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SYSTEMATIC REVIEW

Chronotype, Physical Activity, and Sport Performance: A Systematic Review

Jacopo Antonino Vitale[1] · Andi Weydahl[2]

Abstract

Background Many variables related to sport have been shown to have circadian rhythms. Chronotype is the expression of circadian rhythmicity in an individual, and three categories of chronotype are defined: morning types (M-types), evening types (E-types), and neither types (N-types). M-types show earlier peaks of several psychophysiological variables during the day than E-types. The effect of chronotype on athletic performance has not been extensively investigated.

Objective The objective of the present review was to study the effect of chronotype on athletic performance and the psychophysiological responses to physical activity.

Methods The present review adheres to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) reporting guidelines. We searched PubMed, Scopus, and Web of Science for scientific papers using the keywords “chronotype”, “circadian typology”, “morningness”, and “eveningness” in combination with each of the words “sport”, “performance”, and “athletic.” Relevant reference lists were inspected. We limited the search results to peer-reviewed papers published in English from 1985 to 2015.

Results Ten papers met our inclusion criteria. Rating of perceived exertion and fatigue scores in relation to athletic performances are influenced by chronotype: M-types perceived less effort when performing a submaximal physical task in the morning than did N- and E-types. In addition, M-types generally showed better athletic performances, as measured by race times, in the morning than did N- and E-types. Other results concerning chronotype effect on physiological responses to physical activity were not always consistent: heterogeneous samples and different kinds of physical activity could partially explain these discrepancies.

Conclusions Sports trainers and coaches should take into account the influence of both the time of day and chronotype effect when scheduling training sessions into specific time periods.

Key Points

Chronotype influences ratings of perceived exertion and fatigue scores in relation to submaximal and self-paced physical tasks performed in the morning: morning types (M-types) seem to have more of an advantage because they are less fatigued in the first part of the day than neither types (N-types) and evening types (E-types).

In general, M-types have better athletic performances, as measured by race times, in the morning than N-types and E-types.

The scientific literature is still weak, and future research in this field should consider several important methodological issues, such as the correct chronobiological approach to use to tackle the question being asked.

✉ Jacopo Antonino Vitale
jacopo.vitale@grupposandonato.it

1 IRCCS Ortopedico Galeazzi, Via Riccardo Galeazzi 4, 20161 Milan, Italy

2 UiT-The Arctic University of Norway, Alta, Norway

1 Introduction

The available studies on circadian variations of physiological and psychological variables during the course of the day are not recent and span several decades. These

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psychophysiological functions show maximum peaks at different times of the day, which could have either positive or negative effects on sports performance [1]. However, it is crucial to emphasize that is extremely difficult to control for all factors affecting physical performance and its circadian rhythmicity. Reilly and Waterhouse [2] stated that performance fluctuations are influenced by different multifactorial systems at the same time: external (exogenous), internal (endogenous), and psychobiological (lifestyle) mechanisms. Body temperature, for instance, is generally considered to be the primary endogenous indicator of the innate circadian rhythm of individuals, and past studies observed an association of this variable with athletic performance, especially with short-term physical activities [1]. The peak body temperature occurs in the first part of the evening, and this increase has been shown to lead to higher carbohydrate utilization and to facilitate the mechanics of the actin–myosin crossbridge in the muscle unit [3]. Nonetheless, to the best of our knowledge, no study has exhaustively tested the hypothesis that the circadian rhythm of body temperature is directly associated with time-of-day changes in muscle physiology. In contrast, cortisol, which is considered to be a marker of psychophysiological stress and is associated with a decrease in sports performance, displays an early morning peak under normal conditions [4]. For these reasons, it is assumed that most physical performances reach a peak in the second part of the day.

