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Sleep and psychological factors are associated with meeting discharge criteria to return to sport following ACL reconstruction in athletes

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ABSTRACT: This study aimed to determine if sleep quality and psychological factors were associated with time to meet the discharge criteria to return to sport (RTS) following anterior cruciate ligament reconstruction (ACL-R) among athletes. A cohort-study design included 89 athletes following ACL-R. Each participant completed a battery of questionnaires at 6 different time points: within 3 days of injury occurrence and at post-surgery (1.5 m, 3 m, 4.5 m, 6 m and when discharge criteria were met). Assessment included sleep quality and quantity, symptoms of depression, anxiety, stress, psychological readiness to RTS and fear of re-injury. The primary outcome was the time needed to meet all discharge criteria to RTS. Sleep parameters and psychological factors were not associated with time to meet the discharge criteria to RTS. However, athletes that had lower scores of anxiety (OR 1.2 (95% CI 1.0, 1.3) and insomnia (OR 1.2 (95% CI 1.0, 1.3) at baseline were more likely to meet the RTS discharge criteria. Athletes with better sleep quality at 3m, 4.5m and 6m were more likely to meet the RTS discharge criteria OR 1.3 (95% CI 1.1, 1.7), 2.0 (95% CI 1.1–3.4) and 1.4 (95% CI 1.0, 1.9) respectively. Sleep quality and psychological factors were not associated with time to meet the discharge criteria to RTS but impacted whether athletes adhered and completed their rehabilitation program or not. Monitoring sleep quality and psychological factors of athletes before and following ACL-R surgery is important to identify athletes who could have difficulties in adhering to and completing their rehabilitation program to RTS.

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INTRODUCTION

Sleep is a basic physiological need representing approximately one third of the human life cycle [1]. The National Sleep Foundation recommends 8 to10 hours of sleep per night for adolescents and adults [2] with no specific recommendations for athletic populations. Failing to adhere to the recommended sleep durations can results in negative health outcomes such as cardiovascular disease, diabetes, obesity and/or depression [3]. Moreover, poor sleep across several days/weeks may potentially predispose athletes to injury with the increase of chronic fatigue levels [4]. In addition and more specifically, deep-sleep has been shown to be essential for injury recovery and for accelerated healing [5].

Anterior cruciate ligament (ACL) rupture is the most common major ligament injury in athletes for which ACL-R (ACL- Reconstruction) is routinely [6]. Adequate post-operative rehabilitation lasting between six and twelve months is essential to ensure safe recovery [7, 8], and athletes are expected to follow a standardized daily physiotherapy program until they can return to sport (RTS). RTS is an important outcome when evaluating the success of ACL-R surgery in athletes[9]. However, it has been reported that prolonged stays in hospital or rehabilitation centers are associated with the disruption of the sleep-wake cycle [10] questioning if those disruptions affect injury recovery and RTS. It has been reported that 50% of athletes who undergo an ACL-R (and were free from muscle soreness) have suffered sleep disturbances and report poor sleep quality [11]. Therefore, sleep appears to be an important factor to evaluate during the rehabilitation phase post- ACL-R.

Even if both surgery and rehabilitation are effectively performed, two-thirds of patients may not return to their preinjury sport level 12 months after ACL-R [12–14] . For an athlete population this is even more important not only from a performance prospective, but also because athletes who do not fully recover before returning to sport after ACL-R have a four times higher risk of reinjury, i.e. sustaining an ACL graft rupture [15]. Further, even athletes with good knee function do not often return to their previous level of sports participation after ACL-R, and the rate of return to the pre-injury level and competitive sport remains very low[9]. This suggests that factors other than knee function may influence the RTS. In a recent study, Kosy et al., 2019 [16] investigated the ability of athletes to RTS after ACL-R and the reasons associated with failure to RTS. They concluded that failure was associated with physical symptoms in 67% of the athletes and to psychological factors in 77% of them, with the main factors being anxiety, depression and fear or re-injury. Suffering from anxiety and fear of re-injury often results in higher levels of fear of movement (Kinesiophobia) and is generally exacerbated once an athlete has been cleared to RTS [16, 17]. Finally, depression that can be as high as 42% in patients having undergone ACL-R, and can be aggravated by the decreased quality of sleep during rehabilitation with a significant resulting influence on knee function outcomes [18, 19].

