Edwards 2007).

Anaerobic capacity

Thirty-nine papers were found to have investigated time-of-day effects on a measure of anaerobic capacity (Tables 2, 3). Similarly, to anaerobic power, measures of anaerobic capacity also consistently peaked in the afternoon or early evening (17:00 h – 19:00 h), when compared to the morning (06:00 h – 10:00 h). Four studies (Aziz et al. 2012; Chtourou et al. 2018; Gholamhasan et al. 2013; Giacomoni et al. 2006) did not find time-of-day variation in measures related to anaerobic capacity (10.3%)

All twenty-two studies conducting a 30-s Wingate test found both values for peak power (range: 2.4–9.5%) and mean power (1.8–11.7%) to display significantly better values in the afternoon compared to the morning. Only 3 out of 12 studies which assessed fatigue index during a 30-s Wingate test, found a significant difference between morning and evening measures (4.1%). A 60-s Wingate test also found significant differences in favour of evening performance for peak power (8.2%) and mean power over 30-s and 60-s (7.8%). The modified Wingate test found both peak power and measures of anaerobic capacity to be significantly higher in the afternoon. Only one study observed no differences between morning and evening values for anaerobic power during the Wingate test. Using an electromyographic activity registration, Chtourou et al. (2011) showed a significant increase in muscle power and neuromuscular efficiency in the late afternoon compared to the morning during the first 20-s of a 30-s Wingate test. These findings could indicate that the diurnal variation in muscle power depends on peripheral mechanisms of muscular contraction. Further, the authors indicated a possible intervention of central mechanisms (e.g., central nervous system command, motivation) of the muscular contraction during last 10-s of the Wingate test. Lericollais et al. (2011) reported that the range of motion of the ankle angle decreased in the afternoon compared to the morning indicating a possible relationship between the afternoon increase in muscle power during a 60-s Wingate test and the cycling kinematic parameters. The authors reported two phases of power evolution during a 60-s Wingate test: (i) rapid power decrease while value are higher in the afternoon compared to the morning during the first 20-s) and (ii) slower power reduction with no-significant time of day effect during the last 40-s of the exercise. In addition, Souissi et al. (2007) reported higher aerobic contribution to the energy production in the afternoon compared to the morning. This aerobic contribution was important for maintaining the muscle power over the 30-s maximal cycling and, thus, the authors reported higher fatigue index in the morning compared to the afternoon.

One study performed a RAST test and found peak power, average power and minimal power to be significantly higher in the afternoon compared to the morning (Dergaa et al. 2019). The authors suggest that the increase in temperature in the afternoon compared to the morning could explain the diurnal variation of RAST performance and could also be related to sleep, although findings in the literature related to sleep are inconsistent.

Rhythms in repeated-sprint performance also display diurnal variation, with the majority of repeated-sprint performance variables consistently peaking between 17:00 and 19:00 h with lowest values observed between 06:00 and 10:00 h (range: 3.4 to 10.2%). It was found the magnitude of difference is highly dependent on aspects such as the performance variable measured, the mode of exercise, the sprint duration, the type of recovery, the number of sprint repetitions and the training status of subjects. Only one study out of the ten found no significant differences between morning and evening performance. The authors suggest that the occurrence of fatigue and recovery patterns from all-out intermittent exercise may be differentially affected by time-of-day and that non-significant findings were due to methodological differences with similar studies. Nevertheless, it has been suggested that superiority in repeated-sprint performance can be attributed to a causal link between performance and both core body and and local muscle temperatures. However, recent findings suggest this causal link is not as simple as has previously been suggested (Pullinger et al. 2014). As a result, other factors have been proposed and are determined by both endogenous (outputs from the body clock) and exogenous (environmental) components (Edwards et al. 2013; Zhang et al. 2009). These components are related to motivational aspects, subjective arousal, sleepiness, ionic changes and hormonal fluctuations (cortisol ratio, thyroid secretion and testosterone ratio) (Zhang et al. 2009). More recently, a study performed by Ab Malik et al. (2020) reported a post-translational state of human muscle proteins after exercise in the morning (08:00 h) and the evening (18:00 h), with significant differences in the phosphorylation of proteins within or close to the muscle M-band that could relate the well-established morning versus evening differences in performance. The phosphorylation of these proteins may alter the M-band structure and disrupt force transmission, thus potentially explaining the lower force outputs observed in the morning compared to evening.

