Injury Patterns in Subgroups of Circus Artists by Circus Discipline: A Pilot Study

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ABSTRACT

Background and Purpose: Circus injury research is limited. The purpose of this pilot cohort study was to describe injury frequency and characteristics related to specific circus discipline and similar sub-groups of artists based on discipline-specific physical stresses using the established IADMS injury surveillance guidelines and a novel classification for circus disciplines. **Methods:** Twenty-four circus artists [20 female mean (standard deviation) age 19.4 (7.7), 4 male 31.3 (2.5)] enrolled in the study. Participants were followed for one year. They submitted a weekly circus training log and circus-related injuries were assessed. **Findings:** Twenty-one participants completed the study (87.5%). Over the year, 47 total injuries were reported with an overall injury rate of 5/1000 exposures. Ground acrobatics was associated with 53.2% of all injuries. **Clinical Relevance:** Performing arts physical therapists should understand circus injury patterns and physical stresses related to different circus disciplines. **Conclusion:** Injury prevention strategies should initially focus on ground acrobatics.

Key Words: acrobat, circus, injury

BACKGROUND AND PURPOSE

Historians characterize the start of modern circus by when acrobats started performing in a circus ring in the 1700s in Europe, and the 1800s in the United States.[1–3] Today, some circus performances still take place in a circus ring or under a big top tent, but acrobats also perform in theaters, concerts, nightclubs, street fairs, and corporate events. The seemingly superhuman skills performed by circus acrobats are the result of years of intensive training to gain the required strength, flexibility, and motor control. Over the last decade, participation in circus arts has rapidly grown in popularity in the United States, both as a professional art form and a recreational activity.[4] Despite the growth, there is a lack of circus research to guide strategies for decreasing injury risk for these artistic athletes.

Injury surveillance, to understand injury etiology is a critical foundation for developing injury prevention strategies.[5] Circus is early in its understanding of injuries compared to similar activities like dance or gymnastics,[6–15] and must rely on research from sports and dance medicine to guide injury prevention and rehabilitation despite the unique characteristics and context of the circus arts. The first longitudinal circus injury study was published in 2009,[16] and showed a medical attention injury rate of 11.2/1000 performances in professional acrobats, of which 39% were in female performers. By comparison, injury rates for women's college gymnastics are 9.22/1000 athletic exposures including training and competition.[8]

Current variability in circus injury surveillance methodologies[16-21] makes it difficult to compare findings or extract injury patterns that can guide injury prevention research. In a systematic review, Wolfenden and Angioi[21] highlighted differences for injury definitions (time loss or medical attention), measures of exposure (number of performances, hours, or athletic exposures), and participation level (student to professional). Similar inconsistency in dance injury research prompted the development of the International Association of Dance Medicine and Science (IADMS) Standard Consensus Initiative guidelines,[22] which made specific recommendations for best practices in testing and reporting injuries in dance. Since dance is a performance art that requires a high degree of athleticism, these guidelines could inform the standardization of circus injury research.

Some of the variability in circus injury reporting is due to the complexity of circus, including the wide breadth of acrobatic disciplines, spanning from juggling to high flying trapeze. Circus artists often train in multiple disciplines, but the combination of disciplines varies between artists. Mechanical stresses, such as impact forces with tumbling versus stabilization at end range with contortion, also differ between disciplines. Unlike sports, circus lacks large homogeneous groups of athlete artists. Hence, there is need to categorize circus disciplines with similar physical stresses for injury surveillance and to guide future injury risk-reduction interventions.

In circus, the highest injury incidence (35-36%)[16,17] has been reported in the lower extremities, with the ankle as most common.[16-18] Munro[18] found ground acrobatics/tumbling as the most common mechanism of injury in professional circus students possibly related to greater exposure. Another study of circus students found approximately 50% of injuries were due to floor acrobatics, but specific disciplines were unclear.[17] The floor event has also been associated with the greatest number of injuries in artistic gymnastics.[8,10] Understanding the influence of circus discipline on circus injuries is necessary to appropriately target risk reduction interventions.

