COPYRIGHT NOTICE

FedUni ResearchOnline

<https://researchonline.federation.edu.au>

This is the peer-reviewed version of the following article:

Stares, J., Dawson, B., Peeling, P., Drew, M., Heasman, J., Rogalski, B., Colby, M.
(2018) How much is enough in rehabilitation? High running workloads following
lower limb muscle injury delay return to play but protect against subsequent injury.
Journal of Science and Medicine in Sport, 21(10), pp.1019-1024.

Which has been published in final form at:

<https://doi.org/10.1016/j.jsams.2018.03.012>

Copyright © 2018 Elsevier Inc. All rights reserved.

Accepted Manuscript

Title: How much is enough in rehabilitation? High running workloads following lower limb muscle injury delay return to play but protect against subsequent injury

Authors: Jordan Stares, Brian Dawson, Peter Peeling, Michael Drew, Jarryd Heasman, Brent Rogalski, Marcus Colby

PII: S1440-2440(18)30096-3
DOI: <https://doi.org/10.1016/j.jsams.2018.03.012>
Reference: JSAMS 1833

To appear in: *Journal of Science and Medicine in Sport*

Received date: 29-9-2017
Revised date: 10-3-2018
Accepted date: 20-3-2018

Please cite this article as: Stares Jordan, Dawson Brian, Peeling Peter, Drew Michael, Heasman Jarryd, Rogalski Brent, Colby Marcus. How much is enough in rehabilitation? High running workloads following lower limb muscle injury delay return to play but protect against subsequent injury. *Journal of Science and Medicine in Sport* <https://doi.org/10.1016/j.jsams.2018.03.012>

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

How much is enough in rehabilitation? High running workloads following lower limb muscle injury delay return to play but protect against subsequent injury

Running heading: Rehab running loads and subsequent injury in Australian football

Jordan Stares^{1,2}, Brian Dawson^{1,2}, Peter Peeling^{1,5}, Michael Drew^{3,4}, Jarryd Heasman², Brent Rogalski², and Marcus Colby^{1,2}

¹ Sport Science, Exercise and Health, School of Human Sciences, The University of Western Australia, Australia

² West Coast Eagles Football Club, Australia

³ Department of Physical Therapies, Australian Institute of Sport, Australia

⁴ Australian Collaboration for Research into Injury in Sport and its Prevention (ACRISP), Federation University Australia, Ballarat, Australia

⁵ Western Australian Institute of Sport, Australia

***Corresponding Author:**

Jordan Stares
PhD candidate
University of Western Australia
Perth, Australia

Tel: +61 430569077
Email: staresjordan@gmail.com

Original paper for: JSAMS

Submission type: Original research

Abstract

Objective: Examine the influence of rehabilitation training loads on return to play (RTP) time and subsequent injury in elite Australian footballers.

Design: Prospective cohort study

Methods: Internal (sessional rating of perceived exertion: sRPE) and external (distance, sprint distance) workload and lower limb non-contact muscle injury data was collected from 58 players over

5 seasons. Rehabilitation periods were analysed for running workloads and time spent in 3 rehabilitation stages (1: off-legs training, 2: non-football running, 3: group football training) was calculated. Multi-level survival analyses with random effects accounting for player and season were performed. Hazard ratios (HR) and 95% confidence intervals (CI) for each variable were produced for RTP time and time to subsequent injury.

Results: Of 85 lower limb muscle injuries, 70 were rehabilitated to RTP, with 30 cases of subsequent injury recorded (recurrence rate = 11.8%, new site injury rate = 31.4%). Completion of high rehabilitation workloads delayed RTP (distance: >49775m [reference: 34613-49775m]: HR 0.12, 95%CI 0.04-0.36, sRPE: >1266AU [reference: 852-1266AU]: HR 0.09, 95%CI 0.03-0.32). Return to running within 4 days increased subsequent injury risk (3-4 days [reference: 5-6 days]: HR 25.88, 95%CI 2.06-324.4). Attaining moderate-high sprint distance (427-710m) was protective against subsequent injury (154-426m: [reference: 427-710m]: HR 37.41, 95%CI 2.70-518.64).