Nevertheless, inter-individual differences in circadian rhythmicity should be considered by coaches and trainers when planning training sessions. Although it is crucial to understand how time of day could influence physical performance, other aspects relating to time and the athletes could also be important, such as chronotype. Chronotype is an individual's characteristic predisposition towards morningness or eveningness, and is usually evaluated using self-assessment questionnaires. The most-used questionnaire is the Morningness–Eveningness Questionnaire (MEQ) [5], in which there are three different chronotypes: morning types (M-types), evening types (E-types), and neither types (N-types). Chronotype does not concern just a subjective trait; several studies have shown differences between M-types and E-types with regard to the circadian rhythms of different variables such as physiological variables, synchronization to jetlag, personality, mood, and cognitive performance [6, 7]. For example, peaks in oral temperature and serum cortisol have been observed as delayed by 2 h and 55 min, respectively, in E-types compared with M-types [8, 9]. Furthermore, M-types show an early acrophase of blood and salivary melatonin concentrations, approximately 3 h before E-types; consequently, they generally wake up and go to bed earlier than the other chronotypes [6]. It is essential to note at this point that age and sex significantly affect chronotype: women and older people show a strong predisposition towards morningness compared with men and younger individuals [6].

Over the years, several reviews have summarized the scientific evidence pertaining to circadian rhythms associated with sports performance [10–13]. Conversely, the effect of chronotype on athletic performance has not been extensively investigated and, as far as we are aware, a systematic review is still lacking.

Previous studies have taken different approaches to investigating how chronotype affects athletic performance; some have focused on physiological and psychological parameters, whereas others have directly assessed athletic performance.

The aim of the present review was to study the effect of chronotype on both the results of, and the psychophysiological responses to, physical activity. We hypothesized that our findings would suggest that an individual's chronotype could affect sports performance, especially if performed extremely early or late in the day.

2 Methods

2.1 Search Strategy

The present systematic review of the literature adheres to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) structure and reporting guidelines [14]. We searched up to March 2016 in PubMed, Scopus, and Web of Science databases for papers, using the keywords "chronotype", "circadian typology", "morningness", and "eveningness" combined with each of the words "sport", "performance", and "athletic". In addition, the reference lists of all the papers included were screened manually for additional relevant papers.

2.2 Eligibility Criteria

The inclusion criteria were peer-reviewed journal papers published in English from 1985 to March 2016, reporting data on objective/subjective measures of athletic performance and the physiological responses to exercise in healthy individuals. Studies were excluded if they reported (1) data about animals, children, shift workers, or unhealthy individuals; (2) the effects of medications, such as caffeine and/or melatonin or other stimulants, on performance; (3) data on jetlag or studies conducted in particular settings (forced light exposure and sleep deprivation); or (4) partial results on the effect of chronotype on physical activity. Letters to the editor, conference abstracts, and literature reviews were also excluded.

2.3 Outcomes

The primary outcome referred to the effect of chronotype on athletic performance and the psychophysiological responses to physical activity.

2.4 Study Selection

Two independent reviewers (JAV and AW) conducted the literature search and screened all titles, abstracts, and full texts, in that order, for inclusion and exclusion. Results from these two independent screenings were compared, and disagreements between reviewers were resolved by mutual consensus.

3 Results

The search yielded 1481 records, including duplicates; after application of the inclusion/exclusion criteria, ten papers were finally studied. One relevant study was selected from the reference list and added manually [15], whereas another [16] was finally excluded because it focused on the influence of warm-up in cycling performance and only partially reported the results of the effect of chronotype on that physical task. Figure 1 shows the flow diagram and results of the literature search. Table 1 summarizes the characteristics and main findings of the studies selected for review.

3.1 Maximal and Constant Load Ergometer Test Variables

Studies that considered the effects of chronotype on athletic performance mostly reported conflicting results. Hill et al. [15] conducted the first study that evaluated the effect of college students' chronotype on physical activity. Participants ($n = 32$; 8 men and 24 women; mean age 25 ± 4.5 years), classified as M-types ($n = 14$), E-types ($n = 14$), and N-types ($n = 7$), performed an incremental maximal cycle ergometer test in both the morning (0600–0830 h) and the afternoon (1530–1800 h). The continuous exercise test required cycling on a cycle ergometer; after 4 min with the work rate fixed at 60 W, the intensity was increased by 20 W every minute. During the maximal test, E-types had higher values of maximum oxygen consumption (VO_{2max}) in the evening than in the morning session (+4%), whereas no changes were detected for M-types. No other significant differences were observed with regard to heart rate (HR) response and performance times. In a subsequent study, Burgoon et al. [17] compared HR, respiratory parameters, rating of perceived exertion (RPE), and total exercise time recorded during a maximal treadmill test twice a day (at 0730 and 1930 h) in 26 young men (mean age 23 ± 4.4 years) grouped into M-types ($n = 9$), E-types ($n = 6$), and N-types ($n = 11$). The test consisted of exercise to a voluntary maximum on a treadmill; no statistical effect of chronotype on any variable was observed.

