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Original Research

Preparation For Flight: The Physical Profile of Pre-Professional and Professional Circus Artists in the United States

Stephanie J Greenspan[1,2,a], Melanie I Stuckey[3]

[1] Physical Therapy, Samuel Merritt University, [2] Artletic Science, [3] Centre de recherche, d'innovation et de transfert en arts du cirque, École nationale de cirque

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Background

Established norms for fitness and performance measures are lacking in circus arts. These would assist healthcare professionals and coaches to screen for readiness to participate in training or performance, determine post-injury return to performance, and develop targeted conditioning programs.

Purpose

The purpose of this research was to establish norms for trunk and extremity physical exam and performance measures in circus artists by professional status, assigned sex at birth (ASAB), and age.

Study Design

Descriptive laboratory study

Methods

Circus artists (n=201; ages 13-69y; 172 females ASAB, 29 males ASAB) from 10 cities across the United States underwent a baseline physical examination including shoulder, hip and trunk measures of passive (PROM) and active (AROM) range of motion, measures of flexibility (shoulder and hip), strength (manual muscle tests, grip strength), cardiovascular fitness (3 minute-step test), balance (single limb and handstand), and performance, (pull-ups, and the closed kinetic chain upper extremity stability test [CKCUEST]). ANOVAs were used to determine between group differences by age and T-tests to discern differences by ASAB or professional status.

Results

Differences existed by professional status for shoulder external rotation PROM, hip PROM, hip flexibility, shoulder and abdominal strength, and cardiovascular fitness. Sex differences were seen in active scapular upward rotation, hip and shoulder PROM and flexibility, hip and grip strength, and for functional performance measures (pull-ups, CKCUEST). Differences by age were limited to active scapular upward rotation, shoulder PROM, flexibility and strength, cardiovascular fitness, and balance. Overall, professionals outperformed pre-professionals for lower abdominal strength, pull-ups, handstand balance, cardiovascular fitness, hamstring, and straddle flexibility. Generally, males ASAB demonstrated greater shoulder flexibility and upper body functional strength while females ASAB had greater hip and lumbar flexibility and hip strength. No measures showed consistent declines with increasing age, though some showed differences between adolescents and adults.

a Corresponding author:
Stephanie Greenspan Artletic Science, 785 7th Street, Oakland, CA, 94607, fax: 1-510-244-0571, email: sgreenspan@samuelmerritt.edu

Conclusion

These normative values for physical characteristics and functional performance in pre-professional and professional circus artists may be used to guide screening for readiness to participate in advanced training or performance, return to performance after injury, and the development of targeted strength and conditioning programs.

Level of Evidence

3

INTRODUCTION

Contemporary circus arts integrate artistry with acrobatics requiring high levels of athleticism to express a story or wow an audience. While individual circus disciplines and artistic styles have specific physical requirements including flexibility for contortion and muscle power for tumbling, advanced circus arts practice generally requires balance, strength, flexibility, and coordination beyond that of the general population.[1-3] Circus arts disciplines have been classified into eight subgroups with similar physical demands to facilitate the study of injury patterns and development of prevention strategies.[4,5] The five acrobatic subgroups can be combined into aerial (e.g. trapeze and pole) and ground (e.g. handbalancing, trampoline, and tumbling) categories.[4,5] Established norms are needed for measures of fitness and performance to guide screening for readiness to participate in advanced training or performance, post-injury return to performance, and the development of targeted conditioning programs.

Circus arts are practiced across a variety of recreational to professional contexts and by individuals of all ages, with adults ages 55y and up accounting for 11% of circus arts students in the United States (U.S.),[6] different from acrobatic sports like gymnastics where participation typically spans from early childhood to early adulthood.[7] In a recent survey including 197 U.S. circus educational organizations, 43% had a youth troupe, 29% an adult troupe, 22% a professional program, and 20% a residency program.[6] In pre-professional and professional circus training programs students participate in group training sessions, discipline specific classes, and additional independent training several days a week, as well as program specific shows. Pre-professionals without access to a structured program often create a similar training schedule to prepare themselves to perform in student or community shows. Although some U.S. professionals work for large companies with resident or touring shows that run year-round,[3] many are considered freelance artists hired on individual contracts for theatrical shows, corporate events, nightclub, or other venue entertainment, or by smaller companies producing limited engagement shows.[8] These different contexts likely have different fitness demands that could be important to consider when screening readiness to participate or designing preparatory conditioning or rehabilitation programs.

Two recent studies examined physical characteristics in different circus artist populations. One found that shoulder active range of motion (AROM) and strength were greater in circus artists compared to the general population.[9] They also found acrobats training both aerial and ground acrobatics had greater shoulder flexion and extension AROM versus those that trained only ground or aerial, suggesting that there are discipline specific physical demands.[9] However, participants were only required to train aerial and/or ground acrobatics two hours per month, which may not meet the threshold for physiological adaptations. A small study in recreational aerialists found that VO_2max was similar to collegiate dancers but lower than gymnasts, pull-up and grip strength was lower than gymnasts, whereas hamstring flexibility with a sit-and-reach test was higher in the aerialists than both other groups.[10] While these studies provide initial insight, more extensive study of physical characteristics is needed with a broad sample of circus practitioners.

Normative data would be useful to inform programming for prevention and management of injuries, which can require the modification or cessation of circus training and performance, negatively impacting the artist's mental or physical health and work status. For pre-professional and professional circus artists, injuries were most common to the shoulder (22%), lumbosacral (13%), elbow (10%), wrist (8%), and hip/groin (7%).[11] No differences in injury frequency per body region were found between groups by professional status, age, or assigned sex at birth (ASAB).[2] To provide optimal care, healthcare professionals should have knowledge about typical injuries in circus, the discipline specific physical demands and norms for physical exam and performance measures as they may differ from the general population, other athletes, or performing artists.[10]

There are specific guidelines in dance,[12] gymnastics,[13,14] and Olympic sports[15] but not in circus arts for screening participants prior to participation to detect health conditions or physical characteristics that might increase risk for injury or illness. This type of screening can help identify intrinsic risk factors, for example, a shoulder internal rotation mobility deficit is associated with upper extremity injury in overhead athletes,[16] and muscle flexibility and low or high generalized joint mobility for musculoskeletal injury in elite modern dancers.[17] Determining norms for physical characteristics in circus arts and the relationship with injury risk can inform screening guidelines and assist healthcare professionals and coaches to implement targeted interventions to reduce injury risk and enhance performance. Characteristics of different circus populations should be established so, like in sport talent identification,[18] physical readiness for advanced levels of participation in circus arts such as an intensive training program or high-demand professional contract, or the need for interventions to enhance readiness can be identified.

Dance[19] and sport[20,21] also have reference standards in guidelines to ensure safe return to participation following injury. The lack of similar standards in circus arts may result in healthcare professionals providing inadequate physical preparation for return to participation, potentially reducing performance or increasing the risk of re-injury. The purpose of this study was to establish norms for trunk and extremity physical exam and performance measures in circus artists by professional status, ASAB, and age. The authors hypothesized that the professionals and artists assigned male at birth (AMAB) would perform better on strength and performance measures, artists assigned female at birth (AFAB) on flexibility measures, and that joint range of motion (ROM) and strength would decrease with age.