In order to take into consideration these psychological factors and optimize RTS [20], a commonly used discharge criteria after ACL-R is the psychological readiness to RTS [21]. In a recent study Kitaguchi et al., (2019) [22] compared two groups of athletes, those who returned to sport one year post ACL-R and those who didn't. They determined that single-leg hop and psychological readiness to RTS at 6 months were the main factors that were associated with a greater risk of unsuccessful RTS at 1-year post-surgery.

Taken together these studies suggest that athletes with maladaptive psychological responses to injury and/or having a poor sleep quality and/or quantity may be at risk for suboptimal recovery and resulting delay in the time to RTS [23]. Recently, Webster et al., (2018) [24] acknowledged that factors that contribute to the psychological status of athletes who RTS after ACL-R might be different from those of athletes who do not RTS.

The purpose of the present study was therefore to investigate the impact of sleep and psychological factors on the athletes' rehabilitation outcome following ACL-R. We hypothesized that sleep quality and psychological factors will be associated with time to meet the discharge criteria to RTS with the athletes experiencing better quality of sleep and psychological responses returning faster to full activity.

MATERIALS AND METHODS

Participants

Eighty-nine male athletes who had undergone ACL reconstruction from May 2015 to September 2017 gave written informed consent to participate to this study. Ethical approval was obtained from the Ethics Committee of the Anti-Doping Lab Qatar Institutional Review Board (IRB application number F2014000063). The study was designed in accordance with the 1964 Helsinki Declaration. The inclusion criteria were male athletes having undergone an ACL reconstruction surgery: age above 18 to 37 years; (oldest participant); full time athletes belonging to any sport; only male athletes were included due to unavailability of female athletes; all athletes who stopped their rehabilitation program before 6 months were excluded from the analysis.

Procedure

The participants were assessed for sleep and psychological factors by two clinicians in a quiet environment at 6 time points: (i) within 3 days of post-injury incident: retrospective assessment of sleep (1 month prior to) and psychological factors (1 week prior to ACL injury) (baseline), (ii) at 1.5 month (1.5 m), (iii) 3 months (3 m), (iv) 4.5 months (4.5 m), (v) 6 months (6 m) post-surgery, and (vi) when meeting the discharge criteria to RTS (post-surgery assessments were performed every six weeks as per standard ACL protocol till meeting discharge criteria to RTS). Assessment included sleep quality and quantity and psychological factors using face-to-face administered questionnaires (see below). The RTS where the athlete could return to unrestricted sports activities in his respective sport club were criteria-based, not time-based. Athletes were discharged to RTS only upon completion of eight standardized discharge criteria: < 10% difference between legs for the isokinetic force of the quadriceps at $60°.s^{-1}$, hamstring/quadriceps ratio > 55% during the isokinetic testing at $60°.s^{-1}$, < 10% difference between legs during the hop-testing, all tests performed pain-free ,stable knee, educated on prevention and maintenance and completed surgical review [15]. For the analysis, athletes were assigned to two groups: (i) meeting the discharge criteria group (MDG) to RTS and (ii) did not meet the discharge criteria group (NDG) to return to sport. In our study, the treatment adherence was measured by physiotherapy appointments attendance and eventual withdrawal from the Rehab program.

The discharge dates were different from one athlete to another as surgery dates varied. In addition, it is possible that athletes did meet the discharge criteria to RTS well ahead of the assessments, which were scheduled every six weeks.

Sleep assessment

The Pittsburgh Sleep Quality Index (PSQI) was used to assess subjective sleep quality over the previous month (pre-injury). The PSQI consists of 19 items to assess seven components of sleep: quality, duration, latency, efficiency, disturbances, use of sleep drugs and daytime dysfunction. The PSQI provides score of sleep quality and quantity (range: 0–21) with higher scores indicating poor sleep quality or more sleep difficulties. A PSQI threshold score ≥ 5 was used to indicate poor sleep quality and has been used in similar populations [25].

