Musculoskeletal Injuries and Automation in Aerial Port Operations

Victoria F. H. Bylsma; Bryant J. Webber; Roger A. Erich; Jameson D. Voss

INTRODUCTION: Aerial ports are being modernized with automated technologies, but the impact on musculoskeletal injury (MSKI) is unknown.

METHODS: In this retrospective cohort study of U.S. Air Force aerial port technicians and traffic management technicians, we compared reported injury rates from January 2006–December 2016 and Veterans Benefits Administration disability compensation claims awarded from January 2001–March 2017. Ton-adjusted injury rates, associated lost/affected duty time, and percent risk attributable to lack of automation were compared at Dover Air Force Base (which features base-specific automation), Travis Air Force Base, Ramstein Air Base, and Yokota Air Base.

RESULTS: Injuries most often occurred during aircraft/flight line activities and were typically sprains/strains, with extremities being most affected. Among aerial port technicians there were 8.0 injury reports per 1000 person-years compared to 5.2 per 1000 among traffic management technicians (incidence rate ratio = 1.5; 95% CI: 0.9, 3.0). Of the aerial port technicians with a compensation award, 70.7% included an MSKI component, whereas 75.7% of traffic management awards included an MSKI component. Aerial port technicians at Dover AFB experienced 1.4 injury reports per 1000 personnel per 1000 cargo-tons per year, lower than the other ports: 3.2 (Travis); 3.7 (Ramstein); and 7.6 (Yokota). Overall, 56% of injuries at Travis, 62% at Ramstein, and 82% at Yokota could be attributed to absence of Dover-like automation. However, mean lost/affected duty days at Dover (12.4) far exceeded those at the other bases (range: 4.5–8.6).

DISCUSSION: Automating aerial ports may reduce injury rates, but the impact on lost/affected duty time requires further investigation.

KEYWORDS: musculoskeletal injury, automation, occupational injury, military personnel.

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The mission of the U.S. Air Force's Air Mobility Command, according to its four-star commanding officer, is to "get the right loads in the right place at the right time in the right configuration."[4] To execute that mission more safely and efficiently, in 2016 Air Mobility Command launched "The Aerial Port of the Future," an enterprise-wide initiative to improve aerial port efficiency and safety through automation and modernization. As part of the initiative, current processes and the effects of new technologies were assessed during tours of three port operation facilities: the Port of Virginia, Dover Air Force Base (AFB), and Amazon's Seattle warehouses.[4]

In the private sector, companies from Amazon to Ford have introduced specific technologies, like autonomous vehicles and exoskeletons, with the intent to prioritize safety while reducing costs.[7,13] Warehouse automation was also cited as a key transformation within the air cargo industry in the International Air Transport Association's 2018 "Cargo Strategy."[5] Although the private sector is trending toward greater automation, few published studies have analyzed the impact of these interventions on injury burden.

To support "The Aerial Port of the Future" initiative, Air Mobility Command commissioned the Epidemiology Consult Service Division, U.S. Air Force School of Aerospace Medicine,

From the U.S. Air Force School of Aerospace Medicine Epidemiology Consult Service Division, Wright-Patterson AFB, OH, United States.

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Address correspondence to: Victoria F. H. Bylsma, M.P.H., 2510 Fifth Street, Bldg. 840, Rm W318.26, Wright-Patterson AFB, OH 45433, USA; victoria.bylsma.ctr@us.af.mil.

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to conduct a multiphase study. Its objectives were threefold: 1) characterize aerial port injuries in the U.S. Air Force; 2) assess long-term disability and financial burden of these injuries; and 3) analyze whether injury outcomes are associated with differences in existing automation.

METHODS

This multiphase retrospective cohort study was conducted as routine public health practice. Air Force Personnel Center data were used to identify all enlisted active duty, guard, and reserve airmen who were assigned to either the aerial port career field (Air Force Specialty Code: 2T2) or the traffic management career field (Air Force Specialty Code: 2T0) during relevant time periods. The traffic management career field was selected as the comparison group because it approximates the counterfactual ideal: members are demographically similar to aerial port technicians, conduct similarly nonsedentary activities, and are assigned to the same major command. Demographic information was retrieved from the Air Force Personnel Center database. All statistical analyses were performed using SAS 9.4 (Cary, NC). A two-sided alpha of 0.05 was considered statistically significant for all analyses.

