RESEARCH ARTICLE

Parachute Ankle Brace and Extrinsic Injury Risk Factors During Parachuting

JOSEPH J. KNAPIK, SALIMA DARAKJY, DAVID SWEDLER, PAUL AMOROSO, AND BRUCE H. JONES

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Introduction: This study examined the injury prevention effectiveness of the parachute ankle brace (PAB) while controlling for known extrinsic risk factors. ***Methods:*** Injuries among airborne students who wore the PAB during parachute descents were compared with injuries among those who did not. Injury risk factors from administrative records included wind speed, combat loads, and time of day (day/night). Injuries were collected in the drop zone. ***Results:*** A total of 596 injuries occurred in 102,784 parachute descents. In univariate analysis, students not wearing the PAB (Controls) were 2.00 [95% confidence interval (95% CI) = 1.32–3.02] times more likely to experience an ankle sprain, 1.83 (95% CI = 1.04–3.24) times more likely to experience an ankle fracture, and 1.92 (95% CI = 1.38–2.67) times more likely to experience an ankle injury of any type. PAB wearers and Controls had a similar incidence of lower body injuries exclusive of the ankle [risk ratio (Control/PAB) = 0.92, 95% CI = 0.65–1.30]. After accounting for known extrinsic injury risk factors, Controls were 1.90 (95% CI = 1.24–2.90) times more likely than PAB wearers to experience an ankle sprain, 1.47 (95% CI = 0.82–2.63) times more likely to experience an ankle fracture, and 1.75 (95% CI = 1.25–2.48) times more likely to experience an ankle injury of any type. The incidence of parachute entanglements that persisted until the jumpers reached the ground were similar among PAB wearers and Controls [RR (Control/PAB) = 1.17, 95% CI = 0.61–2.29]. ***Conclusion:*** After controlling for known injury risk factors, the PAB protected against ankle injuries, and especially ankle sprains, while not influencing parachute entanglements or lower body injuries exclusive of the ankle.

Keywords: wind, combat load, night, entanglements, risk factors, epidemiology, airborne, military personnel.

SINCE WORLD WAR II, military airborne operations have delivered troops to key areas of the battlefield, altering the tactical and strategic aspects of warfare. The idea of tactical military airborne operations was first proposed in 1919 by William (Billy) Mitchell and approved by General John J. Pershing. However, with the quick end of World War I, the idea was never realized. In 1928, the U.S. Army Air Corps staged a number of airborne demonstration jumps in Texas that were observed by foreign army representatives; however, the Soviet Union was the first country to develop military airborne units in the 1930s. This was quickly followed by developments in Germany, culminating in the first combat jumps, which spearheaded the German invasion into the Netherlands in May 1940. The U.S. Army formed a platoon of airborne troops in July 1940 and initiated the first jump school at Fort Benning, GA, in April 1941 (9,13).

While military parachuting techniques were being developed, studies indicated that injury incidences were 210 to 240/10,000 descents (8,26). As parachute design and jump procedures improved, injury rates declined to about 60/10,000 descents (5). The ankle was shown to be the most common anatomical location of injury, accounting for 21–43% of all injuries (2,7,11,14).

Stemming from the high rates of ankle injuries and from promising studies showing a reduction in ankle injuries in sports activities (21,24,25), the U.S. Army worked with corporate interests to develop an outside-the-boot ankle brace for military airborne operations. This device, known as the parachute ankle brace (PAB), was tested at the U.S. Army Airborne School (USAAS) in 1993 and was shown to effectively reduce the incidence of inversion ankle sprains (2). In 1994, the U.S. Army adopted use of the brace for all airborne operations (3). A subsequent evaluation among U.S. Army Airborne Rangers showed a 57% reduction in ankle injuries when the brace was employed (23). Despite these positive outcomes, PAB use was discontinued in 2000 because of the costs of maintaining the brace and anecdotal reports that the brace increased injuries in other parts of the lower body and complicated parachute entanglements. After these developments, another study compared the period of PAB use (1994–2000) to the period after the PAB was discontinued (2000–2002) and showed that the risk of an ankle injury hospitalization was 1.7 times higher after the PAB was no longer used (22).