Conclusion: Training load monitoring can inform player rehabilitation programs. Higher rehabilitation training loads delayed RTP; however, moderate-high sprint running loads can protect against subsequent injury. Shared-decision making regarding RTP should include accumulated training loads and consider the trade-off between expedited RTP and lower subsequent injury risk.

Keywords: Training Load, Subsequent Injury, Rehabilitation, Survival Analysis, Sprint Distance

Introduction

Muscle injuries are common in Australian football (AF).¹ Such injuries require structured and graduated rehabilitation programs for players to return to play (RTP). Regardless, an elevated risk of injury recurrence (re-injury) persists following RTP.^{2,3} Orchard et al.³ reported a majority of muscle injury recurrences within the first week of RTP; however, the risk may remain high for several weeks.⁴ In addition to risking a recurrence of the same injury, the risk of sustaining a new injury to another area or tissue may also be greater.² Either of these occurrences have been described as a subsequent injury.⁵ The mechanism by which previous injury modulates subsequent injury is largely unknown, with limited research demonstrating how RTP practices alter subsequent injury outcomes.

With games lost to injury being an obstacle to team sport success,^{6,7} balancing the risks and rewards of RTP strategies can be a difficult decision for clinicians.

Shrier⁸ recently outlined a strategy (adapted from Creighton et al.⁹) to assist in the RTP decision-making process, consisting of three evaluation levels: (1) tissue health (assessing relevant medical information/symptoms), (2) tissue stressors (assessing the stress to be placed on the tissue) and (3) risk tolerance modification (factors affecting the tissue's ability to tolerate the stress). While provision of insufficient healing time (poor tissue health) has previously been attributed to re-injury,¹⁰ recent research has focused on the factors relevant to the risk tolerance modification tier of Shrier's model. One such factor is training load, which may be a key determinant of subsequent injury risk following RTP.¹¹

Internal and external training loads have previously been related to injury in AF players, with both excessively high¹² and low^{13,14} loading conditions placing athletes at increased risk. Maintaining moderate to high chronic (4 week) training loads is considered particularly important for injury prevention, to ensure rehabilitating players are appropriately prepared for competition demands upon their return.¹⁴ Failure to accumulate sufficient chronic training loads when combined with exposure to a workload spike (often encountered upon RTP) represents the highest risk loading condition for AF players.¹⁴ Further, the elevated risk associated with exposure to these conditions can persist for up to 4 weeks.¹⁴ This 'latent period' associated with a training load error is similar to the timeframe of elevated subsequent injury risk reported by Orchard et al.³ following muscle injury. It is plausible that this elevated risk of subsequent injury might be moderated by the workloads completed prior to RTP.

While research regarding training load patterns of injured athletes is limited, it is likely that low chronic workload states often arise during and following the rehabilitation period. This potentially contributes to the heightened risk of sustaining a subsequent injury. In support is recent research reporting decreased weekly running loads (total and high speed distance) by injured AF players in the 3 weeks prior to RTP.¹⁵ Furthermore, altered distribution of training loads were also reported, with a lower proportion of load attained in football drills and higher loads accumulated in running

conditioning. It is currently unclear as to what effect such a training load distribution may have on subsequent injury risk.

Clearly, ensuring injured athletes are exposed to sufficient training load to adequately prepare for RTP is an important rehabilitation goal. However, there is currently no research to inform clinicians on best practice to achieve this outcome, while still respecting the natural process of tissue healing. Further, whether the manipulation of training load alters the timeframe necessary for rehabilitation is also unknown. Therefore, the primary aims of this study were to determine the relationship between: (I) rehabilitation training loads and RTP time and (II) rehabilitation training loads and subsequent injury rate. The secondary aim was to inform practitioner best practice by providing useful rehabilitation guidelines for lower limb muscle injuries in elite Australian footballers.

Methods

In-season data was prospectively collected over 5 seasons from a single elite AF club in players who sustained a lower limb injury. All injury types were initially considered for analysis, but insufficient case numbers for bone, tendon and ligament injuries meant statistical power could not be achieved. Therefore, only lower limb muscle injuries were analysed here. A total of 85 individual injury cases were documented, with 70 being rehabilitated to RTP. All participants provided written consent and all data was de-identified before extraction from the club's database. Ethical approval was obtained from the Human Research Ethics Committee (RA/4/1/5015) of The University of Western Australia, complying with the Declaration of Helsinki.