Phase 1: Characterization of Aerial Port Injuries

The first phase analyzed Air Force Safety Center injury report data from January 1, 2006, to December 31, 2016. Injury reports were classified by the career field of the individual at the time of injury and were limited to occupational injuries (i.e., occurred on duty and were classified as work-related). Injuries in each career field were described according to duty days lost or affected, by mechanism and location, and by type of injury and body region affected. Injuries were classified according to severity as either "minor," if no duty days were lost or affected, or "severe," if at least one duty day was lost or affected. The career fields were compared using incidence rate ratios (IRR) with 95% confidence intervals (CI).

Phase 2: Assessment of Long-Term Disability and Financial Burden

The second phase examined Veterans Benefits Administration (VBA) disability compensation data from January 1, 2001, to March 31, 2017. Musculoskeletal injuries (MSKI) were defined as conditions affecting the musculoskeletal system in the VBA diagnostic field. Because VBA data are inherently postservice and individuals could have served time in both career fields during their service, those who spent at least 6 mo of time in the aerial port career field were classified as exposed. Those with less than 6 mo as an aerial port technician were excluded from the analysis in order to reduce misclassification bias. Descriptive statistics, prevalence rates, and adjusted odds ratios (AOR) using logistic regression analysis were calculated. Median compensation is presented as the measure of central tendency because considerable positive skew was identified during data analysis.

Phase 3: Analysis of Existing Automation

The third phase analyzed aerial port technician injury reports from the Air Force's four major aerial port installations [Dover AFB, Ramstein Air Base (AB), Travis AFB, and Yokota AB] between January 1, 2007, and December 31, 2016. The surveillance start date was selected to correspond with the introduction of automation at Dover AFB. To account for workload differences, base-level injury incidence rates were compared after incorporating annual cargo-tons processed. The relationship between automation at Dover AFB, which features base-specific warehouse automation, and musculoskeletal injuries was explored in three ways: 1) by calculating the percent of injuries at the comparison bases that could be attributed to a lack of automation; 2) by assessing overall severity of reported injuries; and 3) by comparing severity of injuries specifically sustained in the warehouse, the focal point of Dover's automated system. The first was analyzed with percent attributable risk. Each nonautomated base was compared to Dover AFB by calculating the difference between their injury report rates (per 1K person-years per 1K cargo-tons), divided by the rate at the nonautomated base; this corresponds to: (risk ratio − 1)/risk ratio.

RESULTS

Phase 1: Characterization of Aerial Port Injuries

Between January 2006 and December 2016, 901/28,127 (3.2%) aerial port technicians and 134/5993 (2.2%) traffic management technicians reported at least one occupational injury. The injured populations in each career field were similar by mean age (aerial port technicians: 28.7 yr; traffic management technicians: 27.6 yr), rank category distribution (55% E1–E4, 36% E5–E6, and 8% E7–E9 for both career fields), and sex [female aerial port technicians (14% of the field) accrued 14% of the injuries, and female traffic management technicians (37% of the field) accrued 43% of the injuries]. The aerial port career field submitted 1041 injury reports (8.0 per 1000 person-years), while the traffic management field submitted 147 reports (5.2 per 1000 person-years) (IRR = 1.5; 95% CI: 0.9, 3.0). When stratified by year, aerial port technicians submitted significantly more injury reports than traffic management technicians during 2008, 2009, 2013, and 2016 (IRR range: 1.8–3.5) (**Fig. 1**).

Of reported injuries sustained by aerial port technicians, 43% resulted in at least one lost or affected duty day compared to 37% among traffic management technicians. Whereas the aerial port career field accumulated 8283 lost or affected duty days due to injury, averaging 8 d per injury, the traffic management career field had 920 d lost or affected, averaging 6 d per injury (**Table I**).

For aerial port technicians, sprains/strains were the most common type of injury (28%), aircraft/flight line operations were the most common activity at the time of injury (30%), the extremities were the most common body location of injury (upper, 31%; lower, 30%), and objects (caught, crushed, jammed, struck by, striking against an object) were the most