METHODS

This descriptive study was a secondary analysis of a prospective, observational cohort study.[11] Rolling enrollment occurred September - December 2018 (four facilities) and September 2019 - January 2020 (six facilities). This included completion of informed consent/assent forms and an intake questionnaire for demographics, training, and medical history, followed by an examination with the physical therapist (PT) assigned to the facility. PTs had at least five years of orthopedic or sports-related experience and underwent standardized training with the lead investigator (SG), including a study protocol review and practice of the examination procedures. To ensure standardization, each study PT and SG individually performed all baseline physical examination tests/measures on a single participant. Their results were compared and for any discrepancies the procedure was reviewed to ensure proficiency.

PARTICIPANTS

The Samuel Merritt University Internal Review Board approved this study (SMUIRB#18-021).

Ten circus training facilities across the U.S. were selected as host sites based on the size of the eligible target population, presence of long-term intensive training programs, and willingness to assist with study recruitment. Participants were recruited through the host facilities, other local circus businesses, social media, and the American Circus Educators newsletter. Eligible participants included pre-professional circus artists training ⩾ 6 hours a week and performing in ⩾ 2 shows per year, and self-identified professional circus artists over age 13 years, able to read/comprehend English and fulfill the requirements of the study. Participants with ongoing injuries were not excluded. A power analysis determined that 200 was an adequate sample size for a medium-to-large (.25-.50) effect size with p-value .05.

PROCEDURES

All 201 participants (ages 13-69 years; n=172 AFAB; n=29 AMAB) underwent a physical examination by a study PT assigned to the host facility. Participants were identified by ASAB for analysis due to a low number identifying as non-binary (n=8, ages 24-36 years, six pre-professionals and two professionals). Additional demographic information was previously published.[11] Physical examination measures included height, mass, shoulder, hip, and lumbar ROM, shoulder and hip flexibility, accelerated three minute-step test, shoulder, abdominal, and hip manual muscle testing (MMT), and grip dynamometry. Functional tests including single limb and handstand balance, closed kinetic chain upper extremity stability (CKCUEST) test, and pull-ups. Extremity measures were performed bilaterally. Appendices 1 and 2 provide detailed procedures for each testing procedure. Findings were recorded with a secure online survey form in Qualtrics. If participants were unable to perform a test due to an injury, the test was excluded for that participant.

STATISTICAL ANALYSES

Descriptive statistics were conducted using Microsoft Excel 365 (version 2211, Redmond, WA) for baseline intake data. IBM SPSS Statistics (version 26; Armonk, NY) was used to analyze physical examination data with significance set at $p < .05$. Both parametric and non-parametric analyses were conducted. ANOVAs were used to determine between group differences by age (participants 50y or above were excluded due to the small sample, n=9) and T-tests for differences by ASAB or professional status. Pearson Chi-Square analysis was used to determine differences in distribution of MMT scores. If participants were unable to perform a test due to pain or injury, the participant was excluded from analysis for that individual test. Reporting errors were also excluded from the analysis.

RESULTS

HEIGHT/MASS

Height, $t(197)=7.57$, $p < .001$, and body mass, $t(198)=6.62$, $p < 0.001$, were higher in participants AMAB compared to those AFAB (Table 1). Teen participants had lower body mass than those in their 30s ($p < 0.04$).

LUMBAR AROM

Participants AFAB had greater active lumbar extension than those AMAB, $t(196)=1.79$, $p < 0.04$ (Table 1). Average lumbar extension was highest in the teens and 20s then decreased. The difference was significant between 20s and 40s ($p < 0.024$). Active lumbar flexion also decreased with age. Differences were significant between the teens compared to both 20s ($p < 0.048$) and 30s ($p < 0.047$). Though average flexion was less in the 40s group there was no significant difference due to overlapping variances.

SHOULDER ROM

Participants AMAB had greater left active scapular upward rotation AROM compared to those AFAB, $t(198)=2.87$, $p < 0.005$ (Tables 2 and 3). Left scapular upward rotation was also higher in teens compared to both 20s ($p < 0.04$) and 40s

Table 1. Non-sided physical examination and functional performance measures for all groups

	Pre-Professional (n=130)	Professional (n=71)	Female (n=172)	Male (n=29)	Teens (n=19)	20s (n=67)	30s (n=82)	40s (n=24)
Height (cm)	164.22 ± 7.68	164.65 ± 8.50	162.85 ± 6.98	173.69 ± 7.34	164.66 ± 6.82	164.01 ± 9.43	165.20 ± 6.76	162.07 ± 7.86
Mass (kg)	62.57 ± 11.49	62.32 ± 9.82	60.62 ± 9.12	73.95 ± 13.81	58.17 ± 9.56	62.06 ± 11.05	63.69 ± 10.26	60.17 ± 10.60
Handstand (secs)	9.55 ± 15.76 (0-60)	14.29 ± 19.26 (0-60)	10.57 ± 16.79 (0-60)	15.33 ± 19.28 (1-60)	10.84 ± 15.02 (1-60)	10.45 ± 16.80 (0-60)	13.53 ± 18.93 (0-60)	11.55 ± 17.35 (0-55)
CKCUEST (reps)	16.5 ± 4.87 (0-31)	17.10 ± 4.47 (7-26)	16.37 ± 4.72 (0-30)	18.85 ± 4.30 (13-31)	15.37 ± 2.79 (10-20)	16.05 ± 4.80 (0-25)	17.30 ± 4.49 (7-31)	17.22 ± 5.38 (8-30)
Pull-ups (reps)	4.87 ± 3.66 (0-15)	6.63 ± 4.09 (0-16)	4.97 ± 3.61 (0-16)	8.78 ± 4.15 (0-15)	4.21 ± 4.01 (0-13)	4.88 ± 3.34 (0-12)	6.01 ± 3.92 (0-15)	6.63 ± 4.55 (0-16)
Lumbar AROM flexion (°)	56.28 ± 14.17 (20-102)	55.10 ± 13.72 (26-86)	55.82 ± 13.58 (20-90)	56.07 ± 16.52 (36-102)	61.32 ± 12.80 (42-88)	58.40 ± 15.40 (20-102)	54.31 ± 12.85 (22-86)	52.83 ± 13.09 (34-80)
Lumbar AROM ext (°)	27.12 ± 13.24 (0-60)	26.11 ± 13.58 (4-60)	27.45 ± 13.32 (3-60)	22.61 ± 12.87 (0-57)	29.11 ± 10.29 (16-52)	29.52 ± 13.72 (6-60)	25.86 ± 13.55 (4-60)	22.50 ± 10.22 (4-40)
Straddle flexibility (°)	124.50 ± 16.94 (88-168)	134.77 ± 17.86 (88-178)	130.07 ± 17.77 (88-178)	116.32 ± 14.08 (88-141)	131.53 ± 15.90 (104-160)	127.85 ± 18.51 (88-174)	128.19 ± 18.86 (88-178)	127.42 ± 14.80 (103-164)
Lower abdominal MMT (°)	33.71 ± 17.47 (0-84)	28.46 ± 16.94 (3-74)	32.62 ± 17.84 (0-84)	27.14 ± 13.94 (3-51)	33.74 ± 12.46 (0-51)	34.78 ± 18.49 (0-74)	29.73 ± 17.32 (0-84)	29.79 ± 17.24 (2-62)
Accelerated step test 1-minute post-HR (bpm)	92.22 ± 19.05 (52-148)	87.60 ± 17.91 (60-144)	90.04 ± 18.84 (52-148)	93.96 ± 18.07 (60-132)	103.79 ± 20.98 (64-144)	88.75 ± 17.32 (52-140)	88.34 ± 17.44 (60-144)	91.13 ± 22.93 (64-148)

Data are presented as mean ± SD (range). Abbreviations: AROM = active range of motion; bpm = beats per minutes; CKCUEST = Closed Kinetic Chain Upper Extremity Stability test; ° = degrees; ext = extension; HR = heart rate; reps = repetitions; secs = seconds (p <0.04). Right scapular upward rotation showed a between group difference for age, F(3,189)=2.63, p <0.05, with teens significantly higher than all the other groups.

