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# Untangling risk factors including discipline-specific exposure for injuries in preprofessional and professional circus artists in the USA

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## ABSTRACT

**Objective** This prospective cohort study quantified injury patterns related to specific circus discipline exposure in preprofessional and professional circus artists.

**Methods** Circus artists (n=201; ages 13–69; 172 female, 29 male assigned sex at birth) were enrolled in 10 cities across the USA. Participants were followed for 1 year from enrolment, completing a weekly training log and undergoing a physical therapist evaluation for injuries. The circus-specific extension of the International Olympic Committee 2020 consensus on recording injury and illness in sports was used to analyse injury patterns.

**Results** The study completion rate was 77% (n=155). Data were analysed by participant subgroup (age, professional status, sex at birth). The highest injury rates in participant subgroups were for males (5.69/1000 exposures) and related to discipline subgroups, were in aerial with ground elements (5.93/1000 exposures) and aerial (4.26/1000 exposures). Adults had more injuries related to aerial, whereas adolescents had more related to ground disciplines ($\chi^2$ (2)=10.62, p=0.005) and non-time loss injuries ($\chi^2$ (1)=5.45, p=0.02). Females had a higher proportion of repetitive injuries (70% vs 55%) than males ($\chi^2$ (1) = 4.43, p=0.035). Individuals with an eating disorder history had more (p<0.004) injuries (mean 2.27±2.29) than those without (mean=1.48±0.96).

**Conclusions** This study showed that intrinsic factors (age, sex at birth and history of eating disorder) and extrinsic factors (circus discipline exposure) affect injury risk. We need to account for the intersectionality of these factors to address risk management at an individual and group level.

### WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Circus participation involves injury risk as an athletic performing art. Injury research in the circus arts is limited to professionalising students and performers in large companies, and little is understood about the influence of different circus disciplines or contexts on injury risk.

### WHAT THIS STUDY ADDS

⇒ This study examines how age, professional status, sex at birth and different circus disciplines are related to injury patterns. It is the first circus study to integrate the circus-specific extension framework of the International Olympic Committee 2020 consensus into reporting injuries.

### HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This study can inform areas of focus for research and practice for injury prevention strategies in circus arts.

## INTRODUCTION

Injury prevention is a key goal for artistic or athletic recreations or occupations, including circus arts. The first step for developing an injury prevention strategy includes surveillance to understand how personal (intrinsic) and environmental (extrinsic) factors affect injury risk.[1] Circus injury research has been limited to primarily descriptive studies of professional artists in a large company[2] and students at professionalising schools.[3–7] These populations represent a small segment of the overall circus context in the USA.[8] Training or performing environments such as preprofessional programmes, professional freelance work, or small, low-resourced circus companies with different extrinsic factors may impact injury patterns. Research is needed across other settings to broaden the understanding of injury risk for circus arts.

Circus disciplines pose specific extrinsic factors regarding physical, technical and artistic demands, which likely impact injury risk, yet differences have not been explored.[9–11] Early research compared the anatomical location of injuries for floor acrobatics versus acrobatics with equipment, including aerial (trapeze) and ground (tight-wire and slackline) disciplines with inconsistent biomechanical demands.[3] A recent study found clinical injury burden (injury rate plotted against injury duration) was generally higher in ground acrobats, but the exposure was not considered.[7] Two studies[4 12] reported higher proportions of injuries for ground acrobatics,

but the exposure was also higher for these disciplines, which may have accounted for the difference. In contrast, one study showed similar 1-year injury prevalence in aerialists and non-aerialists (73% vs 81%).[6] Still, injury rates were based on the student's primary discipline and not necessarily the discipline attributed to injury.[6] A comprehensive understanding of injury risk in circus discipline subgroups with similar demands (eg, aerial vs ground acrobatics) is lacking.

The purpose of this study was to characterise injuries and exposure in preprofessional and professional circus artists in the USA. Secondarily, the intent was to identify injury patterns by extrinsic (circus discipline subgroup) and intrinsic (age, sex at birth (SAB), medical history and prior health status) using the framework from the circus-specific extension of the International Olympic Committee 2020 consensus on recording injury and illness in sport.[9 13]

## METHODS

### Participants

Ten circus training facilities across the USA were selected as host sites based on the size of the eligible target population, the presence of long-term intensive training programmes, and willingness to assist with study recruitment. Participants were recruited via flyers at area training centres, social media, American Circus Educator newsletter announcements, emails to host students and staff, and other local circus companies. Eligible participants were preprofessional (training ≥6 hours a week and performing in ≥2 shows per year) and professional (self-identified) circus artists over age 13 years, able to read/comprehend English and fulfil the requirements of the study. Exclusion criteria included a planned absence from the area ≥1 month over the next year. A power analysis showed that 200 was an adequate sample size for a medium-to-large (0.25–0.50) effect size with a p value of 0.05. Adults signed an informed consent form, and adolescents signed an assent form. Parents/guardians completed informed consent.