The Insomnia Severity Index (ISI) was used to assess subjective symptoms of insomnia over the previous month. It consists of seven

questions rated on a scale ranging from 0 to 4, with a total score of up to 28 points, with higher scores indicating insomnia. Commonly adopted thresholds were used, with ≥ 11 suggesting subthreshold insomnia and ≥ 15 suggesting clinical insomnia [26].

The Epworth Sleepiness Scale (ESS) was used to measure daytime sleepiness in eight different situations and activities of everyday life (e.g., watching TV, reading) within the previous month. Each item is measured on a scale of 0 ("would never doze") to 3 ("high chance of dozing") and total scores can range from 0 to 24 [27]. Normal ESS values range from 0 to 8 ; however, a cut-off of > 8 indicates excessive daytime sleepiness in clinical sleep disorders populations [28].

Psychological states assessment

The Depression, Anxiety & Stress Scale (DASS-21): a short form of DASS, was used to assess Depression (DASS-D), Anxiety (DASS-A), and Stress (DASS-S) over the previous week through seven items, responses ranged was from 0 (did not apply to me at all) to 3 (applied to me very much). The intensity of any of the three conditions are determined by the sum scores of responses to its 7-item subscale [29].

Anterior Cruciate Ligament RTS After Injury (ACL-RSI) was used to measure psychological readiness to RTS after ACL-R. The ACL-RSI is a 12-items scale that measures 3 types of responses believed to be associated with the resumption of sport following athletic injury: emotions, confidence in performance, and risk appraisal. The total score was obtained by adding the values of the 12 responses then calculating a percentage. High scores correspond to readiness to RTS [30].

Tampa Scale for Kinesiophobia (TSK) is a 17 items questionnaire that was used to assess the subjective rating of Kinesiophobia or fear of movement. The TSK is a self-completed questionnaire and the range of scores is from "17" to "68" where the higher scores indicate an increasing degree of Kinesiophobia [31].

Statistical Analysis

All data were coded and entered to the SPSS software v21.0. Continuous variables were described as mean ± SD and categorical variables were summarized as frequency and percentage. All continuous variables were tested for normality and presence of outliers using Shapiro-Wilk test. The Pearson's correlation coefficient was used to describe the correlation of sleep, and psychological factors at baseline, 1.5 m, 3 m, 4.5 m, 6 m and at discharge among those who met the discharge criteria and returned to sport. An independent samples t-test was used to compare the means of sleep indices and psychological factors at all assessment points between athletes who met the discharge criteria MDG compared with those who did not meet them NDG. Factors that were significantly associated with meeting the discharge criteria in the univariate analysis were added to a binary logistics regression separately for each time point. Odds ratio (OR) with 95% confidence intervals (CI) were reported. A $p < 0.05$ was considered as threshold for statistical significance.

TABLE 1. Characteristics of the athletes at baseline (n = 89).

Summary	Mean ± SD	Median (min-max) or %
Age (years)	23.8 ± 5.3	23 (18–37)
Height (cm)	177.9 ± 8.5	176 (161–203)
Weight (kg)	77.7 ± 12.4	76 (55–109)
Experience	12.6 ± 5.4	12 (4–32)
Ethnicity		
Arab	35	39.3%
Qatar	24	27.0%
African	17	19.1%
Caucasian	6	6.7%
Asian	7	7.9%
Marital status		
– *Single*	65	73.0%
– *Married*	18	20.2%
– *Not mentioned*	6	6.8%
Sport Type		
Team	85	95.5%
Individual	4	4.5%
Sport		
– *Athletics*	1	1.1%
– *Basketball*	5	5.6%
– *Beach ball*	1	1.1%
– *Cycling*	1	1.1%
– *Fencing*	1	1.1%
– *Football*	55	61.8%
– *Futsal*	7	7.9%
– *Handball*	14	15.7%
– *Rugby*	2	2.2%
– *Volleyball*	1	1.1%
– *Wrestling*	1	1.1%
Division		
1st Division	61	68.5%
2nd Division	11	12.4%
Amateurs	17	19.1%
Discharge status		
Discharged after Meeting discharge criteria to RTS (MDG)	46	51.7%
Self-discharged after six months without meeting discharge criteria (NDG)	31	34.8%
Self-discharged prior to six months	7	7.9%
Others*	5	5.6%

*Two athletes (2.2%) returned back to home country, 1 athlete (1.1%) was reinjured during his rehabilitation program in his club, 1 athlete (1.1%) underwent cartilage surgery and 1 athlete (1.1%) was still in rehabilitation program.

