School attendance, chronotype and day-of-the-week effect in adolescent male basketball players

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RUNNING HEAD: School, chronotype, day of the week in adolescents

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Abstract

Adolescents' conflict between circadian rhythm and early school start time is more pronounced in evening chronotypes, who tend to reduce sleep duration during school days compensating during the free days by oversleeping (i.e., social jetlag). Cumulative weekly sleep debt may impair sport performance, which relies on physical and cognitive skills modulated by sleep. We hypothesized that chronotype predicts sport performance, and that it may interact with the day of the week. Moreover, given the role sleep plays in motor memory consolidation, we tested the hypothesis that school attendance, and the related chronic sleep deprivation, might be detrimental for participants in a training phase. Ninety-three adolescent male basketball players performed multiple free throw sessions (n = 7880) both during the school and holiday periods. Chronotype and its interaction with the day of the week significantly predicted shooting accuracy when attending school, but not on holidays. Evening types' performance gradually decreased form Monday to Friday. Participants with a more unstable performance (i.e., who did not complete the acquisition of the free throw motor scheme) worsened their accuracy when attending school. Our results suggest that the impact of chronotype and day of the week on sport performance is related to the presence of an externally imposed sleep/wake schedule and is consistent with evening types' increased likelihood of experiencing social jetlag. Possibly due to early school start time, attending school worsened the performance of participants in a training phase. Further investigations are required to assess whether reducing the mismatch between biological and social clocks might improve sport performance, along with other aspects of adolescents' life.

Keywords: adolescence, school start time, social jetlag, sport performance, memory consolidation.

Introduction

Adolescents experience a physiological delay in sleep timing, often more pronounced in males, that spontaneously reverts in the third decade of life (Carskadon and Tarokh 2014). This shift towards eveningness is so typical of this phase of development that its reversal has been proposed as a marker for the end of adolescence (Roenneberg et al. 2004). It is likely that this modification in sleep phenomenology is due to changes in both the circadian and the homeostatic sleep regulatory mechanisms (Carskadon et al. 1998). First, the transition to puberty is characterized by an increased sensitivity to the phase shifting effect of evening light exposure (Crowley et al. 2015), possibly being accountable for adolescents' delay in melatonin endogenous secretion (Carskadon et al. 1998). In line with this hypothesis, youngsters with a delayed circadian phase show a higher light-emitting devices use in the evening as compared to non-delayed peers (van der Maren et al. 2018). Second, a study conducted following a forced desynchrony protocol showed that adolescents have an internal period longer than 24 hours (Carskadon et al. 1999). This finding could explain the apparent inefficacy of morning light in resetting young humans' circadian internal period (Carskadon et al. 1998). Finally, sleep pressure seems to build up more slowly in teenagers as compared to prepuberal or early puberal children, resulting in a facilitation of late bedtimes. No difference emerged in terms of sleep recovery speed, suggesting that the short sleep duration associated with the delayed sleep onset may not be sufficient to dissipate a cumulative sleep debt (Jenni et al. 2005).

Adolescents' preference for late sleep timings conflicts with their social obligations. In most countries of the world, school attendance forces adolescents to wake up earlier than preferred, while their internal clock prevents them from anticipating sleep onset accordingly to achieve a sufficient amount of sleep (Tarokh et al. 2016). To manage early school start times (SSTs), teenagers tend to reduce the time devoted to sleep during school days (Hysing et al. 2013), compensating during the weekend by oversleeping (Owens et al. 2014). The mismatch between social and biological clocks, reflected by the discrepancy between sleep duration on school and free days, has been defined as social jetlag (SJL) (Wittmann et al. 2006). SJL is a form of circadian misalignment highly prevalent in this population (about 50% of a large sample of high school Japanese students reported more than one hour of SJL) and associated with an impaired daytime functioning (Tamura et al. 2022). The evening drift associated with adolescence could explain the high prevalence of SJL in this population (Wittmann et al. 2006; Levandovski et al. 2011). Sleep debt, indeed, is likely to accumulate faster during the week in evening chronotypes as compared to other circadian typologies: indeed, a delayed midsleep point was significantly associated with the increased likelihood of experiencing less than 8 hours of sleep per night in a sample of high school students whose SST was 7:30 am (Estevan et al. 2020). It is also likely that in evening types a greater sleep debt adds up to a higher degree of circadian misalignment, as eveningness has been associated with greater SJL (Wittmann et al. 2006). It is thus possible that the combination of a more severe chronic sleep deprivation and a higher degree of circadian misalignment leads evening types to a greater cognitive and academic impairment (Cohen-Zion and Shiloh 2018). Plausibly because of the conflict between SST and circadian rhythm, chronic sleep deprivation affects most American adolescents (Buxton et al. 2015). Among cognitive functions, memory encoding and sustained attention (Lo et al. 2016) have been demonstrated to be impaired in adolescents due to chronic sleep deprivation, possibly explaining the association between SJL and poor learning ability and academic performance (Haraszti et al. 2014; Tamura et al. 2022).