In 2004, the Army Center for Health Promotion and Preventive Medicine worked with the U.S. Army Re-

From the U.S. Army Center for Health Promotion and Preventive Medicine, Aberdeen Proving Ground, MD (J. J. Knapik, S. Darakjy, D. Swedler, B. H. Jones) and the Madigan Army Medical Center, Department of Clinical Investigation, Tacoma, WA (P. Amaroso).

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Address reprint requests to: Dr. Joseph Knapik, Research Physiologist, Directorate of Epidemiology and Disease Surveillance, 1570 Stark Road, U.S. Army Center for Health Promotion and Preventive Medicine, Aberdeen Proving Ground, MD 21010; joseph.knapik@apg.amedd.army.mil.

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search Institute of Environmental Medicine and the Defense Safety Oversight Council (DSOC) to reinstitute use of the PAB in military airborne operations. The DSOC required information to determine whether or not: 1) the PAB increased injuries in the lower body (exclusive of the ankles); and 2) complicated parachute entanglements among jumpers. PABs were purchased for the USAAS and were evaluated over a 21-mo period. The major purpose of the investigation reported here was to re-evaluate the PAB with regard to its effectiveness in reducing the incidence of injury during military parachute training while controlling for extrinsic risk factors known to influence injury rates in military airborne operations. Secondary purposes were to: 1) examine the influence of the PAB on other lower body injuries; 2) examine the influence of the PAB on parachute entanglements; and 3) more fully explore the association between specific types of parachute injuries and extrinsic risk factors.

METHODS

The USAAS at Ft. Benning, GA, has the responsibility for training all soldiers, marines, sailors, and airmen in the practical aspects of military parachuting. To become airborne qualified, students must successfully complete a 3-wk training course. The first 2 wk involve training on aircraft exit and ground landing techniques. The third week involves actual parachute descents in which students complete five parachute jumps from C-17 or C-130 aircraft from altitudes of 1000 to 1250 ft. The first jump is an individual effort with 1 s between jumpers and 10 jumpers exiting from each side of the aircraft. The other jumps are mass exits with 15 jumpers exiting in quick succession from each side of the aircraft.

There are four training companies at the USAAS. Batches of PABs (DJO Incorporated, Vista, CA) were purchased for the USAAS from April 2005 to December 2006, and each time enough PABs were provided to equip an entire company. Thus, the PABs were phased in by company and students in a particular company either wore or did not wear the PAB for all five jumps.

The body of the PAB is composed of a plastic material and fits on the outside of the military boot; closed-cell foam in the interior serves to cushion the leg from the brace. The brace is attached to the boot by a single strap fitting under the heel of the boot and by two straps that secure it to the lower leg (2). Students who wore the PAB during parachute descents were instructed on proper fitting and wear and familiarized with the PAB during the first 2 wk of training. While the PAB was being phased into the parachute training, the Quality Assurance Office at Fort Benning periodically provided investigators with an anonymized list of injuries, Jump Closure Reports (JCRs), and a list of companies wearing and not wearing the PAB, as described below.

Injury Data

During all USAAS parachute training operations, three medics were in the drop zone and two medics in an ambulance just off the drop zone. A senior noncommissioned officer (NCO) known as Jump-2 routinely traveled with one of the medics and recorded injury information. If a student was injured in the drop zone, Jump-2 completed a "Report of Injury/Incidence" in consultation with the medics. Jump-2 reported the injury by radio to another NCO, known as the Master Trainer, who was located in the airborne operations office. The Master Trainer then completed an initial "Operations Report" based on information from Jump-2. The Operations Report was subsequently updated by an NCO or officer in the injured student's training company. Information for the update could come from a number of sources. Generally, the NCO or officer spoke to the injured student or (in more serious cases) went to the hospital and questioned the casualty and/or any available medical staff. If additional information was required to determine the specific injury type, the radiology or orthopedics departments in the hospital were contacted. The Operations Report was continually updated based on information from these sources.

The Quality Assurance Office at Fort Benning abstracted injuries from the USAAS Operations Reports. The anonymized list provided to the investigators included the date of the injury, jump number (1 through 5), class, company, and type/anatomical location of the injury, as well as the age and sex of the injured jumper.

