Dance Exposure, Individual Characteristics, and Injury Risk over Five Seasons in a Professional Ballet Company

Short Title: Injury Risk Factors in Professional Ballet

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Abstract

Purpose To describe the relationships between dance exposure, dancer characteristics, and injury risk across five seasons in a professional ballet company.

Methods Dance exposure time and clinician-reported time-loss and medical attention injury data were prospectively collected from 118 professional dancers of The Royal Ballet between 2015/16 and 2019/20. Cox proportional hazards and shared frailty models were fitted to overuse and traumatic injuries; individualized robust Z-scores for 7-day and 28-day accumulated exposure, and week-to-week change in exposure, age, sex, company rank, and injury history were included as time-varying covariates.

Results Across 381,710 h of exposure, 1332 medical attention and 427 time-loss injuries were observed. Positive relationships were observed between week-to-week change in exposure and overuse time-loss (+1 Z-score hazard ratio (HR): 1.27, 95% confidence interval (CI): 1.06–1.53) and medical attention injury risk (+1 Z-score HR: 1.17, 95% CI: 1.06–1.28). A negative relationship was observed between 7-day accumulated exposure and overuse medical-attention injury risk (+1 Z-score HR: 0.74, 95% CI: 0.66–0.84). Overuse time-loss injury risk was greater in soloists compared to the *corps de ballet* (HR: 1.47, 95% CI: 1.01–2.15), and in dancers with a higher previous injury rate (+1 injury·1000 h^{-1} HR: 1.06, 95% CI: 1.02–1.10). Only age was associated with traumatic time-loss (+1-year HR: 1.05, 95% CI: 1.01–1.09) or medical attention injury risk (+1-year HR: 1.04, 95% CI: 1.01–1.07).

Conclusion Professional ballet companies should implement training principles such as periodization and progression, particularly in the case of senior-ranking dancers, older dancers, and dancers with high rates of previous injury. These findings provide a basis for future prospective investigations into specific causal injury pathways.

Introduction

Sports science and medicine departments operate with the twin goals of maximising performance and reducing the risk of athletic injury (1). Understanding the load-injury relationship is therefore fundamental when planning training programmes, such that technical and physical qualities can be developed without excessively increasing the risk of injury (2). The mismanagement of workload may lead to maladaptive responses such as non-functional overreaching, overtraining syndrome, and injury (3,4). The International Olympic Committee position stand on load and injury risk in sport identifies a need for research into specific athletic populations (4). Despite multiple studies suggesting workload may be a risk factor for injury in professional ballet (5–7), the load-injury relationship has not yet been investigated in this population.

Professional ballet companies perform as many as 145 shows per season, comprised of up to 18 productions (8). To prepare for the physical, technical, and artistic demands of these performances, professional ballet dancers rehearse for 3.5–9.0 h per day (9). Weekly dance exposures are therefore regularly above 30 $h \cdot wk^{-1}$ (10), exceeding training and competition exposures reported in elite sporting environments (11,12). Furthermore, whereas sportspeople typically taper their training before competition (13), a ballet company will instead increase rehearsal load in the build-up to the opening night of a production (14). This increase may reflect limited access to theatre stage space, and an effort to improve the execution of the ballet prior to performance.

Several studies have investigated the load-injury relationship in the wider field of dance (15–17), however, inappropriate statistical methods (e.g., Pearson's correlation) or underpowered study designs have been used. Conversely, Jeffries et al. (18) detailed the workloads and injury events of 16 contemporary dancers across one year, to guide future large-scale prospective studies. Whilst the prospective design used in this study is favourable, the resulting small sample size meant that the authors could not determine associations between load and injury risk. The shortcomings of study designs using existing data in load-injury research have been well discussed (19). Nonetheless, the use of existing data can provide direction to prospective investigations, whilst overcoming the sample size limitations faced by short-term prospective research.

The aim of this study was therefore to describe the relationships between dance exposure, dancer characteristics, and injury risk across five seasons in a professional ballet company.

Methods

Study Design and Setting

The present study is secondary use of data (20) recorded as part of a five-year prospective study which aimed to describe the incidence rate, severity, and burden of time-loss and medical attention injury at The Royal Ballet between August 8th, 2015, and March 15th, 2020 (21). All data were prospectively recorded, and all dance events took place at the Royal Opera House, London. Where applicable, the STROBE-SIIS statement has been used to guide the reporting of this study (22).