Optimization of sleep quantity and quality is necessary to achieve an optimal sport performance in adolescents athletes (Copenhaver and Diamond 2017). Results from a seminal work by Mougin showed how sleep-deprived athletes require an excessively high physiological demand for physical exertion that leads them to premature exhaustion (Mougin et al. 1991). Moreover, many sport-specific skills (e.g., shooting accuracy in basketball) are likely not to rely just on physical abilities, but also on neurocognitive dimensions such as alertness and motor planning (Fullagar et al. 2015). It is well known that sleep loss may impair those neurocognitive dimensions (Banks and Dinges 2007). Conversely, sleep extension has been shown to improve, in a sample of collegiate basketball players, both athletic (i.e., sprint time and shooting accuracy) and cognitive performance (i.e., reaction time scores) (Mah et al. 2011). Additionally, a recent work demonstrated that SJL may impair physical abilities, such as postural control (Umemura et al. 2018). Despite the raising awareness on how chronic sleep deprivation negatively affects student-athletes quality of life, mood and performance (Bolin 2019; Kroshus et al. 2019), reduced sleep duration is more common in this population as compared to non-athletes of the same age (Fox et al. 2020). For instance, a study conducted on a sample of 82 Portuguese adolescents gymnasts showed that 91.5% of participants slept less than 8 hours per night (Silva et al. 2018). The need of fulfilling both academic and training demands might play a role in reducing students-athletes sleep duration (Riederer 2020).

Optimal sleep might also improve athletic performance favoring the acquisition and refinement of motor schemes. Experience-dependent acquisition of motor schemes is paralleled by plastic cortical reorganization. Karni and colleagues (1995) demonstrated that an increase in speed and accuracy of motor performance is associated with an extension in the task-subserving area of the primary motor cortex. The authors also suggested that the expansion of movements cortical representation and long-term learning are consequences of the creation of new synapses (Kami et al. 1995). New synapses steadily form during wake, while during sleep a selective downscaling allows the acquisition of new information on the consecutive wakefulness period. Selection is based on use. Synaptic pruning, indeed, equally affects all neural connections, but the strongest are more likely to be retained (de Vivo et al., 2017). This phenomenon could contribute to explain sleep relevance for offline memory processing, which spans across several cognitive domains, including motor learning (Stickgold 2005). A few studies demonstrated a rehearsal-independent post-training improvement in either a motor sequence test (Walker et al. 2002) or a motor adaptation test (Huber et al. 2004) after a night of sleep but not after an equivalent wake duration. The same studies also proved how post-training sleep deprivation interferes with the offline motor enhancement, and chronic sleep deprivation has been associated with an impairment in procedural learning (Curcio et al. 2006). Long-term memory consolidation might be mediated by the coordinated occurrence of sleep spindles and slow oscillations (Klinzing et al. 2019). Using a real-life gross-motor task (i.e., juggling), Hahn and colleagues associated improved task proficiency with overnight slow oscillations-spindles coupling precision in motor areas (Hahn et al. 2022).

The first aim of the study was to explore whether chronotype predicts a basketball-specific skill (i.e., the probability of a successful free throw) interacting with the day of the week, both during the school period and on holidays, in a sample of middle and high school students. We hypothesized that participants with the greatest propensity towards eveningness would experience a decrease in shooting accuracy throughout the week along with the accumulation of the sleep debt only when the sleep/wake rhythm is dictated by an externally imposed schedule (i.e., school times). The second aim was to test whether early school start times negatively impacts the shooting accuracy of participants in a training phase and not of those who already completed the acquisition of the free throw motor scheme. We hypothesized that the school schedule, critically reducing students' sleep duration, would interfere with motor learning consolidation mechanisms.