Jump Closure Reports

The Master Trainer completed a JCR each time there was a USAAS jump operation. The JCR contained the date of the jump, class number, jump number, number of students who jumped, wind speed, type of jump, time of day, and parachute entanglements (if any). Wind speeds were continuously collected in the drop zone using a Weather Wizard® device (Davis Instruments, Hayward, CA) and averaged for the period of the jump operation. The type of jump was either: 1) administrative-nontactical, in which students jumped without any equipment other than their uniform, parachute, and Kevlar helmet; or 2) combat load, in which students jumped with their uniform, parachute, Kevlar helmet, load carrying equipment, weapons container, and rucksack. The rucksack and weapons container were attached to quick release straps that service members were instructed to activate just before impact with the ground. The quick release served to drop the load downward about 15 ft from the student's body, but it remained attached. Combat load jumps were generally performed once during training. Time of day was listed as either day or night. Night jumps were generally conducted after 1900 in the winter and after 2200 in the summer months.

Parachute entanglements were listed in the narrative section of the JCR. An entanglement was defined as a physical contact between two or more jumpers that interfered with a normal parachute descent. Two types of entanglements were derived from the narrative description in the JCR. The first type was an entanglement of any kind. The second type was an entanglement in which the jumpers remained in physical contact until they impacted the ground. Entanglement information included whether or not an injury had occurred but not the type of injury.

Brace Wear Data

The Quality Assurance Office at Fort Benning compiled a list of USAAS classes from April 2005 to December 2006. Investigators extracted the following information from the list: class number, jump dates, number of students, and whether or not the class wore PABs.

Data Processing and Analysis

Based on the date, class number, and jump number, which were reported in all three data sources, injury cases were matched to aggregated information from class lists and JCRs, including brace wear status, wind speed, type of jump, time of day, and entanglements. To analyze the information, a new database was constructed with one line for each student in a class who executed a particular jump during a particular jump operation. If an injury occurred during a particular jump operation, the type of injury, anatomical location, and the age and sex of the injured jumper were listed on one of the case lines for that operation. Injuries were separated into type and anatomical location. Types included sprains, strains, fractures, concussion, dislocation, abrasion/laceration, contusion, and environmental (primarily heat related). Often the injury was just listed by anatomical location with a nonspecific injury type (e.g., "ankle injury," "knee injury"). In these cases, the injury type was listed as "pain."

Because of the DSOC's concern that the PAB might be transmitting forces up the leg and increasing injury incidence in the legs or lower body, injuries were placed into "groups" involving the lower body. These groups included lower body injuries, leg injuries, lower body musculoskeletal injuries, lower body fractures, and lower body strains and sprains. Lower body injuries included all injuries with an anatomical location of pelvis, hip, thigh, knee, calf, shin, or foot/toe, but did not include injuries to the ankle. Leg injuries included the same areas but did not include the ankle or foot/toe. Lower body musculoskeletal injuries included the same anatomical locations as lower body injuries with an injury type of fracture, sprain, strain, contusion, or pain (but not abrasions/lacerations or environmental). Lower body fractures included the same anatomical locations as lower body injuries with an injury type of fracture. Lower body strains and sprains included the same anatomical locations as lower body injuries plus an injury type of strain or sprain.

Data analysis was performed using SPSS version 15.0. Injury incidence was calculated as the sum of all injuries, injury anatomic location/type combinations (e.g., ankle sprains, ankle fractures), injury groups or injury types, divided by the total number of jumps times 10,000 (injuries/10,000 jumps). Denominator data consisted of the number of jumps from the JCRs. Covariates included PAB wear status (brace or no brace), wind speed (0–1 knot, 2–5 knots, 6–9 knots, or 10–13 knots), time of day (day or night), and jump type (administrative-nontactical or combat load). The Chi-square test of proportions was used to assess the association between the covariates and all injuries, various injury anatomic locations/types, injury groups, and injury types. Risk ratios and 95% confidence intervals (95% CI) were calculated. Covariates that were significantly ($P < 0.10$) associated with injury incidence in the univariate (Chi-square) analysis were included in a multivariate logistic regression. In the multivariate analysis, simple contrasts with a baseline variable (defined with a risk ratio of 1.00) were used. Outcomes in the logistic regression were the presence or absence of all injuries, a particular injury anatomic location/type, or an injury type. Entanglements among the braced and not braced groups were compared using the Chi-square test of proportions.