Participants

As part of normal working practices, data were collected from 119 eligible dancers across the ranks of *apprentice*, *artist*, *first artist*, *soloist*, *first soloist*, and *principal*: 108 participants gave written informed consent. The remaining 11 were contacted: 10 did not respond and one declined to participate. A legitimate interest assessment was completed, and written support from both the Data Controller and Clinical Director of the company was provided to use anonymized data pertaining to the 10 participants who could not be contacted. This was approved by the local ethics committee in accordance with the Declaration of Helsinki. Demographics of the included 118 dancers (age 26.9 ± 7.3 y) are provided in Table 1.

Table 1 Demographics of the sample for each season in the study.

Demographic	2015/16	2016/17	2017/18	2018/19	2019/20
All	83	87	82	90	91
Left the cohort	-	6	13	3	5
Joined the cohort	-	10	8	11	6
Female					
Apprentice	2	4	3	4	4
Artist	11	11	10	13	12
First Artist	9	10	11	10	12
Soloist	11	9	8	4	5
First Soloist	7	7	6	9	9
Principal	6	8	8	8	8
Male					
Apprentice	3	4	4	4	2
Artist	7	7	7	10	11
First Artist	5	6	6	7	7
Soloist	8 (1)	7 (1)	7	7	8
First Soloist	7	5	4	5	5
Principal	7	9	8	9	8

Company Rank

Ballet companies are hierarchical, with each dancer assigned a rank. The rank of apprentice is given to dancers in their first year of professional employment. Apprentices, artists, and first artists make up the *corps de ballet*, who typically perform as an ensemble. Dancers can be promoted to the ranks of soloist and first soloist, where they will perform increasingly featured roles. Finally, principal dancers are the most senior, performing leading roles.

Injury

Injury data were recorded by in-house medical staff (Chartered Physiotherapists: five full-time, one part-time, eleven covering staff leave, and two who were consulted to provide historical data; medical doctors: 4 part-time) using the Orchard Sports Injury Classification System (23). Third-party injury registration was established in the company prior to this study, though it has been suggested to underestimate the injury burden in non-professional dance environments (24). In line with previous recommendations (25), both medical attention and time-loss injuries were included in this study. Medical attention injuries were defined as “any musculoskeletal complaint that required medical attention from a healthcare professional” (25). In line with previous research and consensus statements in professional ballet (8,26), association football (27), and rugby union (28), time-loss injuries were defined as “any injury that prevented a dancer from taking a full part in all dance-related activities that would normally be required of them for a period equal to or greater than 24 hours after the injury was sustained” (8,26). Injuries were classified as either overuse or traumatic based on the nature of onset: overuse injuries were defined as “any medical incident that did not have a sudden onset from a discrete event” (29), whilst traumatic injuries were defined as any medical incident that had a sudden onset from a specific identifiable event.

Dance Exposure Time

An online athlete management system (Smartabase v.6.5.11, Fusion sport, Brisbane, Australia) was used to record class and rehearsal exposure time (30). During each week in the study, the company’s Artistic Scheduling Manager entered an individualized schedule for each dancer, detailing their class and rehearsal timetable for the following week. Performance exposure time was estimated from electronic copies of casting sheets from each of the five seasons. Hard copies of the casting sheet for each performance were examined to ensure any last-minute casting changes were amended. For each day in the study, participants’ total ballet class, rehearsal, and performance exposure time was calculated.

For each participant, and each day in the study, accumulated dance exposure time over the previous seven days (i.e. day -1 to day -7; 7-day exposure), accumulated dance exposure time over the 28 days preceding those seven days (i.e. day -8 to day -35; 28-day exposure) (31), and the week-to-week change in dance exposure time (i.e. day -1 to day -7 minus day -8 to day -14) were estimated. These periods were chosen because they are the most frequently used periods in this field of research (32,33).

For each participant, individualized robust Z-scores (34) were calculated for each dance exposure time variable using the equation:

$$robust\ Z\ score = \frac{variable - individual\ median}{individual\ median\ absolute\ deviation}$$

Age, Sex, Injury History, and Company Rank

Participant age, sex, and injury history were included as covariates in the analysis, having been identified as injury risk factors in sport and dance (35–37). Each dancer's historical injury rate, per 1000 h of dance exposure, was calculated at each timepoint based on previous time-loss injuries and exposure in the dataset (previous injury count / previous exposure time × 1000). Differences in activity volume and intensity have previously been observed between company ranks, during a day of rehearsal (7), and during performances (38). Company rank was therefore included as a covariate; participants were categorized as *corps de ballet* members (apprentices, artists, and first artists), soloists (soloists and first soloists), or principals.