Another study conducted almost a decade later evaluated the effect of chronotype on post-exercise vagal reactivation [18]. This variable represents a primary protective mechanism for excessive cardiac work after exercise; however, curiously, no previous study had considered individual differences in circadian rhythmicity and cardiovascular response to exercise. The authors of this study recruited 37 male college students (aged 20–28 years), classified as N-types ($n = 23$), M-types ($n = 6$), and E-types ($n = 8$). They underwent two constant-load cycle ergometer tests at 0700–0800 h and 1700–1800 h to evaluate the index of post-exercise vagal reactivation, monitoring the time constants of the beat-by-beat HR decay for the first 30 s after exercise [18]. A significant interaction between time and chronotype was observed for HR recovery: E-types had a larger morning HR recovery than both M-types (165.5 ± 45.2 vs. 94.4 ± 33.8 s) and their own evening data (119.5 ± 25.7 s). The authors concluded that the post-vagal reactivation was sluggish at 0700 h for E-types, but further research is needed.

3.2 Rating of Perceived Exertion and Mood

As mentioned in Sect. 3.1, Burgoon et al. [17] were the first to study RPE among chronotypes in response to a maximal physical test. While reporting an overall interaction between chronotype and time of day for RPE, subsequent analyses found no significant relationships between chronotype and morning or evening training [17].

Nevertheless, four recent studies have confirmed the association between chronotype and RPE or mood state. Kunorozva et al. [19] reported that 20 trained male cyclists (mean age 39.8 ± 7.7 years), categorized as M-types, had higher RPEs during the submaximal cycle test at 60% (stage 1 at 6 min), 80% (stage 2 at 6 min), and 90% (stage 3 at 3 min) of their maximum HR (HR_{max}) during the evening (1800 and 2200 h) than during the other sessions (0600, 1000, and 1400 h). These differences in RPE were observed even though absolute power output, speed, and cadence did not show any time-of-day effect. The M-type cyclists perceived the same relative intensity workload as being harder in the evening than in the morning; it can therefore be hypothesized that they were more motivated and achieved greater intensities when sessions were scheduled early in the morning.

The second study that highlighted the effect of chronotype on RPE was conducted by Rae et al. [20]. The