RESULTS

A total of 596 injuries occurred in 102,784 jumps for an overall cumulative injury incidence of 58 injuries/10,000 jumps. **Table I** shows the injuries by type and anatomical location. There were 11 multiple injuries but only the more serious type is listed in Table I. The most common injury anatomic location/type combinations were ankle sprains ($N = 144$), ankle fractures ($N = 74$), shin fractures ($N = 41$), shoulder dislocations ($N = 25$), knee sprains ($N = 17$), foot fractures ($N = 15$), and face abrasions/lacerations ($N = 14$).

TABLE I. AIRBORNE INJURIES BY TYPE AND LOCATION ($N = 596$).

	N	Proportion (%)
Injury Type		
Sprain	194	32.6
Fracture	148	24.8
Concussion	96	16.1
Pain	66	11.1
Dislocation	28	4.7
Abrasion/Laceration	28	4.7
Contusion	17	2.9
Strain	9	1.5
Environmental	10	1.7
Injury Location		
Head	102	17.1
Face	19	3.2
Neck	7	1.2
Chest	7	1.2
Shoulders	41	6.9
Elbow	5	0.8
Arm	20	3.4
Hand	1	0.2
Back	23	3.9
Pelvis (including coccyx)	21	3.5
Hip	7	1.2
Thigh	1	0.2
Knee	20	3.4
Calf	3	0.5
Shin	50	8.4
Ankle	219	36.7
Foot/Toe	37	6.2
Location Not Specified	3	0.5

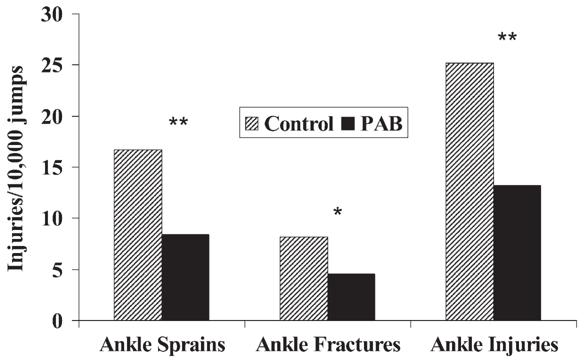

Fig. 1. Cumulative injury incidence in the PAB and Control groups (* $P = 0.03$, ** $P < 0.01$).

There were a total of 33,461 jumps with the PAB and 69,323 jumps without the PAB. **Fig. 1** compares the PAB wearers and PAB nonwearers (nonwearers hereafter referred to as Controls) in terms of the cumulative incidences of ankle sprains, ankle fractures, and all ankle injuries. Compared with students who wore the brace, Controls were 2.00 (95% CI = 1.32–3.02) times more likely to experience an ankle sprain, 1.83 (95% CI = 1.04–3.24) times more likely to experience an ankle fracture, and 1.92 (95% CI = 1.38–2.67) times more likely to experience an ankle injury of any type. **Table II** shows the cumulative injury incidence for various injury types and groups. In all cases, there are only small differences between the brace wearers and Controls.

Table III shows the univariate associations between three covariates (wind speed, time of day, jump type) and all injuries, ankle sprains, ankle fractures, ankle injuries, and concussions. All injuries were associated with each of the covariates. Ankle sprains, ankle fractures, and ankle injuries were associated with time of day and jump type, but not with wind speed. Concussion risk was markedly elevated at higher wind speeds, but concussions were not associated with time of day or jump type.

Table IV shows the multivariate associations of the covariates with all injuries, ankle sprains, ankle fractures, and ankle injuries (from the multivariate logistic regression). Brace wear was associated with fewer ankle sprains and ankle injuries even when time of day and jump type were considered in the analysis. The association between ankle fractures and brace wear was reduced when time of day and jump status were included in the multivariate model.