Statistical Analysis

Associations between dance exposure variables and time-loss and medical attention injury incidence were investigated by fitting Cox proportional hazards and shared frailty models to the data using the R package *survival* (39). The count of injury events per predictor parameter (40; EPP) was: time-loss overuse - 17.6 EPP, time-loss traumatic - 12.9 EPP, medical attention overuse - 70.1 EPP, and medical attention traumatic injuries - 25.0 EPP. An insufficient number of injury events were recorded to further subdivide injuries by tissue type. Daily dance exposure time was entered as the timescale variable and participant identity was entered as the frailty term, accounting for repeated events within individuals and heterogeneity in baseline risk with the shared frailty model. Separate cause-specific hazard models were fitted for overuse and traumatic injuries. Exposure periods which ended with either no injury or with a different injury classification were right-censored (41). Week-to-week change in dance exposure, 7-day accumulated dance exposure, and 28-day accumulated dance exposure were entered as time-varying covariates. In line with previous suggestions to investigate non-linear relationships between training load and injury, quadratic and cubic terms were included in the model (42,43). Hazard ratios (HR) associated with individual characteristics were investigated by including participant age, sex, company rank, and injury history as covariates in each model.

To compare the goodness of fit of the Cox proportional hazards models against the shared frailty models, analysis of deviance tables were constructed using the R function *anova.coxph*. Log-likelihoods, Akaike information criteria, and Bayesian information criteria were calculated, with values closer to zero indicative of better model fits. The proportional hazards assumption for each model was confirmed using the R function cox.zph. Individual predictor variables were determined to have reached statistical significance at $p < .05$; given the exploratory nature of the present investigation, no multiplicity adjustments were made for multiple outcomes (44). Hazard ratios for significant dance exposure variables were simulated and plotted with 50% and 95% shortest probability intervals using the R package *simPH* (45). Hazard ratios reported are indicative of a one median absolute deviation increase in the predictor variable, unless otherwise stated. All statistical analyses took place in R (version 4.0.3, R Foundation for Statistical Computing, Vienna, Austria).

Results

A total of 1547 medical attention injuries, of which 516 were time-loss injuries, were recorded across the five seasons; 135 medical attention injuries, including 59 time-loss injuries, were excluded because they occurred when a dancer was not engaged in a normal rehearsal schedule (e.g., during rehabilitation, sabbatical, maternity, etc.). Eighty medical attention injuries (two bone, 1 central/peripheral nervous system, 40 joint/ligament, seven muscle/tendon, and 29 'other'), including 30 time-loss injuries (two bone, 17 joint/ligament, one muscle/tendon, and 10 'other') were excluded because records indicated that a physiotherapist had not classified the injury as either overuse or traumatic. The final dataset, therefore, consisted of 1332 medical attention (overuse: 982; traumatic: 350) and 427 time-loss (overuse: 246; traumatic: 181) injuries across 381,710 h of dance exposure.

Overuse Injuries

A positive linear relationship was observed between overuse medical attention injury rate and week-to-week change in accumulated exposure (HR: 1.17, 95% CI: 1.06–1.28, $p = .001$; Figure 1), whilst a negative linear relationship was observed between overuse medical attention injury rate and 7-day accumulated exposure (HR: 0.74, 95% CI: 0.66–0.84, $p < .001$; Figure 1). Overuse medical attention injury rate was greater in soloists (HR: 1.29, 95% CI: 1.02–1.62, $p = .034$) but not principals (HR: 1.34, 95% CI: 0.96–1.87, $p = .081$) compared to the *corps de ballet*, and lower in males compared to females (HR: 0.79, 95% CI: 0.64–0.97, $p = .026$).

