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Risk of subacromial shoulder disorder in airport baggage handlers: combining duration and intensity of musculoskeletal shoulder loads

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Abstract

Musculoskeletal shoulder-load among baggage handlers measured by combining duration and intensity based on biomechanical and epidemiological information may be a stronger predictor of subacromial shoulder disorders than baggage handler seniority. In 2012, a cohort of baggage handlers employed at Copenhagen Airport in 1990-2012, and a cohort of unskilled otherwise employed men answered a survey. Self-reported information on work tasks during employment in the airport in combination with work task specific biomechanically modelled forces in the shoulder joint was used to estimate shoulder-load. Exposure measures were accumulated shoulder abduction moment, accumulated shoulder compression force, accumulated supraspinatus force, and baggage handler seniority. The outcome was subacromial shoulder disorder registered in the Danish National Patient Register. When analyses were adjusted by all confounders except age, exposure variables showed close to significant associations with subacromial shoulder disorder. Results could not confirm our hypothesis that combined information on work task duration and shoulder load intensity was stronger associated with subacromial shoulder disorder than seniority.
Introduction

Musculoskeletal disorders are one of the leading contributors to the global burden of disease (Vos et al. 2012). This includes shoulder complaints which have a lifetime prevalence of 7% to 67% depending on the case definition (Luime et al. 2004) and have considerable impact on sickness absence, contacts to the health care system and withdrawal from the labor market (van Rijn et al. 2010; Larsson, Sogaard, and Rosendal 2007).

Age, shoulder intensive sport activities, previous shoulder injury and surgery are identified as risk factors for shoulder disorders, pain and complaints, but also work-related factors have been studied. Previous occupational studies have shown that repetitive work (van Rijn et al. 2010; NIOSH 1997; van der Windt et al. 2000; Miranda et al. 2008; Svendsen et al. 2013; Dalboge et al. 2014), shoulder postures with flexion or abduction above shoulder level (van Rijn et al. 2010; NIOSH 1997; Svendsen et al. 2013; Dalboge et al. 2014), awkward postures (NIOSH 1997; van der Windt et al. 2000; van Rijn et al. 2010), forceful exertions (van Rijn et al. 2010), pushing and pulling tasks (Hoozemans et al. 2002) and vibrations (van der Windt et al. 2000; Miranda et al. 2001; Sutinen et al. 2006) are associated with shoulder disorders and complaints. Airport baggage handling is characterized by repetitive work with heavy lifting in awkward postures (Stalhammar et al. 1986; Bern et al. 2013), and a previous study has found an association between baggage handler seniority and risk of subacromial shoulder disorder (Thygesen et al. 2016).

The pathogenic mechanism relating prolonged musculoskeletal shoulder load to subacromial shoulder disorders is unknown, but is often assumed to be due to a combination of duration and intensity of musculoskeletal shoulder load (Frost et al. 2002; Dalboge et al. 2014). Most occupations include a variety of work tasks of different duration and intensity which may change with time. However, only few studies take these aspects into consideration when examining the relation between cumulative exposure and subacromial shoulder disorders (Dalboge et al. 2014; Svendsen, Bonde, et al. 2004; Svendsen, Gelineck, et
al. 2004; Sutinen et al. 2006). Often, cumulative exposure is measured only by occupational seniority (Thygesen et al. 2016; Frost and Andersen 1999; Kaergaard and Andersen 2000). Previous studies that combine information on duration of work tasks with objective measures of musculoskeletal shoulder load have used muscle activity in shoulder-neck muscles measured by electromyography or upper arm positions measured by inclinometers (Svendsen, Bonde, et al. 2004; Svendsen, Gelineck, et al. 2004).