To allow for meaningful comparison, researchers have attempted to categorize circus artists for injury analysis.[16,17,19] Shrier et al[16] divided professional artists into acrobats, non-acrobats, and musicians. Hamilton et al[19] further subdivided acrobats into sudden load, if the primary act "required high compression or distraction loads" or non-sudden load, if it did not. Physical stresses from traction or pulling with aerial acrobatics are different than the weight-bearing and impact-related forces in ground acrobatics so this sudden load classification still includes a heterogeneous group. Wanke et al[17] divided disciplines into floor and apparatus groups. The apparatus group included tightrope and slack line that have forces similar to most ground acrobatics. Barlati[23] considered the "type of apparatus or rigging used and the skills and abilities required to practice them" to define the categories: aerial acrobatics, balancing, juggling, clowning, equestrian, and floor acrobatics. With this categorization, some disciplines fit more than one category, and in some categories, eg, floor acrobatics, the disciplines included have a broad range of physical stresses, thus limiting the utility for injury analysis.

The purpose of this pilot cohort study was to describe injury frequency and characteristics related to specific circus discipline and similar sub-groups of artists based on discipline-specific physical stresses using the established IADMS injury surveillance guidelines[22] and a novel classification for circus disciplines.

METHODS

The Samuel Merritt University Internal Review Board approved this study (SMUIRB#17-013).

Participants

A sample of convenience was recruited from a 24-member (22 female, 2 male) youth pre-professional training program and 55 (44 female, 11 male) adult coaches employed at Kinetic Arts Center, a circus training facility in Oakland, California. The pre-professional training program included 11 months of multi-disciplinary circus training for a minimum of 6 hours per week, participation in a full-length show that ran for 16 performances, and several additional community event performances. The adult coaches were freelance circus professionals at different stages of their professional careers who trained regularly. Prior to participation, adult participants signed an informed consent, youth participants signed an adolescent assent form, and their parents completed an informed consent. Exclusion criteria included a planned absence exceeding one month, lack of regular circus training, or age younger than 13.

Design

The IADMS guideline was adapted for use in this circus context.[22] First, the guideline recommends mandatory injury reporting.[22] No medical staff or mandatory injury surveillance system existed at the circus training facility, so injury surveillance was limited to self-report by study participants. Second, the guideline recommends use of time loss (TL) and musculoskeletal complaint injury definitions.[22] Time loss was adopted and the musculoskeletal complaint definition was expanded to include injuries to other body systems not resulting in TL, such as concussion. Injury classification by a health care professional was also recommended[22] and included in this study. The third and last recommendation in the guideline was to define one exposure as participation in a single class, rehearsal or performance.[22] Self-directed training was added as another session type since circus artists often do additional independent training outside of class and rehearsals.

Rolling enrollment in the study took place from September to December 2017. Enrollment included a single visit for completion of informed consent/assent forms, an intake questionnaire, and physical examination that integrated elements of the Dance USA[24] and National Institute of Circus Arts screening guidelines.[25] The intake included questions about age, gender, training experience, medical, and injury history. The author, a licensed physical therapist, conducted the baseline physical examination that included height, weight, Beighton score,[26] measures of flexibility, balance, and strength. For grip strength, participants were seated at the edge of the table, shoulder/forearm neutral, elbow flexed to 90°, and wrist slightly extended and ulnarly deviated.[27] The JAMAR® hydraulic hand dynamometer handle was set to position 2.[27] Three trials each side, alternating sides, were recorded in kilograms. For the handstand, participants were allowed 1-2 practice trials and to use any leg position with a vertical trunk (ie, no contortion positions). They were allowed 2 trials and best time was recorded. Pull-ups were performed with pronated grip on a trapeze from a full-hang with elbows extended to chin over the bar. One trial was allowed, with number of complete repetitions recorded. Single limb balance was performed on a firm surface, arms crossed, and hip flexed to 90°. Two trials were given for each side, with maximum time recorded. Hamstring flexibility assessment was done lying on a plinth, using a passive straight leg raise. The examiner palpated the ipsilateral anterior superior iliac spine, then flexed the hip, knee fully extended, until posterior pelvic tilt occurred. The angle was measured at the distal tibia using an inclinometer.[28]