Injury information was classified by the club's senior physiotherapist (as per previous work from this group¹²). Non-contact lower limb muscle injuries that resulted in one or more matches being missed were included as "initial injuries" in this study. All non-contact, sports incapacity injuries to the lower limb that occurred subsequent to an initial muscle injury in the same season were included as "subsequent injuries". If such injuries occurred to the same site on the same side, then these were

classified as recurrent injuries. Initial injury cases where the athlete did not RTP in the same season were excluded.

Both internal (subjective¹⁶) and external (GPS^{17 18}) validated workload measures were used. Internal workload was measured using session rating of perceived exertion (sRPE). Players were shown the 10-point modified-Borg scale¹⁹ after each training session and provided a numeric rating of RPE. Load (arbitrary units) was then calculated as the product of RPE and session duration. This was only collected for field training sessions. Two external loads (SPI Pro X, GPSports, Canberra, Australia; 5 Hz, interpolated to approximate 15 Hz) were quantified. “Distance” was defined as total distance covered (m) and “sprint distance” as total distance covered (m) above 75% of the individual player’s maximum speed, determined from preseason 20m sprint test, using electronic timing gates, (Fusion Sport, Brisbane). Maximum speed values were updated if a higher speed was obtained from subsequent GPS game data. The GPS units used have previously been demonstrated to be reliable in measuring such variables.²⁰ Distance and sprint distance were taken directly from GPSports (TEAM AMS—release 1.9 2012) software.

Four percent of GPS training data cases were missing or unusable over the five season data collection period primarily due to AFL player association restrictions around tracking players during breaks. In such cases, a predicted value was generated based on the individual’s session exposure time and historical GPS intensities.

The start of rehabilitation period were defined as the day of injury and concluded on the day of the athlete’s RTP in either the Australian Football League (AFL) or Western Australian Football League. Rehabilitation periods were described in 3 stages: Stage 1 was characterised by the absence of running loads with all training being “off-legs”; Stage 2 commenced with the resumption of running, but with all loads accumulated in a non-football context (running conditioning); Stage 3 commenced with the resumption of group football training and concluded with RTP.

Three variables were calculated for each workload measure in each stage of rehabilitation. These were: chronic training load (CTL) achieved at the start of the stage (calculated by averaging weekly load over the preceding 4 weeks); total load (TL) accumulated in the stage; and average weekly load (WL) in the stage. Average WL and TL for the whole rehabilitation period, as well as for stages 2 and 3 only (on-legs rehabilitation), were also derived. Additionally, time spent (days) in each phase was also analysed. To prepare for survival analysis, data for each variable were divided into quartile groups (very low, low, high and very high). The “high” group was identified as the reference category for survival analysis, in line with previous load and injury research¹⁴

A-priori power analysis was undertaken, indicating that 66 injury cases were required to achieve $\alpha=0.05$, $\beta=0.20$ and hazard ratios (HR) >2.0 . The HR were produced using multilevel parametric survival analyses²¹, with random effects accounting for the player and season. All analyses were performed in STATA 14 (Stata 14 IC, StataCorp, USA). Each variable was analysed twice: once with RTP as the failure event, and once with subsequent injury as the failure event. This allowed assessment of the influence of training load on rehabilitation time and time to subsequent injury, respectively. For RTP analysis, time to event was calculated as time from injury to time of RTP (days). For subsequent injury analysis, time to event was calculated as time from RTP to either subsequent injury (failure) or season end (censoring). The likelihood ratio test was utilised to assess goodness of fit of each survival model. Statistical significance was determined when the model likelihood ratio test was $p<0.05$ and the 95% confidence intervals of the HR did not include 1.0. Tests of the proportional hazards assumption (log-minus-log plot) were performed for significant models and Kaplan-Meier survival estimates were calculated.