Shoulder passive range of motion (PROM) was greater for participants AFAB than those AMAB for left sided flexion, *t*(197)=1.90, p<0.03, for external rotation on the left, *t*(197)=2.08, p<0.04, and right, *t*(198)=2.14, p<0.033, and shoulder extension on the left, *t*(197)=2.41, p<0.017, and right, *t*(198)=2.14, p<0.034. Professionals had greater left passive shoulder external rotation than pre-professionals, *t*(197)=1.69, p<0.0046. Teens had greater passive shoulder flexion than other age groups on the left side F(3,188)=3.54, p<0.016. Both teens and 30s had greater left passive shoulder internal rotation than the 20s group, F(3,188)=3.2, p<0.025.

SHOULDER FLEXIBILITY

Participants AMAB had a higher left pec minor index,[22] or greater pectoralis minor muscle length, than AFAB, *t*(197)=2.02, p<0.044 (Tables 2 and 3). Teens demonstrated greater latissimus dorsi length bilaterally than other age groups on both the left, F(3,189)=5.03, p<0.002 and right sides, F(3, 189)=0.24, p<0.001.

HIP PROM

Participants AFAB had greater passive hip flexion bilaterally, left, *t*(196)=3.47, p<0.001, and right, *t*(196)=3.46, p<0.001, and internal rotation, left, *t*(198)=2.93, p<0.004, and right, *t*(198)=3.29, p<0.001, whereas AMAB had greater passive hip external rotation, left, *t*(198)=2.44, p<0.016, and right, *t*(198)=3.07, p<0.002 (Tables 2 and 3). Pre-professionals had greater passive hip internal rotation bilaterally, left, *t*(198)=2.42, p<0.016, and right, *t*(198)=1.84, p<.033, 1-sided, and professionals has greater passive hip flexion bilaterally, left, *t*(196)=2.15, p<0.034, and right, *t*(196)=1.74, p<0.042. The only difference in hip ROM by age was for teens with greater left passive hip internal rotation, F(93,189)=3.79, p<0.011, than the other age groups.

HIP FLEXIBILITY

Professionals had greater bilateral hamstring, left, *t*(198)=2.16, p<0.016, and right, *t*(198)=2.06, p<0.02, and straddle flexibility, *t*(198)=4.03, p<0.001, than pre-professionals (Tables 1-3). AFAB had greater hamstring flexibility, left, *t*(198)=4.06, p<0.001, and right *t*(198)=4.74, <0.001, and straddle flexibility, *t*(198)=3.9, p<0.001, than those AMAB. No significant differences by age were found.

SHOULDER MMT

For right middle trapezius MMT, professionals had significantly more scores of normal (72%) than pre-professionals (58%), while pre-professionals had significantly more scores of good (33% vs. 23%), and fair (9% vs. 3%), X^2 (3)=9.33, p<0.025 (Figures 1-3). For left lower trapezius MMT, significant differences included that the teens had more ratings of fair minus than 20s (32% vs. 6%), and ratings of fair (21%) than the 20s (12%) or 40s (0%) groups. The 30s had more ratings of good (34%) than teens and 20s (16 and 28%). The 20s and 40s group had more ratings of normal (54 and 57%) compared to the 30s (42%) or teens (32%), X^2 (9)=20.46, p<0.015. For right lower trapezius MMT, significant differences included teens with more ratings of fair minus than 20s, 30s, or 40s (33% vs. 5%; 7%; 8%), as well as more of fair (17%) than the 40s (4%). Participants ages 20-49y had more ratings of good (33-39%) than the teens (22%). Similarly, teens had less ratings of normal (28%) compared to 20s and 30s (41% and 45%), while the 40s had the most scores of normal (54%), X^2 (9)=18.34, p<0.03.

HIP MMT

There was a significant difference in left hip abduction strength such that AFAB had more scores of normal than AMAB (74% vs. 54%) and less scores of good (22 vs. 43%), X^2 (2)=5.93, p<0.05 (Figures 1-3).

LOWER ABDOMINAL MMT

There was a significant difference in lower abdominal strength, *t*(198)=2.06, p<0.04, such that professionals performed better than pre-professionals (Table 1).

PULL-UPS

Participants AMAB performed significantly more pull-ups than those AFAB, *t*(196)=4.99, p<0.001, as did professionals compared to pre-professionals, *t*(196)=3.10, p<0.002 (Table 1).

CKCUEST

Participants AMAB performed more repetitions in the CKCUEST, *t*(195)=2.57, p<0.011, than those AFAB (Table 1).

GRIP STRENGTH

Maximal grip strength was greater bilaterally for participants' AMAB versus AFAB, left, *t*(197)=6.30, p<0.001, and right, *t*(196)=7.38, p<0.001, even though there was a significant difference in variances by ASAB in left hand grip (p<0.001) (Tables 2 and 3).

RECOVERY HEART RATE WITH ACCELERATED STEP TEST

Professionals had a lower recovery heart rate 1-minute post completion of the 3-minute accelerated step test than pre-professionals, *t*(197) – 1.67, p<0.05, 1-sided. Recovery heart rate for teens was also higher than other age groups F(3,188)=3,86, p<0.01 (Table 1).

BALANCE

There was a significant difference between age groups in left single limb balance with eyes closed, F (3,189)=2.74, p<0.044 (Tables 2 and 3). Balance was better for 20s versus 40s (left p<0.014; right p< 0.013) and 30s versus 40s (left

Table 2. Sided physical examination measures by professional status and sex at birth