### Design

The prospective, observational cohort design was modelled after a pilot study.[11 12] Participants/public were not involved in the study design, conduct or dissemination.

Rolling enrolment occurred from September to December 2018 (cohort 1, four facilities) and from September 2019 to January 2020 (cohort 2, six facilities). Enrolment included online completion of informed consent/assent forms, an intake questionnaire including demographics, training experience and medical history, and a physical examination[11 12] of intrinsic factors by a physical therapist (PT). PTs had at least 5 years of orthopaedic or sports-related experience and underwent standardised training for study procedures.

Participants were tracked for 1 year following their enrolment date. Participants were emailed a Qualtrics (V.9/2017–2012/2018, Provo, Utah, USA) survey link to complete a weekly training log where they reported weekly exposure as the total number of sessions (classes, rehearsals, performances or self-directed training by circus discipline and strength or flexibility conditioning). New or ongoing injuries and missed training sessions due to injury were recorded. For weeks without exposure, participants indicated the reason (eg, vacation, illness, COVID-19 closure). For new or recurrent injuries, the PTs conducted an interview and physical examination to determine the injury's mechanism, body region, tissue and nature. Injuries at study enrolment were not included in the injury frequency calculation unless an exacerbation occurred.

### Injury classification

The injury was defined as an anatomical tissue-level impairment.[11 12 14] Time loss injury (TL) resulted in the full loss of participation in at least one circus discipline for one or more days after injury onset.[11 12 14] Injuries not meeting the TL criteria were defined as non-time loss (NTL). The type of injury and mode of onset followed the circus-specific extension.[9 13] New injury represented the first time a specific injury occurred within the study period.[9 13 15 16] Subsequent recurrent injury was the same location and nature, and subsequent local injury was the same location but different nature after returning to 100% participation from TL injury.[9 13 15 16] Acute sudden onset related to a single traumatic event (eg, fall, awkward landing).[9 13] Repetitive sudden or gradual onset was associated with repetitive use.[9 13 17] Injuries were defined as directly associated with participation in circus training, rehearsal or performance, or indirectly associated if related to the circus context outside of those activities (eg, spotting), or not related if outside of the circus context.[9 13] Disciplines associated with injuries were grouped using the circus arts discipline subgroup classification system, which classified disciplines as aerial acrobatics (aerial, aerial with ground elements), ground acrobatics (human propulsion, apparatus propulsion, balance/control), manipulation and character.[9 11]

### Data analysis

Descriptive statistics were conducted using Microsoft Excel 365 (vV.2211, Redmond, Washington, USA) for baseline intake and examination data, injury rate (frequency per 1000 sessions of circus exposure) and frequency for participant subgroups by age, SAB and professional status. Brief descriptive statistics were also included for the non-binary participants to provide some information on this under-reported group. The remaining analyses used IBM SPSS Statistics (V.26) with significance set at $p<0.05$. A regression analysis used total training sessions, age and years of circus experience in years as predictor variables for injury incidence. Multiple t-tests compared injury types by discipline subgroups, age, professional status and SAB. Pearson's correlational analysis tested the relationship between the duration

of training experience and injuries. The influence of medical history and prior health status was tested using multiple regression analyses.

## RESULTS

Two hundred and one participants (ages 13–69 years) enrolled, and 155 (77.11%) completed the study. Drop-outs (1 adolescent; 45 adults) resulted from non-adherence to weekly training log completion (n=32), personal issues, illness or moving away. Drop-outs' data were included for the duration of their participation. Participants were identified by SAB (172 assigned female at birth, AFAB; 29 assigned male at birth, AMAB) for the primary analysis due to a low number identifying as non-binary (n=8). Non-binary participants included six preprofessionals and two professionals (ages 24–36 years), with seven completing the study.

### Participant characteristics

Select data from study enrolment are in table 1. Average years of circus experience was higher (t(195)=−3.96, p<0.001), accounting for different variances (F=7.26, p<0.008), in professionals (8.63 years; SD=6.01) compared with preprofessionals (5.58 years; SD=3.23). Amenorrhoea was more prevalent in adolescents than adults and preprofessionals than professionals. No adolescents reported an eating disorder, although 36% of adolescent AFAB had amenorrhoea. Fewer participants reported a connective tissue disorder than met the criteria for generalised joint hypermobility (GJH) per their Beighton score.[18]

### Exposure

Circus exposure by discipline subgroup and training context, excluding drop-outs, are in tables 2 and 3. Weekly circus exposure was higher (t(199)=10.76, p<0.001) in professionals (9.27; SD=1.44 sessions) than preprofessionals (6.87; SD=1.65 sessions). Across participant subgroups, exposure was highest for aerial and ground (balance/control), except for adolescents with similar exposure to ground (human propulsion).