Participants were tracked for 1 year following their individual study enrollment date, with the last enrolled participants completing the study in December 2018. Participants received an email with a Qualtrics link (Version 9/2017-12/2018, Provo, UT) to complete an online training log each week for 52 weeks following their enrollment date. In this training log, they reported weekly exposure as total number of sessions (classes, rehearsals, performances, or self-directed training) for each circus discipline. They also reported total time per week for each circus discipline. Participants reported any new or ongoing injuries, and any missed training sessions due to injury in this log. For any new or recurrent injuries, the author conducted an interview and physical examination to determine the associated circus discipline, body region, tissue, and nature of the injury. Injuries that were present prior to study enrollment were recorded in the intake history but not included for calculating injury frequency unless an exacerbation occurred. Injuries that were not attributed to circus training were noted, but not tracked. Treatment was not included as part of the study.

Injury Classification

Injury was defined as an impairment at the "anatomical tissue-level."[22] Time loss injury was an injury that resulted in full loss of participation, in at least one circus discipline, for one or more days from the injury onset.[22] Any injuries that did not meet the criteria for TL were defined as non-time loss (NTL). New injury was in a body region and of a nature that had not occurred within the last 2 months.[29-30] Recurrent injury was in the same body region, of the same nature, within 2 months of returning to 100% participation after a TL injury.[29-30] Traumatic injury was related to a specific macro-traumatic event (eg, fall, awkward landing).[31] Overuse injury was related to repeated exposure to a micro-trauma (eg, movement, position, or activity).[31]

Circus Discipline Classification

For an individual participant, primary circus disciplines were defined as any discipline trained for 2 or more hours a week during the 6 months prior to study enrollment. The author created a classification of acrobatic circus disciplines (**Table 1**) informed by the previous categorizations.[16,19,23] The intent of this classification was to group disciplines with similar physical demands so related injury patterns and later injury prevention strategies would be linked to the group of artists most likely to benefit. Aerial acrobatics includes circus disciplines in which the acrobat spends a majority of time suspended from an apparatus, commonly uses pulling movements, and inverts on or climbs the apparatus. Aerial acrobatics with ground elements are a subset of aerial disciplines that often also include impact movements in contact with the floor or apparatus and/or pushing movements. Ground acrobatics (human populsion) involve acrobatic skills with jumping, diving, or tumbling type movements that might be similar to gymnastics, where height from the ground is due to human propulsion. Ground acrobatics (apparatus propulsion) involves an apparatus or other non-human device that imparts increased acceleration often resulting in landing from significant height. Ground acrobatics (balance/control) typically involves weight bearing on a stable or unstable surface (apparatus or human) with the focus on creating

Table 1. Acrobatic Circus Discipline Classification

Circus Discipline Sub-Groups	Definition	Examples of Disciplines
Aerial acrobatics	Circus disciplines in which the artist is often suspended from an apparatus by various body parts, and commonly uses pulling movements, inverts on or climbs the apparatus.	**Silks (akaTissue/Fabric)*** **Rope (aka Corde Lisse)*/Spanish Web** **Trapeze (Static, Dance, Flying)*** **Aerial hoop (aka Lyra)*** **Sling/Hammock*/**Cloud Swing/ **Straps*/**Loop Straps **Rings (Russian or Gymnastic)** **Aerial pole**
Aerial acrobatics (with ground elements)	A subset of aerial acrobatics which often also includes impact and/or pushing movements in contact with the floor or apparatus.	**Chinese pole*/**Dance Pole/Lollipop Russian cradle base High Bar
Ground acrobatics (human propulsion)	Disciplines that involve repetitive skills such as jumping, diving, rotational or other gymnastics type movements where height from the ground is due to human propulsion.	**Tumbling/Parkour*** **Icarian Games*** Banquine Hoop Diving Cyr/German Wheel **Dance***
Ground acrobatics (apparatus propulsion)	Similar to above except that repetitive movements are performed on an apparatus or with a device that imparts acceleration of the artists' movement that often results in landing from significant height.	Teeterboard Russian swing **Trampoline*/**Tramp Wall Wheel of death **Bungee/Harness*** Trick riding (bicycle, motorcycle)
Ground acrobatics (balance/control)	Includes disciplines where the artist is typically weight bearing on a stable or unstable surface (apparatus or human) with the focus on creating postures or shapes with control and balance. May involve some impact transitioning into and out of postures or on and off base/apparatus.	**Contortion*** **Handbalancing*** **Hand to hand/Adagio/Acrodance*** **Human Stacking*/**Pyramid Rola Bola/Rolling globe Wire (tight, slack, high) **Stilts***
Manipulation	These disciplines involve the artist creating repetitive movements with an object and often requires significant use of fine motor skills and/or coordination.	**Juggling*** Diabolo/Poi Hooping Knife throwing
Character	Disciplines that often include significant acting and theatrics. It may also include some acrobatic skills but typically with low physical demand.	**Clown*** Ringmaster Mime