	Pre-Professional		Professional		Female		Male	
	Left	Right	Left	Right	Left	Right	Left	Right
Scapular upward rotation at rest (°)	0.94 ± 6.10 (-24-11)	2.55 ± 5.05 (-21-10)	1.92 ± 5.18 (-12-20)	3.90 ± 4.08 (-6-20)	1.34 ± 5.89 (-24-20)	2.91 ± 4.83 (-21-14)	0.96 ± 5.27 (-12-11)	3.75 ± 4.33 (-6-20)
Scapular upward rotation full elevation (°)	39.26 ± 13.41 (8-74)	39.46 ± 11.59 (12-72)	38.42 ± 11.61 (18-80)	38.70 ± 10.79 (20-70)	38.00 ± 13.04 (8-80)	38.68 ± 11.30 (12-72)	44.86 ± 9.20 (24-64)	42.23 ± 10.87 (20-64)
Scapular AROM upward rotation (°)	38.32 ± 12.90 (5-68)	36.91 ± 11.32 (2-70)	36.51 ± 12.06 (13-74)	34.80 ± 10.63 (12-64)	36.66 ± 12.69 (5-74)	35.77 ±11.15 (2-70)	43.89 ± 10.28 (22-67)	38.57 ±10.67 (14-55)
Shoulder PROM flexion (°)	184.01 ± 10.82 (159-219)	185.46 ± 12.68 (158-222)	184.56 ± 13.28 (145-216)	186.55 ± 13.29 (145-220	184.84 ± 11.91 (145-219)	186.23 ± 12.86 (145-222)	180.32 ± 9.71 (160-200)	183.50 ± 12.94 (150-210)
Shoulder PROM external rotation (°)	100.54 ± 12.38 (64-137)	104.21 ± 13.74 (70-160)	103.91 ± 15.14 (70-145)	107.06 ± 16.73 (78-178)	102.53 ± 13.26 (64-145)	106.12 ± 14.40 (80-178)	96.86 ± 14.02 (79-134)	99.68 ± 16.87 (70-160)
Shoulder PROM internal rotation (°)	63.00 ± 13.37 (30-92)	60.20 ± 14.34 (30-85)	62.01 ± 14.86 (25-88)	57.62 ± 15.78 (25-85)	62.94 ± 13.82 (25-92)	59.66 ± 14.62 (25-85)	60.93 ± 14.44 (30-83)	57.00 ± 16.51 (30-85)
Shoulder PROM extension (°)	78.60 ± 16.47 (40-126)	78.50 ± 15.83 (40-130)	82.41 ± 20.32 (46-135)	82.08 ± 19.94 (45-142)	81.17 ± 17.75 (40-135)	80.83 ± 17.02 (45-142)	72.46 ± 17.70 (45-120)	73.29 ± 18.90 (40-118)
Latissimus dorsi flexibility (°)	166.71 ± 18.55 (122-215)	168.15 ± 18.72 (119-218)	164.48 ± 18.31 (120-205)	165.68 ± 17.47 (125-205)	166.56 ± 18.56 (120-215)	167.98 ± 18.50 (119-218)	161.96 ± 17.54 (122-194)	162.89 ± 16.52 (125-193)
Pec Minor Index	7.78 ± 1.11 (5.51-10.27)	7.74 ± 1.18 (3.25-10.35)	7.84 ± 1.14 (4.70-10.48)	7.90 ± 1.10 (5.23-10.75)	7.74 ± 1.06 (4.70-10.06)	7.74 ± 1.11 (3.24-10.34)	8.20 ± 1.39 (4.94-10.48)	8.14 ± 1.37 (5.23-10.75)
Max Grip Strength (kg)	29.68 ± 7.67 (13-58)	31.18 ± 7.35 (16-58)	30.39 ± 6.15 (17-51)	31.74 ± 6.41 (16-50)	28.50 ± 5.80 (13-42)	30.08 ± 6.11 (16-48)	39.04 ± 8.38 (28-58)	39.59 ± 6.92 (28-58)
Hip PROM flexion (°)	123.69 ± 8.25 (100-144)	123.44 ± 9.24 (104-150)	126.01 ± 10.20 (105-155)	126.68 ± 10.67 (100-150)	125.41 ± 8.51 (102-155)	125.56 ± 9.44 (104-150)	119.18 ± 10.40 (100-140)	118.79 ± 10.60 (100-144)
Hip PROM external rotation (°)	45.11 ± 13.43 (10-80)	44.80 ± 12.81 (12-74)	46.52 ± 14.66 (10-80)	46.31 ± 15.16 (10-80)	44.66 ± 13.99 (10-80)	44.16 ± 13.70 (10-80)	51.46 ± 11.60 (28-70)	52.54 ± 11.22 (34-70)
Hip PROM internal rotation (°)	39.39 ± 12.09 (14-78)	39.99 ± 11.76 (10-64)	35.17 ± 11.18 (10-58)	36.77 ± 11.87 (9-60)	38.87 ± 11.70 (10-78)	39.94 ± 11.81 (9-64)	31.89 ± 11.71 (14-75)	32.18 ± 10.09 (16-55)
Hamstring flexibility (°)	89.78 ± 13.10 (54-124)	88.89 ± 13.27 (57-130)	94.20 ± 15.21 (52-130)	93.14 ± 15.14 (50-125)	92.91 ± 13.12 (62-130)	92.21 ± 13.21 (58-130)	81.75 ± 15.63 (52-124)	79.29 ± 14.34 (50-110)
Single limb stance - eyes closed (secs)	25.18 ± 19.63 (2-69)	24.14 ± 18.85 (1-61)	29.35 ± 20.34 (2-60)	27.66 ± 20.75 (3-60)	26.65 ± 20.03 (2-69)	25.58 ±19.45 (1-61)	26.75 ± 19.73 (2-60)	24.21 ± 20.60 (3-60)

Data are presented as mean ± SD (range). Abbreviations: AROM = active range of motion; ° = degrees; PROM = passive range of motion; secs = seconds