### Injury rates

Injury rates, excluding drop-outs, are reported per 1000 exposures in table 4. By participant subgroup, AMAB had the highest injury rates (5.69/1000 sessions), and by discipline subgroup, aerial with ground elements, aerial then ground (balance/control) were highest (5.93, 4.26, 3.66/1000 discipline-specific sessions).

### Injury types or patterns

Tables 5 and 6 show injury distribution by subgroup. The proportion of injuries was highest for the shoulder (22%), followed by the lumbosacral region (13%) and then the elbow (10%). Muscle/tendon injuries were most common (52%) across tissue types.

#### Age, sex, professional status and discipline

Adults had more aerial-related injuries compared with adolescents. In contrast, adolescents had more ground-related injuries ($\chi^2$ (2)=10.62, p=0.005) and non-time loss injuries ($\chi^2$ (1)=5.45, p=0.02). There were no differences between participant groups for 1-year injury incidence but a trend towards a correlation between increased age and decreased injury incidence (r=−0.122, p=0.085) was found. No significant differences existed by age or SAB for new versus subsequent injuries, body region or tissue type affected. There was a difference by SAB such that AFAB had a higher proportion of repetitive injuries than AMAB (70% vs 55%) and a lower proportion of acute (30% vs 43%) injuries ($\chi^2$ (1)=4.43, p=0.035). There were no differences between injuries related to aerial versus ground disciplines or by professional status for body region, tissue type affected or mode of onset. TL in days across all participants excluding dropouts was higher for AFAB (21.79; SD=54.96) than AMAB (12.57; SD=23.45), professionals (29.88; SD=70.66) compared with preprofessionals (15.04; SD=33.61) and adults (20.86; SD=51.79) vs adolescents (17.53; SD=50.62). Across participants with TL injuries (excluding dropouts), adolescents had greater average TL over one year compared to adults (65.8; SD=50.62; 30.8; SD=59.93). Among the 8 non-binary participants, 14 injuries occurred in 6 participants. These included four shoulder, three thigh injuries and one each neck, abdominal, hip, ankle, foot, wrist and elbow injury.

#### Medical history and physical status

Individuals with an eating disorder history averaged more injuries (2.27; SD=2.29) than those without (1.48; SD=0.96; p<0.004). There were no significant differences in injury incidence between AFAB with amenorrhoea or participants with a history of connective tissue, musculoskeletal, neurological disorder or head injury/concussion compared with those without, or based on baseline physical characteristics per the enrolment physical examination that included selected measures of strength, flexibility, joint mobility and balance.

### COVID-19 effects

The COVID-19 pandemic impacted cohort 2. Training facility and show closures started 1–7 months into their study period. Overall training and performance exposure were lower by 21.83% and 34.53% compared with cohort 1. There were changes in the disciplines trained due to facility access. The environment for training often changed from facility to home or outdoors, and performances became recorded or virtual. Injury assessments were completed virtually with a modified physical examination, sometimes limiting our ability to specify the affected body tissue.

## DISCUSSION

This was the first multicentred, prospective longitudinal study to examine injury patterns for preprofessional and

**Table 1** Participant demographics (entire cohort)

| | Entire cohort | Subgroups by age | | Subgroups by level | | Subgroups by sex at birth | |
|---|---|---|---|---|---|---|---|
| | All | Adolescent | Adult | Preprofessional | Professional | Female | Male* |
| No of participants | 201 | 16 | 185 | 130 | 71 | 172 | 29 |
| Age | 31.40 (8.91) | 14.50 (1.51) | 32.87 (7.68) | 30.45 (9.97) | 33.13 (6.26) | 31.22 (8.60) | 32.50 (10.72) |
| Years of circus experience | 6.98 (4.17) | 5.88 (2.73) | 7.07 (4.27) | 5.71 (3.50) | 9.27 (4.34) | 7.01 (3.96) | 6.75 (5.38) |
| Height (cm) | 164.37 (7.96) | 164.30 (7.22) | 164.38 (8.04) | 164.22 (7.68) | 164.65 (8.50) | 162.85 (6.98) | 173.69 (7.34) |
| Mass (kg) | 62.48 (10.90) | 57.64 (9.90) | 62.90 (10.91) | 62.57 (11.49) | 62.32 (9.82) | 60.62 (9.12) | 73.95 (13.81) |
| History of eating disorder | 18.00% | 0.00% | 19.57% | 17.83% | 18.31% | 20.35% | 3.57% |
| History of amenorrhoea† | NA | 35.71% | 16.46% | 21.05% | 12.07% | 18.02% | NA |
| History of musculoskeletal injury | 89.50% | 75.00% | 90.76% | 87.60% | 92.96% | 90.12% | 85.71% |
| History of concussion/head injury | 30.50% | 12.50% | 32.07% | 21.71% | 46.48% | 29.07% | 39.29% |
| History of connective tissue disorder | 1.50% | 6.25% | 1.09% | 1.55% | 1.41% | 1.16% | 3.57% |
| Positive Beighton score‡ | 34.50% | 31.25% | 34.78% | 31.78% | 39.44% | 37.21% | 17.86% |