*Disciplines trained by the study participants during the study period.

and moving through postures or shapes with control and balance. Manipulation involves the artist inducing movement into an object and often requires strong fine motor skills and coordination. Character includes clowning, mime, and ringmaster roles that often involve significant time on stage, sometimes include acrobatic skills, but often low in physical demand.

Data Analysis

Descriptive statistics were conducted using Microsoft Excel 365 (version 2008, Redmond, WA) for various measures including selected baseline intake and physical examination data, injury rate (frequency per exposure), frequency, and types comparing participants in subgroups by sex and primary circus discipline. Injury rates were calculated per 1000 sessions of all types of circus training.

Results

From the convenience sample of 79 potential participants, 24 enrolled [20 female mean (standard deviation) age 19.4 (7.7), 4 male 31.3 (2.5)] and 21 (17 female, 4 male) completed the study. For the 3 dropouts, the first left after 8 weeks due to illness, the second ceased participation due to leaving the pre-professional training program after 14 weeks, and the third when ceased tracking training after 36 weeks in the study. Of note, one of the dropouts sustained an injury during the period of their participation. All participants that enrolled in the study (n=24) were included in the results except where noted.

Participant characteristics

In the 6 months preceding the study, most study participants trained in more than one primary discipline (mean 3 ±1.35, range 1-5). The participants were divided into aerial, ground, and mixed subgroups based on these primary disciplines. Although no participants had manipulation or character as a primary discipline, 2 or more hours of training per week, several participants trained them regularly.

Demographic and physical examination data at baseline are shown in **Table 2**. Most participants had both aerial and group primary disciplines (n=14, 58.3%), categorized as the mixed subgroup. The entire cohort was predominantly female (n=20, 83.3%). The male participants (n=4) were evenly distributed between the ground and mixed primary discipline subgroups. The average number of performances in the year prior to the study was skewed for the male and mixed subgroups by one participant who had 175 performances in the prior year. The following comparisons are between all subgroups, including disciplines and sex. The male subgroup had the highest average grip strength and pull-up repetitions. The mixed and female subgroups had greatest average straight leg raise hamstring flexibility. Average handstand balance duration was highest in the ground subgroup, but single limb balance with eyes closed was best in the mixed and male subgroups. The highest proportion of participants meeting the Beighton criteria of 5/9 or more for generalized hypermobility was in the mixed, followed by the female subgroups.

Exposures

Total and weekly exposure by number of sessions (training and performances) are shown in **Table 3**. Participants had difficulty determining time by individual discipline so tracking time was discontinued at week 14 of the study period. See Greenspan's 2021 article for discussion on this point.[32] During the study period, the aerial subgroup had the lowest average total session exposure for aerial, ground, and all disciplines combined. They were the only group to participate in clowning (character) and their volume of average ground exposure exceeded aerial exposure. The ground subgroup had highest average total exposure for all ground disciplines and all disciplines combined. The mixed subgroup had the highest average exposure to aerial disciplines, manipulation, and strength training. The average exposure to aerial and ground disciplines was similar within the mixed subgroup. Only one participant in the ground group had exposure to ground acrobatics with apparatus propulsion.