Of the injured jumpers, 29% of men wore the brace and 31% of women wore the brace (Chi-square $P = 0.80$). The average (± SD) age of injured brace wearers was 25 ± 6 yr while the average (± SD) age of injured Controls was 24 ± 5 yr (*t*-test $P = 0.11$). There were a total of 89 parachute entanglements, of which 51 involved entanglements that persisted to the ground. Only one entanglement involved three jumpers and no entanglements involved more than three jumpers. The overall entanglement incidence was 8.7/10,000 jumps and the incidence of entanglements to the ground was 5.0/10,000 jumps. **Table V** compares entanglements among those who wore the brace with the Controls. Overall entanglements were slightly higher among those wearing the brace but entanglements that persisted until the jumpers reached the ground were slightly lower among those wearing the brace. There were only two injuries among entangled jumpers: both of these were entanglements persisting to the ground and both were among Controls.

DISCUSSION

The present investigation found that the PAB protected against ankle injuries, especially ankle sprains, during military parachute training. This protective effect was manifest even after considering wind speed, night jumps, and combat loads, covariates known to affect injury rates in this and other studies (8,11,18,20). Injuries to other parts of the lower body (exclusive of the ankle) were not significantly influenced by the brace. The age and gender distribution of injured jumpers did not differ between brace wearers or Controls, indicating that these potential intrinsic risk factors (1,6,7,22) were similar across the two groups. The incidence of entanglements was similar in the braced and Control groups.

The finding that the PAB reduced the risk of ankle sprains and ankle injuries in the present investigation is in consonance with other studies examining the PAB (2,22,23), as shown in **Table VI**. Most studies have been conducted with students attending the USAAS, with the exception of the study by Schumacher et al. (23) that examined U.S. Army Rangers. Only Amoroso et al. (2) performed a randomized intervention trial, while other investigations (including the present one) were ecological/observational in design. Amoroso et al. (2) had few cases of ankle injuries and ankle sprains because of the relatively small number of descents, but the ankle sprains in the Control group were more serious than those in the PAB group. In general, these studies

TABLE II. INCIDENCE FOR VARIOUS INJURY TYPES AND GROUPS BY PARACHUTE ANKLE BRACE (PAB) WEAR.

Injury Group or Type	Injury Incidence (Injuries/10,000 Jumps) PAB	Control	Risk Ratio-Control/ PAB (95% CIs)	Chi-Square *P*-Value
All Injuries	52.60	60.59	1.15 (0.97-1.37)	0.11
Lower Body Injuries (exclusive of ankle)	14.35	13.14	0.92 (0.65-1.30)	0.62
Leg Injuries (exclusive of ankle)	11.06	9.38	0.85 (0.57-1.27)	0.42
Lower Body Musculoskeletal (exclusive of ankle)	14.34	13.42	0.94 (0.66-1.33)	0.71
Lower Body Fractures (exclusive of ankle)	6.27	6.20	0.99 (0.59-1.67)	0.97
Lower Body Strains/Sprains (exclusive of ankle)	3.29	4.76	1.45 (0.73-2.87)	0.29
Concussions	10.46	8.80	0.84 (0.56-1.27)	0.41

TABLE III. UNIVARIATE ASSOCIATIONS BETWEEN RISK FACTORS AND AIRBORNE INJURY INCIDENCE.

