Physical Ergonomics & Human Factors, Vol. 223, 2026, 39–49
https://doi.org/10.54941/ahfe1007794

Risk Assessment Through Heart Rate of a Team of Airport Workers Loading Unit Load Devices

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ABSTRACT

Literature shows that musculoskeletal disorders (MSDs) are common among airport baggage handlers, but Unit load Device (ULD) loading/unloading has not been examined before. In this paper we recorded heart rates of six workers handling 12 ULDs each up to 1,000 kg. The workplace precludes the use of ISO 11228-2 standard because the tasks of loading/unloading are performed by a team of workers with no wheeled equipment on a slope surface. Besides, no single method in literature contemplates the assessment of braking tasks in the unloading stage. Both loading and unloading tasks showed low physical effort despite the heavy handled loads. Improvements could include ergonomic handles and better Aircraft Cargo Loader operation to minimize manual handling. Though limited by sample size and reliance on heart rate, the results suggest that heart rate could be a valuable parameter for assessing workers' effort in non-standardized work environments where other risk assessments tools are non appliable. These findings can help enhance workplace safety and reduce MSD risks in air cargo operations. The adoption of these measures may also decrease aircraft loading times. The improvements could result in greater slot availability at the airport and subsequently enhance overall airport profitability.

Keywords: Frimat, Ergonomics, Physiological parameters, Bioharness, Pushing and pulling, Risk assessment, Heart rate monitor, Occupational medicine

INTRODUCTION

Literature reports a high level of musculoskeletal disorders in workers performing manual baggage handling at airports (Andersson, 1984; Stalhammar, 1986). It estimates, over the period from 1992 to 1994, that back injuries to baggage handlers costs an average of 21 million US$ per annum only in the USA and an average cost per back injury of around 10,000 US$ (Dell, 1997). No cost updates have been released since 1994, and the increase in air passenger traffic suggests that current estimates are likely understated.

Recently literature confirmed the previous data and highlights that in several years nothing has changed to improve the health and safety of airport

Received January 16, 2026; Revised April 3, 2026; Accepted April 19, 2026; Available online July 20, 2026

workers. The epidemiological data are substantially unchanged (Kemp, 2010; Tafazzol, 2016; Thygesen, 2016; Mikkelsen, 2016; Wang, 2018; Asadi, 2019, Mikkelsen, 2019; Brauer, 2020, Trivedi, 2022).

The main factors associated with an increased risk of back disorder are heavy physical work, lifting and handling of loads and awkward postures (Dell, 1998; Bern, 2013; Wahlstrom, 2016; Wang, 2018), seniority (Bern, 2013; Møller, 2018), psychosocial factors (Bergsten, 2017) and job satisfaction (Bulduk, 2017).

Some possible solutions to reduce biomechanical overload in workers during baggage handling inside narrow body aircraft could be ramp snakes, power stows or sliding carpets (Gomez, 2009).

A paper (Lenior, 2012) argued that fully automated baggage handling systems are not yet practical for all airports because of factors such as cost, limited space, and the need for operational flexibility.

Since 2012, robotics has advanced to make automated systems smaller, more affordable, and a viable option for reducing workers' biomechanical strain in airports (https://www.schiphol.nl/en/blog/cobot-at-schiphol/).

Recent studies (NIOSH, 2015; Lu, 2018; Brauer, 2020) also show that technical lifting equipment reduces musculoskeletal disorders.

Applying common standardized biomechanical risk assessment tools to baggage handling tasks in airports could be not always possible. This is true because such tasks are frequently carried out in restricted and awkward posture.

Few papers in literature reported a biomechanical risk assessment of manual handling in airport scenario.

A common standardized ergonomic risk assessment tool such as REBA has been applied (Asadi, 2019) in airport. Authors found that the REBA scores for aircraft loading workers were 3.5 to 4.8 points higher than cargo workers, customer service workers, gate workers and VIP club workers.

Only three papers reported an instrumental based tool risk assessment of baggage handling through surface electromyography (sEMG). The first one was a lab simulation on male college students (Korkmaz, 2006). Authors found high levels of muscle activity.

Another investigation, in lab scenario (Lu, 2018), provided evidence of reduction of anterior-posterior shear forces when using a mechanical lift system.

The last paper investigated sEMG and L4/L5 compression forces in real work environments (Koblauch, 2016). The author found L4/L5 compression forces exceeding the recommended thresholds for compression force during lifting.

In our case report, we didn't analyze the typical baggage handling, outside the aircraft, inside the narrow body aircraft baggage compartments, or in the baggage room.