Table 5. Results of the detailed methodological quality assessment scores based on a modified 26-item Downs and Black (1998) checklist.

															Internal validity														
		Reporting (Items 1–10)										External validity (Items 11–13)			Study bias (Items 14–20)							Confounding selection bias (Items 21–26)							
Date	Study Author	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Total Score	Rating
2013	Abedelmalek et al.	1	1	1	1	2	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	1	1	24	89
2013	Aloui et al.	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	1	1	22	81
2017	Aloui et al.	1	1	1	1	2	1	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	1	0	1	1	22	81
2012	Aziz et al.	1	1	1	1	1	1	1	1	1	0	1	1	0	1	0	1	1	1	1	1	1	1	0	0	1	1	21	78
2019	Belkhir et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	0	0	1	1	21	78
2020	Belkhir et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	0	0	1	1	22	81
1998	Bernad et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	0	0	1	1	21	78
2012	Bougard et al.	1	1	1	1	2	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1	1	24	89
2017	Bousetta et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	0	1	1	22	81
2014a	Chaari et al.	1	1	1	1	0	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	0	0	1	1	20	74
2014b	Chaari et al.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1	1	23	85
2015	Chaari et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	0	1	1	23	85
2011	Chtourou et al.	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	1	1	22	81
2012a	Chtourou et al.	1	1	1	1	2	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	26	96
2012b	Chtourou et al.	1	1	1	1	2	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	1	1	23	85
2012 c	Chtourou et al.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	25	93
2013	Chtourou et al.	1	1	1	1	2	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	1	1	23	85
2018	Chrourou et al.	1	1	1	1	2	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	1	1	24	89
2019	Degra et al.	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	1	1	0	0	1	1	19	70
2003	Falgairette et al.	1	1	1	1	2	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1	1	0	0	0	1	0	19	70
2015	Frika et al.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	24	89
2013	Gholamhasan et al.	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	1	1	1	1	1	1	1	0	0	1	1	20	74
2006	Giacomoni et al.	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	1	19	70
2017	Heishman et al.	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	1	1	22	81
1991	Hill and Smith	1	1	1	1	0	1	1	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	0	1	1	21	78
2017	Lopez et al.	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	1	1	22	81
2019	Lopes-Silva et al.	1	1	1	1	1	1	0	0	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	0	1	1	20	74
2006	Kin-Isler et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	0	0	1	1	22	81
2009	Leircollais et al.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1	1	23	85
2011	Leircollais et al.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1	1	23	85
2018	Nikoladis et al.	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1	1	22	81
2018	Otani et al.	1	1	1	1	2	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	1	1	22	81
2018	Pavlovic et al.	1	1	1	1	2	1	1	0	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	23	85
2014	Pullinger et al.	1	1	1	1	2	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	1	1	23	85
2018a	Pullinger et al.	1	1	1	1	2	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1	1	24	89
2018b	Pullinger et al.	1	1	1	1	2	1	1	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	0	0	1	1	22	81
2004	Racinais et al.	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	0	1	20	74
2005a	Racinais et al.	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	1	22	81
2005b	Racinais et al.	1	1	1	1	2	1	1	1	1	0	1	1	1	0	0	1	1	1	1	1	1	0	0	0	1	1	21	78
2010	Racinais et al.	1	1	1	1	1	1	0	1	1	0	0	0	1	0	0	1	1	1	1	1	1	1	1	0	1	1	19	70
2002	Souissi et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	0	1	1	23	85
2003	Souissi et al.	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	1	1	22	81
2004	Souissi et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	0	0	1	1	21	78
2007a	Souissi et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	0	0	1	1	22	81
2007b	Souissi et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	0	1	1	23	85
2008	Souissi et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	0	0	1	1	21	78
2010	Souissi et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	0	0	1	1	22	81
2013a	Souissi et al.	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	1	1	22	81
2013b	Souissi et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	0	0	1	1	22	81
2019a	Souissi et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	0	0	1	1	22	81
2019b	Souissi et al.	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	24	89
2015	Unver and Atan	1	1	1	1	0	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	1	21	78
2012a	Zarrouk et al.	1	1	1	1	2	1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	1	1	23	85
2012b	Zarrouk et al.	1	1	1	1	2	1	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	1	1	21	78
	Total	54	54	54	54	67	54	50	46	54	48	47	47	33	25	1	54	54	54	54	54	54	51	18	5	50	53		
	Maximum	54	54	54	54	108	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54		
	% of lost points	0	0	0	0	38	0	7	15	0	11	13	13	39	54	98	0	0	0	0	0	0	6	67	91	7	2		