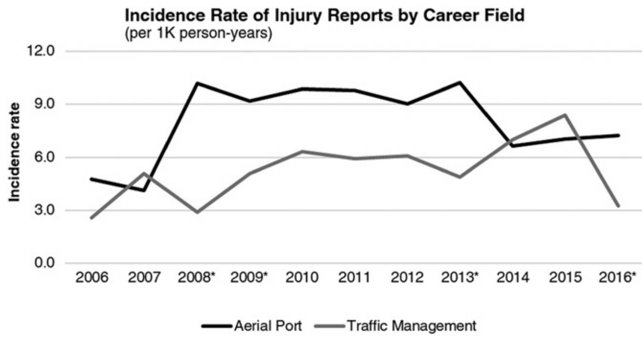

Fig. 1. Incidence of injury reports among U.S. Air Force aerial port and traffic management technicians by year per 1000 person-years, January 2006–December 2016. The asterisk (*) indicates years with statistically significant incidence rate ratios.

common mechanism of injury (48%). Although there were more upper extremity (*N* = 257) than lower extremity (*N* = 252) injuries, the latter resulted in more lost/affected duty days (15 d vs. 11 d per injury). Compared to traffic management technicians, aerial port technicians had 3.2 times the rate of injuries to the lower extremities (IRR = 3.2; 95% CI: 2.0, 4.5) and 1.6 times the rate of torso injuries (IRR = 1.6; 95% CI: 1.0, 2.6).

Phase 2: Assessment of Long-Term Disability and Financial Burden

From January 1, 2001, to March 31, 2017, the VBA identified 42,451 aerial port and traffic management personnel eligible for benefits. A total of 11,044 (26.0%) personnel submitted compensation claims for 66,670 service-connected conditions. In total 10,433 individuals were awarded compensation for 41,430 conditions.

Among aerial port technicians, 25% of the career field submitted a compensation claim and 24% received a compensation award. In the traffic management population, 30% submitted a compensation claim and 28% received an award. Total percent disability among award recipients, categorized in deciles from 10–100%, was largely equivalent for both career fields. For those receiving compensation, the median monthly award among aerial port personnel was $893, with a maximum compensation of $8706. Comparatively, traffic management personnel received a median monthly award compensation of $1062, with a maximum compensation of $7437. Conditions affecting the musculoskeletal system accounted for 42% of all service-connected conditions and 46% of awarded conditions. Of the 8317 aerial port technicians with a compensation award, 5880 (70.7%) included an MSKI component. By comparison, of the 2116 traffic management technicians with a compensation award, 1601 (75.7%) included an MSKI component (**Table II**).

When compared to traffic management personnel, aerial port personnel were 23% less likely to receive any VBA compensation award (AOR = 0.77; CI: 0.73, 0.82) and 28% less likely to receive an award with an MSKI component (AOR = 0.72; CI: 0.68, 0.77) after adjusting for sex and years of service in the career field. When restricting injury reports to members no longer in the service (*N* = 677 reports), aerial port personnel who ever submitted an injury report were 59% less likely than traffic management personnel to receive an MSKI-associated VBA award (AOR = 0.41; CI: 0.25, 0.68) after adjusting for sex and age at report (Table II).

Phase 3: Analysis of Existing Automation

Between January 2007 and December 2016, among the four aerial ports of interest, Dover AFB handled the most cargo [8153 tons annually (range: 2151–14,912)], followed by Ramstein AB [5408 (4159–7850)], Travis AFB [3788 (3304–4454)], and Yokota AB [1218 (891–1897)]. Injury report rates among aerial port technicians at all four bases exceeded the overall career field rate of 8.0 reports per 1000 person-years: Ramstein AB (18.4); Travis AFB (12.0); Dover AFB (11.8); and Yokota AB (9.3). After incorporating annual cargo-tons processed, injury rates were lowest at Dover AFB (1.4 injury reports per 1000 person-years per 1000 tons), followed by Ramstein AB (3.7), Travis AFB (3.2), and Yokota AB (7.6) (**Table III**). Base-specific rates incorporating tons of cargo remained relatively stable over time, with the exception of peaks at Yokota AB in 2012, 2014, and 2015, and a peak at Dover AFB in 2015 (**Fig. 2**).

Injury-specific details—including body part, type, mechanism, and activity—were roughly similar across the four installations. Lower extremity injuries predominated at each base and were slightly more prevalent (range: 30–42%) across these four installations than the average for the career field (29%). Distribution of injury type and mechanism was similar at all four bases and reflected the overall career field. Compared to the other bases, Dover had a slightly lower percentage of injuries attributed to overexertion (lifting, handling, or carrying heavy or bulky objects; strenuous movements; and repetitive movements). At all installations, most injuries occurred during aircraft/flight line operations or supplies/materials handling.