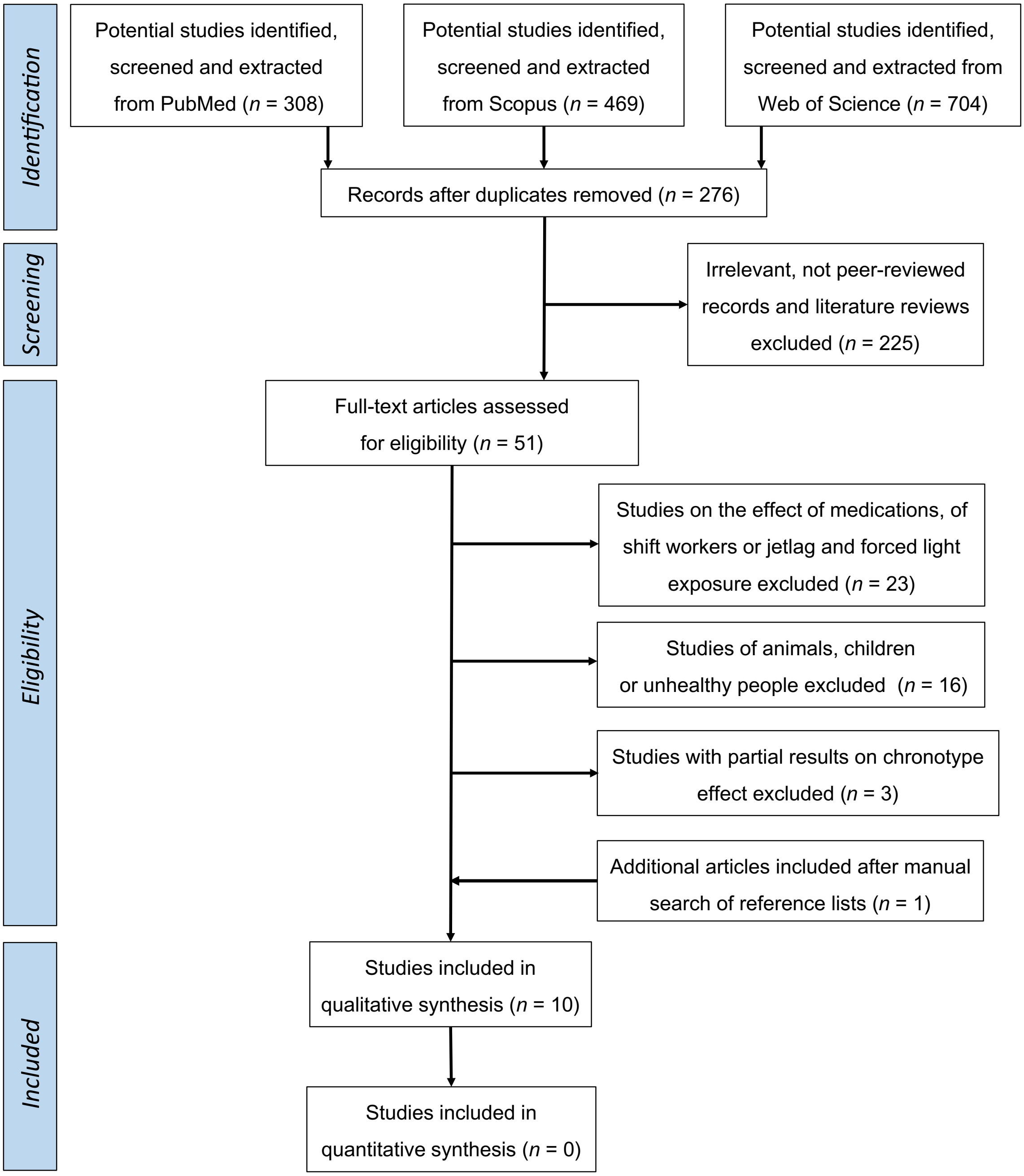

Fig. 1 Study flow diagram and results of the literature search

aim was to compare 200-m time-trial swimming performance, RPE, and mood state at 0630 and 1830 h in 26 trained swimmers (mean age 32.6 ± 5.7 years; 18 men and 8 women), taking into account their chronotype. The participants, after being classified as M-types ($n = 15$) and N-types ($n = 11$), completed the Profile of Mood States (POMS) questionnaire to assess their affective and mental state [21] before performing 200-m freestyle time trials at different times of day. RPE scores post-warm-up did not differ between N-types and M-types. In addition, as expected, since the physical test was performed at maximum intensity, there were no differences in RPE after the two time trials according to chronotype. Nevertheless, there were time-by-group interaction effects for both fatigue and vigor when chronotype was tested for: M-type swimmers had lower fatigue scores before the 0630 h time trial than before the 1830 h time trial (4.9 ± 3.2 vs. 9.1 ± 5.9), whereas the fatigue scores of N-types were similar in both sessions. In addition, M-types also had higher vigor scores before the morning physical test (17.9 ± 7.1) than before the evening (15.6 ± 5.5), although the opposite trend was observed for the N-types

Table 1 Summary of the papers reviewed ($n = 10$) with an overview of the participants, experimental protocols with exercise mode, parameters examined, and the main findings, with time-of-day peak in relation to chronotype

References	Participants	Distribution of chronotype among participants in the article	Experimental protocol: exercise test	Variables examined	Significance (p value)	Main findings: chronotype effect
Hill et al. [15]	32 College students (mean age: 25 ± 4.5; 8 M and 24 F)	14 M-types, 11 E-types, 7 N-types	Maximal cycle ergometer test	HR	NS	
				VO_{2max}	<0.05	E-types: 1530–1800 > 0600–0830 h
				Performance times	NS	
Burgoon et al. [17]	26 Young untrained M (mean age 23 ± 4.4)	9 M-types, 6 E-types, 11 N-types	Maximal ergometer test	HR	NS	
				Ventilation	NS	
				VO_2	NS	
				VCO_2	NS	
				R	NS	
				RPE	NS	
				Total time	NS	
Sugawara et al. [18]	37 M college students (aged 20–28)	6 M-types, 8 E-types, 23 N-types	Constant-load cycle ergometer test	HR recovery	<0.05	E-types > M-types at 0700 h; E-types: 0700 > 1700 h
Kunorozva et al. [19]	20 Trained M cyclists (mean age 39.8 ± 7.7)	All M-types	Submaximal cycle test (60% of HR_{max})	RPE	0.044	Post-hoc analyses not available
				Absolute power	NS	
				Speed	NS	
				Cadence	NS	
			Submaximal cycle test (80% of HR_{max})	RPE	<0.001	M-types: 2200 > 1800, 0600, 1000, and 1400 h
				Absolute power	NS	
				Speed	NS	
				Cadence	NS	
			Submaximal cycle test (90% of HR_{max})	RPE	<0.001	M-types: 1800 and 2200 h > 0600, 1000, and 1400 h
				Absolute power	NS	
				Speed	NS	
				Cadence	NS	