Injury Type	Variable	Level of Variable	Injury Incidence (Cases/10,000 Jumps)	Risk Ratio (95% CI)	Chi-Square *P*-Value
All Injuries	Wind Speed	0-1 knot	44.1	1.00	< 0.01
		2-5 knots	37.3	0.85 (0.65–1.11)	
		6-9 knots	59.1	1.34 (1.06–1.70)	
		10-13 knots	82.2	1.86 (1.35–2.56)	
	Time of Day	Day	52.6	1.00	< 0.01
		Night	118.6	2.25 (1.81–2.81)	
	Jump Type	Admin/Non-tactical	50.4	1.00	< 0.01
		Combat Load	83.1	1.65 (1.38–1.97)	
Ankle Sprain	Wind Speed	0-1 knot	11.1	1.00	0.69
		2-5 knots	10.0	0.90 (0.52–1.54)	
		6-9 knots	13.7	1.24 (0.74–2.05)	
		10-13 knots	8.7	0.79 (0.28–2.04)	
	Time of Day	Day	12.1	1.00	< 0.01
		Night	36.1	2.99 (1.98–4.50)	
	Jump Type	Admin/Non-tactical	12.2	1.00	< 0.01
		Combat Load	20.9	1.71 (1.19–2.45)	
Ankle Fracture	Wind Speed	0-1 knot	6.8	1.00	0.19
		2-5 knots	4.2	0.62 (0.27–1.37)	
		6-9 knots	3.1	0.46 (0.16–1.21)	
		10-13 knots	8.7	1.28 (0.45–3.40)	
	Time of Day	Day	5.9	1.00	< 0.01
		Night	20.6	3.50 (2.00–6.10)	
	Jump Type	Admin/Non-tactical	5.0	1.00	< 0.01
		Combat Load	13.9	2.79 (1.72–4.50)	
Any Ankle Injury	Wind Speed	0-1 knot	18.1	1.00	0.73
		2-5 knots	14.2	0.79 (0.50–1.22)	
		6-9 knots	18.0	1.00 (0.65–1.53)	
		10-13 knots	17.5	0.97 (0.48–1.91)	
	Time of Day	Day	18.2	1.00	< 0.01
		Night	58.0	3.18 (2.30–4.42)	
	Jump Type	Admin/Non-tactical	17.6	1.00	< 0.01
		Combat Load	34.8	1.98 (1.49–2.63)	
Concussion	Wind Speed	0-1 knot	5.1	1.00	< 0.01
		2-5 knots	3.2	0.62 (0.23–1.55)	
		6-9 knots	18.0	3.53 (2.06–6.05)	
		10-13 knots	28.0	5.48 (2.86–10.39)	
	Time of Day	Day	9.6	1.00	0.39
		Night	6.4	0.67 (0.27–1.66)	
	Jump Type	Admin/Non-tactical	9.4	1.00	0.98
		Combat Load	9.5	1.01 (0.61–1.66)	

support the results of the current investigation, indicating that individuals who wear the PAB have about half or less the risk of an ankle injury compared to those who do not wear the PAB.

In the Schmidt et al. study (22), there was little change in the magnitude of the ankle injury risk reduction after controlling for intrinsic risk factors (age, gender, race, rank, service duration). We were unable to specifically examine intrinsic risk factors in our entire group because we had access to the age and gender only for the injured students but not for the uninjured students. On the other hand, the present study was the first PAB investigation to control for extrinsic risk factors, those relating to the external environment. Even after controlling for night jumps and extra equipment in the multivariate model, there was little change in the magnitude of the risk ratio (Controls/PAB) for ankle sprains and ankle injury. Wind speed was not considered in the multivariate model because it had no univariate association with ankle injury.

The general findings of the current study are in accord with the literature with regard to injury incidence. The overall parachute injury rate of 58 cases/10,000 jumps agrees very well with the estimate of 56 cases/10,000 jumps calculated by Bricknell and Craig (5) based on their literature review of 13 post-1946 studies. The ankles were involved in 37% of the injuries in the present investigation and the literature reports that the ankles are involved in 21–43% of all injuries (2,4,7,11,14,16,23). Ankle sprains comprised 24% of all injuries in the present project and they account for 9–33% of all jump injuries reported in the literature (4,7,11,14). Ankle fractures were 12% of all injuries in the current investigation and previous studies reported that 7–23% of all jump injuries were ankle fractures (4,7,11,14).

A number of previous studies of military parachute injuries have examined associations between overall injury incidence and various extrinsic risk factors (see 15). Injury definitions have varied widely, as previously discussed (15), but the overall results have been relatively consistent in identifying specific factors associated with injury. In agreement with previous studies, the present investigation found that overall injury risk was elevated

TABLE IV. MULTIVARIATE ASSOCIATION BETWEEN RISK FACTORS AND AIRBORNE INJURY INCIDENCE (MULTIVARIATE LOGISTIC REGRESSION).