Table 3. Physical examination by side (left and right) measures by age group

	Teens		20s		30s		40s	
	Left	Right	Left	Right	Left	Right	Left	Right
Scapular upward rotation at rest (°)	-1.53 ± 6.83 (-16-6)	3.37 ± 3.22 (-4-10)	1.67 ± 5.03 (-18-10)	2.90 ± 4.39 (-10-14)	2.45 ± 5.33 (-12-20)	4.12 ± 4.35 (-21-20)	0.83 ± 4.91 (-10-6)	1.54 ± 5.19 (-10-8)
Scapular upward rotation full elevation (°)	41.21 ± 15.73 (10-70)	46.16 ± 12.65 (12-72)	37.58 ± 12.08 (18-64)	37.93 ± 9.97 (18-62)	41.00 ± 12.76 (15-80)	39.78 ± 11.75 (15-70)	35.58 ± 10.64 (18-60)	36.83 ± 9.10 (20-62)
Scapular AROM upward rotation (°)	42.74 ± 15.43 (5-68)	42.79 ± 13.77 (2-70)	35.91 ± 11.92 (13-61)	35.03 ± 10.47 (13-59)	38.55 ± 12.58 (7-74)	35.66 ± 11.33 (5-64)	34.75 ± 11.27 (17-57)	35.29 ± 8.74 (19-54)
Shoulder PROM flexion (°)	192.16 ± 10.60 (175-205)	193.42 ± 11.53 (175-213)	183.12 ± 10.46 (160-205)	184.70 ± 13.66 (158-222)	184.20 ± 12.91 (145-219)	185.47 ± 13.21 (145-220)	181.83 ± 9.62 (160-195)	184.54 ± 9.94 (160-198)
Shoulder PROM external rotation (°)	102.32 ± 12.47 (84-127)	103.11 ± 14.04 (70-130)	101.39 ± 12.99 (80-138)	104.94 ± 13.75 (80-160)	100.49 ± 14.19 (64-145)	104.59 ± 16.27 (78-178)	105.70 ± 9.83 (90-130)	108.17 ± 13.65 (90-145)
Shoulder PROM internal rotation (°)	67.58 ± 12.68 (43-87)	63.58 ± 12.70 (35-76)	59.85 ± 13.76 (32-89)	57.64 ± 14.11 (30-80)	65.31 ± 13.73 (25-92)	60.72 ± 15.84 (25-85)	59.87 ± 11.83(39-82)	56.54 ± 13.75 (32-75)
Shoulder PROM extension (°)	89.68 ± 19.32 (65-126)	89.58 ± 18.97 (55-130)	77.90 ± 18.86 (40-128)	78.24 ± 17.18 (40-118)	78.64 ± 17.42 (46-135)	78.42 ± 16.32 (45-132)	82.00 ± 14.14 (55-125)	79.25 ± 15.52 (55-128)
Latissimus dorsi flexibility (°)	180.00 ± 12.54 (160-198)	182.79 ± 13.38 (164-205)	164.13 ± 18.99 (125-205)	165.22 ± 17.88 (127-218)	166.30 ± 18.48 (122-215)	167.23 ± 18.20 (119-212)	159.58 ± 17.96 (120-202)	161.50 ± 18.08 (128-200)
Pec Minor Index	7.85 ± 1.10 (6.15-10.27)	7.50 ± 1.60 (3.25-10.35)	7.52 ± 1.10 (4.70-9.55)	7.61 ± 1.06 (5.29-10.14)	7.93 ± 1.10 (4.49-10.48)	7.91 ± 1.07 (5.21-10.19)	8.07 ± 1.14 (6.12-10.06)	8.05 ± 1.13 (6.15-10.19)
Max Grip Strength (kg)	27.63 ± 7.47 (14-42)	28.42 ± 7.31 (16-42)	29.53 ± 8.00 (13-58)	31.51 ± 7.26 (18-58)	30.77 ± 6.37 (17-48)	32.18 ± 6.68 (16-50)	29.25 ± 5.96 (20-51)	30.25 ± 5.72 (22-49)
Hip PROM flexion (°)	124.42 ± 6.56 (115-135)	126.53 ± 7.43 (115-140)	124.79 ± 9.60 (100-145)	124.55 ± 10.21 (100-149)	124.18 ± 8.69 (105-150)	124.10 ± 9.92 (104-150)	125.91 ± 10.55 (110-155)	125.09 ± 10.59 (109-150)
Hip PROM external rotation (°)	48.11 ± 10.78 (26-64)	46.84 ± 11.28 (20-60)	42.87 ± 13.69 (18-80)	42.12 ± 12.82 (12-70)	46.11 ± 13.84 (10-74)	46.30 ± 13.83 (10-76)	47.42 ± 14.06 (24-76)	48.00 ± 14.03 (22-74)
Hip PROM internal rotation (°)	46.42 ± 13.83 (20-78)	44.74 ± 10.57 (20-62)	38.33 ± 9.43 (14-60)	39.15 ± 10.64 (10-60)	37.31 ± 12.95 (10-64)	38.23 ± 12.65 (9-64)	35.54 ± 9.66 (24-60)	38.25 ± 11.67 (16-60)
Hamstring flexibility (°)	91.26 ± 12.17 (72-110)	89.42 ± 12.00 (72-116)	90.25 ± 14.21 (52-124)	89.22 ± 13.98 (50-130)	92.12 ± 14.10 (56-130)	90.80 ± 14.72 (57-125)	92.00 ± 14.89 (54-120)	92.33 ± 14.88 (66-124)
Single limb stance - eyes closed (secs)	21.11 ± 14.47 (2-60)	23.26 ± 16.80 (4-60)	30.84 ± 21.05 (2-69)	29.06 ± 19.77 (3-61)	28.14 ± 20.34 (3-60)	26.64 ± 20.30 (2-60)	19.21 ± 16.79 (2-60)	17.50 ± 16.88 (1-60)

Data are presented as mean ± SD (range). Abbreviations: AROM = active range of motion; ° = degrees; PROM = passive range of motion; secs = seconds

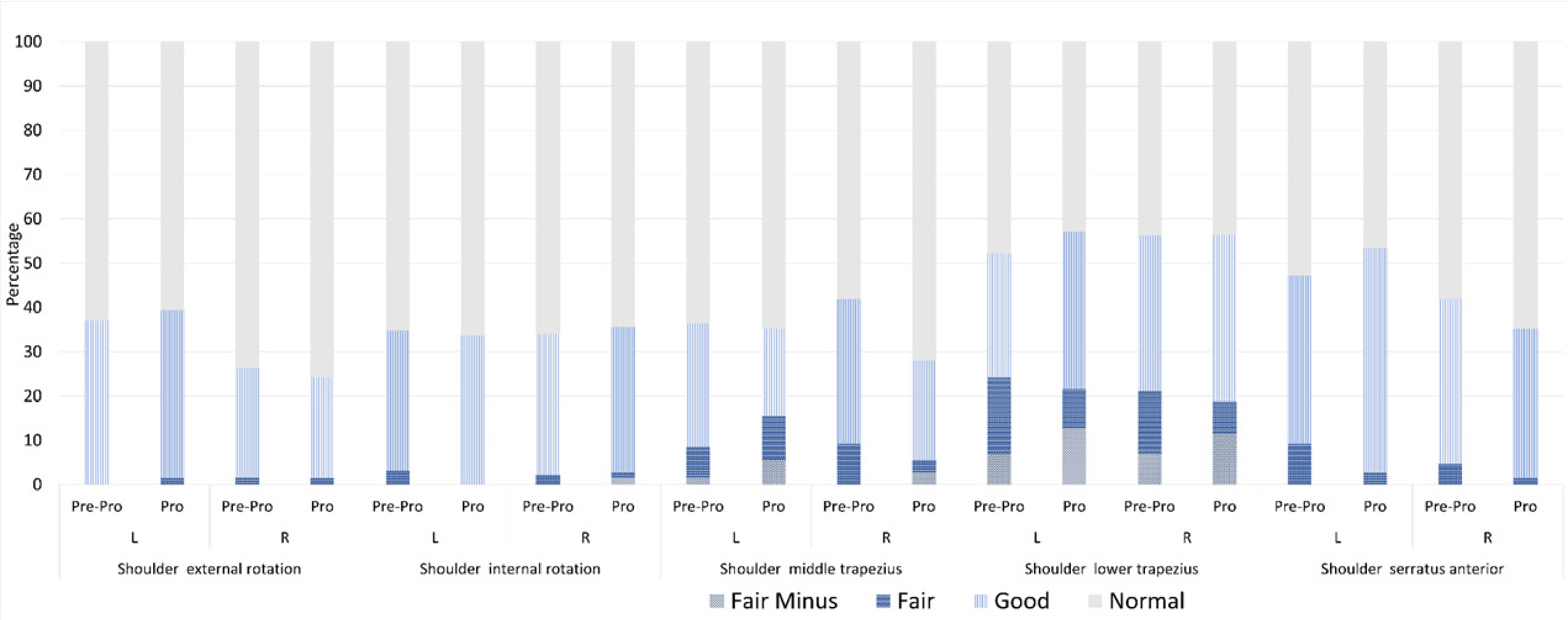

Figure 1. Shoulder manual muscle testing scores by professional status

Each column represents the MMT performance in that group. Abbreviations: Pre-pro = pre-professional; Pro = professional. The light gray portion at the top of each column represents the percentage of participants in the group with normal strength. The categories below represent an increasing degree of weakness (good to fair minus).