Table 1 continued

References	Participants	Distribution of chronotype among participants in the article	Experimental protocol: exercise test	Variables examined	Significance (p value)	Main findings: chronotype effect
Rae et al. [20]	26 Trained swimmers (mean age 32.6 ± 5.7; 18 M and 8 F)	15 M-types, 11 N-types	200-m swimming time trial	RPE	NS	
				Total mood disturbance	NS	
				Fatigue	0.012	M-types: 0630 < 1830 h; N-types: no differences
				Vigor	0.010	M-types: 0630 > 1830 h; N-types: 0630 < 1800 h
				Total time	0.036	M-types: 0630 < 1830 h; N-types: 0630 > 1830 h
Rossi et al. [23]	46 College students (mean age 24.8 ± 7.2; 27 M and 19 F)	9 M-types, 10 E-types, 27 N-types	Self-paced walking task	RPE	0.01	E-types > M-types at 0830 h
				Total time	NS	
				HR_{mean}	NS	
Brown et al. [24]	16 Collegiate rowers (mean age 19.6 ± 1.5; 8 M and 8 F)	4 M-types, 4 E-types, 8 N-types	2000-m rowing sprint	Total time	0.001	M-types: 0500–0700 < 1630–1800 h
			Standing broad jump	Distance	NS	
Henst et al. [25]	92 South African marathon runners (mean age 38 ± 12)	60 M-types, 3 E-types, 29 N-types	FM and HM	Personal best race times	FM: NS HM: 0.006	M-types > N-types and E-types at 0630 h
			FM	Current race times	0.012	M-types > N-types and E-types at 0630 h
	90 Dutch marathon runners (mean age 40 ± 12)	45 M-types, 5 E-types, 40 N-types	FM and HM	Personal best race times	FM: NS HM: NS	
			FM	Current race times	NS	
Facer-Childs and Brandstaetter [26]	20 field hockey players (mean age 20.4)	5 M-types, 5-E-types, 10 N-types	Progressive aerobic endurance test	Total time	<0.05	M-types: 12.19; N-types: 15.81; E-types: 19.66
Tamm et al. [28]	18 Untrained adults (mean age: 26.3 ± 3; 4 F and 14 M)	9 M-types, 9 E-types	Plantar–flexor MVC	Produced torque	0.005	E-types: 2100 > 1700, 1300, 09:00 h

E-type evening-type, *F* female, *FM* full marathon, *HM* half-marathon, *HR* heart rate, HR_{max} maximum heart rate, HR_{mean} mean heart rate, *M* male, *M-type* morning-type, *MVC* maximum voluntary contraction, *NS* no significance, *N-type* neither-type, *R* respiratory exchange ratio, *RPE* rating of perceived exertion, VCO_2 carbon dioxide production, VO_2 oxygen consumption, VO_{2max} maximum oxygen consumption

(0630 h: 13.1 ± 7.1; 1830 h: 17.8 ± 3.3). M-types also showed lower total mood disturbance (TMD) than N-types regardless of the time of day, but no time-by-group interaction was observed for TMD when considering chronotype.

Another recent study, which was based on a previous pilot study [22], investigated the effect of chronotype on RPE [23]. In this study, 46 students (mean age 24.8 ± 7.2 years; 27 men and 19 women) were recruited to perform a walking task in both the morning (0830 h) and the afternoon (1630 h); this consisted of three walks up and down a hill (1042 m with an altitude gap of 45 m overall) performed at the participants' voluntary speed. The variables considered for the analyses were the RPE post-exercise, the total walking time, and the mean HR.