TABLE 2. Correlation of sleep parameters, and psychological factors at baseline, 1.5 m, 3 m, 4.5 m, 6 m and at discharge with time from surgery to discharge

Parameters	Baseline	1.5 m	3 m	4.5 m	6 m	Discharge
PSQI	-.066	.237	.148	.142	.203	.108
ESS	-.024	.037	-.058	-.336	.358*	-.146
ISI	-.153	.047	.039	-.335	.044	.015
Tampa		-.003	.177	-.072	.202	.047
RSI ACL		-.038	-.108	-.068	.119	.149
Depression	.006	-.017	.097	.004	.167	.003
Anxiety	-.108	.054	-.056	.099	-.148	-.043
Stress	.111	.236	.173	.029	.048	.082

PSQI: Pittsburg Sleep Quality Index; ESS: Epworth Sleepiness Scale; ISI: Insomnia Severity Index; RSI ACL: Anterior Cruciate Ligament RTS After Injury (psychological readiness to return to sport).

TABLE 3. Sleep and psychological factors before and post ACL-R surgery until meeting discharge criteria to return to sport (MDG = 46, NDG = 31)

Parameters	Baseline		1.5 m		3 m		4.5 m		6 m		Discharge	
	MDG	NDG	MDG	NDG	MDG	NDG	MDG	NDG	MDG	NDG	MDG	NDG
	n = 32	n = 19	n = 30	n = 17	n = 38	n = 22	n = 26	n = 16	n = 33	n = 17	n = 44	n = 30
Pittsburg Sleep Quality	5.5 ± 2.3	6.8 ± 2.5	6.0 ± 3.3	7.2 ± 3.2	4.9 ± 2.6	7.0 ± 2.5*	4.0 ± 1.5	7.1 ± 3.9*	4.0 ± 1.8	5.9 ± 2.8*	4.3 ± 2.3	5.3 ± 2.6
ESS	7.1 ± 4.2	7.2 ± 3.8	6.1 ± 4.3	4.9 ± 2.4	5.8 ± 4.1	5.5 ± 3.6	4.0 ± 3.5	6.5 ± 4.4	4.3 ± 3.2	3.9 ± 3.7	4.0 ± 3.6	4.9 ± 4.2
ISI	7.6 ± 4.5	12.1 ± 4.2*	7.6 ± 6.3	9.0 ± 5.8	6.7 ± 4.7	10.0 ± 5.5*	6.5 ± 3.7	11.1 ± 7.2*	6.4 ± 5.3	9.5 ± 6.6	6.1 ± 5.4	7.9 ± 5.9
Depression	6.8 ± 6.7	12.4 ± 9.2*	6.5 ± 8.1	10.1 ± 8.5	5.9 ± 7.2	8.3 ± 7.6	4.8 ± 6.6	6.7 ± 7.2	2.5 ± 5.5	5.7 ± 8.6	5.2 ± 8.4	5.2 ± 7.1
Anxiety	3.3 ± 4.9	9.2 ± 6.4*	4.0 ± 5.2	3.3 ± 4.8	2.2 ± 3.9	4.4 ± 5.3	2.5 ± 5.2	5.0 ± 6.7	1.9 ± 3.1	4.6 ± 5.7*	2.7 ± 5.9	4.1 ± 5.8
Stress	8.3 ± 6.9	16.5 ± 9.5*	7.1 ± 7.9	8.8 ± 6.6	5.6 ± 6.2	8.9 ± 7.1	4.2 ± 6.7	8.4 ± 9.2	3.6 ± 4.1	7.8 ± 19.3*	5.4 ± 7.6	7.0 ± 6.3
Tampa			37.1 ± 6.8	34.4 ± 7.3	36.5 ± 6.8	34.8 ± 7.5	35.3 ± 7.3	34.7 ± 6.1	33.3 ± 5.4	34.8 ± 6.7	33.4 ± 5.7	33.9 ± 6.7
RSI ACL			0.7 ± 0.2	0.7 ± 0.2	0.7 ± 6.2	0.7 ± 2.2	0.7 ± 8.2	0.7 ± 4.2	0.8 ± 0.2	0.8 ± 3.2	0.8 ± 1.2	0.8 ± 0.2

Note: MDG: Meeting discharge criteria to return to sport. NDG: Not meeting discharge criteria to return to sport. * Significant difference between MDG and NDG.

