生物节律与运动表现

康 杰(美)[1],刘 畅(译校)[2]

摘 要: 人体内几乎所有的生理生化过程都遵循着生物节律。对于人类而言,视交叉上核根据日出日落调节睡眠-觉醒周期和其他日常生物节律。除其他因素外,这种昼夜变化已被证明对与运动表现有关的关键生理过程具有调节作用。最佳运动状态一般出现在傍晚,与核心体温的最佳状态相一致。核心体温的升高已被证明可以提高能量代谢,改善肌肉适应性,促进肌动蛋白-肌球蛋白的交叉桥接。研究还表明,如果在运动员表现最好的时间段安排训练,可以提升运动员的训练适应性。在研究生物节律对运动表现的影响时,除了考虑昼夜变化外,个人对运动时间(白天或夜间)的偏好也是一个重要因素。经常参加国际比赛的运动员会经历生物节律的改变,这对他们的身体健康和运动表现不利。因此,那些更容易受到时差影响的运动员可以考虑使用适当的应对策略来更快地调整生物节律,确保最佳竞技状态。

关键词: 生物节律起搏点;外周生物钟;昼夜影响;时间特异性;时间型;时差

中图分类号:G808 文献标志码:A 文章编号:1006-1207(2020)02-0001-17

DOI:10.12064/ssr.20200201

Circadian Rhythm and Sports Performance

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Abstract: Almost all physiological and biochemical processes within the human body follow a circadian rhythm. In humans, the suprachiasmatic nucleus regulates sleep-wake cycle and other daily biorhythms in line with solar time. Such diurnal variations, among other factors, have been shown to regulate key physiological processes involved in athletic performance. Generally, peak performances have been found to occur in the early evening, coinciding with the peak of core body temperature. The increase in core body temperature has been shown to increase energy metabolism, improve muscle compliance, and facilitate actin-myosin cross-bridging. Research also suggests that if athletes arrange their training sessions at a time of their peak performance, their adaptations to training would be greater. In addition to diurnal variations in physiological processes, the individual preference for daytime or nighttime activities is another important factor that should be taken into account when studying the effect of circadian rhythm on sports performance. Athletes participating in international competitions often experience shifted circadian rhythms that can be detrimental to their health and performance. Thus, those who are more easily affected by jet lag may consider using proper coping strategies to realign their circadian rhythms more quickly.

Key Words: circadian pacemaker; peripheral clocks; diurnal effects; temporal specificity; chronotype; jet lag

大多数人认为在下午晚些时候和傍晚早些时候他们的运动能力最佳,而在这个时间段内,往往会产生比赛中的最佳表现,甚至可能会诞生新的世界纪录。一方面外部因素起到一定作用,因为在能创造世界纪录的大型锦标赛举行时,通常有大批观众和媒

Most individuals consider that their athletic prowess is best in the late afternoon and early evening, and this is the time period when best performances and even world records are most often set in competitions. External factors may be in part responsible because major champi-

收稿日期: 2019-10-06

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体,他们能够起到激励运动员的作用。另一方面,越来越多的证据表明,时间对运动表现的影响,至少部分是由生物节律调节的。生物节律是生物（包括植物、动物、真菌和蓝藻)的生理过程中一个约为 24 h 的周期。生物节律是内源性的，可以随着外部因素(如日照时间和环境温度)的变化而被调节。本文的目的是列举有关生物节律的现有证据，以及它们可能在急性运动或长期训练中对机体和运动表现的影响。本文还讨论了时间型的概念及其与运动表现的关系,并提供各种应对生物节律受到干扰的策略。

1　生物节律起搏点与外周生物钟

生物节律在人体运动表现中的作用已被广泛研究了几十年。在有氧健身、无氧健身、精细动作运动和粗大动作运动等体育活动中,生物节律表现明显[1-3]。因此,人们对阐明生物节律导致全天运动表现差异的机制很感兴趣。对人类来说,主要的生物节律起搏点是视交叉上核(Suprachiasmatic Nucleus,SCN),它也被称为中枢时钟(图 1)。视交叉上核的功能是同步周围组织的生物钟，如肌肉、脂肪组织、消化道和肝脏。SCN 位于下丘脑，会接收来自视网膜的直接输入,这些输入与太阳周期有关[4]。通过视网膜–下丘脑通路提供的信息,SCN 协调每日的生物节律,如激素分泌、温度波动、神经激活,这也与太阳时间和睡眠–觉醒周期一致[5-6]。这些有节律的生物过程支配着人体的许多习惯和行为,也影响着日间的正常活动。已有研究证实,许多与运动表现相关的生理功能遵循着特定的生物节律[7]。研究发现,静息状态下的感受、知觉和认知能力在傍晚时提高,与体温峰值节律一致[8]。

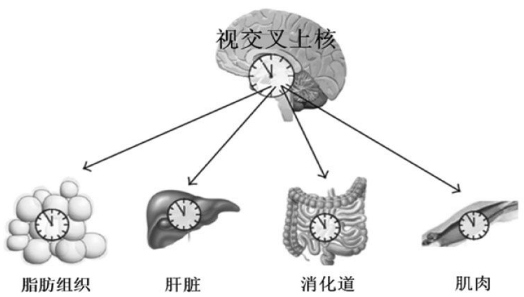

图 1 调节昼夜节律的中央和外周时钟

Figure 1 Central and Peripheral Clocks that Mediate Circadian Rhythms

长期以来,人们认为中枢时钟是调节机体各组织同步生物节律的唯一起搏点。1998 年,Balsalobre等人证明，有一种血清蛋白可使细胞培养的大鼠成纤维细胞同步化[9]。这是首次证明在周围器官的细胞中存在自主时钟。此后有研究报道了 SCN 在控制外周时

onships that often produce world records are usually held in front of large crowds and the media that can motivate athletes. However, evidence is mounting to suggest that this time-of-day effect on sports performance is mediated at least in part by circadian rhythms. A circadian rhythm is a roughly 24 h cycle in the physiological processes of living beings, including plants, animals, fungi, and cyanobacteria. Circadian rhythms are endogenously generated, although they can be modulated by external cues such as sunlight and environmental temperature. The present review aims to highlight existing evidence concerning circadian rhythms and the role they may play in mediating physiological and performance responses during both acute and chronic exercises. This article also discusses the concept of chronotype and its association with athletic performance. Various coping strategies for dealing with circadian disruptions are also provided.

1　Circadian Pacemaker and Peripheral Clocks

The concept of circadian rhythms in human physical performance has been extensively researched for several decades. Physical activities involving aerobic fitness, anaerobic fitness, fine and gross motor skills have displayed a clear circadian rhythms[1-3]. As such, there has been great interest in trying to elucidate the mechanisms responsible for the distinction in exercise performance throughout the day. In humans, the primary circadian pacemaker is the suprachiasmatic nucleus (SCN), which has also been referred to as the central clock (Figure 1). The SCN, located within the hypothalamus, receives direct input regarding the solar cycle from the retina[4]. With this information provided through the retinohypothalamic pathway, the SCN coordinates daily biological rhythms, i.e., hormone secretion, temperature fluctuation, neural activation, in line with the solar time and sleep-wake cycle[5-6]. These rhythmic oscillations of biological processes govern many of our habits and actions, and also influence the activities that we perform during the day. Many physiological functions associated with athletic performance have been shown to follow a specific circadian rhythm[7]. Functions such as resting levels of sensorimotor, perceptual, and cognitive performance have been found to elevate in the early evening, in line with peak body temperature rhythm[8].