Our aim is to investigate the loading and unloading of Unit Load Devices (ULDs) on an aircraft cargo. The UDL is a container used to group and secure baggage/goods for efficient air transport on wide-body aircraft and specific narrow-body aircraft.

In literature, this task has not yet been investigated. Only a paper reported that the workers involved in pushing and pulling containers inside wide body aircraft performed an overloading task but only when the aircraft's built-in equipment is out of service (Dell, 1997). However, the paper also indicated that this task did not result in worker injuries when the equipment was operational.

Our paper aims to assess the tasks of loading and unloading ULDs through the analysis of the Heart Rate (HR) of a team of workers in a real work environment during daily real work. We also propose suggestions for risk mitigation.

TASK DESCRIPTION

A team of four, including one "Aircraft Cargo Loader" (ACL) driver and three workers pushing ULDs, completes the tasks in around 30 minutes.

The workers must store 12 ULDs in the air cargo weighing over 1,000 kg each. We acquired two sessions of loading and two sessions of unloading during real loading/unloading acitvity. Table 1 shows the weight handled for each of the four sessions in our case scenario.

Table 1: Table shows the weight in Kg of each of the ULDs handled by the workers in the four acquisitions (two loadings and two unloadings). ULD 11 and 12 of Loading 2 were empty, the weight is referred to those of ULDs.

Weight	Loading 1	Loading 2	Unloading 1	Unloading 2
ULD 1	496	150	1170	1185
ULD 2	1102	1180	220	435
ULD 3	1168	1316	700	555
ULD 4	1248	934	740	850
ULD 5	1202	1270	865	880
ULD 6	1330	632	885	925
ULD 7	1208	660	990	935
ULD 8	1282	932	1045	975
ULD 9	1008	856	1060	1060
ULD 10	870	912	1075	1185
ULD 11	1010	220 (empty)	1165	1090
ULD 12	986	223 (empty)	495	465
Total	**12910**	**9285**	**10410**	**10540**

The driver uses the ACL to mechanically lift the ULDs (Fig. 1). The ACL rises the ULDs from the runway up to the level of the aircraft fuselage.

Following, a team of workers manually push on a roller floor (Fig. 2) the ULDs inside the Air Cargo (Fig. 3 and 4).

Workers move ULDs inside the aircraft according to ULD weight, ensuring proper balance and stability of the aircraft. Unloading is backward.


[redacted]

Figure 1: The driver of the ACL and the ULD.

Figure 2: The roller floor inside the aircraft.

Figure 3: Two of the acquired workers involved in the loading of the ULD from the ACL inside the airplane.

Figure 4: Two of the acquired workers involved in the task of pushing the ULD on the roller floor inside the airplane.

METHODS

Risk assessment limitations with common ergonomic risk assessment tools

Common push and pull risk assessment tools (Snook, 1991; ISO, 2007) cannot be used because:

1) the task is performed by a team of workers, the push and pull thresholds established by Snook and ISO are intended for tasks performed by a single worker;
2) this task is done on a roller floor, not with wheeled equipment; Snook and ISO thresholds apply only to tasks using wheeled equipment (trolleys, pallet trucks, wheelbarrows etc.);
3) is not possible to use because the front surface of UDL is soft (Fig.1 and 4). The dynamometers require a rigid and stable surface for accurate readings (Annex D of ISO 11228-2).
4) the airplane is on a sloped surface. The pushing and pulling thresholds recommended by Snook and ISO standard are intended for flat surfaces. Additionally, when unloading, workers have to "brake" the UDLs as they slide downward, and no ergonomic tools available in the literature assess the "braking tasks";
5) surface electromyography has been applied to measure muscle effort in actual airport settings (Koblauch, 2016). However, it is not suitable for our scenario because the tasks lack standardization and because sEMG cannot be used to monitor all four workers throughout the entire task.

Heart Rate

Heart rate (HR) has often been applied to evaluate cardiac workload within occupational medicine (LeBlanc 1956; Maxfield 1961; Davis 1969; ACGIH 1971; Meyer 1996). Previously, equipment was expensive and cumbersome, but wearable technology now allows easy and reliable HR monitoring (Papoutsakis, 2022; Moon, 2024; Lee, 2024; Sammito, 2024).

All the workers of our study wore a chest strap (Fig. 5) equipped with the Zephyr Bioharness 3.0, a sensor that records heart rate and trunk flexion (Johnstone 2012a; 2012b). The Zephyr Bioharness 3.0 is commonly used to assess workers' kinematics and physiology in actual work scenarios where ISO standards are not appliable (Lee, 2017; Masci, 2022). In previous figures (3 and 4) the workers are wearing the equipment.