Materials and Methods

Study design and participants

Ninety-three male basketball players (mean age 15.44 years; range 13-17) from four sport clubs from Pisa area (Italy) participated in the study. They performed multiple 10-free throw sessions (overall number of free throws, n = 7880), both during the school period (n = 2720) and the summer holidays (n = 5160). Free throws were performed in the last part of a 2-hour training session. During each session, participants performed 5 pairs of free throws in a random shooting order. On average, each participant performed 75 free throws. Two experimenters, in their capacity of youth basketball coaches (FF and IG), assessed the number of successful throws and a number of session-related variables specified below. Participants also filled in a questionnaire exploring age and chronotype. During the school period, all participants attended school from 8:30 am to 1:30 pm, from Monday to Saturday. Informed written consent from participants' parents and assent from participants were obtained before joining the experiment. The study was conducted in accordance with the declaration of Helsinki and received the approval of the Bioethical Committee of the University of Pisa on 2020 April 10th, with protocol number 0036351/2020.

Measures

Within-session shooting accuracy was considered as an index of sport performance. An estimate of the probability of scoring was calculated dividing the number of successful free throws out of 10 shots by the total number of free throws (i.e., 10). A high standard deviation of the shooting accuracy across sessions was treated as a proxy for being in a training phase. A high standard deviation reflects performance instability, which in turn is an index of not having completed the acquisition of a motor scheme (Wu and Latash 2014). Therefore, we operationalized participants' learning phase through the between-session standard deviation of shooting accuracy and participants' performance through the within-session shooting accuracy.

Chronotype was assessed using the reduced version of the Morningness/Eveningness Questionnaire (rMEQ). rMEQ is the 5-item version of the questionnaire first validated by Horne and Ostberg. Its score ranges from 4 to 25; a high score stands for a great propensity towards morningness, while a low score for eveningness. The Italian validated rMEQ version was administered to participants of the current study (Natale et al. 2006).

Session-related variables included:

- The day of the week in which the session took place. As a regressor, it was converted into a quantitative variable reflecting the distance from Sunday expressed in days (i.e., Monday = 1, Tuesday = 2…). No session was performed on Saturdays and Sundays.
- The time of the day in which the free throw-session started. As a regressor, it was converted into a quantitative variable indicating the number of minutes between the previous midnight and the start of the free throw session (i.e., 8:45 = 525 minutes, 19:10 = 1150 minutes…).
- School attendance, that is whether participants were attending school or were on holidays during the session, as reported by them before each session started.
- Participants' category, an index used by sport clubs to stratify athletes by age and expertise (e.g., U14 ELITE stands for Under 14 best players). Participants from categories U13, U14 ELITE, U15, U15 ELITE, U16, U17 ELITE, U18, U18 ELITE took part in the study.

To explore possible differences in sleep-related parameters between school and holiday periods and their possible association with chronotype, a subsample of 39 participants continuously wore an actigraph (Fitbit Inspire 2) for seven days on their non-dominant wrist, with the exception of 10 participants who took it off for two hours during an official competition, as prescribed by the Italian Basketball Federation. 24 participants wore the actigraph when attending school, 6 on holidays, 9 during both school and holiday periods, for a total of 48 actigraphic recordings (33 during school, 15 during holiday). Sleep parameters (Total Sleep Time, TST; Wake After Sleep Onset, WASO; Sleep Efficiency, SE; Sleep Regularity Index, SRI; (Littner et al. 2003; Phillips et al. 2017)) were derived through the artificial neural network (ANN)-based validated algorithm Dormi by sleepActa s.r.l. (Banfi et al. 2021). Dormi is a medical, risk class I device registered within the Italian Ministry of Health Data Bank of Medical Devices (CND: 217 Z12030682).

Based on Ancoli-Israel and colleagues (Ancoli-Israel et al. 2003) recommendations, participants' circadian rhythm was assessed based on activity detected through accelerometric sensors by using both a parametric and a non-parametric approaches. The cosinor method (Cornelissen 2014) applied to actigraphy consists in fitting a 24-hour period sine wave to activity data and computing the following metrics to describe the fitted curve:

- The Midline Estimating Statistic of Rhythm (MESOR), that is the rhythm-adjusted mean which represents the mean activity level;
- The amplitude, that is half of the peak-to-nadir difference. It ranges from 0 to 1, with higher values indicating greater rhythm robustness;

- The acrophase, that is the timing of peak activity, which depends on chronotype (Vitale et al. 2015; Roveda et al. 2017).