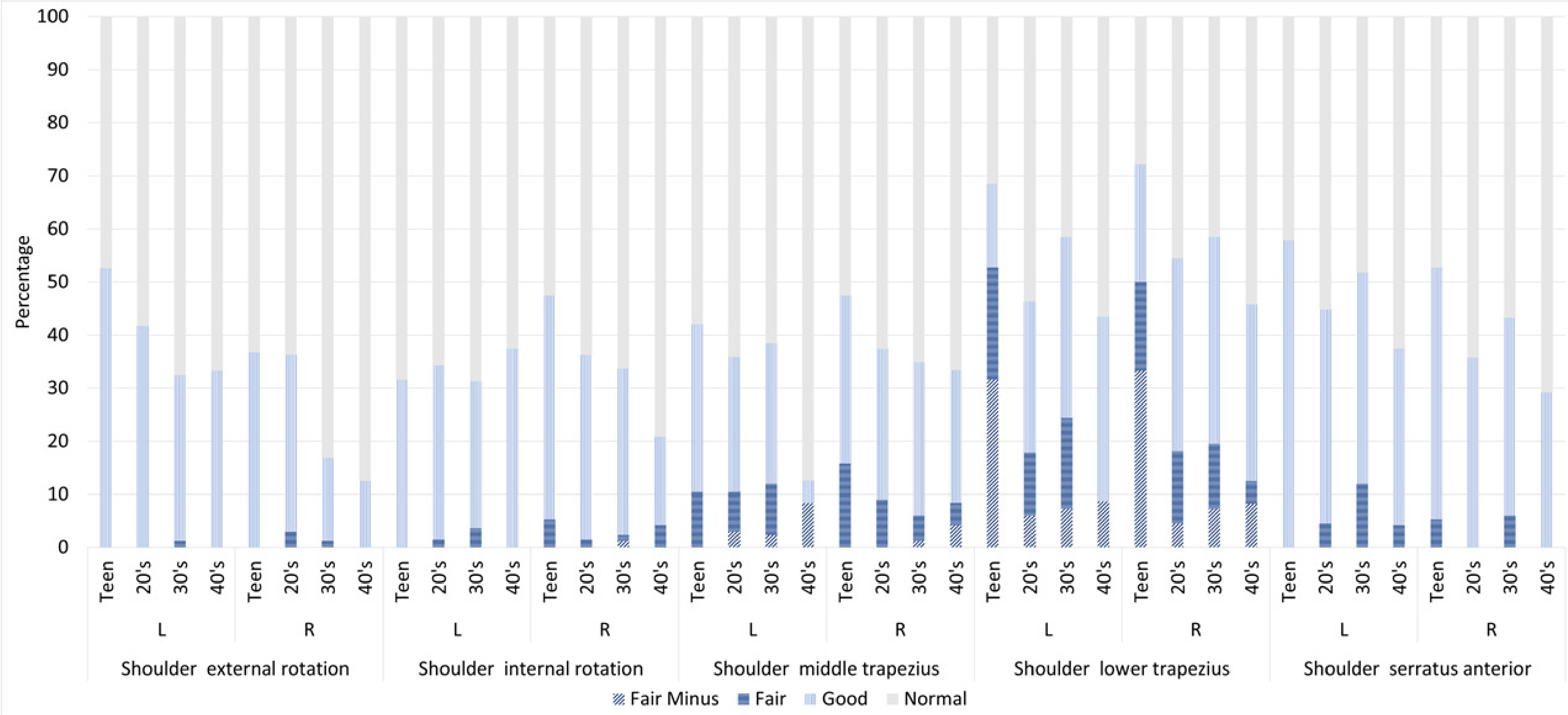

Figure 2. Shoulder manual muscle testing scores by age group

Each column represents the MMT performance in that group. The light gray portion at the top of each column represents the percentage of participants in the group with a normal strength. The categories below represent an increasing degree of weakness (good to fair minus).

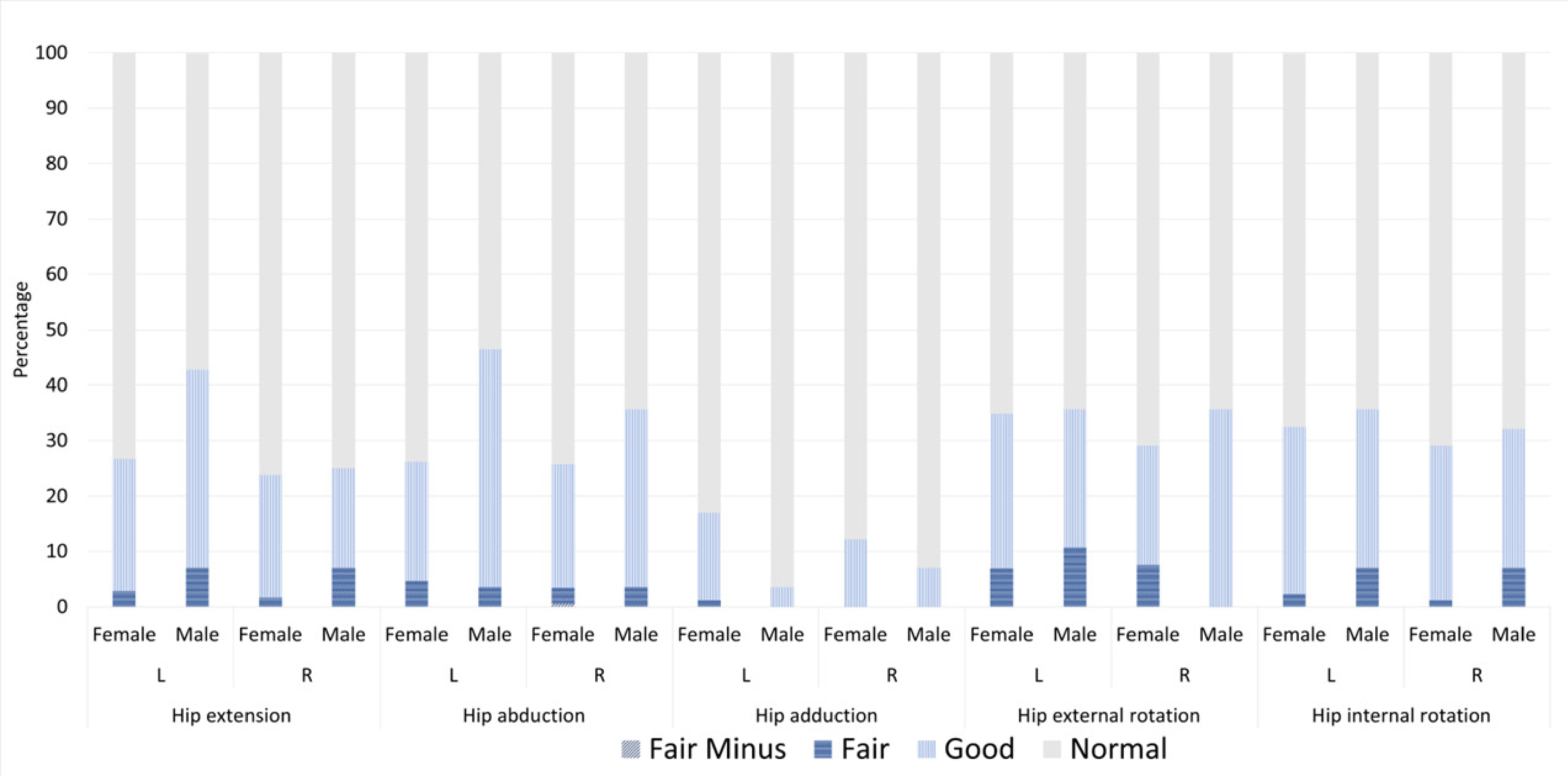

Figure 3. Hip manual muscle testing scores by sex at birth

Each column represents the MMT performance in that group. The light gray portion of the column represents the percentage of participants in the group with a normal strength. The categories below represent an increasing degree of weakness (good to fair minus).

p<0.052; right p<0.044). There was a significant difference in variance in handstand balance (p<0.015) by professional status, with professionals demonstrating longer handstand balance than pre-professionals, $t(193)=1.86$, $p<0.04$, 1-sided (Table 1).