TABLE 4. Summary of logistic regression analysis of athletes' meeting discharge criteria to return to sport status (MDG) as a function of sleep and psychological response at baseline, 1.5 m, 3 m, 4.5 m, 6 m and discharge

Predictors		B	SE	Wald	Odds ratio	95% CI		p-value
						Lower	Upper	
Baseline	ISI	.154	.0691	4.991	1.17	1.02	1.34	.025
	Anxiety	.143	.0574	6.191	1.15	1.03	1.29	.013
3 months	PSQI	.286	.1116	6.571	1.331	1.07	1.66	.010
4.5 months	PSQI	.671	.2873	5.450	1.956	1.11	3.43	.020
6 months	PSQI	.337	.1632	4.256	1.400	1.02	1.93	.039
Discharge	PSQI	.209	.1139	3.375	1.233	.986	1.541	.066

RESULTS

Total 89 athletes aged 23.8 ± 5.3 years were included (height 177.86 ± 8.53 cm and weight 77.70 ± 12.38 kg) with 12.63 ± 5.44 years of experience in their respective sports. Most athletes were football players (61.8%), playing in first (68.5%), second Division (12.4%), and amateurs (19.1%), with 10 to 14 hours of training and match per week. Participants were Arabs (66.3%), Africans (19.1%), Caucasians (6.7%) and Asians (7.9%) (Table 1). The mechanism of ACL injury was either contact (33.3%) or non-contact (66.7% of the 89 cases). The grafts used during surgery were either hamstring (HS) 57.3%, bone to bone (BTB) 40.4% or quadriceps tendon graft 1.1%.

For the compliance with the administration of the battery of questionnaires, of the 89 athletes, 59 (66.2%) completed the battery at 3 days of post-injury (baseline), 56 (62.9%) at 1.5 m, 71 (79.7%) at 3 m, 46 (51.6%) at 4.5 m, 53 (59.5%) at 6 m. For the post 6 months' period, the following data do not comprise the participants who were discharged: 46 (51.7%) at 7.5 m, and 25 (28.1%) at 9 m. At 9 and 24 m the participation rate was low (8 to 1 participant, respectively).

Of the 89 athletes, 46(51.7%) met the discharge criteria to RTS (MDG). 7 (7.9%) athletes self-discharged prior to six months and 31(34.8%) athletes self-discharged after 6 months without meeting the discharge criteria to RTS (NDG) (Table 1). The seven athletes who self-discharged themselves against hospital medical advice prior to six months and other 5 athletes who either returned back to home country for treatment or had reinjury were excluded from subsequent analysis. The average follow-up duration for MDG was 274.1 ± 87.8 days. The 31 athletes that self-discharged themselves without meeting the discharge criteria (NDG) had a post-surgery follow-up time of 312.4 ± 115.3 days.

There was no correlation between either sleep or psychological factors with time to meet the discharge criteria to RTS for the MDG (Table 2). At 3 m, 4.5 m, and 6 m time points the sleep quality was significantly better among MDG compared to NDG ($p < 0.05$) (Figure 1). In addition, MDG had significantly lower insomnia index compared to baseline, at 3 and 4.5 months (Table3).

The depression, anxiety and stress assessments at baseline were significantly higher among NDG compared to MDG ($p < 0.05$) and NDG had higher insomnia score than MDG (ISI = 12.1 ± 4.2 vs 7.6 ± 4.5 for NDG and MDG, respectively, $p = 0.001$) (Figure 2).