For a long time, it was thought that the central clock is the only pacemaker governing the synchronous circadian

钟中的作用[10-11]。有趣的是，有研究表明 SCN 的病变并不会破坏外周器官的生物节律，而是会使各组织无法同步[11]。有观察提出，SCN 是一种同步器，而不是外周生物节律的诱导器。过去几十年的研究已经指出了存在于每个组织中的自主外周时钟的重要性。"生物钟基因"的发现使人们认识到，与时钟相关的基因表达的能力在人体中广泛存在[12]。这些外周时钟对外界信号很敏感。这些外周信号也被称为"授时因子(Zeitgebers)"，比如进食或锻炼。授时因子是一种来自外部或环境的提示，它将有机体的生物节律与地球 24 小时的明 / 暗周期和 12 个月的周期同步化。与 SCN 相比，外周时钟对输入信号的反应不同，控制不同的生理输出，彼此相互作用，并与整个组织器官系统相互作用，从而参与生物体的环境适应。

2 运动表现的昼夜节律变化

生理节律和运动表现之间的联系已得到了大量证据的支持，这些证据表明生理过程的节律性与达到峰值运动表现的时间有关。以前的研究使用不同类型的运动测试来支持运动表现生物节律效应的存在，在傍晚时候(约 16:00—20:00)的成绩高于早晨醒来后(约 07:00—10:00)。这些例子包括腿部和背部肌肉的最大力量[13-17]、手臂肌肉的最大力量[18]以及最大无氧功率[19-20]。在模拟比赛或计时赛中的运动表现也表现出类似的生物节律，包括跑步[21]、游泳[22-23]、自行车[24-28]等运动，以及与足球[3]、网球[29]、羽毛球[30]项目相关的运动表现。所有这些测试涵盖了从粗大动作运动到精细动作和复杂动作的一系列动作技能。

目前的大多数研究表明，最佳的运动表现出现在下午晚些时候－傍晚早些时候（即 16:00—18:00)，与核心体温的峰值保持一致[2]。相反，当核心体温处于最低值时(即 03:00 左右)[6]，运动表现会被削弱。核心体温历来被认为是体现生物过程和运动表现中生物节律的主要指标。早期的一些研究表明，核心体温和短时间最大强度运动的同时提高是互为因果的，且在此效应下的核心体温的增加可能会施加一个被动的热身效果，增强代谢反应，增加结缔组织的可扩展性，降低肌肉黏度，增加神经脉冲的传播，促进肌动蛋白－肌球蛋白的横桥相互作用[31-33]。Bergh 等人在 30~39℃ 的肌肉升温和降温的实验中发现，肌肉温度每下降 1℃，输出功率下降 5%[34]。最近的研究表明，只有在早晨且当体温最低时，暴露在温暖(高于 28℃）而潮湿的环境中才会提升短期的最佳表现[35-36]。有研究者认为，除了白天体温升高外，炎热的外部环境可以帮助提高肌肉收缩力[37]。

rhythm in all tissues of the organism. In 1998, Balsalobre et al. showed that a serum shock can synchronize cultured rat fibroblasts in cell cultures[9]. This was the first evidence of the presence of an autonomous clock in cells of peripheral organs. Studies have since reported on the role of the SCN in the control of peripheral clocks[10-11]. But, interestingly, it was shown that lesions of the SCN do not abolish circadian rhythms in peripheral organs but desynchronize tissues from each other[11]. These observations suggest that the SCN acts as a synchronizer rather than an inducer of peripheral circadian rhythms. Studies conducted during the last decades have pointed out the importance of an autonomous peripheral clock existing in every tissue. The discovery of ‘clock genes’ led to the realization that the capacity for circadian gene expression is widespread throughout the body[12]. These peripheral clocks are sensitive to external signals, also called “Zeitgebers”, such as feeding or exercise. A zeitgeber is any external or environmental cue that entrains or synchronizes an organism's biological rhythms to the Earth's 24 h light/ dark cycle and 12-month cycle. Comparing to SCN, the peripheral clocks respond differently to entraining signals, control different physiological outputs, interact with each other and with the organ system as a whole, and are consequently involved in the environmental adaptation of organisms.

2 Circadian Variations in Sports Performance

The linkage between circadian rhythm and sports performance is now supported by a wealth of evidence suggesting that the rhythmicity of physiological processes is correlated with peak performance times. Previous studies using different exercise tests support the existence of circadian effect of exercise performance with higher values observed in the late afternoon (around 16:00-20:00) than in the morning soon after waking(around 07:00-10:00). Examples include peak force of leg and back muscles[13-17] and of arm muscles[18] as well as in maximal anaerobic power output[19-20]. Performance in simulated contests or time-trials also show a similarly timed diurnal rhythm, including running[21], swimming[22-23], cycling[24-28], skilled tasks related to football[3], tennis[29], and badminton[30]. These activities cover a range of skills from gross locomotor functions to fine and complex tasks.

The majority of current research suggests that optimal athletic performance occurs in the late afternoon-early

为了进一步证明体温对运动表现的影响,Taylor等人发现，在早晨进行热身运动可以降低反向跳(CMJ)时的功率和肌力损失[38]。在这项研究中,研究者注意到,通过在受控的热身项目中增加额外的 20 min 的积极热身,能够提高受试者的体温,这与在下午时间进行的活动的效果差不多。因此得出结论是体温的升高是肌肉功能提高的原因。Taylor 等人的研究结果也与 Atkinson 等人[24]的早期关于热身运动对自行车计时赛成绩的影响研究结果部分一致。后一项研究的结果表明,25 min 的热身通常可以提高一天中两个时间段的计时赛成绩，但即使在热身之后,07:30 时的平均骑行时间仍然比 17:30 时的慢。Souissi 等人[20]也证实了时间对高强度运动时有氧能力的影响。他们的研究比较了上午和下午测试时段 Wingate 测试的峰值功率、平均功率、总功和耗氧量。研究发现,随着体温的升高,下午的有氧供能增加。从这些实验中可以清楚地看出,核心体温与身体机能之间存在着一种关系。

最近也有研究证据对关于体温和运动表现之间关系的传统观点提出了挑战。一些研究观察了一天不同时间内,生物节律对神经肌肉功能的影响,发现在不受温度变化影响的生理反应中存在一个独特的生物节律。例如,Martin 等人研究了生物节律对内收肌全身肌肉神经活动和收缩特性的影响[39]。他们观察到，在最大自主收缩时产生的肌力在晚上比早上高。由于体温保持不变,这一发现归因于外周的收缩机制,如肌浆网钙释放的增加,收缩蛋白对钙敏感性的增强,肌球蛋白 ATP 酶活性的改变。Guette 等人的研究也证实，肌肉功能的波动可能来自力的昼夜变化[13]。这些研究表明,在不改变体温的情况下,膝关节伸展的最大自主收缩力矩昼夜值有显著不同,研究者认为这来自于无机磷酸盐水平在细胞内的日变化。