Measures are reported as mean (SD) or percentage (%).
*One male preprofessional participant did not complete a medical history questionnaire, so percentages were adjusted.
†History of amenorrhoea excludes males and accounts for the onset of puberty and the use of birth control.
‡Positive Beighton score as criteria for generalised joint hypermobility was ≥6/9 in prepubertal children, ≥5/9 for postpubertal up to age 50 and ≥4/9 for over age 50.[18]
NA, not available;

**Table 2** Average total and weekly session exposure to disciplines subgroups or conditioning (excludes drop-outs)

| | All | Adolescent | Adult | Preprofessional | Professional | Female | Male |
|---|---|---|---|---|---|---|---|
| Total sessions/participant | | | | | | | |
| All | 403.13 | 411.73 | 402.21 | 357.25 | 482.00 | 401.15 | 415.07 |
| Aerial | 130.16 | 71.87 | 136.41 | 103.45 | 176.09 | 122.34 | 177.43 |
| Aerial with ground elements | 29.36 | 5.13 | 31.96 | 31.37 | 25.91 | 31.99 | 13.45 |
| Ground (human propulsion) | 47.02 | 81.93 | 43.28 | 43.64 | 52.82 | 46.94 | 47.50 |
| Ground (apparatus propulsion) | 3.10 | 3.47 | 3.06 | 2.00 | 4.98 | 3.15 | 2.77 |
| Ground (balance/control) | 100.42 | 121.40 | 98.18 | 84.20 | 128.32 | 101.92 | 91.36 |
| Manipulation | 19.08 | 43.67 | 16.45 | 20.01 | 17.49 | 18.00 | 25.64 |
| Character | 0.38 | 0.00 | 0.42 | 0.47 | 0.23 | 0.44 | 0.00 |
| Conditioning—flexibility | 0.35 | 0.00 | 0.39 | 0.40 | 0.26 | 0.41 | 0.00 |
| Conditioning—strength | 73.25 | 84.27 | 72.07 | 71.71 | 75.89 | 75.95 | 56.91 |
| Weekly sessions/participant | | | | | | | |
| All | 7.75 | 7.92 | 7.73 | 6.87 | 9.27 | 7.71 | 7.98 |
| Aerial | 2.50 | 1.38 | 2.62 | 1.99 | 3.39 | 2.35 | 3.41 |
| Aerial with ground elements | 0.56 | 0.10 | 0.61 | 0.60 | 0.50 | 0.62 | 0.26 |
| Ground (human propulsion) | 0.90 | 1.58 | 0.83 | 0.84 | 1.02 | 0.90 | 0.91 |
| Ground (apparatus propulsion) | 0.06 | 0.07 | 0.06 | 0.04 | 0.10 | 0.06 | 0.05 |
| Ground (balance/control) | 1.93 | 2.33 | 1.89 | 1.62 | 2.47 | 1.96 | 1.76 |
| Manipulation | 0.37 | 0.84 | 0.32 | 0.38 | 0.34 | 0.35 | 0.49 |
| Character | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 |
| Conditioning—flexibility | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 |
| Conditioning—strength | 1.41 | 1.62 | 1.39 | 1.38 | 1.46 | 1.46 | 1.09 |

professional circus artists in the USA by intrinsic (age, SAB, medical history, physical characteristics) and extrinsic (circus discipline) risk factors. Injury risk is multifactorial and environmental factors are an important consideration.[19] Many contextual differences were apparent in our sample compared with previous studies. Circus students at professionalising schools trained 19 or more hours per week,[3–5 7] whereas preprofessionals in this study trained 6.68 sessions per week on average. Sessions had close to a 1:1 relationship to hours in the pilot study.[12] In