Manual lifting and handling of baggage in airports is associated with a considerable musculoskeletal shoulder load, which may differ between work tasks (Koblauch 2015). The present study includes a historical cohort of baggage handlers in Copenhagen Airport and a reference group of unskilled men working in the greater Copenhagen area. The study examines the incidence of subacromial shoulder disorders among airport baggage handlers in relation to a combined measure of duration and intensity of musculoskeletal shoulder loads. We used retrospective survey information to track typical baggage handling work tasks across calendar years, and a biomechanical computer model to assess shoulder joint forces for each of these work tasks. The model provides detailed information on the 3-dimensional forces acting in the shoulder during dynamic work. We hypothesized that our cumulative measure of shoulder load would have a stronger relation to subacromial shoulder disorders than seniority.

**Methods**

**Cohort**

Our analyses were based on the Copenhagen Airport Cohort which includes unskilled men employed at Copenhagen Airport in addition to men employed at other companies in the Greater Copenhagen area at any time between 1990 and 2012. Information on employment was based on Copenhagen Airport company employment registers and Greater Copenhagen union member registers for unskilled workers. The
Copenhagen Airport Cohort consisted of both a baggage handler sub-cohort of former and present baggage handlers (n=3,473) as well as a reference sub-cohort of unskilled workers without any employment as baggage handlers (n=69,175). We chose a large reference group to get a large variation in unskilled jobs, work loads and other characteristics, and to increase the power to study rare outcomes. Only men were included as there were no women employed as baggage handlers. The Copenhagen Airport Cohort has been described in more detail elsewhere (Møller et al. 2017).

Data collection
Exclusions during the data collection process are illustrated in a flow chart (Fig. 1). In 2012 all baggage handlers (n=3,047) and a stratified random sample of the reference group (n=2,427) were invited to participate in a survey if they met the following criteria: 1) alive on April 2012, 2) permanent residence in Denmark, 3) aged 25-75 years and 4) had not previously requested not to participate in research projects (research protection, an option in the Danish Civil Registration System). In total, 2089 (69%) baggage handlers and 1660 (68%) from the reference group responded. Participants were included as baggage handlers in the analyses only if they were identified as baggage handlers in the electronic registers as well as in the survey. Participants who stated that they had never worked as baggage handlers (329 individuals) were transferred to the reference group.

Due to the complete, nationwide registration of Danish residents and the unique personal identification number (Thygesen et al. 2011), we were able to identify contacts to the secondary health care system in the National Patient Register (Lynge, Sandegaard, and Rebolj 2011) and obtain information on migration in the Civil Registration System (Pedersen 2011). We excluded persons who emigrated before 1994 or were diagnosed with a subacromial shoulder disorder before first employment along baggage handlers who had supplied insufficient information on their work as a baggage handler to estimate musculoskeletal shoulder load. This resulted in a cohort of 1688 men currently or formerly employed as baggage handlers and a reference cohort of 1973 men.
Exposure

Baggage handling work is performed indoors in the baggage sorting area and outdoors on the apron where aircrafts are parked at the gates. Work on the apron consists of work on the ground and work in the aircraft baggage compartment, and baggage handlers usually change between the two work tasks during a work shift (Mikkelsen et al. 2016). Work in the baggage sorting area consists of loading and unloading of baggage to and from baggage carts or containers. Work on the ground on the apron consists of loading and unloading of baggage between baggage carts and belt-loaders. Work in the aircraft baggage compartment consists of stowing or moving stowed baggage to or from belt-loaders in work postures based on baggage handler preferences and the size of the compartment.

Survey

The survey included questions on calendar periods with work in the baggage sorting area, on the apron, or mixed. The respondents with work on the apron were asked to assess if their baggage handling was done equally on the ground and in the aircraft baggage compartment or if they primarily worked in one of these two locations. Baggage handlers working in the aircraft baggage compartment were also asked how often they worked in stooped, sitting, standing, squatting and kneeling work positions (response categories almost never, a small part of the time, half of the time, a large part of the time, almost always). We used this information to assess work task duration for each calendar year, i.e. the percentage of time with work in the baggage sorting area, on the ground on the apron, and in the aircraft baggage compartment by work postures. For these calculations we applied quantitative weights to the ordered qualitative survey information (e.g. the “half of the time” time category was assigned a weight of 50%, “almost always” a weight of 90% etc.).