关于运动认知能力的日间变化一直存在争议。有研究显示早间的准确性更好[29],精细运动控制和短期记忆等在早间测量结果也更好[40]。有研究建议,以技巧为基础、需要复杂的技战术、需要教练指导的运动在早间的运动表现最佳，而那些大强度的运动应该在晚些时候进行[40]。

想要正确理解生物节律对运动成绩的影响是具有挑战性的，因为有许多因素可以对一个人生物节律造成破坏,从而降低运动表现[41]。如图 2 所示,这些因素分为:(1)外在因素,包括光和温度、媒体的关注和人群行为的场合感;(2)内部因素,包括身体的生物钟基因和计时系统;(3)生活方式因素,包括睡眠不足导致的精神疲劳或长途旅行导致的身体疲劳。应当注意的是,图 2 只是简单描述了每个因素是

evening, coinciding with the peak of core body temperature (i.e., 16:00-18:00)[2]. In contrast, performance would be impaired when core body temperature is at its lowest (i.e., 03:00)[6]. Core body temperature has been traditionally used as the primary indicator for circadian rhythm in biological processes and physical performance. Some earlier studies have suggested that the simultaneous increases in core temperature and short-term maximal efforts are causally related and that an increase in core temperature could exert a passive warm-up effect enhancing metabolic reactions, increasing the extensibility of connective tissue, reducing muscle viscosity, increasing transmission of neural impulse, and facilitating actin-myosin crossbridge interaction[31-33]. Bergh and Ekblom demonstrated that power output decreased by 5% for every 1℃ decline in muscle temperature in warming and cooling experiments for muscle temperatures between 30 and 39℃[34]. Recent studies suggest that exposure to a warm (i.e., > 28℃) and humid environment can increase short-term maximal performances only in the morning, when body temperature is at its lowest[35-36]. The authors concluded that in addition to the diurnal increase in body temperature, heat exposure in a hot environment can also improve muscle contractility[37].

To further demonstrate the effects of body temperature on exercise performance, Taylor et al. found that extending the warm-ups in the morning could attenuate power and force losses during countermovement jumps[38]. In this study, the authors noticed that by adding an additional 20 minutes of active warm-up to a controlled warm-up program, subjects were able to increase body temperature that was comparable to that in an afternoon session. It was therefore concluded that the increase in body temperature was responsible for the improved muscular performance observed. The results by Taylor and colleagues were also in partial agreement with an earlier study by Atkinson et al. who examined the influence of warm ups on cycling time trial performances[24]. Results from this latter study demonstrated that 25-min warm-up generally improved time trial performance at both times of the day, but mean cycling time was still slower at 07:30 than 17:30 even after warm-ups. Souissi et al. also confirmed a time-of-day effect on the aerobic contribution during high-intensity exercise[20]. Their study compared peak power, mean power, total work done, and oxygen consumption between a morning and afternoon testing session using a Winga-

如何影响生物节律和运动表现的，事实上这些因素是相互作用的,而不是独立地影响生物节律的。

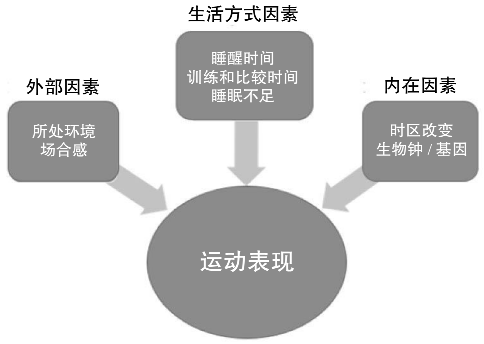

图 2 相互作用影响昼夜节律和运动表现的因素
Figure 2 Factors Affecting Circadian Rhythms and Sports Performance

3 运动训练的生物节律特异性

体育科学研究者经常会被问到这样一个问题:“一天中什么时候才是进行有效训练的最佳时间？”如果时间对运动训练的反应存在一定影响，这可能意味着如果训练在一天中的某个特定时间段进行,那么运动表现或训练诱导的身体适应性将会更强。训练中时间特异性的理论基础是几乎所有生理变量都表现出的生物节律特征,包括前文提到由急性运动带来的一些反应。例如,以往的研究表明,下午进行运动锻炼时,心率、摄氧量、通气量以及次最大运动量时的运动感觉评分都高于上午[42-43]。一天内的时间变化对最大反应速度和最大运动能力也有一定影响,如耐力能力[24]、力量和灵活性[13,39,44]、无氧能力[42,45-47]。此外有研究显示,运动后的血乳酸(无氧能力贡献率指标)和最大累积氧亏(评价无氧能力的指标)在下午的测量值要高于上午[42,45]。

早期关于训练时间特异性的研究已经使用有氧训练作为一种方式来检验在一天的特定时间进行训练是否更有利。Hill 等人提出有氧训练对提高厌氧阈值存在时间特异性[48]。他们的研究结果表明,在 6 周的训练后，晨训组的无氧阈值在早间测定时高于晚间,晚训组的无氧阈值在晚间测定时高于早间,而对照组(研究对象不进行训练)的无氧阈值在早间和晚间测试时均无差别。Torii 等人发现,4 周的耐力训练可提高最大摄氧量，但这只是在测试时间与训练时间吻合的条件下出现[49]。参与者被分为 3 组,每组分别被分配在早上、下午和晚上进行训练。然而,最大摄氧量测试只在训练当天的下午进行。研究者进一步认为,在下午进行有氧训练时,由降低心率和乳酸水平来衡量的训练适应性优于其他时段。类似地，

te test. It was found that aerobic contribution was higher in the afternoon session in conjunction with increased body temperature. From these experiments, it is clear that a relationship exists between core body temperature and physical performance.

Recent evidence has challenged the traditional views on the relationship between body temperature and exercise performance. Some studies looking at time-of-day effects on neuromuscular performance have revealed a distinct circadian rhythm in physiological responses independent of temperature changes. For example, Martin et al. investigated the effect of circadian rhythm on the neural activation and contractile properties of the adductor pollicis muscle[39]. They observed that the force produced during a maximal voluntary contraction was higher in the evening than the morning. As body temperature remained the same, the finding was ascribed to peripheral contractile mechanisms including enhanced calcium release from the sarcoplasmic reticulum, increased calcium sensitivity of the contractile proteins, and altered myosin ATPase activity. Guette et al. also reported similar findings supporting the evidence that changes at the muscular level may be responsible for diurnal fluctuations in force[13]. Their study demon strated a significant time-of-day effect on maximal voluntary torque of the knee extensors without the concurrent change in body temperature. They attributed this finding to intracellular diurnal variations of inorganic phosphate.