**Table 3** Average total and weekly session exposure by context (excludes drop-outs)

| | All | Adolescent | Adult | Preprofessional | Professional | Female | Male |
|---|---|---|---|---|---|---|---|
| Total sessions/participant | | | | | | | |
| All | 403.13 | 411.73 | 402.21 | 357.25 | 482 | 401.15 | 415.07 |
| Classes | 125.07 | 216.4 | 115.29 | 151.53 | 79.58 | 127.35 | 111.27 |
| Additional training | 130.59 | 115.87 | 132.17 | 120.96 | 147.16 | 126.14 | 157.52 |
| Rehearsal | 31.08 | 33.13 | 30.86 | 19.33 | 51.3 | 32.01 | 25.5 |
| Performance | 15.03 | 22.67 | 14.21 | 9.89 | 23.86 | 15.87 | 9.91 |
| Teach | 101.35 | 23.67 | 109.68 | 55.55 | 180.11 | 99.78 | 110.86 |
| Weekly sessions/participant | | | | | | | |
| All | 7.75 | 7.92 | 7.73 | 6.87 | 9.27 | 7.71 | 7.98 |
| Classes | 2.41 | 4.16 | 2.22 | 2.91 | 1.53 | 2.45 | 2.14 |
| Additional training | 2.51 | 2.23 | 2.54 | 2.33 | 2.83 | 2.43 | 3.03 |
| Rehearsal | 0.6 | 0.64 | 0.59 | 0.37 | 0.99 | 0.62 | 0.49 |
| Performance | 0.29 | 0.44 | 0.27 | 0.19 | 0.46 | 0.31 | 0.19 |
| Teach | 1.95 | 0.46 | 2.11 | 1.07 | 3.46 | 1.92 | 2.13 |

Table 4 Injury rates by subgroup (excludes drop-outs)

| Subgroup | Injury rate |
|---|---|
| All | 3.82 |
| Adolescent | 2.42 |
| Adult | 3.98 |
| Preprofessional | 4.08 |
| Professional | 3.49 |
| Female | 3.5 |
| Male | 5.69 |
| Aerial | 4.26 |
| Aerial with ground elements | 5.93 |
| Ground (human propulsion) | 2.2 |
| Ground (apparatus propulsion) | 2.08 |
| Ground (balance/control) | 3.66 |
| Manipulation | 0.33 |
| Character | 0 |

For participant subgroups, the injury rate is per 1000 exposures (sessions of all circus training and performances). For circus discipline, the subgroup injury rate is the number of discipline subgroup-related injuries per 1000 exposures only in the same circus discipline subgroup.

large circus companies with resident shows, professionals may work 300 or more shows annually,[10] compared with our professionals, who averaged 23.86 performances annually by discipline (cohort 1=29.94). Further, professionalising schools and large companies,[2–5 7] had dedicated medical staff, and our training facilities did not, which may impact injury management. Finally, our sex distribution differed from previous studies, with 80% compared with 29%–59%[2–7] AFAB. This study demonstrates the importance of describing and accounting for contextual differences in circus injury research to ensure injury risk is understood across the breadth of settings.

## Discipline

Determining extrinsic risk for circus disciplines, including accounting for exposure and artists training multiple disciplines, is challenging[9–12] but important to inform injury prevention practices. We found higher injury rates attributed to aerial versus ground acrobatics, but rates varied across discipline subgroups. Aerial with ground elements, including Chinese pole and pole dance, had the highest injury rate (5.93/1000 session exposures). In a professional training programme, injuries from Chinese pole were most prevalent among aerial disciplines but less frequent than ground acrobatics.[4] Injury rates for recreational pole dance were higher (7.65/1000 hours training)[20] than in circus arts (0.3–3.3/1000 hours).[3 5 7] Although study methods and population differences limit comparison between studies, aerial with ground elements may have an elevated injury risk.

Ground acrobatics-related injury rates were highest for the balance/control subgroup (3.66/1000 sessions), which includes contortion, hand-balancing and partner acrobatics. In contrast, Munro[4] found ground acrobatics was the leading cause of injury with a similar proportion in balance/control and human propulsion disciplines. Exposure was not quantified, but the tumbling practice was a sizeable part of the school curriculum. Similarly, floor exercise is associated with the highest proportion of gymnastics injuries.[21 22] Future studies should account for discipline exposure in injury rates to improve our understanding of injury risk across disciplines and to avoid misrepresenting injury risk by just reporting frequency.

## Age

Age is an intrinsic risk factor. Like the pilot study,[12] adults had a higher injury rate than adolescents (3.98 vs 2.42/1000 session exposures), although incidence decreased with age. Adolescents had more ground than aerial-related injuries (60%;14%) but also higher exposure to the ground than aerial (3.98; 1.48 sessions/week). Adults showed the opposite pattern with lower injury frequency (37%;44%) and exposure (2.78; 3.23) in ground than aerial disciplines, highlighting the importance of interpreting injury risk relative to exposure. Adolescents had significantly more NTL injuries (77%) than adults (47%), suggesting that adults have more severe injuries. However, across participants with TL injuries (excluding dropouts), adolescents had greater average TL over one year (65.8; SD=50.62; 30.8; SD=59.93). Accounting for injury management might be useful to understand this contrast as high school circus arts students were less likely than basketball players to report the injury to the athletic trainer.[23] Adults may also be better at implementing rest or accessing healthcare resources.