DISCIPLINE-SPECIFIC EFFECTS

No statistically significant differences were found in any of the physical examination or functional performance measures based on discipline exposure for six months prior to the physical examination characterized by aerial only (n=50), ground only (n=10), or both aerial and ground disciplines (n=135).

DISCUSSION

This research presents trunk and extremity physical exam and performance measures by professional status, ASAB, and age to establish norms for circus artists. It broadens the scope of current literature[9,10] and strengthens the validity by having the physical examinations performed by experienced PTs with standardization training. In alignment with the hypothesis, professional artists performed better on functional and cardiovascular measures but also demonstrated greater mobility than pre-professional artists. Partially contradicting the hypotheses, artists AMAB tended to have greater upper extremity flexibility and functional strength, while artists AFAB tended to have greater lower extremity ROM and strength. Finally, contrary to the hypothesis, there was not an age-related decline in ROM.

PROFESSIONAL STATUS

Professionals outperformed pre-professionals on several measures including lower abdominal strength, pull-ups, handstand balance, and cardiovascular fitness (Table 1). In the year following the examination, professionals trained more than pre-professionals (9.27 vs 6.87 sessions/week).[11] Training load for the period prior to testing was not collected and may have been very different since some training time was reduced due to the COVID-19 pandemic. However, average pull-ups in the pre-professional group (4.87+/-3.66) was similar to recreational aerialists who reported a similar training load (6 hr/week; 4.56+/-3.81 pull-ups),[10] suggesting that training time may be a factor. Professionals demonstrated greater hamstring and straddle flexibility than pre-professionals despite both groups participating in a low number of flexibility-specific conditioning sessions (0.01 /week).[11] Differences may be due to the content of the conditioning sessions or professionals may better integrate relevant exercises into skills-based training. Differences by professional status may demonstrate physiologic adaptations necessary for the performance demands of a professional career and could potentially be used as screening measures to assess preparedness for performance in professional companies or progression to professional status, but it may be context specific based on the demands of the show or professional company.[11]

SEX-RELATED DIFFERENCES

As hypothesized, participants AMAB scored higher than AFAB on several upper extremity functional and strength tests including pull-ups, CKCUEST, and grip strength whereas participants AFAB demonstrated greater hip flexibility, lumbar extension, shoulder flexion, extension and external rotation AROM. Sex differences have been shown for similar measures in comparable athletic populations except lumbar mobility which has only been assessed in the general population.[23-26] Differences are likely due to physical sex differences, including the center of gravity location, combined with gender asymmetry in circus training, where boys and men tend to be encouraged toward strength and dynamic skills versus girls and women toward grace and flexibility.[27] Women aerial artists in social circus have reported concerns about gaining strength and looking too masculine.[28] Thus, it is possible that circus artists identifying as women may limit upper body training to maintain a more feminine aesthetic. More research is needed to explore associations between gender identity and bodily aesthetic ideals in various contexts, as pressures may differ for artists working, for example in theatrical, street, or corporate performances. With growing awareness of gender identity, gender may be challenged in circus, and there may be a shift away from gender-specific training making it important to regularly update normative data by sex and gender, as social views and practices change.

AGE-RELATED DIFFERENCES

Contrary to the hypothesis, consistent declines in average strength or ROM by age were not apparent, though in some cases, teens were different from some or all categories of adults. Teens tended to have greater shoulder ROM and flexibility than adults, but also more middle and lower trapezius weakness, though differences between teens and each age group were not always significant. This suggests conditioning exercises for shoulder overhead function may be inadequate in younger circus artists, or that strength develops with longer participation. However, adults had on average only 1.19 years more experience than teens in this study.[11] Age differences were also seen in lumbar flexion and extension with teens showing generally greater AROM compared to adults, though differences between teens and each adult age category were not always significant. In adults, aged 20-60+, lumbar mobility decreased with age, with extension more affected than flexion and what visually appears as the greatest declines between the 40-49y and 50-59y age groups.[23] The 50y+ age group was excluded in the circus study analysis, potentially missing the expected decreases. Alternatively, the training effects of circus could mitigate normal age-related declines.

Considering that 10% of the U.S. circus student population were reportedly over 55 years of age,[6] and circus artists up to 69 years of age have participated in American[11] and international[29] circus research, investigation of circus students and artists over age 50 appears warranted. In this study adults in the 40-49 age category scored lower on balance than both the 20-29 and 30-39 age groups. Similarly, in the general population, there was a slight decrease in balance between the 18-39 and 40-49 age category with accelerated declines thereafter.[30] Importantly, despite the decline, this population of circus artists scored higher on balance than the general population for both the 18-39 and 40-49 age categories.[30] If this trend extends into the 50+ age categories of circus artists, it could mitigate fall risk in older adulthood. Participation in circus arts could have implications for healthy aging and warrants further investigation.

DISCIPLINE EFFECTS

An interesting finding is that there were no differences in any physical exam or performance measures based on exposure to aerial and/or ground acrobatics six months prior to the examination (aerial, n=50; ground, n=10; both aerial and ground, n=135). This could be due to the large discrepancies in group size. However, a previous study with similarly skewed group sizes showed significant differences such that the "both aerial and ground" group had greater shoulder extension AROM than the ground only group and greater shoulder flexion PROM, flexion, and extension AROM than the aerial only group.[9] It is possible that tracking exposure and breaking down the participants into smaller discipline subgroups[4,5] would reveal different physiologic effects by discipline. While the biomechanical stresses of various disciplines have not been tested in artists bodies, forces on rigging points (where an apparatus is attached to a support structure) when artists are performing dynamic tricks, range from 2.5-7.3x body weight for nine different circus apparatuses.[31] The materials and characteristics of different apparatuses may result in different impacts on artists' bodies, requiring different bodily characteristics and training adaptations. Larger study populations will be needed for discipline-specific study and the common practice of cross-training multiple disciplines will add complexity to the analysis.

PHYSICAL FACTORS

Several physical factors are considered particularly relevant to circus practice. Grip strength is important for object manipulation, gripping of an apparatus or a partner's wrists or hands, sometimes holding full body weight, and often for prolonged time. Maximal isometric grip strength in this study (Table 3) was similar to a study of amateur to professional circus acrobats.[9] Like the general population,[32] AMAB participants in this study demonstrated greater grip strength than those AFAB (Table 2), although these findings are not consistent with another circus study.[9] Interestingly, AMAB artists in both studies had lower isometric grip strength than the general population, while AFAB participants' strength was similar (present study) or statistically higher[9] than the general population. These findings are surprising due to the prevalent use of grip in circus arts practice. Interestingly, maximal grip strength of recreational female aerialists was 66% less than female gymnasts, though they had as little as six months of aerial training and their maximal grip strength was lower than AFAB participants in this study.[10] Collectively, these studies highlight the need to better understand the functional requirements of forearm and grip strength for circus, as it seems that similar sports, such as gymnastics, may not be relevant surrogates for this information. It may be useful to additionally establish norms for grip endurance with dynamometry, or with a task like a double or single arm hang for aerialists to have more functional relevance for circus arts.