There has been controversy surrounding the diurnal variation of cognitive performance in sports. Accuracy has been reported to be better in the morning[29], along with measures such as fine motor control and short-term memory[40]. It has been suggested that the performance of skill-based sports and those requiring complex competitive strategies, decisions making, and recall of plays or coaching instructions is best completed in the morning, whereas sports that require substantial physical efforts should be performed later in the day[40].

Understanding the circadian impact on sports performance is challenging in that many factors can disrupt one′s circadian rhythms, hence reducing performance[41]. As shown in Figure 2, these factors are categorized as (1) external, which include light and temperature, sense of occasion from media attention and crowd behavior, (2) internal, which include body′s own clock genes and timing system, and (3) life style, which include mental

Hill 等人在经过为期 5 周的，旨在提高运动表现能力的高强度训练后，结果显示出一定的时间特异性。他们发现晚间训练组在晚间计时赛中有更好的表现，而上午训练组的表现不受时间影响[50]。研究者认为，当评估运动表现时间与高强度训练时间吻合，会呈现最佳运动表现。然而，在该研究中，并没有进行训练前的评估。因此，不能确定是否由训练引起的运动适应性改善也呈现时间特异性。

最近，人们开始研究一天中在特定时间训练是否会影响对抗阻训练的适应性。然而，与有氧训练相比，研究结果似乎不那么有说服力。Souissi 等人在为期 6 周的旨在增强肌肉力量和功率的抗阻训练后，显示时间对适应性有明显的影响[51]。在这项研究中，早上训练的受试者在早上和晚上的 Wingate 测试中，他们的肌肉功率都有增强。然而，在晚上训练的受试者只有在这个时段才能改善他们的运动表现。研究者认为，力量训练适应性评估应安排在平时常规力量训练的时间段内。Chtourou 等人也表明，在为期 6 周的抗阻训练后，肌肉力量和功率的改善效果在与常规训练时间吻合时为最佳[52]。在该研究中，早晨 07:00 训练的受试者在晨间 1RM、深蹲跳、反向跳和 Wingate 测试中的表现会更好，而在 17:00 训练的受试者在晚间的测试中的表现更好。此外，这两项研究均表明，在一天的特定时间内进行训练可以改变运动最佳表现的典型昼夜模式。例如，在早间训练组中，无氧运动的昼夜变化差异缩小，而在晚间训练组中，这种变化差异未减反增，也就是晚间表现较早间改善更多。同样地，Sedliak 等人表明，在为期 10 周的抗阻训练后，最大等长力量的典型昼夜差异在晨训组中减少，但此变化在晚训组中没有发生[16,53-54]。Souissi 等人在青年受试者中进行了 6 周的抗阻训练后也观察到了同样的结果[55]。

然而，Blonc 等人的研究表明，为期 5 周旨在增强肌肉力量的多模式训练，可以在早间组和晚间组以同样的程度，改善深蹲和反向跳的表现[56]。研究者认为，环境的被动热身效应可能是他们未能观察到时间对运动表现产生影响的原因。事实上，该研究是在法属西印度群岛的瓜德罗普进行的，该地区环境温暖湿润，平均温度和湿度分别为(27.9±0.5)℃和 65.4%±12%。有研究表明，这种气候可以作为一种被动的“热身”来改变正常的与生物节律相关的反应[37,56]。Kuusmaa-Schildt 等人也未能证明时间对运动反应的影响，他们比较了同步但分别在早上和晚上进行的 24 周训练项目中身体的表现[57]。在该研究中，训练计划是周期性的，包括常规的抗阻训练、循环训练和间歇训练，并通过最大摄氧量和双侧等长腿部推举

fatigue due to time awake and sleep loss or physical fatigue due to long-distance travel. It should be noted that Figure 2 illustrates only a simplified description of how each factor may influence circadian rhythms and thus performance. In reality, these factors interact with each other rather than exert their effects on one′s circadian rhythms independently.

3 Circadian Specificity of Exercise Training

Sports cientists are often asked the question "When is the best time of day to train effectively?" If there is a time-of-day effect on responses to exercise training, it could mean that performance or training-induced adaptations at a particular time of day will be greater if the training has occurred at that time. The theoretical basis for temporal specificity in training centers on the characteristic circadian rhythms that are demonstrated in almost all physiological variables, including many responses to acute bouts of exercise as mentioned earlier. For example, it has been consistently shown that heart rate, oxygen uptake, minute ventilation, and ratings of perceived exertion during submaximal exercise are higher when exercise is performed in the afternoon than in the morning[42-43]. The time of day also influences maximal responses and abilities, such as endurance performance[24], strength and flexibility[13,39,44] and anaerobic power[42,45-47]. In addition, post-exercise blood lactate, an index of anaerobic contribution, and maximal accumulated oxygen deficit, a measure of anaerobic capacity, have been reported to be higher when measured in the afternoon as compared to that measured in the morning[42,45].

Early studies on temporal specificity of training have used aerobic training as a way to examine whether training at a specific time of day would be more advantageous. Hill et al. have suggested that there is a time-of-day specificity in aerobic training designed to improve anaerobic threshold[48]. The authors showed that, after 6 weeks of training, the anaerobic threshold was higher in the morning than in the evening for the morning training group, and it was higher in the evening for the evening training group. However, anaerobic threshold in the control group (i.e., subjects who did not train) was the same in the morning and the evening be fore and after the experimental period. Torii et al. found that 4 weeks of endurance training enhanced VO_{2max} only when testing was conducted at the same time of day (bilateral isometric leg press)测试评估体能表现。研究发现，早上和晚上的训练对肌肉力量和心肺健康有相同程度的改善。

尽管在无氧和抗阻训练方面存在一些争议,但似乎在设计运动计划时,训练的时间安排(即训练的时间特异性)是一个需要考虑的重要变量。从实践的角度来看,如果比赛时间是已知的,那么在重大比赛之前的训练应该安排在与比赛时间相同的时间段内进行,以确保最佳运动表现。然而,在不知道比赛时间的情况下,部分训练应该安排在早上,以抵消由生物钟导致的晨间运动表现惰性,从而提升运动表现。值得注意的是,上述研究都没有使用高水平运动员。这很重要,因为与缺乏训练的受试者相比,高水平训练的受试者的昼夜变化幅度要大得多[58]。

4 时间型(chronotype)对运动表现的影响

除了生理系统的昼夜变化外，在研究生物节律对运动表现的影响时，参与运动的人对白天或夜间活动的偏好是另一个必须考虑的重要心理因素。人们早就认识到,有些人喜欢白天活动,而有些人则喜欢夜间活动[59]。个体之间的对比鲜明的时间偏好被称为时型(时间型)。拥有不同时间型的人在睡眠－觉醒模式、核心体温、激素分泌和运动期间的最大摄氧量等不同的行为和生理节律上存在差异[60-62]。虽然了解一天内的时间如何影响运动成绩很重要，但其他方面,如运动员的时间型也很重要,因为它可以改变生物节律和生理功能或运动表现之间的关系,大多数关于一天中不同时间对认知表现和身体表现的影响的研究都没有调查或控制时间型的潜在影响。