The following non-parametric measurements of rest-activity rhythms (van Someren et al. 1999) were computed based on accelerometry:

- Interdaily stability (IS), an estimate of the variability in rest-activity patterns across all days. It ranges from 0 to 1, where higher values indicate higher rest-activity rhythm regularity;
- Intradaily variability (IV), which measures circadian fragmentation within each day by quantifying rest-activity transitions. In healthy participants usually range from 0 to 2, where higher values indicate more frequent transitions (e.g., frequent naps, increased night-time awakenings);
- Relative amplitude, measuring the robustness of the 24-h rest-activity rhythm by calculating the normalized mean difference in activity between the most active 10 hours and the least active 5 hours. It ranges from 0 to 1, where higher values indicate increased circadian pattern robustness.

Social jetlag was computed as absolute values based on Jankowski formula (Jankowski 2017), which add a correction for cumulative sleep debt to the classic one. The sleep debt corrected sleep midpoint was computed according to Roenneberg and co-workers (Roenneberg et al. 2007).

Statistical analysis

Mean and standard deviation were reported for quantitative variables (i.e., age, rMEQ score, shooting accuracy, standard deviation of shooting accuracy, actigraphy-derived parameters), frequency and percentage for categorical ones (i.e., sport category, time of day, day of the week). Student t-test was used to compare quantitative variables between school and holidays period sessions; Fisher exact test to compare the categorical ones. Pearson test was used to correlate rMEQ score, sleep midpoint and acrophase with social jetlag. A random-effects logistic regression model was fitted to identify predictors of shooting accuracy. Natural cubic splines, with a single knot at the median, were used to describe the effect of chronotype, the day of the week, the time of day and the standard deviation of shooting accuracy. Moreover, some of the regression equations include the tensor product between two spline bases, that defined an interaction term, as specified in the following sections. To test our first hypothesis, Likelihood Ratio Test was used to compare two nested random effects logistic regression models with and without chronotype and day of the week interaction. The analysis was repeated in the whole sample, considering only school sessions, and considering only holidays sessions. To test our second hypothesis, Likelihood Ratio Test was used to compare two nested random-effects logistic regression models with and without school attendance, standard deviation of shooting accuracy, and their interaction. Models were adjusted for the following covariates: age; sport category; chronotype, time of day and their interaction. Models on school attendance also included as regressors chronotype and its interaction with the day of the week. All analyses were conducted using R version 4.1.0. Parametric circadian metrics were computed using R package "cosinor"; non-parametric, using the "nparACT" R package (Blume et al. 2016). All tests were two-sided, and the level of significance was set at 0.05.

Results

Descriptive statistics of the whole sample, as well as stratified by school/holidays, are displayed in Table 1. Athletes who performed the free throws when attending school were on average younger, with greater expertise and lower degree of eveningness. Moreover, since they were attending school in the morning, during the school period no data collection took place before 2 p.m. Finally, a significant difference emerged also in the distribution of the free throw sessions across the days of the week. The models predicting sport performance were hence adjusted for all these potential confounders.

PLEASE INSERT TABLE 1 ABOUT HERE

To identify predictors of shooting accuracy, we estimated a random-effects logistic regression model considering the binary indicator of scoring as dependent variables, and including the following regressors: age, chronotype (rMEQ score), time of day, day of the week, sport category, attending school, and performance stability (standard deviation of the shooting accuracy). Sport category and chronotype emerged as the only significant predictors of sport performance (Table 2). In particular, shooting accuracy increased along with both sport expertise and morningness.

PLEASE INSERT TABLE 2 ABOUT HERE

Table 3 summarizes regressors and samples of the models estimated in the current study. All models were fitted considering shooting accuracy as dependent variable.

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To further assess the role of chronotype and of its interaction with the day of the week in predicting scoring accuracy, we compared M1 and M2. The models were significantly different ($p = 0.02$), suggesting that chronotype significantly predicted sport performance interacting with the day of the week. Figure 1a illustrates the relationship binding chronotype, day of the week and shooting accuracy in the whole sample.