Results

There were 66 individual univariate survival analyses performed for this study. For brevity, results are only reported for those that achieved a statistically significant likelihood ratio test ($p<0.05$). A summary of all results is contained in Supplementary on-line material. Table 1 displays descriptive statistics for the initial injury data. The subsequent injury incidence of RTP players in this study was

[illegible]

Of the 33 variables analysed for time to RTP, 12 produced a statistically significant survival model. The HR from these models are presented in Table 2. A HR greater than 1 indicates a faster RTP time compared to the reference category (as the time to RTP was set as the time to event variable).

[illegible]

For time to subsequent injury analysis, only 2 variables (Time in Stage 1 and total rehabilitation sprint distance) produced a significant survival model. The HR for these are presented in Table 3. Kaplan-Meier survival estimates are presented in supplementary on-line material (Figure 1) for significant variables. A HR greater than 1 indicates a faster time to subsequent injury compared to the reference category (as time to subsequent injury was set as the time to event variable).

[illegible]

This is the first study to examine the relationship between rehabilitation training loads, RTP time and subsequent injury risk. While acute management of muscle injury has been well documented, only limited research regarding late stage rehabilitation exists, particularly with respect to running loads. Here, most subsequent injuries were found to affect a different site/tissue to the initial injury. This finding supports previous research demonstrating injury to a new site poses a greater risk than recurrence, and the hypothesis that a general state of under-loading may be the mechanism.² Greater weekly and total rehabilitation training loads were associated with longer RTP times and high sprint running loads were found to be protective against subsequent injury following RTP. This indicates

that training load is an important component of rehabilitation and warrants consideration in RTP decision-making.¹¹

This study advocates delaying the resumption of running for at least 5 days following muscular injury. Returning to running *within* 4 days of injury resulted in significantly higher risk of subsequent injury compared to after 4 days. Notably, extending this time off-legs did not delay RTP time, suggesting that extra time taken to running resumption does not delay the total rehabilitation program. Previous clinical recommendations for muscle injury management suggest that mobilisation of the injury should be delayed until after the first few days post-injury.^{22 23} Our findings provide some support for these recommendations; however it should be noted that our study only included running loads. Therefore, the influence of other training modalities, such as resistance and cross training, plus (rehabilitation) range of motion and low level muscle contractions cannot be accounted for.

Of the load conditions analysed, total sprint distance accumulated in rehabilitation was the only variable related to a reduction in subsequent injury risk. Attaining a moderate to high (427-710m) volume of sprint distance in rehabilitation was found to be protective against subsequent injury. This supports evidence that under-loading predisposes athletes to injury, likely due to insufficient conditioning to tolerate the intense competition demands.¹⁴ Prior to the present study, no research has examined this concept in injured athletes. Blanch & Gabbett¹¹ proposed that accumulation of sufficient training load is necessary for safe RTP, as it promotes the avoidance of workload spikes in the progression to RTP. However, such findings had not been demonstrated in rehabilitating athletes. It is plausible that accumulating moderate to high sprint loads in rehabilitation reduces subsequent injury risk by increasing chronic training load, which facilitates physiological adaptation, thus reducing the effects of workload spikes after RTP. Such factors have previously been identified as risk factors in uninjured AF players.^{13 14} However, chronic training load at RTP was not identified as a significant factor for subsequent injury risk in the present study. This may have been influenced by excluding non-running based loads (see limitations). Based on this finding, selective subsequent injury prevention strategies for rehabilitating players should include graduated high-speed running to

ensure adequate volumes are achieved prior to RTP. An example of this strategy is documented in a recently published muscle rehabilitation protocol²⁵, however such recommendations are notably absent in many publications relating to lower limb rehabilitation.^{24 25}

A key finding here was that higher running loads accumulated through rehabilitation resulted in delayed RTP times. This is logical, as higher workloads take time to safely accumulate. Furthermore, higher average WL (sRPE) also delayed RTP. Given higher sprint loads are required for a relatively safer RTP, it is likely that a trade-off will exist between subsequent injury risk and time taken for RTP. Attempting to accelerate rehabilitation (and RTP) by not allowing sufficient time to attain appropriate training loads may compromise the athlete's chances of a safe RTP. Consequently, decisions about determining a RTP timeframe are complex. Extended RTP times resulting in more games missed may impact team success^{6 7}, but this must be considered against increasing subsequent injury risk, and (potentially) future games lost. A shared decision-making process between all relevant stakeholders (coach, athlete, sports medicine practitioner), which includes consideration of accumulated training loads, may be necessary when making decisions regarding RTP.²⁶