Athletes with good quality of sleep and positive psychological factors at baseline were more likely to complete their rehabilitation program and meet the discharge criteria to RTS (MDG). Logistic regression analysis showed that PSQI at 3 m (OR 1.33 (95% CI 1.1–1. 7), at 4.5 m (OR 2.0 (95% CI 1.1–3.4), at 6 m post-surgery (OR 1.4 (95% CI 1.0–1.9) and at discharge (OR 1.2 (95% CI 1.0–1.5) were the main factor for probability of meeting discharge criteria to RTS. Lower Anxiety (OR 1.17 (95% CI 1.0–1.3) and insomnia (OR 1.15 (95% CI 1.0–1.3) at baseline were also predictive of meeting discharge criteria to RTS (Table 4).

DISCUSSION

The aim of the present study was to determine if sleep quality and psychological factors were associated with time to meet the discharge criteria to RTS following ACL-R among athletes experiencing better quality of sleep and psychological responses returning faster to full activity. The main findings were: (i) sleep quality and psychological

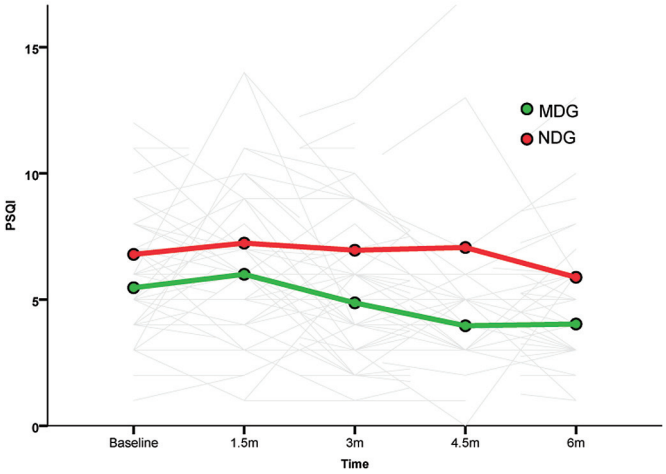

FIG. 1. Sleep quality assessed by PSQI following ACL-R surgery among those who met criteria of discharge to return to sport (MDG) vs athletes self-discharged without meeting criteria of return to sport (NDG).
Note: * Indicates the PSQI score was significantly higher in NGD compared to MDG. Higher values of PSQI indicates poor sleep quality.

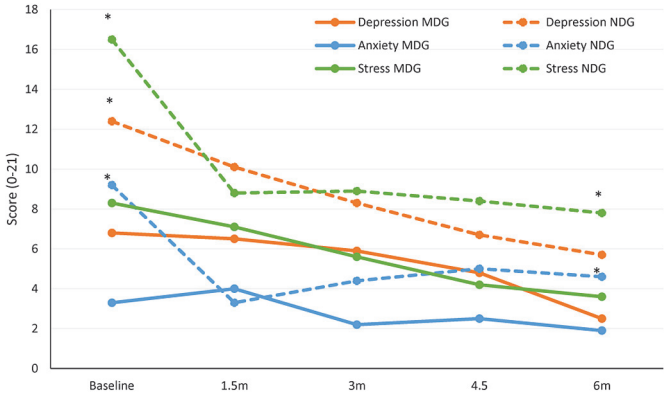

FIG. 2. Psychological factors assessed by DASS-21 following ACL-R surgery among those who met criteria of discharge to return to sport (MDG) vs athletes who did not meet criteria of discharge for return to sport (NDG).
Note: Dashed lines correspond to NDG group. * indicates the psychological factors score were significantly higher in NDG compared to MDG. Higher score indicates higher levels of depression, stress, and anxiety.

factors were not associated with time to meet the discharge criteria to RTS, but (ii) lower scores in anxiety and insomnia prior to injury occurrence, and better sleep quality during rehabilitation were associated with athletes' adherence to rehabilitation program until meeting the discharge criteria to RTS.