Injury Rates

The overall injury rate for all participants, combined for TL and NTL injury, was 5 per 1000 session exposures. Injury rate (excluding the dropouts) was 2.35 for the aerial group, 7.0 for the ground group, and 3.84 for the mixed group per 1000 session exposures. All male participants reported multiple injuries (range 4-5 injuries) versus 6/20 female participants (range 2-6 injuries). From the baseline intake data, there was a trend between a history of disordered eating/amenorrhea and higher injury rates.

Injury Type

There were 47 total circus-related injuries (53.2% TL, 46.8% NTL) reported across

Table 2. Baseline Demographic & Physical Examination Findings

	Subgroups by Primary Circus Disciplines			Entire Cohort	Subgroups by Sex	
	Aerial n=7	Ground n=3	Mixed n=14	All n=24	Female n=20	Male n=4
Female sex	100%	33.30%	85.7%	83.30%	100%	0%
Age (years)	16.3 (4.9)	30.3 (0.6)	22 (8.9)	21.4 (8.3)	19.4 (7.7)	31.3 (2.5)
Height (cm)	164.9 (9.4)	171.2 (6.2)	164.5 (7.3)	165.5 (7.8)	163.8 (7.3)	173.7 (5.0)
Mass (kg)	55.1 (7.3)	63.0 (12.1)	58.9 (9.0)	58.3 (8.9)	56.4 (7.5)	68.2 (9.8)
Circus experience (years)	5.7 (1.4)	13.3 (5.0)	6.9 (4.4)	7.3 (4.4)	6.6 (3.6)	11.0 (6.8)
Performances prior year	17.4 (8.5)	21.0 (20.1)	24.2 (39.6)	21.7 (30.4)	15.1 (11.2)	53.5 (66.3)
Peak Grip L (kg)	23.4 (3.8)	27.7 (5.9)	30.9 (7.7)	28.3 (7.2)	27.1 (5.7)	34.5 (11.1)
Peak Grip R (kg)	26.0 (4.2)	30.3 (2.9)	30.1 (6.3)	28.9 (5.6)	28.0 (4.5)	33.8 (8.4)
Pull-ups (repetitions)	4.3 (3.2)	10.0 (3.5)	7.8 (3.0)	7.0 (3.6)	6.3 (3.1)	10.8 (3.8)
Single limb stance L (secs)	28.9 (17.8)	32.0 (17.6)	35.9 (20.0)	33.3 (18.6)	31.9 (18.4)	40.5 (20.3)
Single limb stance R (secs)	24.4 (18.8)	32.3 (24.8)	39.9 (18.7)	34.4 (19.8)	33.9 (20.2)	37.3 (20.4)
Handstand balance (secs)	6.9 (13.0)*	45.3 (14.0)	33.9 (27.2)	27.4 (26.0)*	25.0 (25.5)*	39.8 (28.3)
Straight leg raise L (°)	73.9 (8.1)	65.0 (13.2)	83.8 (12.5)	78.5 (13.0)	81.1 (12.0)	66.0 (11.2)
Straight leg raise R (°)	78.3 (11.0)	71.7 (16.3)	82.9 (11.7)	80.1 (12.1)	81.7 (11.4)	72.5 (14.5)
Beighton score >4/9	28.5%	33.3%	50.0%	41.7%	45.0%	25.0%

Aerial and ground subgroups included participants with primary disciplines only from aerial or ground acrobatic disciplines (see Table 1) whereas the mixed subgroup had primary disciplines in both. Female sex and Beighton score are represented as a percentage of the group. All other measures are given as mean (standard deviation). *One female participant, part of the aerial primary discipline group, was not able to perform the handstand assessment in the initial screen due to an ongoing wrist injury.