Notwithstanding, subsequent injury is common following a rehabilitation period^{1 2}; the incidence for this cohort was 43%, which is consistent with previous reports in AF.² Given the frequency with which subsequent injuries were sustained in this study, controlling known risk factors should be a high priority for practitioners. As such, the use of evidence-based RTP criteria is suggested.^{24 25} While such RTP criteria have previously used radiological and clinical assessments, the present findings suggest that training load should also be considered to provide a more complete assessment of post-RTP injury risk. The magnitude by which the survival rate was influenced by training load in this study is significantly greater than the risk relationships previously demonstrated by meeting radiological, strength or flexibility criteria.²⁷ This suggests that evidence-based load monitoring practices are valuable during rehabilitation.

This study only involved players from one AFL club and therefore results cannot be generalised outside of this population. Furthermore, whilst this paper was intended to include analyses of multiple

tissue types, there were limited cases affecting bones, tendons and ligaments, which prevented statistical power being reached for these injuries. Therefore, the study was limited to muscle injury cases only. Additionally, only in-season load and injury data were included, as the continuity of load data was disrupted through the pre-season period (off-season and Christmas break). It is possible that relationships seen here would differ in pre-season, given that pre-season workload modulates injury risk in uninjured players.²⁸ Only training load from on-field training sessions (excluding off-legs, cross training and weights) was available for analysis. Therefore, the actual physical loads encountered were higher than reported here.

A “naïve” statistical model was used in this study.²⁹ The random effects did account for player and season, however, only a single subsequent injury observation was allowed for each initial injury case. Therefore, multiple subsequent injuries over the same or multiple seasons could not be accounted for. For this reason, the “initial injury” in this study was defined as the first injury for a player in a given season. In some cases, the true “initial injury” is likely to have been sustained in a previous season. It is recommended that future research utilises “longitudinal” statistical methods appropriate for handling the complex nature of recurrent events.²⁹ Statistical significance using p-values was not reported in this study to limit Type 1 errors associated with multiple analyses. Alternatively, confidence intervals were presented to allow the reader to ascertain the certainty of the results presented.³⁰ Wide confidence intervals are reported for some analyses, and are likely due to the relatively low sample size, even though *a priori* power calculations were determined. Replication in similar and alternative cohorts is recommended. Finally, staff at the AFL club participating in this study had knowledge of current load and injury research, and consequently interventions and adjustments were made to the rehabilitation programs based on the load data collected; this cannot be accounted for in the statistical analysis.

Conclusions

The results here support the use of load monitoring for rehabilitation of AF players and subsequent RTP decisions. The results demonstrate that accumulating higher training loads in rehabilitation delays RTP following muscle injury. Further, commencement of running <4 days following muscle

injury decreases post-RTP survival. However, accumulating moderate to high sprint running loads has protective effects against subsequent injury after RTP. As such, shared decision-making around RTP timeframes should carefully consider accumulated training loads.

Practical Implications

- Training loads should be planned and monitored as a component of best practice rehabilitation.
- Attaining appropriate sprint running loads through graduated prescription of supplementary running may be used to protect against subsequent injury.
- Decision-making around RTP should consider that accelerating rehabilitation may increase subsequent injury risk. This may result in longer timeframes for RTP than a smaller delay in the initial rehabilitation process.