Biomechanical modeling
To assess shoulder load intensity, we used the AnyBody Modeling System™ (AMS) (Damsgaard et al. 2006). The different baggage handling tasks were modelled in the AMS. The AMS models were based on experimental recordings from one representative currently employed baggage handler. Details of the experimental measurements have previously been described (Koblauch 2015). The AMS is a general modeling system for musculoskeletal models applying inverse dynamics, i.e. muscle activation based on known movement pattern. The geometry of the shoulder joint applied in the current shoulder model of the AMS has previously been described by van der Helm et al. (1992). The model contained 118 muscle fascicles that wrap on the geometrical surfaces of the bones. This increases the validity of the muscles’ moment arm. Five joints (acromioclavicular, glenohumeral, sternoclavicular, and two virtual ellipsoid joints) were included in the model. The virtual ellipsoid joints were included for the definition of the movements between the scapula and thorax.

The AMS shoulder model, used in the present study, has been validated for both joint forces and muscle forces and activity. Rasmussen et al. (2007) validated the model by comparing in vivo data from an instrumented shoulder implant (Bergmann et al. 2007) with the output of the model. The comparison was performed by letting the model perform similar movements as the individual with the instrumented implant. Joint forces were compared and the model’s estimate was within 13 % of the in vivo data. The joint forces were used for the validation as the second best option in the absence of direct muscle force measurements. A more activity-based validation was performed by Dubowsky et al. (2008), where the muscle activity was estimated during propulsion of a wheelchair. The model was based on motion capture and force measurements. The 3D model calculated muscle activities with an average Mean Absolute Error (MAE) of 0.165, which was interpreted as indicating a good quantitative correlation. This is in agreement with previously reported MAE from other validation studies (de Zee et al. 2007).

The AMS models were used to assess the shoulder load intensity for loading and unloading of baggage carts in the baggage sorting area, loading and unloading of baggage carts on the apron, and work in the aircraft
baggage compartment in a stooped, sitting, squatting and kneeling work posture with or without using an extending belt loader. The included baggage handler had 16 years seniority as baggage handler and matched the average age, weight, and height of the baggage handlers, obtained from the survey data, i.e., 48 years, 87 kg, and 1.81 m. Input to the model was kinematic data recorded with a custom-built motion capture system of eight synchronized high-speed HD cameras (GZL-CL-41C6M-C, Gazelle, Point Grey, Richmond, Canada). The recordings took place in a laboratory setting using a full body luminous marker setup of 37 luminous markers (custom-made markers of battery-powered mini LED lights) with a diameter of 5 mm and three markers placed on the suitcase. The force input to the models was the ground reaction force measured with floor-embedded force plates (AMTI OR 6-7, Watertown, MA, USA). Signals from the force platforms were sampled at 1000 Hz and synchronized with the cameras. Video data were digitized and three-dimensional coordinates calculated using the Ariel Performance Analysis System (Ariel Dynamics, San Diego, USA) and the coordinates were subsequently low-pass filtered at 6 Hz.

Inverse dynamics-based musculoskeletal models of the tasks were built in the AnyBody Modeling system v. 5.3 (AnyBody Technology A/S, Aalborg, Denmark). The models were modifications of the GaitFullBody model available from the AnyBody Managed Model Repository v. 1.5 (20) and were scaled to match the bodily measures of the subject through optimization using the method of Andersen et al.

For each work task we calculated for a representative work cycle the time course of the shoulder joint abduction moment (Newton-meter (Nm)), defined as the net moment in the abduction direction; the shoulder joint compression force, defined as the force (N) with which the humerus acts on the glenoid cavity; and the supraspinatus force (N), defined as the sum of forces in the different parts of the supraspinatus muscle. A representative work cycle consisted of the baggage handler performing handling tasks in a setup designed based on observations of baggage handlers in Copenhagen Airport. The baggage
handler confirmed that the tasks were representative of work cycles in the airport before recording was initiated.