The participants were characterized as N-types ($n = 27$), M-types ($n = 9$), and E-types ($n = 10$), and the study found a significant overall interaction of chronotype and time of day for dependent variables. The post hoc analysis revealed a significant difference between M- and E-types for RPE only at 0830 h, with E-types showing higher RPE than M-types (14.33 ± 2.45 vs. 12.0 ± 1.66, respectively). No differences were found for walking time and mean HR.

3.3 Performance Results

The effects of chronotype on physical performance are not yet entirely clear. Rae et al. [20], in addition to analyzing the results of the POMS, showed that grouping the participants by chronotype revealed a significant diurnal variation in performance, with M-types swimming faster in the morning session and N-types at 1830 h. There was a weak but significant correlation between the time difference for morning–evening time trials and the MEQ score: swimmers with higher MEQ scores tended to swim faster in the 0630 h session.

These results are in line with the study by Brown et al. [24], in which 16 collegiate rowers (mean age 19.6 ± 1.5 years; 8 men and 8 women) had to perform a 2000-m rowing test and a standing broad jump test, in both the morning at 0500–0700 h and the afternoon at 1630–1800 h. The analyses highlighted an interaction between chronotype and time, indicating that the four M-types significantly slowed in rowing speed from morning to afternoon by 4.8 s. They also showed a larger decrement in performance across the day than did E-types ($n = 8$) and N-types ($n = 4$). No significant changes in rowing speed were found for E-types and N-types, and no statistically significant group difference occurred from morning to afternoon in broad jump distances.

Recently, Henst et al. [25] determined the relationship between chronotype and marathon performance in South African ($n = 95$, mean age 38 ± 12 years) and Dutch ($n = 90$, mean age 40 ± 12 years) marathon runners. The authors observed that South African runners, who were more morning oriented than their Dutch colleagues, showed a negative correlation between MEQ score and their personal best half marathon and current marathon race times. However, the same trend was not found in the Dutch group. As South African marathons start early in the morning, and as this is better suited to morning-oriented individuals, this suggests that M-types have a better chance of a peak performance in the morning than do E-types.

Facer-Childs and Brandstaetter [26] conducted the most recent study, examining the results of physical performance by different chronotypes. First, 121 competition-level field hockey players (70 women and 51 men; mean age 22.5 years) were recruited, and a new chronometric questionnaire (RBUB chronometric test) was compiled that was specifically designed to study sleep-/wake-related parameters and performance variables in athletes. From this sample, 20 participants (M-type, $n = 5$; N-type, $n = 10$; E-type, $n = 5$) were selected to conduct the Bleep test (also known as the multi-stage fitness test) at six different times of day (0700, 1000, 1300, 1600, 1900, and 2200 h). Analysis of circadian phenotype revealed significant differences in peak performance, with the highest performance, expressed as number of shuttles reached, for M-types at 12.19 ± 1.43 h, for N-types at 15.81 ± 0.51 h, and for E-types at 19.66 ± 0.67 h. Diurnal changes in performance were 26.2 ± 3.97% in E-types, 7.62 ± 1.18% in M-types, and 10.03 ± 1.62% in N-types. In addition, the authors suggested a novel concept that reflects Borbèly's two-process model of sleep regulation [27]. As time of day is an exogenous factor (circadian pacemaker) and only partly related to an individual's circadian physiology, they also evaluated the data as a function of "time since awakening", considering this variable as an endogenous factor (homeostatic process) that clearly interacts with external cues. It was observed that the average peak performance time for E-types was 11.18 ± 0.93 h after entrained wake-up, i.e., the average wake-up time for the previous 2 weeks, and it was significantly delayed compared with peak performance times of N- and M-types (6.54 ± 0.74 and 5.60 ± 1.44 h, respectively). This variable could be considered a key point for future studies. It seems that E-types need longer before the body is sufficiently active and will not reach maximum performance levels as quickly after wake-up as M-types. The authors concluded that the time of day is not a necessary factor in reaching best performance; it seems that what really matters for an athlete is chronotype and how many hours after entrained wake-up the competition or performance evaluation takes place.