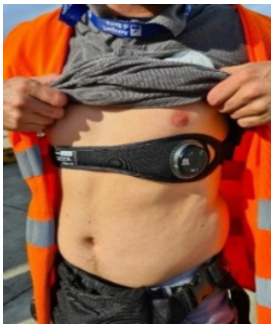

Figure 5: A worker wearing the Zephyr Bioharness chest strap.

Baseline recordings

Before the data collection began, we recorded each participant's resting heart rate for 15 minutes while they were seated in a quiet and climatized room.

The software OmniSenseTM 5.1 (Medtronic, Minneapolis, MN, USA) was used to eliminate HR artifacts.

To have a trunk posture baseline for all workers, we recorded the resting erect trunk posture at the start of the acquisitions. The workers stood in an anatomical position with their heads, upper backs, buttocks, and heels touching a vertical wall for ten seconds. In that position, the trunk was at 0 degrees inclination.

Subjects

Six skilled employees were recruited over the course of two loading and unloading cycles. All participants had no history of musculoskeletal, neurological, or heart disease and were non-smokers.

Table 2 shows the anthropometric data of the workers, and the task (loading or unloading). Two subjects (3 and 4) performed both tasks.

Table 2: Anthropometric data of each worker and mean and SD of the sample. The table also shows the task that each worker executed in the recordings.

Subject	Height (cm)	Weight (Kg)	BMI	BMI Class	Age	Experience (Years)	Task
1	185	105	30,7	Obesity 1°	30	7	Loading
2	170	65	22,5	Normal	27	2	Loading
3	174	75	24,8	Normal	51	1	Unloading
3	174	75	24,8	Normal	51	1	Loading
4	186	95	27,5	Overweight	45	1	Unloading
4	186	95	27,5	Overweight	45	1	Loading
5	180	84	25,9	Overweight	51	22	Unloading
6	175	75	24,5	Normal	33	1	Unloading
Mean ± SD	**178.3 ± 6.4**	**83.2 ± 14.7**	**26.0 ± 2.8**	----	**39.5 ± 10.8**	**5.7 ± 8.3**	----

Methodology

We used the Frimat criterion (Frimat, 1988; Frimat, 1989) to analyze HR because it is preferred for short-duration tasks (Narvaez, 2019). The five Frimat criteria are as follows: 1) mean heart rate (HR_{mean}), 2) maximum heart rate in the recording (HR_{peak}), 3) Absolute Cardiac Cost (ACC) (1), 4) Relative Cardiac Cost (RCC) (2), and 5) cardiac acceleration (ΔHR) (3). Each parameter receives a score from 1 to 6 (Table 3). The five scores are summed to determine a final ranking (Table 4).

Multiple formulas are available in literature for determining HRmax. In this paper, we applied the method proposed by Fox (1971) (220-age).

$$(1)\ ACC = HR_{mean} - HR_{rest};\ (2)\ RCC = ACC/(HR_{max} - HR_{rest}) * 100;$$

$$(3)\ \Delta HR = HR_{peak} - HR_{mean}$$

Table 3: The scoring criteria for each of the five parameters in Frimat's score.

Frimat's Coeffs. Value	Variable Ranges				
	ACC (bpm)	RCC (%)	HRpeak (bpm)	HRmean (bpm)	ΔHR (bpm)
1	10	0.10	110-119	90-94	20-24
2	15	0.15	120-129	95-99	25-29
4	20	0.20	130-139	100-104	30-34
5	25	0.25	140-149	105-109	35-39
6	30	0.30	>150	>110	>40

Table 4: Ranking of an activity according to its Frimat's score.

Frimat's Score Values	Ranking
25	Extremely hard
24	Very hard
22	Hard
20	Distressing
18	Bearable
14	Light
12	Very light
≤10	Minimum workload

RESULTS

Table 5 shows the mean (±SD) values for each parameter measured by the Frimat' score during both loading and unloading tasks. It also shows the mean (±SD) of the final Frimat' score.

The loading task showed higher mean values for the following parameters: ACC (34.8 vs 28.8), RCC (31.3 vs 26.7), HR_{peak} (127.3 vs 125.5), and HR_{mean} (104.3 vs 95.8). By contrast, the unloading task showed a higher mean value only for ΔHR (29.8 vs 23.0). The final Frimat' score was greater in the loading task (16.0 vs 14.8). Nevertheless, as indicated in Table 4, both loading and unloading tasks were ranked as Bearable.

Table 5: Mean (±SD), minimum, and maximum for each of the five Frimat's score parameters and the total score for both tasks.