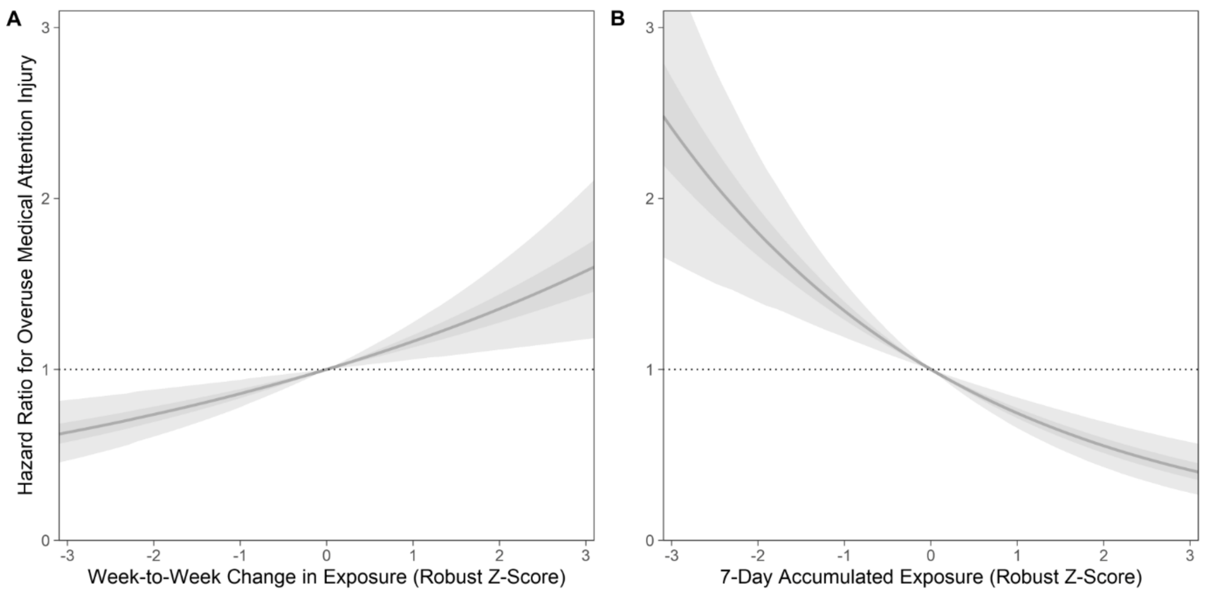

Figure 1 Significant linear associations between A) week-to-week change in dance exposure time and overuse medical attention injury risk, and B) 7-day accumulated exposure and overuse medical attention injury risk. The central line represents the median of all simulations, whilst the darker and lighter areas represent the 50% and 95% shortest probability intervals, respectively.

The shared frailty model revealed a positive linear association between week-to-week change in accumulated exposure and overuse time-loss injury rate (HR: 1.27, 95% CI: 1.06–1.53, p = .011; Figure 2). No significant linear or non-linear relationships were observed between overuse time-loss injury and 7-day or 28-day accumulated exposure time. Injury history was positively associated with overuse time-loss injury, with an increase of one injury per 1000 h resulting in an HR of 1.06 (95% CI: 1.02–1.10, p = .005). An increase in overuse time-loss injury rate was observed in the soloist group compared to the *corps de ballet* (HR: 1.47, 95% CI: 1.01–2.15, p = .045), though no significant difference in overuse time-loss injury rate was observed between the *corps de ballet* and principal dancers (HR: 1.40, 95% CI: 0.81–2.41, p = .230). No significant associations were observed between overuse time-loss injury rate and either age (HR: 1.00, 95% CI: 0.96–1.03, p = .840) or sex (male HR: 0.91, 95% CI: 0.66–1.26, p = .580).