Abbreviations: cm, centimeters; kg, kilograms; yrs, years; secs, seconds

Table 3. Total and Weekly Exposure to Circus Training

	Aerial (n=5)	Ground (n=3)	Mixed (n=13)	Total (n=21)
Total sessions/participant				
All	339.6 (±65.6)	714.8 (±146.7)	540.1 (±109.3)	517.3 (±109.7)
Aerial	92.8 (±52.6)	92.2 (±191.3)	173.6 (±184.7)	142.7 (±159.1)
Aerial with ground elements	0.00	18.4 (±53.3)	89.4 (±31.3)	70.7 (±27)
Ground (human propulsion)	102.2 (±68.5)	260.5 (±117.3)	92.6 (±46.2)	118.8 (±84.3)
Ground (apparatus propulsion)	0.0	0.3 (±N/A)	0.0	0.0 (±N/A)
Ground (balance/control)	99.6 (±87.2)	299.2 (±117.8)	179.5 (±41.8)	177.5 (±87.7)
Manipulation	0.0	9 (±N/A)	4 (±31.1)	2.9 (±24.1)
Character	3.8 (±N/A)	0.0	0.0	19 (±N/A)
Strength Training	38.2 (±45.6)	6.7 (±5.7)	59.1 (±62.4)	46.6 (±55.8)
Weekly sessions/participant				
All	6.5 (±1.3)	13.7 (±2.9)	10.4 (±2.1)	9.9 (±2.1)
Aerial	1.8 (±1)	2.9 (±2.9)	3.3 (±3.6)	2.9 (±3.1)
Aerial with ground elements	0.0	1.5 (±0.4)	2 (±1.7)	1.8 (±1.4)
Ground (human propulsion)	2 (±1.3)	5 (±2.3)	1.8 (±0.9)	2.3 (±1.6)
Ground (apparatus propulsion)	0.0	0.0 (±N/A)	0.0	0.0 (±N/A)
Ground (balance/control)	1.9 (±1.7)	5.8 (±2.3)	3.5 (±0.8)	3.4 (±1.7)
Manipulation	0.0	0.2 (±N/A)	0.5 (±0.6)	0.4 (±0.5)
Character	0.4 (±N/A)	0.0	0.0	0.4 (±N/A)
Strength Training	0.7 (±0.9)	0.1 (±0.1)	1.1 (±1.2)	0.9 (±1.1)

Exposure is reported as mean (SD) number of sessions per training type for each group. Sessions were recorded by individual discipline (eg, if a participant had one training session that included tumbling and Chinese Pole it was counted as one session for each discipline). The 3 participants that dropped out of the study are not included in this data set.

the study, including 3 recurrent injuries. Time loss was not normally distributed with a range of 1 to 185 days and median of 19 days. **Table 4** shows the frequency of injury types for the entire cohort and by circus discipline subgroup. Overuse and traumatic injuries were similarly distributed in all groups, except for the ground group that had twice as many overuse as traumatic injuries. The highest frequency of injuries occurred in the shoulder/arm, followed by wrist/hand for the entire cohort (21.3%, 17%) and mixed subgroup (14.9%, 12.8%). Almost half of all injuries were to a joint (46.8%). Muscle and tendon injuries were the most frequent type in the aerial subgroup and second most frequent in all other groups.

When analyzing specific circus activity associated with the injury, 25 injuries (53.2%) were related to doing ground acrobatics, 18 (38.3%) to aerial acrobatics, while the remaining 4 injuries (8.5%) were related to stretching, tripping on mats, and pulling safety lines to support another artist's weight. Of the aerial-related injuries, 6/18 (33%) occurred on an aerial apparatus with ground elements. For ground-related injuries, 15/25 (60%) were related to ground disciplines within the balance/control subgroup, 9/25 (36%) to human propulsion and 1/25 (4%) to apparatus propulsion ground subgroups. Of note, 3/5 (60%) of the injuries in the aerial primary discipline subgroup involved participation in a ground discipline and 3/15 (20%) of injuries in the ground primary subgroup involved an aerial discipline.

DISCUSSION

This prospective pilot cohort study described injury frequency and characteristics related to participation in specific circus disciplines. A novel acrobatic circus discipline classification was introduced with the intent to define subgroups of circus disciplines in which the artists incur similar physical demands so as to determine injury patterns that can inform injury prevention strategies. The study participants were grouped by primary discipline(s) based on their training in the 6 months prior to the study. In the aerial subgroup, their training volume was actually higher for ground than aerial disciplines during the study period showing that their circus participation changed during the study. This demonstrates the complexity of classifying circus artists as training patterns can be influenced by a variety of factors including disciplines that are available to train in a particular facility, show casting, opportunities in a training program, or general market demands.