时间型是一个人对“清晨型(morningness)”或“夜晚型(eveningness)”的性格倾向,通常通过自我评估问卷进行评估,使用最多的问卷是晨型人－夜型人问卷(Morningness-Eveningness Questionnaire ,MEQ)[63]。这份问卷识别出 3 种不同的时间型，分别是早上型(M 型)、晚上型(E 型)和非早晚型(N 型)。时间型不仅仅是一种主观特征，几项研究表明,M 型和 E 型在体温、激素分泌、时差同步、个性、情绪和认知表现等生物节律方面存在差异[64-65]。例如,E 型与 M 型相比,口腔最高温度和血清皮质醇水平峰值出现时间分别晚了 2 h 和 55 min[60,66]。此外,M 型表现出血液和唾液褪黑激素浓度的早期峰值期，约比 E 型早出现 3 h,因此,M 型人的起床和入睡时间通常比其他时间型的人早[64]。值得注意的是,年龄和性别会影响时间型,与男性和年轻人相比,女性和老年人更容易早起[64]。

在时间型问卷中使用的问题大多是主观题,将

as training had been scheduled[49]. The participants were divided into 3 groups and each group was assigned to train either in the morning, afternoon, or evening. However, VO_{2max} testing was administered only in the afternoon both before and after training. In addition, the authors suggested that the training-induced adaptations as measured by a reduction in exercising heart rate and lactate responses were greater when aerobic training was performed in the afternoon than at other times. Similarly, Hill et al. showed a temporal specificity after 5 weeks of high-intensity training designed to increase work capacity[50]. While the evening training group had greater time-trial performance at this time of day, performances of the morning training group were not time-of-day dependent. The authors suggested that a greater improvement appeared to occur at the same time of day at which high-intensity training is regularly performed. In this study, however, no pre-training evaluation was conducted. Hence, the authors could not determine if the improvement of performance was greater when assessed at the same time of day of regular training.

More recently, studies have been launched to examine whether training at a specific time of day could influence adaptations to resistance training. Nevertheless, findings seem less conclusive as compared to aerobic training. Souissi et al. showed significant time-of-day effects on adaptations after 6 weeks of resistance training designed to promote muscle strength and power[51]. In this study, subjects who trained in the morning hours improved their muscle power during the Wingate test both in the morning and in the evening. However, those who trained in the evening hours improved their performances only at this time of day. The authors suggest that adaptations to strength training are greater at the time of day at which training was conducted than at other times. Chtourou et al. also showed that improvements in muscle strength and power after 6 weeks of resistance training were greater at the time of day at which training was scheduled than at other times[52]. In this study, performance during 1-repetition maximum, squat jump, countermovement jump, and Wingate tests was greater in the morning in subjects who trained at 07:00 hours and in the evening in subjects who trained at 17:00 hours. Additionally, both studies showed that training at a specific time of day could modify the typical diurnal pattern of short-term maximal performances.

睡眠和活动时间与个人“感觉最佳节律”[63]或他人的习惯联系在一起(如“我起床比大多数人都晚”)[67],或让实验对象评估假设的情况(如“如果你能完全自由地计划你的一天,你大约什么时候起床?”)[68]。这些问卷得出了貌似合理的结果,但奇怪的是,就“真正的”行为而言,这些问卷没有明确地分别评估休息日和工作日,也没有调查实际的睡眠时间或暴露在户外光线下的时间[69]。到目前为止,这些细节仅在评估情感性精神障碍的季节性问卷中被提及[70-71]。最近,有一种新开发的问卷定量评估 24 h 内的睡眠时间,从而确定睡眠类型[72]。该问卷分为工作日和休息日,使用简单的问题,如受试者何时起床、何时睡觉、睡了多久或醒了多久。这项新问卷的验证研究表明,尽管睡眠时间与时间型有密切的相关性,但工作日和休息日之间有很大的差异[72]。

最近,人们研究了 M 型和 E 型之间的昼夜表现变化,以探讨在考虑生物节律时间的个体差异时差异是否显著。Rae 等人除了分析情绪状态的结果外,还表明按时间型分组的参与者表现出显著的日变化,M 型游泳者在上午游泳速度更快,而 E 型游泳者在 18:30 的时候游得更快[73]。上午和晚上的时间测试的时差与 MEQ 分数之间存在微弱但显著的相关性,MEQ 分数较高的游泳运动员在 06:30 的时间游得更快,这些结果与 Brown 等人的研究结果一致[74]。在该研究中,16 名大学生赛艇运动员(8 名男性和 8 名女性)必须在 05:00 至 07:00 和 16:00 至 18:00 进行 2 000 m 赛艇和立定跳远测试。这些分析突显了时间型和测试时间之间的相互作用,表明 4 名 M 型运动员在下午明显比上午慢 4.8 s。与 E 型运动员(8名)和 N 型运动员(4 名)相比,他们在一天中的运动表现下降幅度也更大。E 型和 N 型运动员在当天的划船速度方面没有显著变化,在跳远距离上,上午到下午的组间比较也没有显著差异。

最近,Henst 等人探索了南非(95 名)和荷兰(90 名)马拉松运动员的时间型和马拉松表现之间的关系。作者观察到,南非的跑步者比荷兰运动员更倾向于早晨型,MEQ 分数与他们个人最好的半程马拉松或马拉松比赛成绩呈负相关[75]。然而,同样的趋势在荷兰组没有发现。研究者认为,由于南非马拉松运动员更多地倾向于早间训练,他们更适合参加清晨开始的耐力项目比赛,因为他们在早间比 E 型选手有更大的几率达到最佳表现水平。

Facer-Childs 和 Brandstaetter 进行的最新研究,考察了不同时间型的身体表现[76]。首先招募了 121名竞技级别的曲棍球运动员(女性 70 名,男性 51 名),

For example, the diurnal variations in anaerobic performances were reduced in the morning training group, whereas such variations were increased in the evening training group, which is the time of day when performance typically is most impressive. Likewise, Sedliak et al. showed that the typical diurnal pattern of maximum isometric strength was blunted after 10 weeks of resistance training in the morning but not the evening group[16,53-54]. The same results were also observed by Souissi et al. after 6 weeks of resistance training in youth subjects[55].

Nevertheless, Blonc et al. showed that 5 weeks of multi-modal training designed to develop muscle power improved performance in squat and countermovement jump to the same extent in both the morning and the evening groups[56]. The authors suggested that the pas sive warm-up effect of the environment might be the cause for why they failed to observe any time of day effect on performance. In fact, this study was conducted in Guadeloupe, French West Indies, which has a warm and moderately humid environment with the mean temperature and humidity of (27.9±0.5) ℃ and 65.4%±12%, respectively. It has been suggested that this climate could play a role as a passive “warm-up” to alter normal circadian-related responses[37,56]. A lack of time of day effect on exercise responses was also demonstrated by Kuusmaa-Schildt et al. who compared physical performance following a 24-week concurrent training program administered in the morning and the evening[57]. In this study, the training program was periodized and consisted of conventional resistance training, circuit training, and interval training, and physical performance was assessed by VO_{2max} and bilateral isometric leg press test. It was found that training in the morning and the evening induced similar improvements in muscle strength and cardiorespiratory fitness.