	Loading			Unloading		
	Mean ± SD	Min	Max	Mean ± SD	Min	Max
ACC	34.8 ± 4.2	28.0	40.0	28.8 ± 1.4	23.0	34.0
RCC	31.3 ± 5.3	23.9	39.6	26.7 ± 4.8	23.0	29.7
HRmax	127.3 ± 11.3	113.0	135.0	125.5 ± 4.2	114.0	132.0
HRmean	104.3 ± 21.2	86.0	116.0	95.8 ± 3.5	92.0	100.0
ΔHR	23.0 ± 9.9	13.0	28.0	29.8 ± 0.7	22.0	34.0
Frimat's score	16.0 ± 4.9	10.0	19.0	14.8 ± 3.5	12.0	18.0

Table 6 presents the Frimat' score and corresponding ranking for each acquisition. The loading task yielded scores ranging from 10, indicating minimum workload, to 19, reflecting a distressing level of workload. Scores for the unloading task ranged from 12, classified as very light, to 18, considered bearable.

Table 6: Frimat' score and ranking per acquisition.

Subject	Task	Frimat' Score	Ranking
1	Loading	17	Light
2	Loading	19	Distressing
3	Unloading	18	Bearable
3	Loading	18	Bearable
4	Unloading	12	Very light
4	Loading	10	Minimum workload
5	Unloading	16	Light
6	Unloading	13	Very light

DISCUSSION AND CONCLUSION

A review by Sammito (2024) suggests analyzing HR data, given the growing use of wearable technologies, to assess workers' occupational efforts. Moon (2024) also confirms that HR monitors can be easily integrated into workplaces to collect workers' physiological data.

Based on these reviews, we examined two non-standardized pushing and braking tasks in an actual scenario where standard ergonomic risk assessment tools are not applicable.

We measured HR and trunk flexion using the Zephyr Bioharness 3.0, a gold-standard HR monitor (Cosoli, 2022).

Kinematic data of trunk flexion were not reported here due to the lack of standardized postures adopted by the workers when pushing or braking ULDs. Workers could execute the task by keeping the back straight and relying on leg strength rather than pushing or braking the ULD with their arms. Workers sometimes also had to manually lock the ULDs to prevent sliding, which could cause trunk flexion over 90°, unrelated to pushing or braking tasks.

HR results indicate that four of the five Frimat's score parameters (ACC, RCC, HRpeak, HRmean) were higher during the uphill loading task compared to the downhill unloading task. This outcome also yields an increased mean overall Frimat's score (16.0 versus 14.8). Nevertheless, the rankings for both mean values of the Frimat's score were assessed as "bearable". For single recordings, Frimat's scores for the loading task ranged from 10 (minimum workload) to 19 (distressing), while the unloading task ranged from 12 (very light) to 18 (bearable). Our findings, like Dell (1997), indicate that UDL is not considered an overloading task when the aircraft's built-in equipment functions properly.

Although we found low levels of Frimat's scores in both loading and unloading, is it possible to improve the task. In informal feedback, workers recommended modifying ULD handles for better coupling during loading and unloading. Figure 3 illustrates the inadequate coupling of the ULD handles observed in this scenario. Additionally, the loading and unloading processes within the aircraft may be mechanized. These operations are not managed by airport facilities, as they are contingent upon the specific aircraft model.

Minimizing manual handling mainly depends on the ACL drivers' skill. Proper placement of ULDs during transfer from ACL to air cargo can significantly reduce manual activity.

There are limitations to the study. We only analyze HR, which can be affected by various factors such as BMI, mental state, fitness level, smoking, and drug use. Nevertheless, HR confirms to be a valuable physiological measure that offers relevant feedback in workplaces where ergonomic risk assessments tools or ISO standards cannot be applied.

A further issue is the small size of the sample. We were unable to include more workers because airports have unique logistical challenges and permitting requirements. The last issue is about the Fox formula that could affect the RCC. This could be true if RCC was the only parameter but, Frimat criterion consider also other four parameters. Based on our experience Frimat method is not affected by how theoretical maximum HR is computed.

Although these limitations, we assessed workers' efforts in an actual scenario, that had not previously been analysed, where no observational ergonomic risk assessment tools can be applied.

HR can now be measured quickly, affordably, and accurately using wearable devices that provide real-time data on workers' physiological status (Papoutsakis, 2022; Moon, 2024; Lee, 2024; Sammito, 2024).

Our findings may help airport health and safety services to reduce musculoskeletal disorders among workers. This leads to a reduction in costs due to the workers losing working days and to the reduction of workers' compensation costs.

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