Another layer of complexity is the variability in the physical stresses related to a single discipline, where one circus artist may primarily perform flexibility-based movements, and another might perform more dynamic, power movements. Some differences in training or performance within a discipline may be due to an artist's physical

Table 4. Frequency (Percentage) of Injury Types by Subgroup of Circus Discipline

	Aerial (n=7)	Ground (n=3)	Mixed (n=14)	Total (n=24)
All	5 (10.6%)	15 (31.9%)	27 (57.4%)	47 (100.0%)
Non-Time Loss	3 (6.4%)	8 (17.0%)	11 (23.4%)	22 (46.8%)
Time Loss	2 (4.3%)	7 (14.9%)	16 (34.0%)	25 (53.2%)
Overuse	2 (4.3%)	10 (21.3%)	14 (29.8%)	26 (55.3%)
Traumatic	3 (6.4%)	5 (10.6%)	13 (27.7%)	21 (44.7%)
Ankle/Foot	0	2 (4.3%)	4 (8.5%)	6 (12.8%)
Knee/Leg	2 (4.3%)	1 (2.1%)	1 (2.1%)	4 (8.5%)
Hip/Thigh	0	3 (6.4%)	3 (6.4%)	6 (12.8%)
Lower Trunk/Pelvis	1 (2.1%)	1 (2.1%)	1 (2.1%)	3 (5.4%)
Upper Trunk	0	3 (6.4%)	2 (4.3%)	5 (10.6%)
Head/Neck	0	0	3 (6.4%)	3 (6.4%)
Shoulder/Arm	2 (4.3%)	1 (2.1%)	7 (14.9%)	10 (21.3%)
Elbow/forearm	0	2 (4.3%)	0	2 (4.3%)
Wrist/Hand	0	2 (4.3%)	6 (12.8%)	8 (17.0%)
Bone	1 (2.1%)	0	2 (4.3%)	3 (6.4%)
Central Nervous System	0	0	1 (2.1%)	1 (2.1%)
Integument	0	0	1 (2.1%)	1 (2.1%)
Joint	1 (2.1%)	7 (14.9%)	14 (29.8%)	22 (46.8%)
Ligament	0	0	1 (2.1%)	1 (2.1%)
Muscle/Tendon	3 (6.4%)	5 (10.6%)	4 (8.5%)	12 (25.5%)
Nerve	0	3 (6.4%)	4 (8.5%)	7 (14.9%)
Stretching	0	0	2 (4.3%)	2 (4.3%)
Contortion	1 (2.1%)	1 (2.1%)	2 (4.3%)	4 (8.5%)
Hand balancing	0	1 (2.1%)	4 (8.5%)	5 (10.6%)
Partner acrobatics	0	5 (10.6%)	1 (2.1%)	6 (12.8%)
Tumbling	2 (4.3%)	0	4 (8.5%)	6 (12.8%)
Trampoline	0	1 (2.1%)	0	1 (2.1%)
Dance	0	3 (6.4%)	0	3 (6.4%)
Rope	0	0	5 (10.6%)	5 (10.6%)
Silks	0	1 (2.1%)	3 (6.4%)	4 (8.5%)
Straps	0	0	1 (2.1%)	1 (2.1%)
Trapeze	1 (2.1%)	0	1 (2.1%)	2 (4.3%)
Chinese pole	0	1 (2.1%)	3 (6.4%)	4 (8.5%)
Aerial bar apparatus	1 (2.1%)	1 (2.1%)	0	2 (4.3%)
Trip on mats	0	1 (2.1%)	0	1 (2.1%)
Pulling lines	0	0	1 (2.1%)	1 (2.1%)

characteristics like flexibility or strength, choreographic style, or artistic direction. In order to accurately capture injury patterns in related circus disciplines, it will be important for future research to track discipline specific exposure as well as the specific mechanisms involved with injuries. The acrobatic circus discipline classification will be useful for comparing and combining this information across injury surveillance studies.