Conflicts of interest: Nil

Acknowledgements: The Australian Collaboration for Research into Injury in Sport and its Prevention (ACRISP) is one of the International Research Centres for Prevention of Injury and Protection of Athlete Health supported by the International Olympic Committee (IOC)

References

1. Orchard J, Seward H, Orchard J. 20th Annual Injury Report: Season 2011. Available Online: <http://www.afl.com.au/injury%20report/tabid/13706/default.aspx>, 2012.
2. Finch CF, Cook J, Kunstler BE, et al. Subsequent injuries are more common than injury recurrences: An analysis of 1 season of prospectively collected injuries in professional Australian football. *Am J Sports Med* 2017;0363546517691943.
3. Orchard J, Best TM. The management of muscle strain injuries: an early return versus the risk of recurrence. *Clin J Sport Med* 2002;12(1):3-5.
4. Orchard JW. Intrinsic and extrinsic risk factors for muscle strains in Australian football. *Am J Sports Med* 2001;29(3):300-03.
5. Finch CF, Cook J. Categorising sports injuries in epidemiological studies: the subsequent injury categorisation (SIC) model to address multiple, recurrent and exacerbation of injuries. *Br J Sports Med* 2013;bjsports-2012-091729.
6. Drew MK, Raysmith BP, Charlton PC. Injuries impair the chance of successful performance by sportspeople: a systematic review. *Br J Sports Med* 2017;bjsports-2016-096731.
7. Häggglund M, Waldén M, Magnusson H, et al. Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study. *Br J Sports Med* 2013;47(12):738-42.
8. Shrier I. Strategic assessment of risk and risk tolerance (StARRT) framework for return-to-play decision-making. *Br J Sports Med* 2015;49(20):1311-15.
9. Creighton DW, Shrier I, Shultz R, et al. Return-to-play in sport: a decision-based model. *Clin J Sport Med* 2010;20(5):379-85.
10. Saartok T. Muscle injuries associated with soccer. *Clin Sports Med* 1998;17(4):811-17.
11. Blanch P, Gabbett TJ. Has the athlete trained enough to return to play safely? The acute: chronic workload ratio permits clinicians to quantify a player's risk of subsequent injury. *Br J Sports Med* 2015;bjsports-2015-095445.
12. Colby MJ, Dawson B, Heasman J, et al. Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. *J Strength Cond Res* 2014;28(8):2244-52.
13. Colby MJ, Dawson B, Peeling P, et al. Multivariate modelling of subjective and objective monitoring data improve the detection of non-contact injury risk in elite Australian footballers. *J Sci Med Sport* 2017
14. Stares J, Dawson B, Peeling P, et al. Identifying high risk loading conditions for in-season injury in elite Australian football players. *J Sci Med Sport* 2017
15. Ritchie D, Hopkins WG, Buchheit M, et al. Quantification of training load during return to play following upper and lower body injury in Australian rules football. *Int J Sports Physiol Perform* 2016;1-19.
16. Impellizzeri FM, Rampinini E, Coutts AJ, et al. Use of RPE-based training load in soccer. *Med Sci Sports Exerc* 2004;36(6):1042-47.
17. Hiscock D, Dawson B, Heasman J, et al. Game movements and player performance in the Australian Football League. *Int J Perform Anal Sport* 2012;12(3):531-45.
18. Waldron M, Worsfold P, Twist C, et al. Concurrent validity and test-retest reliability of a global positioning system (GPS) and timing gates to assess sprint performance variables. *J Sports Sci* 2011;29(15):1613-19.
19. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *J Strength Cond Res* 2001;15(1):109-15.
20. Johnston RJ, Watsford ML, Kelly SJ, et al. Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands. *J Strength Cond Res* 2014;28(6):1649-55.