To clarify the role of school attendance in modulating the predictive power of chronotype on performance, we compared M3 with M4, and M5 with M6. Results showed that chronotype interacting with the day of the week held its predictive power only during the school period ($p = 0.05$), but not on summer holidays ($p = 0.12$). Figure 1b and 1c illustrate the relationship binding chronotype, day of the week and probability of scoring during the school period and during the holidays period, respectively.

PLEASE INSERT FIGURE 1 ABOUT HERE

To test the hypothesized influence of school attendance on SJL, and therefore on performance of participants in a training phase, we compared M7 with M8. Results showed that attending school predicted a significant drop in sport performance of participants with a high standard deviation of shooting accuracy (i.e., greater performance instability) ($p = 0.02$). Figure 2 graphically displays the relationship binding the predicted shooting accuracy and its standard deviation both during the school period and the holidays period.

PLEASE INSERT FIGURE 2 ABOUT HERE

To support our assumption that participants in school/holiday periods have different sleep/wake rhythms, we compared the actigraphy-derived metrics of participants who wore the device when attending school and of those who wore it on holiday. Overall, results suggest that on holidays participants experienced a delay in sleep/wake cycle (about 75 minutes, as measured both as the rest/activity acrophase and as the sleep debt corrected midsleep point) which was paralleled by an increase in sleep duration (about one hour), particularly apparent during weekdays. When attending school, participants increased sleep/wake cycle and rest/activity rhythm regularity, while also increasing rest/activity fragmentation. Results are fully displayed in table 4.

PLEASE INSERT TABLE 4 ABOUT HERE

Participants on average experienced 49 (41) minutes of Social Jetlag. To support our hypothesis that SJL might explain chronotype differences in sport performance across the days of the week, more specifically, that SJL might explain the decline in shooting accuracy from Monday to Friday associated with eveningness, we tested SJL correlation with both subjective (i.e., rMEQ score) and objective (i.e., sleep debt corrected midsleep point and rest/activity rhythm acrophase) measures of circadian typology. SJL showed a negative, non-significant correlation with rMEQ score ($r = -0.19$, $p = 0.30$), a positive significant correlation with the acrophase ($r = 0.30$, $p = 0.04$) and a strong, positive, significant correlation with sleep midpoint ($r = 0.80$, $p < 0.001$). Although not fully conclusive, these results suggest that also in our sample eveningness is associated with a higher degree of SJL.

Discussion

In the present study we aimed at exploring the effect of chronotype and its interaction with the day of the week on sport performance in a sample of adolescent male basketball players, both during school and holiday periods. Moreover, we tested whether early school start times (SST) might be particularly detrimental for participants in a training phase. Our results support the hypothesis that chronotype interacts with the day of the week in predicting performance only if participants follow an externally imposed sleep schedule (i.e., school attendance). We also found a drop in performance throughout the week in participants with the greatest propensity towards eveningness attending school, which is consistent with a cumulative sleep debt secondary to social jetlag (SJL). Finally, we observed a drop in the shooting accuracy of participants with a larger performance instability during the school period as compared to the holiday period, thus confirming also our second hypothesis, claiming that school attendance, and the related chronic sleep deprivation, negatively interferes with motor learning.