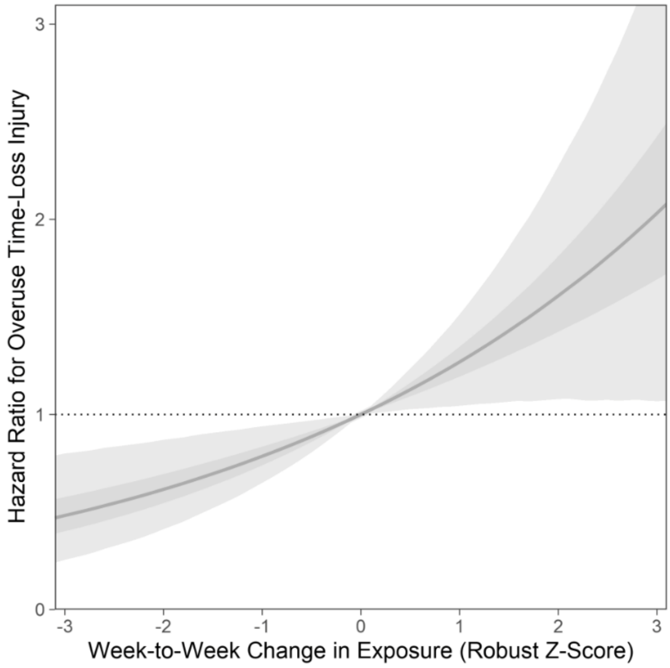

Figure 2 Significant positive linear association between week-to-week change in dance exposure time and overuse time-loss injury risk. The central line represents the median of all simulations, whilst the darker and lighter areas represent the 50% and 95% shortest probability intervals, respectively.

Traumatic Injuries

For traumatic medical attention injuries, a significant association was only observed with age (+1-year HR: 1.04, 95% CI: 1.01–1.07, $p = .016$). A large but non-significant difference in traumatic medical attention injury rate was observed in principals compared with the *corps de ballet* (HR: 1.51, 95% CI: 0.95–2.41, $p = .083$).

No dance exposure variables were associated with traumatic time-loss injury rate. A cubic relationship between 28-day accumulated exposure and traumatic time-loss injury rate demonstrated the best fit to the observed data of any dance exposure time variable but was not statistically significant ($p = .053$; Figure 3). Hazard ratios for traumatic time-loss injury were greater for soloists and principals compared with the *corps de ballet*, though were not significant (principals HR: 1.57, 95% CI: 0.92–2.68, $p = .096$; soloists HR: 1.36, 95% CI: 0.90–2.06, $p = .140$). A significant increase in traumatic time-loss injury was observed with increasing age (+1-year HR: 1.05, 95% CI: 1.01–1.09, $p = .005$), however, no association was observed between traumatic time-loss injury rate and injury history (+1 injury·1000 h^{-1} HR: 1.02, 95% CI: 0.96–1.09, $p = .500$) or sex (male HR: 0.95, 95% CI: 0.70–1.31, $p = .772$).

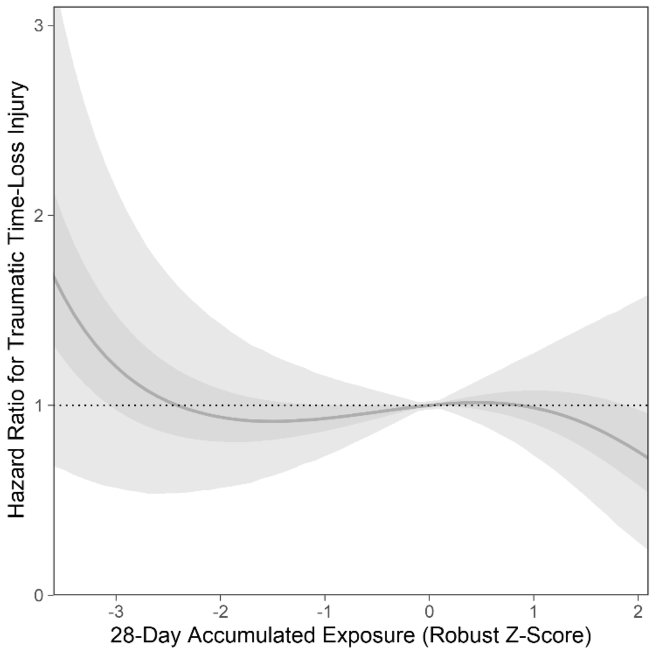

Figure 3 Non-**s**ignificant quadratic association between 28-day accumulated dance exposure time and traumatic time-loss injury risk. The central line represents the median of all simulations, whilst the darker and lighter areas represent the 50% and 95% shortest probability intervals, respectively.

For both overuse and traumatic injuries, and for both medical attention and time-loss injuries, shared frailty models indicated better fits to the observed data than Cox proportional hazard models (Table 2).

Table 2 Model selection criteria for the Cox proportional hazards and shared frailty models

Model	Model Selection Criteria		
	LL	BIC	AIC
Overuse Time-loss			
Cox PH	-1046.6	2170.2	2121.1
Shared Frailty	-1005.0[A]	2258.7	2100.3
Overuse Medical Attention			
Cox PH	-4205.7	8507.9	8439.5
Shared Frailty	-4101.5[A]	8702.9	8348.1
Traumatic Time-loss			
Cox PH	-755.6	1584.1	1539.3
Shared Frailty	-738.8[B]	1628.6	1533.2
Traumatic Medical Attention			
Cox PH	-1477.3	3036.7	2982.7
Shared Frailty	-1416.7[A]	3157.9	2944.2

LL – log-likelihood; AIC – Akaike information criterion; BIC – Bayesian information criterion; PH – proportional hazards.