Despite some controversies with anaerobic and resistance training, it seems that the time of day at which training sessions are scheduled (i.e. temporal specificity of training) is an important variable to consider when designing an exercise program. From a practical standpoint, if the time of competition is known, training sessions before a major competition should be conducted at the same time of day at which one′s critical performance is programmed. However, if the time of competition is not known, some training sessions should be scheduled in the morning to improve short-term maximal

并编制了一份新的时间型问卷,针对性研究运动员的睡眠和觉醒相关的参数和身体表现变量。在这个样本中,20 名参与者（M 型 5 名,N 型 10 名,E 型 5 名)在一天中的 6 个不同时间段（07:00,10:00,13:00,16:00,19:00,22:00)进行 Bleep 测试(多阶段体能测试)。时型分析显示，在峰值表现的出现时间上不同类型存在显著差异,其中以达到的折返次数来表示最佳表现,M 型出现的时间为(12.19±1.43) h,N 型为(15.81±0.51) h,E 型为(19.66±0.67) h。E 型运动员的表现日变化幅度为 26.2%±3.97%,M 型为 7.62%±1.18%,N 型为 10.03%±1.62%,表明 E 型运动员对表现的昼夜变化更为敏感。由于一天中的时间是一个外源因素,并且只与个体的生物节律生理有部分关系，因此他们将“自睡醒以来的时间”作为变量来评估数据,认为这个变量是一个内源性因素，可以与外部因素相互作用。观察发现,E 型运动员睡醒后的平均峰值时间,即前 2 周内自唤醒后达到峰值表现的平均时间,为(11.18±0.93) h,与 N 型和 M 型运动员相比[分别为(6.54±0.74) h 和(5.60±1.44) h]明显推后。E 型运动员需要更长的时间才能使身体充分活跃起来，并且在唤醒后不会像 M 型运动员那样快速地达到最佳表现状态。研究者认为,运动表现不仅会受到一天中不同时间的影响，还会受到比赛或测试与唤醒后之间的时间长短的影响。

有趣的是,在高水平运动中,E 型运动员估计约占 10%[77]，这一数值远低于一般人口中的约 40%的比例[78]。这一观察结果反映出达到了国家或国际水平的 E 型运动员较少，表明时间型是决定运动员成功的潜在因素。

5 生物节律中断和应对策略

正常情况下,体内的生理节律与生物钟和外界的明－暗环境同步。人类是昼行性的,主要在白天活动,晚上睡觉，因此他们的生物节律系统会自动调节,如日出时醒来,在入睡前有微弱光线或无光线,刺激褪黑素的产生[79-80]。这种调节可以被跨时区的旅行打乱,因此正常的活动,如睡觉、起床和吃饭,可以在不正常的外部光线和黑暗条件下发生。由于快速的跨时区旅行,如东向西或西向东旅行,跨越了时区,生物节律的不同步或时差会由于身体的生物节律和外部 24 h 的光暗周期不匹配而出现[81]。时差反应的严重程度随着跨越时区数量的增加而增加,跨越 3 个时区就会不可避免地导致时差反应[82]。无论飞行时间长短,从北向南或从南向北旅行后都不会有时差反应。

许多症状通常是由于时差反应引起的,常见的主

performances and to counteract the morning nadir of performances. It should be noted that none of these aforementioned studies used high-level athletes; this is important because the amplitude of the diurnal variation is much higher in active compared with inactive subjects[58].

4 Effects of Chronotype on Sports Performance

Apart from diurnal variations in physiological systems, the preference for daytime or nighttime activities is another important psychological factor that must be considered when studying the effect of circadian rhythm on exercise performance. It has long been recognized that some people have the consistent preference for daytime activities, whilst others have the preference for nighttime activities[59]. Such contrasting time preference between individuals is referred to as chronotype. People with different chronotypes have been shown to differ in various behavioral and physiological rhythms concerning sleep-wake patterns, core temperature, hormonal secretion, and VO_{2max} during exercise[60-62]. Although it is crucial to understand how time of day could influence sports performance, other aspects such as a chronotype of athletes are also important because it can alter the relationship between circadian rhythm and physiological functions or sports performance. The majority of research on the effect of time of day on cognitive and physical performance in sports has failed to investigate, or control for, the potential impact of 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)[63]. From this questionnaire three different chronotypes can be identified and they are 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 body temperature, hormonal producion, synchronization to jet lag, personality, mood, and cognitive performance[64-65]. For example, peaks in oral temperature and serum cortisol levels have been observed as delayed by 2 h and 55 min, respectively, in E-types compared with M-types[60,66]. Furthermore, M-types exhibit an early acrophase of blood and salivary melatonin concentrations, approxima-

观症状包括睡眠障碍,注意力难以集中,易怒,抑郁,定向障碍,对时间、空间和距离的估计扭曲,头晕,食欲不振和胃肠道紊乱[83-84]。据有关空乘机组人员的研究报道,在跨越一个时区后的第一个晚上,大约有60%~70%的人会出现睡眠障碍,而在第3天,这一比例降至30%[85],而睡眠不足程度在这些空乘人员中可达到相当于每晚少睡5~6 h[86]。此外,女性空乘人员的月经周期更不规律[87]。众所周知,旅行者乘坐西进航班(相位延迟)比乘坐东进航班(相位提前)恢复和再同步生物节律地更快,特别是东进航班后睡眠质量下降[88]。Klein 和 Wegmann 计算出,从德国向西飞行到美国后,需要3 d才能重新同步心理和运动表现节律,而反向飞行则需要8 d[89]。症状通常在飞行后48 h内出现,跨越的时区越多,恢复的时间越长[90]。

虽然每个人对时差反应的敏感度有所不同,但这些差异似乎很小。拥有更好的体适能水平会产生益处,因为它有促进睡眠的作用,能增强心理韧性,更好应对主观不适。年轻人,尤其是运动员,可能有能力更好地应对生物节律的不同步,而年长的旅行者则能从以前的旅行经历中获益。令人惊讶的是,年轻人在睡眠不足的情况下会比那些白天已经行动缓慢的老年人更加容易困倦,表现也更差[91]。经常旅行的女性旅客可能会出现继发性闭经,但女运动员的生活方式往往需要频繁而非习惯性的旅行。M型的人可能在适应向东旅行方面有优势,E型的人可能在适应向西飞行方面有优势,但大多数运动员在时间型方面处于中间位置[92]。

时差反应是否会影响运动表现还没有定论,但这可以部分归因于方法学上的差异[93]。大多数的研究证据都是用小样本来完成新的测试(如握力测试),其测试方式与更复杂的运动技能是否有相关性便值得怀疑。这些调查还经常有设计缺陷的特征,如缺乏控制组或控制条件。的确,生理参数,如心率、通气量和血乳酸,与生物节律相关[40]。另外,对生理活动的直接测量,如肌肉力量峰值、无氧输出功率和纵跳,也与生物节律有关[94]。然而,许多研究表明倒时差对运动员在比赛中的表现影响并不明显或没有定论。游泳运动员在长时间向东旅行后,手臂和肘关节屈曲力以及冲刺次数都有所下降[95]。英国奥运选手在向西穿越5个时区后,腿部和背部肌肉力量以及反应时间都有所下降[96]。相反,大学游泳运动员在横跨4个时区后的高强度训练中没有表现出消极的生理、知觉或情感变化[97]。此外,也有报道显示来自澳大利亚的雪橇运动员的运动表现没有变化,尽管在飞行前后唾液皮质醇浓度发生了变化[98]。

tely 3 h before E-types, and as a consequence they generally wake up and go to bed earlier than the other chronotypes[64]. It is important to note that age and sex will affect chronotype with women and older individuals demonstrating a strong predisposition towards morningness compared with men and younger individuals[64].