21. Yau KK. Multilevel models for survival analysis with random effects. *Biometrics* 2001;57(1):96-102.
22. Järvinen MJ, Lehto MU. The effects of early mobilisation and immobilisation on the healing process following muscle injuries. *Sports Med* 1993;15(2):78-89.
23. Järvinen TA, Kääriäinen M, Järvinen M, et al. Muscle strain injuries. *Curr Opin Rheumatol* 2000;12(2):155-61.
24. Erickson LN, Sherry MA. Rehabilitation and return to sport after hamstring strain injury. *J Sport Health Sci* 2017 doi: 10.1016/j.jshs.2017.04.001
25. Hickey JT, Timmins RG, Maniar N, et al. Criteria for progressing rehabilitation and determining return-to-play clearance following hamstring strain injury: A systematic review. *Sports Med* 2017;47(7):1375-87. doi: 10.1007/s40279-016-0667-x
26. Dijkstra HP, Pollock N, Chakraverty R, et al. Return to play in elite sport: a shared decision-making process: BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine, 2016.
27. De Vos R-J, Reurink G, Goudswaard G-J, et al. Clinical findings just after return to play predict hamstring re-injury, but baseline MRI findings do not. *Br J Sports Med* 2014;bjsports-2014-093737.
28. Windt J, Gabbett TJ, Ferris D, et al. Training load--injury paradox: is greater preseason participation associated with lower in-season injury risk in elite rugby league players? *Br J Sports Med* 2016;bjsports-2016-095973.
29. Twisk JW, Smidt N, de Vente W. Applied analysis of recurrent events: a practical overview. *J Epidemiol Commun Health* 2005;59(8):706-10.
30. Rothman KJ. Curbing type I and type II errors. *Eur J Epidemiol* 2010;25(4):223-4. doi: 10.1007/s10654-010-9437-5 [published Online First: 2010/03/17]

Footnote: Figure 1A illustrates that shorter times spent in stage 1 resulted in a quicker time to subsequent injury. Figure 1B illustrates the improved survival rate with the accumulation of moderate-high sprint distance through rehabilitation.

Footnote: Figure 1A illustrates that shorter times spent in Stage 1 resulted in a quicker time to subsequent injury. Figure 1B illustrates the improved survival rate with the accumulation of moderate-high sprint distance through rehabilitation.

Table 1 Descriptive statistics for muscle injury data.

Variable		Injury Site						Total
		Hamstring	Quadriceps	Calf	Gluteal	Adductor	Other	
Injury Cases (n)	Total	37	13	21	3	9	2	85
	RTP	29	11	16	3	9	2	70
RTP Time (days)	median (IQR)	22 (21-27)	15 (11.5-18.5)	19.5 (14-23)	21 (15-24)	14 (13-15)	36 (36-36)	21 (14-24)
Subsequent Cases (n)	Recurrent	7	0	1	0	0	0	8
	Non-Recurrent	4	4	5	2	6	1	22

RTP = Return to Play; IQR, interquartile range

Table 2 Hazard ratios for RTP time (statistically significant models only).