1 = criteria was met; 0 = criteria was not met.

Methodological quality and control

With reference to methodological quality, the included studies all reached a quality assessment score of ≥70%, of which two reached values > 90% (Table 5; Chtourou et al. 2012a, 2012 c). As far as we are aware only one review has looked into the chronobiological study design perspectives (Pullinger et al., 2019), and in agreement with their findings, we also established an apparent lack of control for important factors which specifically relate to investigations of chronobiological nature. It has long been established that the periodicity of the body clock in human beings is affected by external environmental rhythmic cues which affect the continual adjustment of the body clock (zeitgebers). Rhythmic cues such as the light-dark cycle (recording of light intensity), the feeding-fasting cycle (control of meals) and the activity-inactivity cycle (Aschoff 1965; Aschoff and Wever 1980; Dunlap et al. 2004) are primary factors that require control in studies related to time-of-day. Only seven studies (12.7%) reported information for the consideration of light or dark exposure by recording light intensity (Table 4). However, thirty-eight studies (69.1%) did control for meals, either through calorific intake and/or timing of meals, a factor previously stressed to play a vital role in chronobiology studies (Table 4; Bougard et al. 2009). Further, forty-three studies (78%) used, the Horne and Ostberg (1976) morningness-eveningness questionnaire as the chronotype questionnaire to assess their participant's chronotype scores. Three studies reported participants to belong to either the "extreme" morning (5.4%) or "extreme" evening (0.6%) chronotype. It has previously been established that extreme chronotype influences RPE, fatigue and submaximal performance in the morning (Vitale and Weydahl 2017). In addition, evening-types have shown to reach higher $\dot{V}O_{2\,max}$ values, increased cortical and spinal excitability levels and were able to generate more torque in the evening compared with the morning (Roden et al. 2017). Therefore, more research is required to gain a better understanding on the diurnal effects of anaerobic performance and extreme chronotypes.

The evening superiority in muscle force production and power output has long been attributed and associated to the causal link present between core body/local muscle temperatures and performance (Zhang et al. 2009). The higher evening core body temperatures (~0.6 to 0.8°C in rectal and gut sites; Edwards et al. 2013, 2002) and local muscle temperature (~0.30°C in vastus lateralis; Edwards et al. 2013; Robinson et al. 2013) have shown to increase both neural function (Martin et al. 1999) and force-generating capacities of the muscles (Bernard et al. 1998; Coldwells et al. 1994; Giacomoni et al. 2005; Melhim 1993). Evidence in the literature has found muscle force development to increase by ~ 5% with every 1°C increase in resting core temperature (Bergh and Ekblom 1979) and through passive warming of the musculature (Asmussen and Bøje 1945; Ball et al. 1999), with recent findings suggesting that the diurnal variation in performance can be partially attributed to core and/or local muscle temperatures (Pullinger et al. 2018b; Robinson et al. 2013). However, the causal link between temperature and performance is complex with recent findings suggesting that different physiological mechanisms are involved when core body and local muscle temperatures are decreased or increased, respectively (Pullinger et al. 2018b). Nevertheless, changes in core body and/or local muscle temperatures potentially negate some of the diurnal variation present within anaerobic performance, further highlighting the importance for controlling room temperatures. In our cohort of studies, only slightly more than half of the studies (56.4%) reported on factors related to temperature, which is in agreement with Pullinger et al. (2019), would seem to be more of an oversight rather than through choice.