Injury Type	Variable	Level of Variable	Odds Ratio (95% CI)	Wald Statistic *P*-Value
All Injuries	Brace Status	Brace	1.00	—
		No Brace	1.15 (0.93–1.42)	0.18
	Wind Speed	0-1 knot	1.00	—
		2-5 knots	1.01 (0.77–1.32)	0.97
		6-9 knots	1.53 (1.20–1.97)	< 0.01
		10-13 knots	2.13 (1.55–2.92)	< 0.01
	Time of Day	Day	1.00	—
		Night	2.24 (1.70–2.96)	< 0.01
	Jump Type	Admin/Nontactical	1.00	—
		Combat Load	1.26 (1.01–1.57)	0.04
Ankle Sprain	Brace Status	Brace	1.00	—
		No Brace	1.90 (1.24–2.90)	< 0.01
	Time of Day	Day	1.00	—
		Night	2.62 (1.70–4.03)	< 0.01
	Jump Type	Admin/Nontactical	1.00	—
		Combat Load	1.38 (0.95–2.01)	0.09
Ankle Fracture	Brace Status	Brace	1.00	—
		No Brace	1.47 (0.82–2.63)	0.19
	Time of Day	Day	1.00	—
		Night	2.51 (1.37–4.60)	< 0.01
	Jump Type	Admin/Nontactical	1.00	—
		Combat Load	2.34 (1.42–3.85)	< 0.01
Any Ankle Injury	Brace Status	Brace	1.00	—
		No Brace	1.75 (1.25–2.48)	< 0.01
	Time of Day	Day	1.00	—
		Night	2.57 (1.80–3.65)	< 0.01
	Jump Type	Admin/Nontactical	1.00	—
		Combat Load	1.65 (1.22–2.22)	< 0.01

by higher wind speeds, night jumps, and additional equipment. Past studies have reported minor elevations in injury risk at wind speeds of 6 knots (8) to 9 knots (18), with higher risk when wind speeds exceed 9 to 13 knots (18,20). Higher wind speeds can result in elevated landing velocities, landings away from preplanned areas, less control on landing, and greater oscillations (15). Night jumps have been shown to increase injury risk (11,17,18,20), possibly because of difficulties in seeing the ground, perceiving distance and depth, and/or determining the direction of lateral drift (15). Additional equipment may increase injury risk (18,20) because the added weight increases the descent rate, resulting in higher ground impact forces (15). Furthermore, the release of the equipment on its suspension line can increase horizontal oscillations and lead to less controlled landings.

This is only the second study to perform a multivariate analysis controlling for extrinsic covariates likely to influence injury rates during airborne operations. The other investigation, by Lillywhite (18), involved a group of experienced parachutists. Lillywhite (18) showed, in a logistic regression model, that greater injury risk was independently associated with greater wind speeds, night descents, more equipment, more jumpers, and the type of drop zone. Likewise, the variables examined in the present study (wind speed, night descents, extra equipment) were independently associated with injury (18).

While previous studies (6–8,10,11,17–20) have examined associations between overall injury incidence and various extrinsic risk factors, the present study examined some specific types of injuries and found that risk factors differed depending on the anatomic location/type of injury. Ankle sprains, ankle fractures, and overall ankle injuries were associated with greater loads and night jumps, but not with higher wind speeds. On the other hand, concussions were not associated with greater loads or night jumps, but their occurrence was elevated more than fivefold as wind speeds increased from 0–1 knot to 10–13 knots. Head injuries are likely to occur during descents in which a proper parachute landing fall cannot be executed and the head impacts the ground. This is especially likely in situations where horizontal drift forces the parachutist into a backward landing in which the heels, buttocks, and head hit the ground in sequence (8,14). It is not clear why elevated wind speed was not associated with ankle sprains, ankle fractures, or overall ankle injuries.

The protective effect of the PAB for ankle fractures decreased when considered in a multivariate model with

TABLE V. ENTANGLEMENTS IN THE PARACHUTE ANKLE BRACE (PAB) AND CONTROL GROUPS.

	Incidence (Cases/10,000 Jumps)		Risk Ratio-Control/ PAB (95% CI)	*P*-Value
	PAB	Control		
Any Entanglements	9.6	7.5	0.76 (0.50–1.25)	0.33
Entanglements to Ground	4.2	4.9	1.17 (0.61–2.29)	0.73

TABLE VI. COMPARISON OF RESULTS FROM INVESTIGATIONS OF THE PARACHUTE ANKLE BRACE (PAB).