Total weekly exposure and injury rate was highest in the ground subgroup (13.7 ± 2.9, 7/1,000 sessions). This group also had twice as many overuse versus traumatic injuries, different than the others that had more equal distribution. The ground subgroup also had the lowest participation in strength training. A higher workload with less strength capacity could contribute to the higher injury rate and proportion of overuse injuries. This was also the smallest subgroup (n=3) and predominantly male (66.7%), so these findings might be different in a larger group with a more even sex distribution.

Across all subgroups in this study, ground acrobatics was the most common mechanism of injury, accounting for 53.2% of all injuries. Similar patterns have been found in other circus and gymnastics studies.[8,10,18,21] Fifty percent of injuries were related to ground acrobatics in the Wanke et al[17] study of circus students, where overall circus training exposure but not exposure to specific disciplines was reported. Munro[18] reported acrobatics/tumbling as the most common cause of injury in circus students at the Australian National Institute of Circus Arts, where more time in the curriculum was allocated to training these disciplines. Due to limited information on discipline specific exposure across studies, it is unclear if the higher injury frequency associated with ground acrobatics is due to higher exposure or to discipline specific physical stresses, such as impact forces. Consistent methods for tracking discipline specific exposure and classifying circus disciplines in future research may differentiate the effect of overall workload and discipline specific physical stresses.

Across the entire cohort, upper extremity injuries were most common (48.9%) differing from other circus studies[16,17] where lower extremity injuries were most common. The proportion of lower extremity injuries was similar however, 34.0% in this study compared to 35-36% in the others.[16-17] The size, age, and skill level of this study population (n=24, pre-professionals and professionals ages 13-37) compared to Wanke et al[17] (n=169, circus students ages 11-22) and Shrier et al[16] (n=1107 professional acrobats) may contribute to some differences in injury patterns. The context of participation by circus discipline could be another factor, but exposure by specific circus discipline was not reported in these studies. With the diversity in circus disciplines and multidisciplinary nature of artist participation, more detailed reporting on artist participation is needed to effectively compare circus injury studies.

One trend that emerged was an apparent relationship between disordered eating/amenorrhea and higher injury rates. This finding is consistent with other sports.[39-41] In addition, aesthetic sports are associated with a higher risk of low energy availability or inadequate energy for normal physiologic function.[40] Clinicians working with circus artists should include screening for signs of low energy availability such as amenorrhea, decreased performance, irritability, depression and bone stress injuries.[40]

The overall cohort injury rate including TL and NTL was 5/1000 session exposures, lower than for female college gymnasts (9.22/1000 athletic exposures).[8] Since both activities involve ground and aerial acrobatics, the difference in injury rates could be influenced by the broader age range in the circus cohort.[32] Differences in injury definitions (TL/NTL vs medical attention) and exposure measures (sessions vs performances vs time) between the adapted IADMS guideline[22] used in this study and other circus injury studies,[16-20] does not allow for valid comparison of injury rates in circus. This variability in injury reporting highlights the need for a consensus in circus injury research methodology as has been developed in dance and other sports.[22,34-38]

Limitations

The small sample size in this study was underpowered and therefore may limit the generalizability of the study findings to the larger circus population, the ability to use inferential statistics to compare the different subgroups, or determine relationships between the medical history or baseline physical examinations findings and injury patterns. There was a low number of male participants in the study cohort although it was reflective of the study population. The study did not include a mechanism to capture when breaks in training were due to vacation, illness, or non-circus related injuries. This led to some challenges in interpreting the fluctuations in training across the year.

CONCLUSION

This pilot study found more injuries associated with ground acrobatics participation, the upper extremity and joints suggesting the need to focus on these areas for injury prevention in circus. The introduction of a novel classification of acrobatic circus disciplines and the adaptation of the IADMS Standards Measures Consensus[22,32] for circus helped to refine methodology for injury surveillance and structure analysis for the larger cohort study that followed. Circus professionals need to recognize the unique demands of the circus arts and move beyond relying on other sports or performing arts research to guide the coaching and health care for circus artists. In order to build the body of knowledge around circus injuries and compare studies, the circus research community needs to develop common injury surveillance methodology including a consistent way to report exposure and mechanism of injury by circus discipline. A circus specific guideline is essential to understanding injury patterns in the complex world of circus, successfully implementing injury prevention interventions, and evaluating outcomes.

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