Previous studies have suggested that a lack of sleep can affect an athlete's recovery by altering their post-exercise endocrine response and may promote muscle loss and prevent muscle recovery after injury or exercise-induced injury [32]. Although, these variables were not measured during our research we could argue that the lack of sleep and/or its decreased quality may have influenced these processes and affected the athletes' recovery. Furthermore, there is evidence that sleep helps healing and improving tissue growth and recovery from injury [33]. Moreover, the post-operative period has been associated with issues related to falling asleep and reduced duration of sleep that adversely affect postoperative recovery of patients [34]. A recent review has suggested that healthy elite athletes generally experience sleep disturbances characterized by symptoms of longer sleep latencies, higher sleep fragmentation, non-restorative sleep, and excessive daytime fatigue [35]. These disturbances are likely to be exacerbated after injury and during post-surgery rehabilitation due to the potential addition of pain which has been identified as the most common cause of sleep disturbance post-surgery [36].

In the present study, at 1.5 m post-surgery, the PSQI scores for both NDG and MDG were higher, indicating a poor quality of sleep probably due to the pain experienced by ACL athletes at this stage (Table 3). However, the present findings showed that none of the sleep parameters at baseline, 1.5 m, 3 m, 4.5 m, 6 m and discharge were associated with time to meet the discharge criteria to RTS. Thus, the present study does not support the research findings stating the importance of sleep and psychological factors for a faster recovery [37, 38].

In addition to sleep, psychological factors are important following injury, during rehabilitation and contribute to the overall quality and progression of rehabilitation and were shown to detrimentally affect recovery time and RTS[39]. However, in our study psychological factors, including anxiety, stress and depression were not associated with the time to recovery. Taken together, these results do not support the hypothesis that sleep quality and psychological factors are associated with time to meet the discharge criteria to RTS.

Previous studies suggest that psychological factors such as motivation, confidence, self-efficacy, optimism, and lower fear of re-injury are associated with the likelihood of returning to the pre-injury level following ACL reconstruction [40]. This is supported by our findings that showed that NDG group had higher depression, anxiety and stress scores at baseline assessment, 3 m and 4.5 m and also higher stress and anxiety scores at 6 m post-surgery. This timeline of psychological factors, is also in line with previous literature suggesting increases in depression, tension and anger reported immediately after athletic injury and at later stages in recovery [17].

However, unlike other studies we did not observe an improvement in these psychological factors as rehabilitation progressed until the last phases where these should generally be compromised by the fear of re-injury at the RTS phase [41]. This discrepancy in the results might be related to the poor adherence to the rehabilitation program of the NDG, whom progress would have been slower than expected and therefore potentially promoting higher levels of psychological depression, anxiety and stress.

The second novelty of our findings is that other than the psychological factors athletes that had better sleep quality at 3 m, 4.5 m, 6 m and at discharge were more adherent to the rehabilitation program and more likely to meet the RTS discharge criteria. Sports medicine personnel reports, suggest that low or non-adherence to the rehabilitation program post-injury can be an issue compromising recovery. Some authors have reported that adherence to sport injury rehabilitation rates range from 40% to 91%. [42] . Our findings (51.7%) of adherent athletes to rehabilitation program fall within the latter rates.

The current results support a recent review and meta-analysis showing that both positive affective responses and rehabilitation adherence were related to a successful RTS after a sport injury [43]. Indeed, the NDG had significantly higher attendance, reported negative psychological factors at baseline and self-discharged themselves before meeting the discharge criteria to RTS. Pizzari et al. [44] investigated the relationship between adherence to rehabilitation programs after ACL-reconstructive surgery and 6 knee-function scales and 2 hop tests. They found a significant relationship between home-exercise adherence and rehabilitation outcomes for participants under 30 years of age (Spearman's correlation coefficients r_s = .33 – .44) but none with physical therapy appointments. Our results add that the adherence to physiotherapy appointments until meeting discharge criteria to RTS in athletes may also determine the success of the rehabilitation programs. This is in accordance with Brewer et al. [45] who found that greater attendance at rehabilitation sessions following ACL-R led to more positive outcomes at 6 months' post-surgery. The discrepancies across studies on adherence may be the result of the complexity in the adherence outcome relationship and the multifaceted nature of adherence.