Contrasting the nested models including or excluding chronotype and its interaction with the day of the week revealed a significant predictive power of the variables of interest on sport performance in the whole sample, only when considering participants attending school, but not when considering the same participants on summer holidays. This result suggests that the impact of chronotype in interaction with the day of the week on sport performance relies on externally imposed sleep/wake schedule. Moreover, taking into account the predicted values of chronotype, i.e., rMEQ score, day of the week, and shooting accuracy, we showed that during the school period, participants with a greater propensity towards eveningness reached their performance peak on Mondays, whereas their shooting accuracy gradually decreased throughout the week reaching the minimum on Fridays. This weekly performance trend is absent in the same participants during the holiday period and in participants with a lower eveningness propensity during the school period, suggesting it is both chronotype- and school-related. The weekly performance pattern of participants with the lowest rMEQ score mirrored the typical SJL sleep pattern. Indeed, they achieved their best performance soon after their free days, after they had the chance to compensate for their chronic sleep deprivation. As the days of the week pass, sleep debt gradually accumulated again, causing cognitive and physical impairments (Suppiah et al. 2016) reflected by a decrease in shooting accuracy. The correlations between SJL and chronotype measures in the subsample who wore an actigraph, although not fully conclusive, seems to support our assumption. With respect to other circadian tipologies, morning types showed a bimodal weekly performance pattern both in the whole sample and during the school period, with performance peaks on Mondays and Fridays. Participants with an intermediate rMEQ score, instead, seemed to be insensitive to the day-of-the-week effect. To the best of our knowledge, there is no strong theoretical background that could explain weekly performance fluctuations (or lack of fluctuations) across different chronotypes. However, Brooks and colleagues (Brooks et al. 2021) recently demonstrated, in a sample of young males, that morning types more effectively manage circadian rhythm transitions between free days and weekdays as compared to evening types. Their findings might contribute to explain the shooting accuracy trajectories across the days of the week predicted by our model and their distribution according to rMEQ score. Indeed, it is possible that the performance peak showed on Mondays by both morning and evening types is due to the possibility of recovering on Sunday. As the days of the week pass, both morning and evening types pay, in term of sport performance, the consequences of adjusting to the workdays rhythm. Towards the end of the week, the differences between the most morning and the most evening participants become strikingly apparent. Having quickly adjusted to the new sleep/wake cycle, which is close to their individual preferences, morning types show an increase in shooting accuracy which peaks on Fridays; on the other hand, too slowly adapting to the new sleep/wake cycle, which works against their individual preferences, evening types shooting accuracy keeps degrading reaching the minimum on Fridays. Brooks et al. did not address intermediate types sleep/wake cycle across the week. However, we might speculate that not having an extreme chronotype might make smoother the transitions between free days rhythm and weekdays rhythm, which reflects on a more constant performance across the week. Further studies are required to explore whether more factors might contribute to explain weekly trends of sport performance according to chronotype.

The final models revealed a significant effect of the interaction between the standard deviation of the shooting accuracy across sessions and attending or not school in predicting the binary indicator of scoring. Several models of motor learning describe the acquisition of a motor scheme through practice as the reduction of output variability (Wu and Latash 2014). It is thus likely that a high standard deviation of the shooting accuracy (i.e., an unstable performance) would identify participants who did not complete the acquisition of the free-throw scheme. It is unlikely that attending school could directly interfere with learning processes. It is more probable that early SST acted as sleep and circadian disruptor for adolescents (Owens et al. 2014; Crowley et al. 2018), and that sleep disruption interfered with learning processes. Indeed, in the subsample who wore the actigraphs, participants on holiday slept on average one hour more as compared to participants attending school. In line with our result, the 63.2 % of a large sample of Suisse high school students declared their preference for a delay in SST of about an hour (Werner et al. 2022). Early SST-related insufficient sleep duration has been associated with poor academic performance in high school students (Wahlstrom and Owens 2017). Conversely, several studies have proven the association between later SST and longer sleep duration (Gariépy et al. 2017), higher perceived quality of life (Lo et al. 2018), lack of SJL (Carvalho-Mendes et al. 2020) and improved academic performance (Wahlstrom and Owens 2017) in adolescents from several countries. These results suggest that school schedule could be currently mismatched with students' chronobiology, and that a delay in SST would grant them several benefits. Moreover, sleep plays a crucial role in motor learning consolidation (Walker et al. 2002). Sleep-related training-independent motor task proficiency improvements have been demonstrated for motor sequence tests (Walker et al. 2002), motor adaptation tests (Huber et al. 2004) and, more recently, for gross-motor tasks, i.e., real-life situations similar to the acquisition of abilities instrumental to optimize sport performance (Hahn et al. 2022). Early SST-related chronic sleep deprivation might hence interfere with students' offline sport skills improvement, being thus accountable for their worse performance during the school period as compared to the holiday period (that is, when no external schedule determined sleep duration). If our interpretation is correct, this result would be consistent with previous works assessing the negative impact of SJL on learning and academic performance (Haraszti et al. 2014), translating this notion into the realm of sport science.