Compared to Dover AFB, 56% of injuries at Travis AFB, 62% at Ramstein AB, and 82% at Yokota AB could be attributed to a lack of Dover-like automation (Table III). Over half of the injuries at all four installations were minor, causing no lost/affected

Table I. Comparison of Injury Severity Among U.S. Air Force Aerial Port and Traffic Management Technicians, January 2006–December 2016.

	AERIAL PORT (*N* = 28,127)		TRAFFIC MGMT (*N* = 5993)	
DUTY DAYS LOST OR AFFECTED	NO. OF REPORTS (%)	TOTAL DAYS	NO. OF REPORTS (%)	TOTAL DAYS
0	597 (57)	0	92 (63)	0
1–2	123 (12)	207	19 (13)	29
3–14	176 (17)	1290	17 (12)	131
15–30	63 (6)	1430	10 (7)	209
>30	81 (8)	5356	8 (5)	551

Table II. Comparison of Veterans Benefits Administration Compensation Among U.S. Air Force Aerial Port and Traffic Management Technicians, January 2001–March 2017.

	AERIAL PORT ($N = 34,983$)	TRAFFIC MGMT ($N = 7468$)	ADJUSTED ODDS RATIO (95% CI)	*P*-VALUE ($\alpha \leq 0.05$)
Total (%)	8317 (23.8%)	2116 (28.3%)	0.77 (0.73, 0.82)	<0.001†
MSKI component (%)	5880 (70.7%)	1601 (75.7%)	0.72 (0.68, 0.77)	<0.001†
Had injury report (% awarded)*	598 (31.4%)	79 (46.8%)	0.41 (0.25, 0.68)	<0.001‡
Total monthly value, median (max)	$893 ($8706)	$1062 ($7437)	–	–
MSKI monthly value, median (max)	$111 ($7437)	$134 ($7437)	–	–

MSKI: musculoskeletal injury.
* Restricted to injury safety reports from January 2006 – March 2017; †adjusted for sex and years of service; ‡Adjusted for sex and age.

duty days. The mean lost/affected duty days per injury, however, varied substantially among the installations: 12.4 (Dover), 4.5 (Travis), 6.1 (Ramstein), and 8.6 (Yokota). At Dover, injuries specifically sustained in the warehouse were predominantly severe (82%), and these severe injuries resulted in a mean of 21.8 lost/affected duty days. At Yokota, Travis, and Ramstein, however, warehouse injuries were less likely to be severe (50%, 48%, and 28%), and their severe injuries resulted in fewer lost/affected duty days—means of 11.0, 8.8, and 18.8 d, respectively.

DISCUSSION

About 1 in 40 U.S. Air Force aerial port technicians reported sustaining an occupational injury between January 2006 and December 2016. Sprains/strains were the most common type of injury, objects were the primary mechanism of injury, and aircraft/flight line operations predominated as activity during injury. When compared to the traffic management career field, the aerial port career field had a higher overall injury rate, more lost or affected duty days as a result of injury, and a greater mean duration of lost or affected days per injury. Nonetheless, after military retirement or separation, traffic management technicians were more likely to receive a VBA compensation award (28% vs. 23%) and had higher award components for MSKI (75% vs. 71%). Although VBA compensation for injury cannot necessarily be attributed to injuries reported to the Air Force Safety Center and compensation awards are not limited to reportable injuries, the discrepancy between in-service injury epidemiology and postservice compensation merits further research.

Despite some annual variability in cargo-ton adjusted injury rates, Dover AFB, the only port featuring warehouse automation, had the lowest rate for the entire 10-yr surveillance period. Annual intrabase variability over time, which was greatest at Yokota AB, has no obvious explanation, but it could relate to changes in personnel (e.g., an influx of less experienced workers) or in the safety culture (e.g., a command that emphasizes event reporting). Since no definitive explanation can be given, the 10-yr rate was used to calculate percent attributable risk. Based on this analysis, lack of automation could account for 56% of injuries at Travis AFB, 62% at Ramstein AB, and 82% at Yokota AB. Severity of injuries showed the opposite pattern. Injuries at Dover AFB, and specifically injuries sustained in the warehouse, were associated with more lost or affected duty time. Future research on warehouse automation should seek to elucidate any mechanisms that could explain the higher injury severity we identified. Whenever new automation programs are implemented, consideration should be given for human system integration, complacency mitigation, and unintended consequences. Murashov and colleagues suggest a direct relationship between worker familiarization with industrial robots and injuries caused by those robots.[8] Air Force units that use automation should emphasize this during annual safety training and consider additional refresher training commensurate with the level of automation.