3.4 Cortical Excitability, Spinal Excitability, and Torque During Maximum Voluntary Contraction

Tamm et al. [28] designed some experiments to determine the influence of an individual's chronotype on the ability to generate torque during a maximum voluntary contraction, and on cortical, spinal, and peripheral mechanisms that may be related to torque production. Participants ($n = 18$; mean age 26.3 $\pm$ 3 years; 4 women and 14 men), classified as M-type ($n = 9$) and E-type ($n = 9$), were recruited for the experimental protocol, but N-types were excluded. The participants took part in four data-collection sessions in a single day (0900, 1300, 1700, and 2100 h). Magnetic stimulation of the cortex, electrical stimulation of the tibial nerve, electromyographic recordings of muscle activity, and isometric torque measurements were used to evaluate the excitability of the motor cortex and spinal cord, and the torque-generating capacity of the triceps surae muscles. Opposite trends were observed for the two chronotypes: M-types had higher values of cortical excitability at 0900 h, with spinal excitability highest at 2100 h, and there were no significant differences in torque produced during maximum voluntary contractions throughout the day. In contrast, E-types showed parallel increases in cortical and spinal excitability throughout the day and generated more torque at 2100 h (13%), 1700 h (8%), and 1300 h (3%) than at 0900 h (0%).

4 Discussion

The aim of the present review was to study the effect of chronotype on both the results of and the psychophysiological responses to physical activity. We hypothesized that we would detect a major chronotype effect on sports activities, particularly those performed extremely early or late in the day. To answer the present research question, we investigated both intergroup differences, comparing the results of M-types and E-types at different times of day, and intragroup differences, studying how a single chronotype group changed its results during the day.

We identified relatively few papers ($n = 10$) that investigated the effect of chronotype on physical activity. Curiously, we observed a growing interest in this topic because five [19, 20, 23, 25, 26] of the ten studies (50.0%) were published in or after 2012, so it appears the scientific community is paying increasing attention to the chronobiological approach to sport. Nine studies (90.0%) utilized the MEQ to determine participants' chronotype [5], whereas only one recent study utilized another kind of questionnaire: Facer-Childs and Brandstaetter [26] utilized the RBUB chronometric test, a new chronometric questionnaire specifically designed to study performance variables in athletes.

Most of the selected studies focused on the psychophysiological responses to physical activity (such as HR, VO_{2max}, torque generated, cycling power, and RPE), whereas others investigated the effect of chronotype on performance.

With regard to the psychophysiological responses to physical performance, the clearest result can be observed for RPE and fatigue in relation to physical activity. M-types perceived less exertion when performing a self-paced or submaximal physical task in the morning, whereas E-types and N-types showed higher fatigue values in the first part of the day [19, 20, 23]. However, such differences were not observed when evaluating RPE after maximum-intensity performance [17, 20]. This result was expected because the exertion should be maximal at the end of a physical task requiring all-out effort for each individual. The findings for other psychophysiological responses were not totally consistent and did not provide clear evidence of better performance by athletes according to their chronotype. However, it was observed that E-types had higher values of VO_{2max} [15] and produced more torque [28] in the late afternoon or evening than in the morning; furthermore, they exhibited sluggish post-vagal reactivation in the morning compared with both M-types and their own evening data [18]. The discrepancies in the psychophysiological responses to physical activity could be partially explained by the fact that some variables were objective and others were subjective. It is probable that a subjective measure, such as the submaximal RPE, is more likely to be influenced by chronotype than another objective measure of the same physical performance. This aspect could be a key factor for consideration by trainers when planning a training session. M-type athletes feel better performing a submaximal physical task in the morning, whereas E-types perceive a need for greater effort to achieve the same results. For this reason, it could be crucial to determine an athlete's chronotype.

With reference to the influence of chronotype on performance results, we observed that M-types had faster race times in the morning for the half marathon, full marathon [25], 2000-m rowing sprint [24], and 200-m swimming trial [20] than the other chronotypes. Conversely, we did not detect the same trend when evaluating the time used to complete a self-paced physical task [23] and maximal ergometer tests [15, 17]. More attention should be paid to the study by Henst et al. [25], who observed an association between chronotype and half- or full-marathon time trials. These authors suggested that participating in an endurance sport with earlier start times, 0630 h in South Africa versus 1100 h in the Netherlands, could influence the athlete's chronotype and, for this reason, only South African runners, who were strongly morning oriented, had their best race times during morning competitions. Nevertheless, it is necessary to highlight that it is extremely difficult to determine whether chronotype influences the choice of the kind of sport or whether a chronic effect resulting from a particular sports discipline, with habitual morning or evening training hours, could shift or modulate an individual's chronotype. What has certainly been demonstrated is only that the habitual training time of day could influence physical performance [20]. In light of these considerations, it is clear that there is a need for future research to utilize a correct chronobiological approach within well-defined and strict experimental protocols.