Variable	Stage	Load Variable	Categories	Average Time to RTP ($\pm$ SD)	Hazard Ratio	95% Confidence Intervals		
Time Spent in Rehab Stage	Stage 2 (Return to Running)		<5 days	13.6 $\pm$ 3.89	9.03	2.30	-	35.46
			6-8 days	18.95 $\pm$ 7.08	2.38	0.79	-	7.20
		Days	9-12 days (Ref)	21.14 $\pm$ 6.87	-			
			>12 days	30.14 $\pm$ 11.20	0.27	0.09	-	0.77
	Stage 3 (Return to Training)		<3 days	18.57 $\pm$ 10.29	0.82	0.24	-	2.82
			3-4 days	14.95 $\pm$ 4.57	2.87	1.25	-	6.54
		Days	5-8 days (Ref)	20.18 $\pm$ 4.29	-			
			>8 days	30.06 $\pm$ 11.61	0.18	0.07	-	0.42
Chronic Training Load	Beginning of Stage 3 (Return to Training)	sRPE	<535 AU	29.24 $\pm$ 13.69	0.28	0.11	-	0.69
			535-744 AU	20.39 $\pm$ 6.01	0.89	0.38	-	2.07
			744-961 AU (Ref)	18.94 $\pm$ 8.47	-			
			>961 AU	17.78 $\pm$ 6.76	1.39	0.58	-	3.31
Average Load/week	Total Rehab (Stages 1,2,3)	sRPE	<259 AU	17.06 $\pm$ 10.16	2.72	0.79	-	9.39
			259-333 AU	19.67 $\pm$ 7.65	1.56	0.52	-	4.67
			333-445 AU (Ref)	20.65 $\pm$ 6.71	-			
			>445 AU	28.39 $\pm$ 11.65	0.34	0.12	-	0.98
Load Accumulated	Stage 2 (Return to Running)	Distance	<13629m	14.71 $\pm$ 4.45	8.88	4.40	-	32.86
			13629-21041m	17.56 $\pm$ 6.27	5.29	1.49	-	18.77
			21041-30743 (Ref)	22.94 $\pm$ 7.87	-			
			>30743m	30.56 $\pm$ 11.84	0.30	0.10	-	0.91
		sRPE	<263 AU	14.29 $\pm$ 4.55	7.03	1.85	-	26.71
			263-492 AU	19.78 $\pm$ 7.49	1.55	0.52	-	4.57
			492-791 AU (Ref)	21.06 $\pm$ 7.42	-			
			>791 AU	30.5 $\pm$ 11.82	0.20	0.06	-	0.66
	Stage 3 (Return to Training)	Distance	<6271m	16.65 $\pm$ 7.52	2.23	0.78	-	6.36
			6271-10830m	16.12 $\pm$ 4.39	3.21	1.11	-	9.29
			10830-19167m (Ref)	21.41 $\pm$ 6.39	-			
			>19167m	29.88 $\pm$ 11.44	0.23	0.07	-	0.70
		Sprint Distance	<38m	17.88 $\pm$ 7.63	1.03	0.38	-	2.79
			38-106m	18.18 $\pm$ 5.78	1.14	0.42	-	3.13
			106-196m (Ref)	19.41 $\pm$ 7.43	-			
			>196m	28.59 $\pm$ 12.15	0.16	0.04	-	0.60
		sRPE	<136 AU	16.88 $\pm$ 7.63	1.16	0.59	-	3.99
			136-281 AU	15.88 $\pm$ 4.12	2.29	0.94	-	5.56
			281-562 AU (Ref)	19.71 $\pm$ 4.18	-			
			>562 AU	31.59 $\pm$ 10.83	0.41	0.05	-	0.48
	Total Rehab (Stage 2 and 3)	Distance	<20952m	13.47 $\pm$ 4.02	11.49	2.95	-	44.81
			20952-34613m	17.35 $\pm$ 6.57	2.60	0.90	-	7.49
			34613-49775m (Ref)	21.64 $\pm$ 2.50	-			
			>49775m	31.59 $\pm$ 10.84	0.12	0.04	-	0.36
		Sprint Distance	<154m	15.82 $\pm$ 6.49	5.04	1.35	-	18.81
			154-426m	19.83 $\pm$ 6.13	1.74	0.61	-	4.95
			426-710m (Ref)	22.47 $\pm$ 8.40	-			
			>710m	25.98 $\pm$ 12.98	0.48	0.15	-	1.59
		sRPE	<527 AU	13.18 $\pm$ 3.68	14.19	3.13	-	64.42
			527-852 AU	17.88 $\pm$ 6.58	2.45	0.77	-	7.83
			852-1266 AU (Ref)	20.88 $\pm$ 2.89	-			
			>1266 AU	32.12 $\pm$ 10.25	0.09	0.03	-	0.32

RTP = Return to Play; SD= standard deviation; sRPE = On-legs Sessional Rating of Perceived Exertion; Bolded hazard ratio's indicate statistically significant results as indicated by the 95%CI not crossing 1.0; all reported models had p<0.01 except Total rehab accumulated load (p=0.02).

Table 3 Hazard ratios for subsequent injury (statistically significant models only).

Variable	Stage	Load Variable	Category	# Recurrent Injuries	# Subsequent Injuries	Hazard Ratio	95% Confidence Intervals		
Time Spent in Stage	Stage 1		0-2 days	0	5	15.73	1.24	-	199.57
			3-4 days	2	8	25.88	2.06	-	324.40
			5-6 days (Ref)	1	4	-			
			>6 days	4	4	0.91	0.07	-	11.35
Load Accumulated	Total Rehab	Sprint Distance	<154m	0	7	17.62	0.83	-	373.72
			154-426m	0	7	37.41	2.70	-	518.64
			426-710m (Ref)	2	3	-			
			>710m	3	4	17.04	0.79	-	369.42

Bolded hazard ratio's indicate statistically significant results as indicated by the 95%CI not including 1.0; model statistical significance, time spent in Stage 1 ($p=0.03$), Total rehab accumulated load ($p=0.05$)