Investigation	Descents	Outcome Measure	Outcomes (Injuries)	Injury Incidence (Injuries/10,000 Jumps) PAB	Injury Incidence (Injuries/10,000 Jumps) Control	Risk Ratio-Control/ PAB (95% CI)
Amoroso et al. 1998 (2)	3674	Ankle Injury*	15	27.4	54.1	2.0 (0.7-5.8)
		Inversion Ankle Sprains	8	5.5	37.9	6.9 (0.9-56.1)
		All Ankle Sprains*	12	16.4	48.7	3.0 (0.8-10.9)
Schumacher et al. 2000 (23)	13,782	Ankle Injury	44	15.1	44.5	2.9 (1.4-6.1)
		Ankle Fracture*	12**	5.1	11.5	2.3 (0.6-8.4)
Schmidt et al. 2005 (22)†	973,715‡	Hospitalized Ankle Injury	526	3.0	6.7	2.2 (1.8-2.8)
Present Investigation	102,784	Ankle Injury	219	13.2	25.2	1.9 (1.4-2.7)
		Ankle Sprains	144	8.4	16.7	2.0 (1.3-3.0)
		Ankle Fractures	74	4.5	8.2	1.8 (1.0-3.2)

* Derived from data in article.
** Estimated from incidence reported in article.
† Compared only pre-brace period to brace period.
‡ Estimated from sample sizes assuming five jumps per service member.

night jumps and combat loads; the risk ratio (no brace/brace) decreased from 1.89 in the univariate analysis to 1.47 in the multivariate analysis. Jumps with combat loads were associated with almost twice the risk of an ankle fracture when compared with the risk for all injuries or for ankle sprains only. As noted above, combat loads probably increased the descent rate, resulting in higher ground impact forces. Rucksacks (the largest single item of the combat load) were attached to the jumper by a quick release strap that the jumper was instructed to activate just before impact with the ground. If this was done with proper timing, the load hit the ground before the jumper; however, this process probably slowed the jumper's descent rate just before impact and could alter the "timing" of the jumper's ground impact, thereby inhibiting the proper execution of the parachute landing fall. Additionally, the load represented a drop zone hazard in that a jumper could land on top of it, also resulting in an improper parachute landing fall. Parachutists were in training and generally performed only one combat load jump, making the possibility of errors greater. It should also be noted that the PAB provides lateral support and may be able to reduce ankle fractures due to excessive lateral movement, but not fractures due to vertical impacts, those in which excessive force is experienced along the long axis of the body. Higher vertical impacts may be more likely with combat loads and/or with landings under zero wind speed conditions.

There are several limitations to this investigation. First, this study was ecological/observational in design and not a randomized intervention trial, the type that provides the strongest test of an intervention (12). The companies that received the braces could have had lower injury risk because of factors not associated with ankle brace use. However, this is unlikely, since airborne training procedures were well standardized regardless of the unit involved. Further, the present study had well defined groups (brace wearers and Controls) and the results were supported by other studies that found similar results (2,22,23). Another potential limitation was that the present investigation recorded only injuries that occurred in the drop zone and that were initially treated by medics on site. There was strong incentive to delay treatment of minor injuries so that students could complete training. However, the method of data collection used here was likely to obtain the more serious injuries, those most in need of acute medical care. Another limitation was the recording of wind speeds. Wind speeds were averaged over the entire jump operation and may not have reflected what an individual jumper experienced during his or her jump. Wind gusts are intermittent and could have large effects on the lateral drift and oscillations of individual jumpers. Finally, accuracy in defining injuries was likely to vary depending on the level of medical care reached by the student and the persistence of follow-up by those responsible for doing so.

This study provided further support for the use of the PAB by showing that: 1) the protective effect of the PAB is still present when other risk factors are considered; 2) the PAB does not influence the incidence of other lower body injuries; and 3) based on the current study, the PAB does not appear to complicate entanglements. The PAB should be used during military parachute training to reduce injuries. Further studies in operational units should be conducted with experienced parachutists to see if the PAB can increase operational combat capability through injury reduction.

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