It is also important to mention that a novel methodological approach has recently been presented by Facer-Childs and Brandstaetter [26]: they established that not only circadian typology but also time since awakening should be considered as major determinants for athletic performance. Wake-up time appears to be one of the most important and reliable predictors of optimal performance, and this variable has been demonstrated to vary across chronotypes [7]. It seems that E-types need more time to get physically ready for a sports activity after waking up than M-types. It is therefore crucial to highlight that a physical performance could be influenced by both exogenous and endogenous factors, i.e., time of day and time since awakening, the latter being considered an expression of the individual's circadian typology.

4.1 Methodological Issues

In addition to the different chronobiological approaches to the problem, other methodological issues must be discussed. There are several possible reasons for the conflicting evidence from the study of chronotype effect on physical activity, and the removal of confounding factors in future research could help investigators obtain clearer results. Most of the studies had fewer than 40 participants and did not report power calculations; moreover, most studies included only men, although a number of studies mixed samples without taking sex into account. As chronotype could be strongly influenced by individual factors, and as the sex ratio and age vary across different sports disciplines, recruiting a more homogeneous sample for future studies is absolutely crucial.

In the selected studies, all chronotypes were not always represented, and extreme M- and E-types were lacking. Having the same number of each chronotype could help to achieve more accurate results.

The participants' physical condition could also influence the results: some of the studies were conducted using untrained individuals, whereas others recruited expert athletes. The times of day selected for the physical tests differed: some studies assessed performance at specific times of the day (at two time points or more frequently throughout the day), whereas others used a larger window of time. In addition, some authors measured performance several times on the same day whereas others included one or several days as a recovery period. All these variables could have influenced the outcomes.

Other important variables that must be well defined in the future are the choice of the type of physical activity, the exact protocol, and the environment in which it takes place. In the papers selected for the present review, the authors used different kinds of physical activity: self-paced aerobic performance, short-term physical tasks, sport-specific skills, and maximal or submaximal tests. Moreover, some types of athletic performances were not represented. It is known that different kinds of physical exercise peak at different times of the day [1] and, in light of this, it is necessary to select specific physical tests to observe clearer results for the effect of chronotype on sports performance. Different kinds of protocols should, moreover, be considered in future work: free running, forced desynchronization, modified sleep times, and constant routine protocols could significantly affect the body clock's effect on sports performance [2] and possibly chronotype. In addition, it is necessary to make appropriate decisions when choosing between simulated field-based or laboratory-based performance trials, because there are many differences between these two options: one example is that the environmental conditions (humidity, temperature, light/darkness) can be controlled in laboratories but not in the field. Another crucial aspect to consider concerns the differences between training and competition when evaluating chronotype effect. In a competition with all-out performances and high levels of motivation for all athletes, the chronotype effect is less likely to be observed. For example, the study by Rae et al. [20] included no differences in RPE after two maximum-intensity swimming time trials between M-types and N-types. Evaluation of submaximal RPE appears to be more useful, and, to confirm this, a significant chronotype effect on RPE was observed after submaximal cycle tests and self-paced walking tasks [19, 23].

Further studies should strongly consider strict protocols, including the monitoring of sleep behavior, controlled diet, and environmental conditions, all of which are factors that could significantly influence sports performances and, consequently, the effect of chronotype.

5 Conclusion

Studies in the scientific literature are insufficient to provide reliable indications about the effect of chronotype on physical activity and sports performance. One clear outcome is that chronotype influences the RPE and fatigue scores in relation to submaximal physical tasks performed in the morning: M-types seem to have more of an advantage and to be less fatigued in the first part of the day than N- and E-types. In addition, M-types in general showed better athletic performance, as measured by race times, in the morning than N- and E-types. Future studies should consider several important methodological issues: first, the correct chronobiological approach; second, control of potential confounders; and third, computation of power calculations to be sure the sample is large enough to observe the influence of chronotype on athletic performance.

Compliance with Ethical Standards

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