## Preprofessional versus professional

A high absolute workload can positively or negatively impact injury risk depending on ramp-up and internal factors such as stress, anxiety and fatigue.[24] Fatigue is a known injury risk factor in sport[25] and dance,[26 27] and is affected by training load in circus students, despite sufficient sleep.[28] Professional circus artists reported less fatigue than students at a circus college,[29] which could explain why despite higher exposure (9.27 vs 6.87 sessions/week), professional circus artists experienced a lower injury rate than preprofessionals (3.49 vs 4.08/1000 sessions).

Injury rate differences may also relate to greater professional experience (9.27 years) than preprofessionals (5.71 years). Third-year students at a circus college experienced lower injury rates than first-year students suggesting that experience may be protective.[7] This could be attributed to training adaptations, mental performance or focus on artistry and consistency for a marketable act rather than technical development and building a skill repertoire. Professional circus artists have also reported lower social isolation, better social skills, fewer problems in shows/evaluations and greater performance satisfaction

**Table 5** Injury frequency (percentage) of injury types (entire cohort)

| | All | Adolescent | Adult | Preprofessional | Professional | Female | Male |
|---|---|---|---|---|---|---|---|
| Total injuries | 276 | 22 (8%) | 254 (92%) | 169 (61%) | 107 (39%) | 222 (80%) | 54 (20%) |
| Time loss | 115 (42%) | 5 (23%) | 110 (43%) | 71 (42%) | 44 (41%) | 96 (43%) | 19 (35%) |
| Non-time loss | 161 (58%) | 17 (77%) | 144 (57%) | 98 (58%) | 63 (59%) | 126 (57%) | 35 (65%) |
| New | 257 (93%) | 20 (91%) | 57 (22%) | 156 (92%) | 101 (94%) | 205 (92%) | 52 (96%) |
| Subsequent recurrent | 9 (3%) | 2 (9%) | 7 (3%) | 6 (4%) | 3 (3%) | 8 (4%) | 2 (4%) |
| Subsequent local | 10 (4%) | 0 | 10 (4%) | 7 (4%) | 3 (3%) | 9 (4%) | 0 |
| Acute—sudden | 89 (32%) | 7 (32%) | 82 (32%) | 57 (34%) | 32 (30%) | 66 (30%) | 23 (43%) |
| Repetitive—sudden | 34 (12%) | 4 (18%) | 30 (12%) | 23 (14%) | 11 (10%) | 28 (13%) | 6 (11%) |
| Repetitive—gradual | 150 (54%) | 14 (64%) | 136 (54%) | 89 (53%) | 61 (57%) | 126 (57%) | 24 (44%) |
| Unknown | 3 (1%) | 1 (5%) | 2 (1%) | 1 (1%) | 2 (2%) | 3 (1%) | 0 |
| Head/face | 1 (0%) | 0 | 1 (0%) | 1 (1%) | 0 | 1 (0%) | 0 |
| Neck/cervical spine | 15 (5%) | 0 | 15 (6%) | 7 (4%) | 8 (7%) | 11 (5%) | 4 (7%) |
| Thoracic spine/upper back | 10 (4%) | 0 | 10 (4%) | 5 (3%) | 5 (5%) | 8 (4%) | 2 (4%) |
| Chest | 10 (4%) | 0 | 10 (4%) | 4 (2%) | 6 (6%) | 8 (4%) | 2 (4%) |
| Lumbosacral | 35 (13%) | 5 (23%) | 30 (12%) | 21 (12%) | 14 (13%) | 30 (14%) | 5 (9%) |
| Abdomen | 10 (4%) | 1 (5%) | 9 (4%) | 8 (5%) | 2 (2%) | 8 (4%) | 2 (4%) |
| Shoulder | 61 (22%) | 5 (23%) | 56 (22%) | 36 (21%) | 25 (23%) | 47 (21%) | 14 (26%) |
| Upper arm | 1 (0%) | 1 (5%) | 0 | 1 (1%) | 0 | 1 (0%) | 0 |
| Elbow | 27 (10%) | 0 | 27 (11%) | 17 (10%) | 10 (9%) | 21 (9%) | 6 (11%) |
| Forearm | 8 (3%) | 0 | 8 (3%) | 6 (4%) | 2 (2%) | 5 (2%) | 3 (6%) |
| Wrist | 21 (8%) | 4 (18%) | 17 (7%) | 13 (8%) | 8 (7%) | 17 (8%) | 4 (7%) |
| Hand | 11 (4%) | 1 (5%) | 10 (4%) | 9 (5%) | 2 (2%) | 9 (4%) | 2 (4%) |
| Hip/groin | 20 (7%) | 1 (5%) | 19 (7%) | 12 (7%) | 8 (7%) | 19 (9%) | 1 (2%) |
| Thigh | 15 (5%) | 1 (5%) | 14 (6%) | 8 (5%) | 7 (7%) | 11 (5%) | 4 (7%) |
| Knee | 15 (5%) | 1 (5%) | 14 (6%) | 8 (5%) | 7 (7%) | 13 (6%) | 2 (4%) |
| Lower leg | 3 (1%) | 2 (9%) | 1 (0%) | 3 (2%) | 0 | 3 (1%) | 0 |
| Ankle | 7 (3%) | 0 | 7 (3%) | 6 (4%) | 1 (1%) | 5 (2%) | 2 (4%) |
| Foot | 6 (2%) | 0 | 6 (2%) | 4 (2%) | 2 (2%) | 5 (2%) | 1 (2%) |
| Muscle/tendon | 144 (52%) | 12 (55%) | 132 (52%) | 95 (56%) | 49 (46%) | 114 (51%) | 30 (56%) |
| Cartilage/synovium/bursa | 57 (21%) | 6 (27%) | 51 (20%) | 35 (21%) | 22 (21%) | 49 (22%) | 8 (15%) |
| Ligament/joint capsule | 32 (12%) | 1 (5%) | 31 (12%) | 15 (9%) | 17 (16%) | 26 (12%) | 6 (11%) |
| Bone | 2 (1%) | 1 (5%) | 1 (0%) | 1 (1%) | 1 (1%) | 2 (1%) | 0 |
| Nervous | 16 (6%) | 1 (5%) | 15 (6%) | 7 (4%) | 9 (8%) | 11 (5%) | 5 (9%) |
| Superficial tissues/skin | 6 (2%) | 0 | 6 (2%) | 5 (3%) | 1 (1%) | 5 (2%) | 1 (2%) |
| Non-specific | 19 (7%) | 1 (5%) | 18 (7%) | 11 (7%) | 8 (7%) | 15 (7%) | 4 (7%) |