The majority of studies (87.3%) within this systematic review controlled for factors related to sleep "control," such as rising and waking times, keeping similar sleeping habits to "normal life," not staying up late and no prevalence of insomnia or sleep deprivation. Sleep is not only essential for the brain and body to function, but a lack of sleep has previously shown to be closely associated with impairment in human performance (Walsh et al. 2020), with measures of anaerobic power and anaerobic capacity severely impaired (Souissi et al. 2003). A large body of research has previously investigated the effect of sleep and sleep deprivation on performance measures and central fatigue (Edwards and Waterhouse 2009; Kirschen et al. 2020; Waterhouse et al. 2011) and found performance to be negatively associated with disturbed sleeping patterns and lack of sleep. Considering increased levels of fatigue associated with time-since-last-sleep and the known restorative influences of sleep, measures of cognitive performance and central arousal are suggested to decline as time-awake increases (Ball et al. 1999).

Given most studies provided some detail related to control of sleep, such as timings of retiring/waking times and the amount of rest allowed during testing days, this would suggest that sleep loss did not affect findings in the majority of studies.

All studies reported information related to background (e.g. students, cyclists, team-sport players) and/or fitness levels (e.g. active, trained, healthy) of their participants, thus unlikely to represent issues with the interpretation of findings (Guette et al. 2005; Häkkinen 1989). Nevertheless, training status has previously shown to affect cycling performance (Hopker et al. 2013), Wingate performance (de Salles Painelli et al. 2014) and measures of peak power (Bishop and Spencer 2004) when comparing elite, trained and untrained individuals. In addition, it is of great importance that participants taking part in time-of-day studies are fully familiarised with the procedures and that protocols used within each study, and that the mode of exercise used is specific to the sport/background of the individuals. It has previously been proposed that the observation of diurnal variation in performance are closely related to subject familiarisation, training status and mode of exercise specificity (Bambaeichi et al. 2005; Giacomoni et al. 2006; Reilly et al. 1997). A lack of control related to the number and timing of familiarisation sessions impacts subsequent experimental findings as a result of neuromuscular adaptations still taking place within the experimental time-of-day sessions. Very few studies provide detailed information related to the number of familiarisation sessions participants undertook or used statistics to show systematic and random bias. Therefore, it is of paramount importance to utilise an objective method to assess whether the cohort of participants are fully familiarised is (Pullinger et al. 2019). In addition, counterbalancing of sessions, to guarantee internal validity by controlling the potential confounds created by sequence and order effects, and randomisation, to eliminate selection bias and balance known and unknown confounding factors are equally imperative. In this systematic review, it was established that only half the studies (50.9%) randomised sessions, while approximately two-thirds (70.9%) used counterbalancing within their research. These findings suggest that a number of studies have potential biased results due to learning effects and time-of-day observations could in part be due to acute neuromuscular adaptations associated with a lack of familiarisation, randomisation, and counterbalancing through the initial learning of motor recruitment pathways as opposed to any endogenously driven diurnal rhythm. It must be noted that randomisation of sessions is highly dependent on the aims of the study, with studies merely looking at differences between morning and evening without the need of a control group, not requiring randomisation within the methodological set-up. Interestingly, only four studies (7.2%; Bougard and Davenne 2012; Pullinger et al. 2014, 2018a, 2018b) quantified all aspects relating to research design and factors deemed specifically important in investigations of chronobiological nature (Table 4), not taking into consideration randomisation due to the nature of the studies.

Finally, it must be highlighted that there is a clear diurnal type bias in the majority of studies where participants where free to live a normal life, and diurnal measures were taking in the morning (05:30 to 11:00 h) and evening (16:00 to 19:30 h), respectively. Nine studies (16.4%) performed a more circadian type study, ranging from 3 to 6 “equally” spaced time-points across a 24 h day period, although no cosinor analysis was undertaken. Timings of sessions are affected by factors such as opening times of the laboratory and the willingness of participants to take part in sessions scheduled early morning, thus finding large ranges in morning testing sessions. In addition, training habits of individuals potentially play a role in the range of established diurnal variation in values, due to habitual previous training times and preferences. Further, few authors align testing time-points in accordance to previously established findings related to the lows and highs of the rhythms of core body/local muscle temperatures, and anaerobic performance variables.