For all variables the forces and moments were calculated with an inverse dynamics method (Anyscript Community 2013). The experimentally recorded marker trajectories were subjected to an optimization procedure as described by Andersen et al. (Andersen, Damsgaard, and Rasmussen 2009) and these signals together with the output from the ground reaction force plates were used to drive the musculoskeletal models. The models computed the shoulder joint abduction moment and joint contact forces (compressive and shear forces). All segment coordinate systems were in accordance with the standards from the International Society of Biomechanics (van der Helm 1997). These results have been described in more detail elsewhere (Koblauch 2015). The 90th percentile was calculated over the complete time course of the work task. Thus, the 90th percentile represents the near-maximal load throughout the task.

**Combining survey and biomechanical data**

We combined the survey derived information on work task percentage times with the AMS information on musculoskeletal shoulder load, i.e. combined work task duration with shoulder load intensity for the corresponding work tasks. We calculated four different time and load weighted exposure measures: three measures using the work task median value across a work cycle of 1) the shoulder abduction moment, 2) the shoulder compression force, and 3) the supraspinatus force, and one measure using the 90th percentile value of the supraspinatus force as weights to the corresponding work task time proportion. All measures were based on shoulder load intensity on the right arm during a work cycle with a 15-kg work load.

The overall musculoskeletal shoulder load for each of the four exposure modalities was then calculated as the sum of the exposure weighted work task proportions for each calendar year. We accumulated these exposure estimates over years of employment as baggage handler from the first year of employment and taking into consideration any interruptions in employment. The exposure was thus a combination of the
accumulated years of employment as baggage handler, the self-reported information on work tasks performed each year, and AMS quantification of musculoskeletal shoulder load for each task. Work tasks in the baggage sorting area were defined as the mean of loading and unloading baggage carts and loading and unloading baggage containers. Work tasks on the apron on the ground were defined as the mean of loading and unloading baggage carts. Work tasks on the apron in the aircraft baggage compartment were defined depending on baggage handlers’ self-reported preference for working positions.

Fig. 2 illustrates the process of combining AMS information on shoulder joint compression force with information on work task percentage times to assess the accumulated shoulder joint compression force during an example of three years of employment.

**Outcome**

The outcome of the study was diagnosis or surgical treatment of subacromial shoulder disorder, identified through linkage of the cohort with the National Patient Register including all contacts to the secondary health care system (Lynge, Sandegaard, and Rebolj 2011). We only included diagnoses in the International Classification of Diseases version 10 (ICD-10) used from 1994, since subacromial shoulder disorders were not a diagnostic entity before 1994. We included the following primary diagnoses: rotator cuff syndrome, bicipital tendinitis, calcific tendinitis of the shoulder, impingement syndrome of shoulder, bursitis of shoulder, other shoulder lesions, and unspecified shoulder lesion (ICD-10 codes: M75.1, M75.2, M75.3, M75.4, M75.5, M75.8, and M75.9). For surgical treatment we only included procedures classified by the NOMESCO classification used from 1996 (Nordic Medico-Statistical Committee 2011), since surgical procedures for subacromial shoulder disorders were not an entity in coding of surgical procedures before 1996. We included the following surgeries: exploratory procedures on the shoulder, surgeries on capsules and ligaments of joints of the shoulder, humeroscapular arthroplasty, excision of osteophyte of humeroscapular joint, suture of tendon of the shoulder, and excision of bursa of the shoulder (NOMESCO codes:
Confounders