compared with circus students,[29] reinforcing the need for a more holistic consideration of factors related to an injury.

## Sex

Sex differences included a higher injury rate (5.69 vs 3.5/1000 exposures) and a higher proportion of acute than repetitive injuries for AMAB than AFAB. A study in collegiate athletes also found AMAB had more acute injuries.[30] However, differences were no longer apparent when analyses were limited to 10 sports with similar movement skills for both sexes.[30] In gymnastics, AFAB had more overuse injuries than AMAB,[30] possibly due to apparatus differences. These studies suggest that gender biases in training are more likely responsible for this difference than anatomical or physiological sex differences.

In circus arts, sex differences in overall injury rates are uncommon,[2 4 6 7] but become apparent for injury location. In our study, lumbosacral (14%; 9%) and hip/groin (9%; 2%) injuries were higher in AFAB than in AMAB. In other studies, AFAB had more hip/groin injuries[2 4] and AMAB more wrist, forearm and ankle injuries.[4] These differences may arise from gender biases in circus education, where women are often encouraged to train

Table 6 Injury frequency in relationship to activity (entire cohort)

| | All | Adolescent | Adult | Preprofessional | Professional | Female | Male |
|---|---|---|---|---|---|---|---|
| Warm-up | 4 (1%) | 0 | 4 (2%) | 2 (1%) | 2 (2%) | 3 (1%) | 1 (2%) |
| Training | 187 (66%) | 13 (57%) | 174 (67%) | 115 (66%) | 72 (65%) | 151 (66%) | 36 (55%) |
| Rehearsal | 16 (6%) | 2 (9%) | 14 (5%) | 12 (7%) | 4 (4%) | 11 (5%) | 5 (9%) |
| Performance | 16 (6%) | 0 | 16 (6%) | 6 (3%) | 10 (9%) | 11 (5%) | 5 (9%) |
| Conditioning flexibility | 22 (8%) | 2 (9%) | 20 (8%) | 15 (9%) | 7 (6%) | 19 (8%) | 3 (5%) |
| Conditioning strength | 13 (5%) | 2 (9%) | 11 (4%) | 10 (6%) | 3 (3%) | 12 (5%) | 1 (2%) |
| Indirectly circus related | 11 (4%) | 2 (9%) | 9 (3%) | 6 (3%) | 5 (5%) | 9 (4%) | 2 (4%) |
| Not circus related | 7 (2%) | 1 (4%) | 6 (2%) | 5 (3%) | 2 (2%) | 6 (3%) | 1 (2%) |
| Unknown | 7 (2%) | 1 (4%) | 6 (2%) | 2 (1%) | 5 (5%) | 6 (3%) | 1 (2%) |
| Aerial | 95 (34%) | 2 (9%) | 93 (36%) | 50 (29%) | 45 (41%) | 76 (33%) | 19 (35%) |
| Aerial with ground elements | 27 (10%) | 0 | 27 (10%) | 22 (13%) | 5 (5%) | 27 (12%) | 0 |
| Ground (human propulsion) | 20 (7%) | 3 (13%) | 17 (7%) | 14 (8%) | 6 (5%) | 15 (7%) | 5 (9%) |
| Ground (apparatus propulsion) | 1 (0%) | 1 (4%) | 0 | 1 (1%) | 0 | 1 (0%) | 0 |
| Ground (balance/control) | 69 (24%) | 9 (39%) | 60 (23%) | 42 (24%) | 27 (25%) | 48 (21%) | 21 (38%) |
| Manipulation | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Character | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Multidisciplinary | 7 (2%) | 0 | 7 (3%) | 4 (2%) | 3 (3%) | 6 (3%) | 1 (2%) |
| Warm-up | 4 (1%) | 0 | 4 (2%) | 2 (1%) | 2 (2%) | 3 (1%) | 1 (2%) |
| Conditioning flexibility | 22 (8%) | 2 (9%) | 20 (8%) | 15 (9%) | 7 (6%) | 19 (8%) | 3 (5%) |
| Conditioning strength | 13 (5%) | 2 (9%) | 11 (4%) | 10 (6%) | 3 (3%) | 12 (5%) | 1 (2%) |
| Indirectly circus related | 11 (4%) | 2 (9%) | 9 (3%) | 6 (3%) | 5 (5%) | 9 (4%) | 2 (4%) |
| Not circus related | 7 (2%) | 1 (4%) | 6 (2%) | 5 (3%) | 2 (2%) | 6 (3%) | 1 (2%) |
| Unknown | 7 (2%) | 1 (4%) | 6 (2%) | 2 (1%) | 5 (5%) | 6 (3%) | 1 (2%) |