Strength and weaknesses

The primary limitation of the present review is associated to several methodological limitations. Considerable differences in methodological and clinical heterogeneity among the 55 studies meant we were unable to conduct a meta-analysis and pool the observed data-sets to evaluate the evidence related to findings in anaerobic power and anaerobic capacity performance (Borenstein et al. 2009). Our findings with reference to chronobiological study design perspectives of studies encountered considerable inconsistencies in the methods and scientific rigor of the past research, in addition to the relationship between time-of-day and anaerobic performance. Future studies ought to consider stricter protocols which take into account these factors to reduce external influences on anaerobic performance.

The primary strength of the present systematic review is that it was performed using a structured analysis according to the PRISMA guidelines (Page et al. 2021) and is the first to provide an in-depth overview of all the literature considering time-of-day and anaerobic performance. As far as we are aware, this is only the second review providing in-depth analysis relating chronobiological factors and how these factors may influence anaerobic performance. Another strength of this systematic review is the diversity of databases used within the search strategy and the strong method created to incorporate search terms that are specific and important. Importantly, the current review focused solely on the anaerobic performance paradigm and only included studies designed to assess diurnal variation.

Conclusion

The present systematic review confirms that most studies demonstrated that both anaerobic power (2.7 to 13.1%) and anaerobic capacity (1.8–11.7%) are time of day dependent with higher afternoon (16:00 and 19:30 h) values compared to the morning (05:30 to 11:00 h). These diurnal variations in performance are principally explained by higher core body and/or muscle temperature and better muscle contractile properties in the afternoon, although the recent literature would suggest it is more complex than this. Differences in methodology, motivation/arousal, habitual training times and chronotypes could provide an explanation as to why some studies/variables did not display time-of-day variation. Therefore, there is a strong requirement for more rigorous research to be conducted that control factors that specifically relate to investigations related to chronobiology (time-of-day), such as appropriate familiarization of participants with the performance test, randomization, counterbalancing, record of light intensity, control of meals, control of room temperature, control of sleep and fitness level. It is of paramount importance that future studies utilise appropriate testing times, as close to the time-points of the core body temperature minimum and maximum values as possible, whilst taking into account effects of sleep inertia and restriction.

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APPENDIX

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	3–5
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	5
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	5
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	6
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	6–7
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Appendix 2
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	7–8
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	7–8
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	7–8
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	8–9
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	8–9
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	n/a
Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	8–9
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	n/a
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	9
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	Tables 1, 2, 3
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	Tables 4 and 5
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	Tables 1, 2, 3
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	n/a
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	13–14
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	n/a
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	14–24
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	25
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	25–26
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	26

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit: www.prisma-statement.org.

Appendix 1. Literature search strategy example for PubMed (MEDLINE)

Search syntax:

("time of day" OR "time-of-day" OR "daily rhythm" OR "daily variation" OR "daily fluctuation" OR "diurnal rhythm" OR "diurnal variation" OR "diurnal fluctuation" OR "circadian rhythm" OR "circadian variation" OR "circadian fluctuation")

AND

("anaerobic power" OR "anaerobic capacity" OR "force-velocity test" OR "vertical jump test" OR "Countermovement Jump Test" OR "standing long jump test" OR "Margaria Kalamen Power Test" OR "Ball throw test" OR "staircase test" OR "stair climb test" OR "Wingate test" OR "critical power test" OR " Cycle ergometer test" OR "sprint test" OR "Running Based Anaerobic Sprint Test" OR "Maximal Anaerobic Running" Test OR "Cunningham Faulkner test" OR "Repeated sprint test" OR "Repeated sprint ability test" OR "Swim Test" OR "Row ergometer test" OR "Agility Test")

Filters: Publication date to 2021/04/30

Records identified and screened for PubMed (MEDLINE): N = 104

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