While this study provides novel observations about automation and aerial port injuries in the Air Force, it should be interpreted in light of several methodological limitations. Though injuries occurring on and off duty requiring formal medical care must be reported to the Safety Center,[10,11] there are ascertainment limitations. First, in addition to the limitations regarding VBA compensation data described above, exclusion of members who were not yet eligible for compensation reduced the sample size and statistical power of those analyses. Second, while serious workplace injuries were likely reported, there could be underreporting of less serious injuries, which may result in overestimation of injury severity. Third, nearly 20% of reports from each base had incomplete injury detail fields (e.g., type or mechanism of injury), and missing details could be nonrandom. Fourth, this study relied on base and career field

Table III. Aerial Port Technician Injury Rate Comparison by U.S. Air Force Base, January 2007–December 2016.

	DOVER AFB	RAMSTEIN AB	TRAVIS AFB	YOKOTA AB
Annual cargo tons processed, mean (range per thousand tons)	8153 (2.2–14.9)	5408 (4.2–7.9)	3788 (3.3–4.5)	1218 (0.9–1.9)
Injury reports per 1K person-years	11.8	18.4	12.0	9.3
Injury reports per 1K person-years per 1K cargo-tons	1.4	3.7	3.2	7.6
Lost/affected duty days per injury, mean	12.4	6.1	4.5	8.6
Injuries with ≥ 1 lost/affected duty day, %	82%	28%	48%	50%
Percent risk attributable to absence of automation	Referent	62%	56%	82%

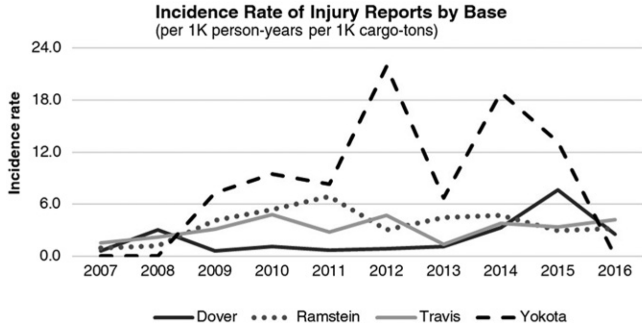

Fig. 2. Incidence of injury reports among U.S. Air Force aerial port technicians by base per 1000 person-years per 1000 cargo-tons, January 2007–December 2016.

denominator data from the Air Force Personnel Center, which does not account for manning assistance (i.e., external personnel assigned temporary duty away from their home installation); consequently, the injury rates may be overestimated. Fifth, with regard to the third phase of the study, complete tonnage data for the entire aerial port operation were unavailable, preventing calculation of and comparison with an Air Force-wide baseline, and percent attributable risks could not be adjusted for all possible differences between Dover AFB and the other bases (e.g., dissimilar weather, changes to local processes). Sixth, this study could not entirely control for the potential confounding variable of physical fitness. However, since all Air Force members must achieve the same minimum level of fitness,[12] regardless of installation or occupation, discrepancy in fitness should not be a major contributor to the findings. Finally, this study was conducted entirely within a military environment and was not intended to be generalizable to commercial industry.

Warehouses[3,7] and factories[13] in the private sector use a variety of automated technologies, including professional service robots (e.g., self-driving forklifts) and collaborative robots (e.g., exoskeletons and prostheses designed to work symbiotically with humans). However, human health risks associated with these technologies are not well understood. The National Institute for Occupational Safety and Health has drawn attention to this knowledge gap, noting that robotics may inadvertently increase risk.[8] Our study suggests an "automation paradox" within the military aerial port setting, where the warehouse with highest automation had lower injury incidence but greater injury severity. Investigating this apparent paradox is crucial for worker safety. Irrespective of automation, aerial ports should continue to emphasize proven injury prevention techniques.[1,2,6,9]

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Authors and affiliations: Victoria F. H. Bylsma, M.P.H., Bryant J. Webber, M.D., Roger A. Erich, Ph.D., and Jameson D. Voss, M.D., Public Health and Preventive Medicine Department, U.S. Air Force School of Aerospace Medicine, Wright-Patterson AFB, OH; Victoria F. H. Bylsma, STS Systems Integration, LLC, Fairborn, OH; and Jameson D. Voss, Air Force Medical Support Agency, Falls Church, VA.

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