In this context, a review has identified different barriers (bio-psycho-social) to musculoskeletal physiotherapy treatment adherence including: low levels of physical activity at baseline or in previous weeks, low in-treatment adherence to exercise, low self-efficacy, depression, anxiety, helplessness, poor social support or activity, greater perceived number of barriers to exercise and increased pain levels during exercise [46]. The findings of the present study add to these findings that higher anxiety and insomnia at baseline, poor quality of sleep at 3 m, 4.5 m ,6 m post-surgery and at discharge may also compromise adherence to rehabilitation following ACL-R.

In fact, the current data suggest that adherence might be the mediating factor between psychological factors, sleep quality and quantity and the rehabilitation programs' outcomes. Indeed, using logistic regression, our results showed that sleep quality at baseline, 3 m, 4.5 m, 6 m post-surgery and at discharge assessment were important factors associated with patient's adherence to complete their rehabilitation program until meeting the discharge criteria to

RTS. At baseline assessment, lower scores in anxiety was also associated with high odds for meeting discharge criteria.

The main findings of the present study were that sleep quality and psychological factors were not associated with time to meet the discharge criteria to RTS, however low anxiety and insomnia scores at baseline and sleep quality at post-surgery were predictive factors of athletes' adherence to rehabilitation program until meeting the discharge criteria to RTS.

This highlights the need to provide consistent psychological monitoring and support to athletes and a close monitoring of sleep before and during rehabilitation. Indeed, the present study shows that simple psychological assessments of anxiety, stress and depression and sleep monitoring of athletes could alert the health practitioners about the threat of poor adherence and consequently poor outcome of the rehabilitation program following ACL-R. This would allow to eventually put in place the adequate counter measures to hopefully help athletes to successfully RTS.

Study Limitation

Although, a cohort study design with lengthy and multiple follow-up of only athletes is one of the strengths of the study, it was limited to small sample size of 89 athletes. Future studies should consider the relatively high dropout rate of ACL injured athletes from their rehabilitation programs. The present study could not determine if athletes who did not adhere to the rehabilitation program or who did not complete it may have been at a higher risk of ACL re-injury as post-RTS as ACL re-injuries were out of scope.

The sleep measurements were limited to subjective measures (sleep questionnaires). Actigraphy devices and sleep diaries would have provided complementary valuable information, albeit long term studies using such tools show a high drop-out. In addition to that, one of weaknesses of the PSQI is that it does not capture daytime naps. Recent studies reported that naps after sleep deprivation improved some sleep parameters, perception of fatigue and physical performances, cognitive function measures and mood and oxidative stress [47]. Therefore, future studies should track eventual naps that would complement night sleep, potentially influencing the outcome of the studies. The psychological initial assessment was performed within 3 days of injury, to assess baseline psychological factors (independent of the injury), but despite the precautions taken during these assessments, we cannot rule out that some of the answers were impacted by the actual status of recently injured athlete.

Finally, all the baseline as well as post-surgery findings were discussed with the athletes as an education tool to enhance awareness of sleep and mental health condition and may have influenced their behavior and their adherence or non-adherence to the rehabilitation program completion. However, given that health-related behavior is relatively difficult to influence in human being [48] we do not foresee that these discussions over 6 sessions might have had a major impact on the results of the our study.

CONCLUSIONS

Sleep quantity and quality and psychological factors were not associated with time to meet the discharge criteria to return to sport following ACL-R. However, lower scores of anxiety and insomnia prior to injury occurrence, sleep quality at 3 m, 4.5 m, 6 m post-surgery and at the moment of meeting the discharge criteria to RTS were all associated with athletes' adherence to the rehabilitation program and RTS. Monitoring sleep quality and anxiety of athletes before and following ACL-R surgery is important to identify athletes who might have difficulties in adhering to completing rehabilitation programs to successfully RTS. Future studies should investigate the post- rehabilitation program period dynamics and successful RTS, and even return to performance.

Practical Applications

These results will hopefully help health care providers to monitor sleep parameters and psychological factors of athletes before and following ACL-R surgery and to identify the patient-athletes at risk of poor adherence and difficulties to complete their rehabilitation program until meeting discharge criteria to RTS and to eventually put in place the appropriate strategies to support them.

Author contributions

All authors contributed in a complementary way to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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Conflict of interests

The authors declared no conflict of interests regarding the publication of this manuscript.

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