[A] Significant ($p < .001$) improvement compared with Cox PH model.
[B] Significant ($p < .01$) improvement compared with Cox PH model.

Discussion

This is the first study to investigate relationships between dance exposure and medical attention and time-loss injury risk in professional ballet. In line with previous recommendations (46,47), we fitted shared frailty models to a dataset of 381,710 exposure hours, 1332 clinician-reported medical attention injuries, and 427 clinician-reported time-loss injuries to identify potential risk factors for injury. Overuse time-loss injury rate was associated with week-to-week change in dance exposure, company rank, and injury history, whilst traumatic time-loss and medical attention injury rates increased with age but were not associated with any other variables. Ballet companies can manage potential injury risk factors by implementing training principles such as periodization and progressive overload.

In the present results, week-to-week increases in dance exposure were positively associated with the rate of overuse injury. This finding agrees with several studies identifying excessive increases in load as a potential risk factor for athletic injury (33,48). Furthermore, dancers have suggested that injury is related to a lack of consistency in workload, resulting from factors such as a congested performance schedule, or an increase in stage calls before an opening night (14,49). Although the aetiological role that a spike in workload may play in injury has been speculated, causal mechanisms have not yet been established. Several frameworks for overuse injury outline an interplay between structure-specific load and structure-specific load capacity (50). In the current results, dance exposure may be a proxy measure of the former, with large week-to-week increases in exposure representing an increase in load beyond the tolerance of any given tissue—at present, however, this is speculative. It is also important to note that given the non-linear relationship between the magnitude of a loading stimulus and the resulting tissue damage (51), using dance exposure as a proxy for tissue damage in any one specific dancer, at a single point in time, is likely futile. Instead, when scheduling rehearsals and performances, professional ballet companies should employ company-wide and season-long strategies that alleviate sharp increases in dance exposure; for example, distributing workload uniformly across the company, periodizing the repertoire, or progressing loads gradually before congested periods of performances.

No associations were observed between 28-day accumulated dance exposure and either overuse or traumatic injury rate in the present results, consistent with recent research in professional soccer (52). Research in rugby union (47) and cricket (53), however, has suggested that low chronic workloads are indicative of undeveloped physical qualities, whilst high chronic workloads are indicative of well-developed physical qualities, and subsequently robust athletes. Although the direction of the relationship between 28-day accumulated dance exposure and traumatic injury rates supports this hypothesis, the strength of the relationship does not; ultimately, our results do not justify conclusive statements on this topic. Future investigations into chronic workloads and injury risk should account for confounders; for example, periods of low chronic exposure likely occur at the beginning of the season (following reduced strength training, or concurrent with large increases in load), or following rehabilitation from an injury (when affected tissues may still be remodelling). Contrasting multiple studies that have identified high acute workloads as a potential injury risk factor in sportspeople (2), we report no association between 7-day accumulated exposure and either overuse or traumatic time-loss injury risk in professional ballet dancers. These results support previous suggestions that high workloads alone are not problematic; instead, the risk of injury is influenced by the manner in which an athlete progresses to those high workloads (54). When scheduling rehearsal and performances, however, ballet companies should consider that whilst time-loss injury incidence rates may not increase with high acute loads, the absolute number of time-loss injuries will likely increase proportionally with exposure time. Surprisingly, the hazard ratio for overuse medical attention injuries was greatest following lower seven-day accumulated exposures, contradicting an established paradigm for athletic injury risk (55).