Our findings are based on a relatively large set of observations: the results of almost eight thousand free throws have been fed into our models. Moreover, our study should be credited to be one of the few exploring the day-of-the-week effect in adolescence, and, to the best of our knowledge, the only one stratifying for chronotype and focusing on sport performance. Before us, only Suppiah and colleagues (2016) reported that adolescents athletes' reaction times in the second part of the week are slower as compared to the first part of the week (Suppiah et al. 2016). Previous works focusing on individual chronobiology and basketball-specific skills, instead, mainly explored the effect of the interaction between chronotype and time of day (Pengelly et al. 2022). However, our study has limitations that should be discussed. To interpret our results, we made assumptions on participants' sleep schedule. In particular, we hypothesized that on holidays participants had a longer sleep duration as compared to school days and that evening types experienced a greater SJL as compared to other circadian tipologies. Even if our assumptions are solidly supported by the literature background, and also the actigraphic data we collected in a subsample of our participants seem to support them, these findings should have been coupled with a sleep/wake cycle monitoring in every student/athlete who took part in the study, making the interpretation partially speculative. Moreover, females were not included in the study, and we cannot exclude that SJL has gender-specific effects. Further investigations should assess the replicability of our results in a female sample. Finally, the difference between the time of day in which performance was addressed during school and holiday periods might have made comparisons a challenge. This difference is due to participants school schedule, which prevent them from engaging in sport activity in the morning during the school period. Nevertheless, this asymmetry in time-of-day distribution might have been a source of undesired heterogeneity, which we addressed by including the time of the day and its interaction with chronotype as a regressor in our models. Adjusting the models for the time of the day and its interaction with chronotype might have alleviated discrepancies in time-of-day distribution between school/holiday periods and improved results generalizability.

In conclusion, the day of the week modulates chronotype predictivity on sport performance only if an externally imposed sleep schedule is present. Moreover, during the school period, evening types' weekly performance pattern was consistent with their increased likelihood of experiencing social jetlag, suggesting that circadian misalignment negatively affects sport performance. Performance was also negatively affected by school attendance in participants who showed a highly fluctuating accuracy, confirming the role sleep plays in motor memory consolidation, in a naturalistic setting. Our results are in line with previous works demonstrating that, whenever possible, school start time should be delayed to let students achieve a sufficient amount of sleep. Alternatively, sleep hygiene intervention aimed at advancing the circadian phase might allow a better match between students' actual and preferred sleep timings. Finally, trainers and athletes should be aware that, according to chronotype, performance could be influenced by the day of the week, and not only by the time of the day. Further investigations are required to assess whether later school start times might improve sport performance along with other aspects of students' life.

Data Availability Statement

The data underlying this article cannot be shared publicly for the privacy of individuals that participated in the study. The data will be shared on reasonable request to the corresponding author.

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Declaration of conflicting interests

U.F. is co-founder and president of Sleepacta S.r.l., a spin-off company of the University of Pisa operating in the field of sleep medicine. All other authors declare no competing interest.

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Figure captions

Figure 1. Chronotype, day of the week and shooting accuracy

Figure 1 graphically displays the weekly performance trends of shooting accuracy predicted by our models in the whole sample (1a), during the school period (1b) and during the holiday period (1c) for three rMEQ values (i.e., chronotype) representative of our sample distribution: the minimum (i.e., 10, Evening types), the median (i.e., 15, Intermediate types), the maximum (i.e., 20, Morning types). Chronotype interacting with the day of the week significantly predicted sport performance in the whole sample (Likelihood Ratio Test, $p = 0.02$; Figure 1a), during the school period (Likelihood Ratio Test, $p = 0.05$; Figure 1b), but not on holidays (Likelihood Ratio Test, $p = 0.12$; Figure 1c). Moreover, participants with the greatest propensity towards eveningness showed a weekly performance pattern consistent with a typical social jetlag weekly sleep pattern, but only when attending school (Figure 1b). Their shooting accuracy, in fact, gradually decreases throughout the week in parallel with their cumulative sleep debt; it achieves instead the peak on the first day after their free day (i.e., Sunday), when they had the chance to compensate for their school days chronic sleep restriction.

Figure 2. School, motor learning and shooting accuracy

Figure 2 displays performance instability (standard deviation of the probability of scoring) and performance accuracy (probability of scoring) relationship during school period and during holiday period. Within the conceptual framework proposing motor learning as the acquisition of a motor scheme through practice, measured as the reduction of output variability, we considered performance instability as a proxy of learning. School attendance interacting with performance instability significantly predicted performance accuracy (Likelihood Ratio Test, $p = 0.02$), suggesting that attending school did not equally affect the sport performance of participants in different learning phase. In particular, participants with a higher performance instability show a worse shooting accuracy during the school period as compared to summer holidays. School-related chronic sleep-deprivation interfering with motor learning processes might explain this finding.