To decide which confounders to include in our analyses, we developed a directed acyclic graph (DAG) by which we defined the minimum sufficient adjustment set (Greenland, Pearl, and Robins 1999; Shrier and Platt 2008). This DAG included age, sex, calendar year, educational level, pre-employment shoulder injury, shoulder intensive sport activities, use of lifting equipment, and use of extending belt loaders in the aircraft baggage compartments. We had information on all confounders except shoulder intensive sport activities. Educational level and age were included as categorical variables and calendar year was included as a continuous variable. Information on pre-employment shoulder injury was obtained from registered contacts in the National Patient Register with the following diagnoses: fracture of the shoulder; dislocation, sprain and strain of joints and ligaments of the shoulder girdle; and injury of muscle and tendon at the shoulder (ICD-8 codes from 1977-1993: 810, 840, and 905; ICD-10 codes from 1994 onwards: S42, S43, and S46). Lifting equipment in the baggage sorting area (from 1998) was included as a binary covariate for baggage handlers working in the baggage sorting area from this year. Extending belt loaders were introduced in the aircraft baggage compartments from 2004. To take this into account, we applied estimations of musculoskeletal shoulder load both with and without using the extending belt loader. Musculoskeletal shoulder load in the different work positions was thus estimated as a weighted mean of estimations with and without using the extending belt loader for baggage handlers working in the aircraft baggage compartment after 2004.

Statistical analyses
The cohort was followed from start of employment, January 1994, or immigration after employment, whichever came last. Follow-up ended at first diagnosis or surgical procedures for subacromial shoulder disorders, emigration, death, or end of follow-up (31 December 2012), whichever came first.

We categorized the four exposure variables (accumulated median shoulder abduction moment, accumulated median shoulder compression force, accumulated median supraspinatus force and 90th percentile supraspinatus force) into low, medium and high loads based on tertiles obtained from the distribution of each measure in the study population.

The association between musculoskeletal shoulder load and diagnosis or surgical treatment of subacromial shoulder disorder was estimated applying accumulated median shoulder abduction moment, accumulated median shoulder compression force, accumulated median supraspinatus force and accumulated 90th percentile supraspinatus force as estimates of musculoskeletal shoulder load. Associations were estimated through Cox regression analyses with accumulated musculoskeletal shoulder load as the exposure and subacromial shoulder disorder as the outcome. The four measures of musculoskeletal load were included in four different regression models. Statistical significance of the exposure variables was tested with Type 3 Wald-tests. As our hypothesis was that musculoskeletal shoulder load had a stronger association with subacromial shoulder disorder than seniority, we also included a regression model estimating the association between seniority and subacromial shoulder disorder. Seniority was defined as the number of years employed as baggage handler in Copenhagen Airport.

We performed both unadjusted and adjusted analyses including the identified confounders; age, sex, calendar year, educational level, pre-employment shoulder injury, and use of lifting equipment. To address the collinearity between age and our exposure measures, we included additional analyses that were adjusted by all confounders except age.

To assess if associations were sensitive to the choice of measure for musculoskeletal shoulder load, we made sensitivity analyses with two additional measures, i.e. musculoskeletal shoulder load estimated by
accumulated 90th percentile shoulder abduction moment and accumulated 90th percentile shoulder compression force. Data were analyzed using Cox regression in SAS version 9.3 (SAS Institute Inc, Cary, North Carolina, USA).

Results

Baggage handlers were slightly younger than the reference group at start of follow-up (Table 1), and χ²-tests indicated differences in distribution of educational level, BMI, smoking and physical activity between the two groups.

Exposure contrast between the three work tasks (baggage sorting hall, on the apron on the ground, and on the apron in the aircraft baggage compartment) is presented in Table 2. For all measures the majority of exposure contrast was found between different work positions in the aircraft baggage compartment.

The overall number of cases was 135 with 64 among non-baggage handlers and 71 among baggage handlers. The unadjusted analyses showed that the incidence of subacromial shoulder disorder was highest for exposure to the highest category of accumulated median shoulder abduction moment, accumulated median shoulder compression force, accumulated median supraspinatus force and accumulated 90th percentile supraspinatus force (Table 3). The incidence was significantly increased for the highest category of musculoskeletal shoulder load variables (e.g. accumulated median abduction moment (hazard ratio (HR)=1.93; 95%CI: 1.09-3.40)) with no large variations in HR’s between different estimations of exposure.