Shoulder flexibility and scapular controlled mobility are beneficial to many circus disciplines including aerial disciplines, handbalancing, and tumbling. Decreased flexibility of the latissimus dorsi and pec minor can limit scapular upward rotation, external rotation, and posterior tilt.[22,33,34] Though average pec minor flexibility in all groups was above the threshold for a short muscle (pec minor index > 7.44[35]; Tables 2 and 3), artists AMAB demonstrated greater pec minor flexibility than artists AFAB, but it was significant only on the left. Teens had greater latissimus dorsi flexibility than other age groups. The AMAB and teens also had greater scapular upward rotation with active shoulder flexion compared to the AFAB or adult age groups respectively, though ASAB differences were only apparent on the left. The serratus anterior, upper and lower trapezius muscles upwardly rotate the scapula with shoulder elevation.[36,37] Interestingly, despite having more active scapular upward rotation a greater proportion of teens had ratings of fair or fair minus indicating significant weakness with lower trapezius MMT than adults, although these differences were not present for the serratus anterior. Other research has shown that limitations in scapular upward rotation along with medial rotation and posterior tilt of the scapula have been shown to be present with subacromial impingement syndrome and shoulder instability.[33] With the high prevalence of shoulder injuries in circus arts[2,11] the influence of flexibility limitations and scapular muscle function should be further investigated to guide preventative strategies.

Overhead shoulder mobility, combining shoulder flexion and external rotation, is advantageous for many circus disciplines making it a focus of mobility training for many artists. Hypermobility for the shoulder joint is considered PROM flexion greater than 180° or 180° of combined internal and external rotation according to the Upper Limb Hypermobility Assessment Tool.[38] Average shoulder flexion but not combined rotation across groups met the hypermobility criteria (Tables 2 and 3). However, similar to overhead athletes,[39] average external rotation for all groups exceeded the norm of 90° for the general population. Therefore, shoulder mobility differences in the circus population may be due to adaptive changes from training and possibly also the higher prevalence of generalized joint hypermobility (34.5%) compared to the general population.[11]

There is no similar criterion for hip joint hypermobility but combined average internal and external hip rotation in this study was higher (AFAB 84°, AMAB 84°) than a study of college athletes across multiple sports (female 73°, male 70°).[40] Similarly, both studies showed participants AFAB had greater passive hip internal rotation compared to AMAB which could contribute to greater dynamic knee valgus, a risk factor for anterior cruciate ligament injuries and patellofemoral pain.[40] Differently, in the athletes, average internal rotation was higher than external rotation[40] whereas, the opposite was true in the circus artists. Hamstring muscle hyperflexibility, or flexibility that exceeds the normal ROM of 80° with the straight-leg raise hamstring length test,[41] was the average for the AFAB and professional groups. Increased hamstring flexibility, like overhead shoulder mobility, is advantageous and a focus of flexibility training for many circus disciplines including, aerial, contortion, and handbalancing (to get the palms flat the floor with the legs straight), likely contributing to this finding.

IMPLICATIONS

Some of the study findings suggest that strength and conditioning practices could be improved for younger artists and pre-professionals (Figures 1-3). Shoulder weakness was more prevalent for teens for the lower trapezius muscles compared to adults, and the teens and twenties had more prevalent weakness of the right shoulder external rotators than the 30-40s. Pre-professionals had more prevalent weakness for the right middle trapezius than professionals. Weakness of these muscles are associated with various shoulder injuries[42] and improving strength may improve shoulder mechanics especially with the high demand on the shoulder with many circus disciplines and the frequency of shoulder injuries.[2,11] There were not similar findings for hip strength where weakness appeared less prevalent than for the shoulder. Although there wasn't a relationship between shoulder weakness and overall injuries in the study, and injury risk is always multifactorial, a more focused study of the relationship between these factors and shoulder injuries may provide further insight. Based on the study findings, a focus on shoulder strength and conditioning programs is recommended for younger artists and pre-professionals. Future research should investigate the impact of shoulder conditioning on upper extremity injury risk.

STRENGTHS

Strengths of this study include the large sample of circus artists from across the United States with varied training practices. Multiple body regions were assessed with focus on those more commonly injured in circus artists, and a broad range of assessments including functional performance measures were performed. The CKUEST was tested with knees off the ground for both sexes making it make more valid comparison between these groups and demonstrating that circus artists AFAB may not be adequately challenged using the standard method with females having knees on the ground.[43,44]

LIMITATIONS

Limitations include the small samples of adolescents (n=16) due to recruitment challenges in this population, and participants AMAB (n=29) which seems to reflect U.S. circus demographics.[6,9] Only handedness and not limb dominance was determined, so extremity measures were not reported by dominant and non-dominant side; however, limb dominance may be challenging to determine in circus where, due to the asymmetry of certain skills, artists may have different "dominant" strengths and flexibilities for each limb (e.g. dominant pushing vs pulling arm, dominant hip flexor vs hamstring flexibility, etc). To reflect a typical circus population, participants were not excluded if they had a pre-existing injury possibly affecting performance on some tests/measures although tests were excluded if participants reported specific pain or limitations with a test due to injury. The straddle flexibility, pull-ups on trapeze, and handstand balance tests were created by SG and standardized for the study but have not been validated; however, similar tests were createdtests were created specific to a gymnastics context.[14] The CKCUEST was not adapted to height as has been recently recommended,[45] possibly preventing one participant from performing it and limiting performance in others. Handheld dynamometry would have provided more precise data on muscle performance than traditional MMT, but adequate resources were not available. Handstand balance tests were stopped at 60 seconds, so peak performance was not captured in some participants, which may have limited the detection of differences in balance between groups. Pull-ups were performed on a trapeze bar but the rigging (single vs. double point) varied between facilities which may have affected pull-up performance and limited comparison to studies with a rigid pull-up bar. To avoid contact between the inclinometers in individuals with very mobile lumbar extension, lumbar spine extension AROM was repeated twice, once with an inclinometer at the sacrum and again with the inclinometer at T12.

FUTURE RESEARCH

Normative studies across the diverse circus population are needed to strengthen the understanding of the variations in the physical profiles in circus artists by age, participation level, ASAB or gender identity, specific disciplines, and training or performance context. Larger populations are needed to see if deficits in physical exam or performance measures predict injury and if addressing deficits reduces injury risk. Longitudinal monitoring of training and physiological characteristics according to discipline subgroups[4,5] would also be useful to determine training adaptations, which could inform performance and injury prevention interventions.

CONCLUSION

This normative data generated in this study offers information regarding physical characteristics and performance in a group of pre-professional and professional circus artists. Differences were found by age, ASAB, and professional status. The physical profile of circus artists also differed from the general population and other athletes. The findings from this study can be used to guide screening for readiness to participate in advanced training or performance, return to performance after injury, and the development of targeted strength and conditioning programs for circus artists.

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CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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SUPPLEMENTARY MATERIALS

Appendix 1

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Appendix 2

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