The questions used in chronotype questionnaires are mostly subjective, relating sleep and activity times to a personal "feeling best rhythm"[63] or to the habits of others (i.e., "I get up later than most people")[67], or they ask subjects to assess hypothetical situations (i.e., "Approximately what time would you get up if you were entirely free to plan your day?")[68]. These questionnaires yield plausible results, yet oddly enough, in terms of "real" behavior, they do not explicitly assess free days and workdays separately nor do they ask for actual sleep times or exposure to outdoor light[69]. These details have, so far, been addressed only in a questionnaire assessing seasonality of affective disorders[70-71]. More recently, a new questionnaire was developed to quantitatively assess the timing of sleep within the 24 h day, thereby determining a chronotype[72]. This questionnaire is divided between work days and free days and uses simple questions such as when subjects wake up and go to bed and how long they sleep or stay awake. Validation studies of this new questionnaire showed that although indicated sleep times correlated well with chronotypes, they were very different between workdays and free days[72].

More recently, diurnal performance profiles have been studied between M-types and E-types in order to explore whether there is significant variation when individual differences in circadian timing are taken into account. Rae et al., in addition to analyzing the results of the profile of mood state, showed that grouping the participants by chronotype revealed a significant diurnal variation in performance, with M-types swimming faster in the morning session and E-types at 18:30[73]. There was a weak but significant correlation between the time difference for morning-evening time trials and the MEQ score, and swimmers with higher MEQ scores tended to swim faster in the 06:30 session. These results are in line with the study by Brown et al. in which 16 collegiate rowers (8 men and 8 women) had to perform a 2,000 m rowing test and a standing broad jump test in both the morning at 05:00-07:00 and the afternoon at 16:30-18:00[74]. The analyses highlighted an interaction

虽然有些运动员在乘飞机旅行后表现不佳，但没有一致或令人信服的证据表明，跨越多个时区的飞机旅行或时差症状会导致运动表现下降。那些经过多年训练，通过数万次的训练实践磨练了自己技能的优秀运动员，在表现能力上可能较为可靠，而且特别能抵御时差的潜在影响。尽管缺乏坚实的科学证据，一些运动员，特别是那些更容易受到时差影响的运动员，可以考虑根据他们的旅行计划调整他们的生物节律，以确保最佳竞技状态。对于接近 12 h 的时区转换，有一些证据表明，将旅程分成 2 d，中途停留一晚可以减轻主观症状[94]。至于团队项目，由于后勤和财政方面的原因，或由于失去训练机会，这种中途停留可能是不可行的。当到达目的地的时间是下午晚些时候或晚上时，应对策略更容易实施[99]，因为在此情况下，人们有机会在到达新时区后更早地在晚上睡个好觉。运动员也应该意识到，由于机舱内空气干燥，环境温度高会加剧长途飞行后的脱水，而高原缺氧会加重运动员穿越时区前往高原训练场地的主观不适。

为减轻时差带来的负面影响而制定的旅行指南可以帮助运动员尽快调整生物节律系统[100]。如表 1 所示，该指南是根据不同旅行阶段而制定的，如“飞行前”“飞行中”“飞行后”。建议具体包括适当的休息、睡眠调整、保持水合、避免过度饮食、低强度运动、使用明亮的光线和摄入褪黑素以促进生理调整。

表 1 运动员应对时差的旅行指南[100]

Table 1 Travel Guidelines for Athletes Coping with Jet Lag[100]

时间	建议
飞行前	提供有关时差和昼夜节律的基本科普信息
	仔细计划旅行，使之少些压力，多些乐趣
	避免睡眠不足
	在出发前的几天内，可以考虑将睡眠时间（每天 30~60 min）逐渐调整为目的地时间
	可以考虑使用适当的灯光调控，褪黑素，或运动来改变昼夜节律
飞行中	应该饮用大量的水或果汁，限制酒精和咖啡因的摄入，以对抗干燥空气引起的脱水
	为了减少肌肉僵硬和因长时间不活动而导致血栓形成的风险，应至少进行拉伸、慢走和 / 或等长肌肉收缩的运动
	考虑使用耳塞来减少噪音带来的压力
	避免在没有咨询医生的情况下服用安眠药。
飞行后	由于肠胃不适是时差反应最常见的症状之一，所以应避免进食过多或摄入辛辣食物
	考虑进行低强度的运动来减少肌肉僵硬。运动可能需要在室内进行，因为目的地的光照可能会抵消所需的昼夜节律调整
	考虑在长途飞行后的最初几天里避免高强度的训练
	考虑使用适当的灯光调控，褪黑素，或运动来改变昼夜节律

between chronotype and time, indicating that the 4 M-types were significantly slower by 4.8 s in the afternoon than the morning. 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 across the day were found for E-types and N-types, and no significant group differences occurred from morning to afternoon in broad jump distances.

Recently, Henst et al. determined the relationship between chronotype and marathon performance in South African(N=95) and Dutch(N=90) marathon runners[75]. 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 or marathon race times. However, the same trend was not found in the Dutch group. The authors suggested that as South African marathon runners are more morning-orientated, they are better suited to competing in endurance events with early-morning start times because they will have a better chance to reach their peak performance in the morning than do E-types.

Facer-Childs and Brandstaetter[76] 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) were recruited, and a new chronometric questionnaire was compiled that was specifically designed to study sleep- and 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 undergo the Bleep test (also known as the multi-stage fitness test) at six different times of day (07:00, 10:00, 13:00, 16:00, 19:00, and 22:00). Analysis of chronotype 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 variations 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, suggesting that E-types are more sensitive to diurnal fluctuations in performance. As time of day is an exogenous factor 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

6 结论

现有的证据已清楚地支持了生物节律和运动表现之间的关系，即生物节律的变化可以对身体机能和表现产生重大影响。在运动表现中观察到的生物节律效应可以在很大程度上归因于体温的变化,尽管也有人提出了解释生物节律变化的其他生理机制。最佳表现通常出现在傍晚,当体温达到峰值的时候。考虑到体温和肌肉表现之间的密切关系,运动员必须在任何比赛或训练前进行充分的热身，特别是在早晨或寒冷的环境中。生物节律对运动成绩的影响也会因运动员的时间型而改变。因此,在设计一个旨在最大限度地提高训练适应性的训练计划时,应同时考虑训练的时间效应和运动员的时间型。长时间的旅行可能会导致生物节律失调或时差反应,对健康和运动表现不利。容易受时差影响的运动员可以考虑采取适当的应对策略，以便更快地调整他们的生物节律,确保最佳竞技状态。

factor that can interact 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 Nand M-types [(6.54 ±0.74) h and (5.60±1.44) h, respectively]. It seems that E-types need longer time 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 performance will be affected by not only the time of day, but also how many hours after entrained wake-up the competition or performance evaluation takes place.