In agreement with previous investigations in pre-professional ballet (56), we observed an increased rate of time-loss overuse injury in dancers with a higher prior injury incidence (36,57); however, no evidence was observed for any relationship between injury history and traumatic time-loss or medical attention injuries. In contrast, the rate of traumatic injury, but not overuse injury, increased with age. When interpreting this result, it is important to consider not only the physiological effects of aging but also the contextual implications; for example, age is positively associated with company rank. Furthermore, within company-ranks the casting of different roles, and subsequently a dancer's activity, may be influenced by age. Consistent with previous research in professional ballet and modern dancers (58), we observed differences in injury risk across company ranks, as soloists demonstrated significant increases in overuse injury compared to *corps de ballet* dancers. This finding may reflect the fact that senior-ranking dancers are typically cast in more physically demanding roles (38), and work at higher activity intensities (7,59) compared to their junior counterparts. Despite the differences in the activity and biomechanical demands of typical male and female roles (38), no differences in either overuse or traumatic time-loss injury risk were observed between sexes; a lower hazard ratio for overuse medical attention injuries, however, was observed in males compared with females.

Strengths, Limitations, and Considerations

This is the largest investigation to date into potential risk factors for injury in professional ballet. Both the number of participants and injuries in the present study exceed sample sizes often used in similar sporting research; nonetheless, the injury count was insufficient to subcategorize injuries by tissue type. Several reviews have recommended the time-to-event models used in the present analysis for sports injury research, allowing for time-varying covariates, recurrent events, cause-specific hazards (46,60).

Whilst the secondary use of data facilitates the large sample size, it has several implications for the findings. Firstly, the results are not evidence of a causal link between dance exposure and injury risk (61); the present design is unable to account for several potential confounding factors (62). Retrospective studies have been highlighted as being at-risk of researcher bias, in part due to the flawed selection of multiple or seemingly arbitrary time windows (19). Without being able to pre-register analyses before data collection, we have therefore used the most commonly investigated time windows from this research field in an attempt to alleviate this limitation.

Although exposure data were prospective, individualized, and recorded by a single individual, it was not possible to calculate each dancer’s exact time involvement in performances. We must therefore accept that some level of error in the calculation of exposure time. Although injury data were recorded by 23 different clinicians over the five seasons, 98% of injuries were recorded by five primary physiotherapists and all injuries were entered using a standardized form. We must acknowledge, however, that the recording of injury data may not have been entirely uniform.

Finally, it is important to highlight the shortcomings of time exposure as a measure of athletic load compared to quantifications of volume and intensity. Whilst these measures are regularly collected in sport, they are not yet commonplace in dance environments, particularly in a company of this size. We also acknowledge several contextual factors that may contribute to injury risk which are not quantified, for example, variations in choreographic genres, the differing demands of class, rehearsal, and performance, and the psychological load associated with live performance.

Future Research and Practical Applications

This study provides a platform from which future prospective observational and experimental studies in professional ballet may develop causal injury pathways. In line with existing aetiological frameworks (50), measurements of both structure-specific load and structure-specific load capacity should underpin research in dance (63). Given that the development of physical qualities may be more practical than manipulating rehearsal and performance load, understanding the role of structure-specific load capacity may be particularly valuable.

Increases in injury rate were associated with larger week-to-week increases in dance exposure, agreeing with several previous investigations in sport, though it should be noted that research in this field has yielded mixed results. Whilst specific thresholds with which to manipulate a dance schedule are not warranted based on the current results, they do support the use of established training principles. At present, it appears to be rare for a ballet schedule to include meaningful recovery periods or facilitate progressions in load; instead, training loads are highly variable because of factors such as studio, stage, or choreographer availability, changes in casting due to injury, and unequal distribution of work both between and within company ranks. Artistic and medical staff working in professional ballet companies should be mindful of excessive progressions in load, therefore rehearsal and performance schedules should be periodized when planning a repertoire. Practically, this may entail strategies such as the gradual progression of load before congested periods of performances; providing regular periods of offload to facilitate recovery; or organizing the repertoire such that the most physically demanding productions are not performed consecutively, or by the same primary casts. This may be particularly relevant for higher-risk dancers: senior-ranking dancers, dancers with a higher rate of previous injury, or older dancers.

Conclusion

In a five-season cohort study in a professional ballet company, increases in overuse time-loss injury rate were associated with week-to-week increases in dance exposure, injury history, and the company ranks of soloist and first soloist. Traumatic injury rate was associated with age, but no dance exposure variables or dancer characteristics. These results provide a basis for the development of causal pathways in future prospective studies. Science and medicine practitioners and artistic staff working in professional ballet should consider the training principles of progression, periodization, and recovery when planning rehearsal and performance schedules.

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Conflicts of Interest

The authors have no conflicts of interest to declare. The results of the present study do not constitute endorsement by ACSM. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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