Indirectly circus related, if related to circus but did not occur from participation in training or performance (eg, walking across the gym, spotting); not circus related, known cause outside of circus context (eg, riding a bike); unknown, insidious onset or participant unable to identify a cause; multidisciplinary, multiple disciplines involved in more than one discipline subgroup.

in disciplines exhibiting grace and flexibility and men in more dynamic disciplines.[31] Understanding the impact of gender identity is also important, including the implications for for non-binary (3.9% of our study population) and transgender/gender diverse artists (4.6% in another study).[32]

### Medical history

Overall self-reported eating disorder prevalence (18%) was lower than in another study of circus artists (36%),[33] however, 35.71% of AFAB adolescents in our study had a history of amenorrhoea despite none reporting an eating disorder. Amenorrhoea could indicate the physiological effects of underfuelling and an undetected eating disorder. Similarly, only 1.5% of participants reported having a connective tissue disorder despite 34.5% meeting the GJH criteria. Lack of healthcare access may have contributed to the underdiagnosis of eating and connective tissue disorders and impacted injury burden and should be further examined in future research. Similar to other studies,[34 35] eating disorders were associated with higher injury risk, but unlike other sports research,[36 37] amenorrhoea and history of connective tissue disorders were not. Baseline physical characteristics such as strength, flexibility and balance did not influence injury incidence. However, these factors are often the focus of injury prevention, suggesting that prevention strategies must shift to address our emerging understanding of risk factors.

### Strengths

Despite the required weekly training log, the study had a high completion rate (77.11%). Including NTL injuries versus only TL or medical attention injuries better represents the breadth of circus injuries. Injury assessment by a PT enhances diagnostic accuracy for the injury cause and type compared with self-report.[14] Using the circus-specific extension framework, including the circus discipline subgroups to report our data, will allow for valid comparisons to future research.

### Limitations

Based on challenges during the pilot study,[12] exposure by hours was not tracked, limiting the comparison to some

research. Future studies should include total circus exposure in hours.[9] Recruitment challenges limited adolescent participation (n=16), which could be increased with greater parent and coach engagement. There were also limited AMAB participants (n=29/201), which seems to reflect the circus demographics in the USA.[38]

## CONCLUSION

This study characterised injuries in preprofessional and professional circus artists in the USA. It showed that intrinsic (age, SAB and eating disorder history) and extrinsic factors (specific circus discipline exposure) affected injury risk in circus artists. When considering injury risk management, these factors must be applied holistically and contextually to the artist and their environment.

**Correction notice** The article has been corrected since it was published online. The acknowledgement section was missing which has been reinstated.

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