Interestingly, the prevalence of E-types in elite sports is estimated to be~10%[77], a value much lower than the estimated~40% in the general population[78]. This observation could reflect that a lower number of E-types are reaching national/international level, suggesting chronotype as a potential factor that determines the path to a successful athletic career.

5 Circadian Disruption and Coping Strategies

Normally, internal physiological rhythms are synchronized by the body clock to the external light-dark conditions. Humans are diurnal, primarily active during the day and asleep at night, and their circadian system therefore regulates physiology such that waking occurs around sunrise and sleep onset is preceded by dim or no light, stimulating melatonin production[79-80]. This regulation can be disrupted by trans-meridian travel, and normal activities such as sleeping, waking, and eating, can therefore occur in abnormal external light-dark conditions. Due to a rapid trans-meridian travel, such as east-to-west or west-to-east travel, where time zones are crossed, circadian desynchronization, or jet lag, occurs due to a mismatch between the body's circadian rhythms and the external 24 h light-dark cycle[81]. The severity of jet lag increases with the increasing number of time zones crossed-travelling over three time zones almost invariably leads to jet lag[82]. No jet lag is experienced following north-to-south or south-to-north travel regardless of the flight length.

Numerous symptoms are commonly experienced as a consequence of jet lag. The subjective symptoms usually associated include sleep disorders, difficulties with concentrating, irritability, depression, disorientation, distorted estimation of time, space, and distance, lightheadedness, loss of appetite, and gastrointestinal disturbances[83-84]. Air crews report sleep disturbances in about 60%-70% of cases on the first night after crossing a time zone, which is reduced to 30% on the third day[85] and loss of sleep amounts to as much as five or six hours per night flight[86]. Moreover, female flight attendants experience more irregular menstrual cycles[87]. It is well known that westward flights (characterized by a phase delay) are followed by faster recovery and resynchronization than eastward flights(phase advance), and sleep quality decreases particularly after eastward flights[88]. Klein and Wegmann calculated that 3 days were needed to resynchronize psychomotor performance rhythms after a westward flight from Germany to the United States, whereas 8 days were required for the reverse direction[89]. Symptoms are commonly reported during the 48 hours immediately after a flight, and the more time zones that have been traversed, the longer is the period of recovery[90].

Although there are differences between individuals in their sensitivity to jetlag, these differences appear to be small. Physical fitness may be beneficial due either to its sleep-promoting effects or its association with mental toughness to cope with subjective discomfort. Younger individuals, notably athletes, may have a capability to cope better with circadian desynchronization, while older travelers derive benefit from experience of previous trips. Surprisingly, the young experience greater sleepiness and performance deficits with sleep deprivation than the old who are already slower during the day[91]. Habitual female travelers may experience secondary amenorrhea but the lifestyle of female athletes entails frequent but not habitual travelling. M-type individuals may have an advantage in adjusting to eastward travel, and E-types to a westward flight, but the majority of athletes are intermediate in chronotype[92].

Whether jet lag would affect sports performance remains inconclusive. This can in part be attributed to the methodological difficulties in demonstrating that jet lag impairs sports performance[93]. Most of the research evidence has been generated with small samples performing novel laboratory tasks (i.e., grip strength) of questionable relevance for more complex types of sport performance. These investigations also have been frequently characterized by design flaws such as lack of a control group or condition. Physiological parameters, such as heart rate, ventilation, and blood lactate, are associated with circadian rhythms [40]. Direct measures of physical performance, such as peak muscle force, anaerobic power output, and vertical jump, are also associated with circadian rhythms[94]. However, no clear jet lag influence on individual athletic performance in competition has been shown. Swimmers demonstrate decreases in arm and elbow flexion strength as well as sprint times after prolonged eastward travel[95]. British Olympic athletes showed a decrease in leg and back strength as well as reaction time when traveling westward across 5 time zones[96]. In contrast, collegiate swimmers traveling across 4 time zones did not demonstrate negative physiological, perceptual, or affective changes during heavy training[97]. Furthermore, skeleton athletes traveling from Australia showed no change in performance, despite alterations in saliva cortisol concentrations before and after air travel[98].

Although some athletes, anecdotally, report impaired performance after air travel, there is no consistent or compelling evidence showing that either air travel across multiple time zones or jet lag symptoms cause a reduction in sport performance. Elite athletes who have honed their skills by performing tens of thousands of practice trials over years of training may be especially reliable in their ability to perform and particularly resistant to the potential effects of jet lag. Despite a lack of solid scientific evidence, some athletes, especially those who are more easily affected by jet lag may consider adjusting their circadian rhythms in accordance with their travel schedule in order to optimize performance. For time-zone transitions approaching 12 h, there is some evidence that splitting the journey into 2 days with an overnight stopover can lessen the subjective symptoms experienced[94]. Such stopovers may not be feasible in the case of sports groups for logistic and financial reasons, or because of losing training opportunities. Coping strategies are easier to implement when arrival times at destination are in the late afternoon or evening[99]. In these cases, individuals have the opportunity to take a full sleep at night in the new time-zone sooner after arrival. Athletes should also be aware that a high environmental temperature can accentuate the dehydration following a long-haul flight due to the dry cabin air, and hypoxia at altitude could compound subjective discomfort for athletes travelling across time- zones to training venues at altitude.

Travel guidelines for alleviating the negative effects of jet lag have been developed with the goals of realigning the circadian system as quickly as possible [100]. As shown in Table 1, the guidelines are made specific to different time periods such as "before the journey", "during the flight", and "after arriving" and recommendations include proper rest, sleep adjustment, hydration, avoid heavy meals, low-intensity exercise, and possible use of bright light and melatonin to facilitate circadian realignment.

6 Summary

The existing evidence clearly supports the relationship between circadian rhythm and sports performance and a shift in circadian rhythms can have major impact on physical performance. The circadian effects observed in performance can be largely attributed to the change in body temperature, although other physiological mechanisms that explain the circadian variations of performance have also been proposed. Enhanced performance is most frequently seen in the early evenings when body temperature peaks. Given a close relationship between body temperature and muscle performance, it is imperative that athletes warm up sufficiently prior to any competitions or training especially in the mornings or cold environments. Circadian effects on sports performance can also be altered by chronotype. As such, both the time-a-day effect and chronotype should be considered when designing a training program aimed to maximize training-induced adaptations. Prolonged travel may cause circadian desynchronization or jet lag that can be detrimental to health and performance. Athletes who are more easily affected by jet lag may consider adopting proper coping strategies in order to realign their circadian rhythms more quickly.

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