Exposure to the medium category of musculoskeletal shoulder load variables was not associated with an increased incidence compared to exposure to the lowest category. The incidence for non-baggage handlers was similar to that of the lowest exposure groups, indicating that baggage handlers with low exposure are an appropriate reference group as they have a similar risk as non-baggage handlers. When adjusting the analyses for age, educational level, calendar year, pre-employment shoulder injury and use of lifting
equipment, there were no statistically significant associations between musculoskeletal shoulder load variables and subacromial shoulder disorder. However, as age was closely correlated with all exposure variables (Pearson’s correlation coefficient between 0.60 and 0.63) we also made adjusted analyses not including age as a confounder. These showed that accumulated median shoulder abduction moment, accumulated median shoulder compression force, and accumulated 90th percentile supraspinatus force were close to significant (Table 3 - Adjusted2). Seniority was generally associated with subacromial shoulder disorder in a similar manner as the different measures of musculoskeletal load (Table 3).

Sensitivity analyses showed that results on exposure to accumulated 90th percentile shoulder abduction moment and accumulated 90th percentile shoulder compression force were similar to those presented in Table 3 (Table 4).

Discussion

We found that all estimates of musculoskeletal shoulder load were associated with an increased risk of subacromial shoulder disorders. None of these associations persisted after adjustment for potential confounders including age. When age was excluded from the adjusted models, all exposure variables except one had a close to significant association with risk of subacromial shoulder disorder. The results on musculoskeletal load did not differ from those on seniority. Therefore, the results could not confirm our initial hypothesis that the biomechanically estimated musculoskeletal shoulder load, including information on both work task duration and shoulder load intensity, was stronger associated with subacromial shoulder disorder than baggage handler seniority.

Baggage handling as a risk factor

Previous studies on baggage handlers have found 1-year prevalence of shoulder complaints from 25-60% (Bergsten, Mathiassen, and Vingard 2015; Bern et al. 2013; Stalhammar et al. 1986) and possible
prevention strategies to reduce this are therefore desirable. Numerous studies have shown associations between work-related factors and shoulder disorders or pain and complaints in the shoulders (Miranda et al. 2008; NIOSH 1997; van Rijn et al. 2010; Dalboge et al. 2014; Svendsen et al. 2013), including factors that are characteristic for a baggage handler’s working day (Bern et al. 2013). Seniority as baggage handler has also been shown to be associated with increased risk of subacromial shoulder disorder (Thygesen et al. 2016). The present results confirm that baggage handling is associated with increased risk of subacromial shoulder disorder, and AMS findings also indicated that musculoskeletal load differed between work tasks in the airport. This indicates that baggage handling is characterized by work increasing the risk of subacromial shoulder disorder, and that some aspects of baggage handling resulted in musculoskeletal shoulder load than others. This has also been reported in studies on baggage handlers and on miners also working in constrained spaces which have shown that the baggage handlers experience excessive strain during manual handling of baggage (Ruckert, Rohmert, and Pressel 1992), and that asymmetrical lifting tasks in limited work space may also be associated with increased spinal loading. (Gallagher et al. 1994). Biomechanical analyses have shown differences in lateral force peaks between sitting, squatting and kneeling in the aircraft baggage compartment (Stalhammar et al. 1986). A previous study also found that baggage handlers in the baggage sorting area spent less time with the arm >90° and had lower peak exposure than baggage handlers on the apron (Wahlstrom et al. 2016), which corresponds with our finding that baggage handlers in the baggage sorting area have the lowest musculoskeletal load on most exposure measures (Table 2). The present results along with previous findings indicate differences in musculoskeletal load between different work tasks in the airport suggesting that shifts between work tasks may be a strategy to reduce accumulated musculoskeletal load among baggage handlers.

**Combining duration with intensity of musculoskeletal shoulder load**

We found that our estimations of musculoskeletal shoulder load were associated with risk of incident subacromial shoulder disorder but our analyses did not indicate that they were stronger associated than
seniority. As we believe that both duration and intensity of musculoskeletal load contributes to baggage handlers’ risk of subacromial shoulder disorder, we propose three possible explanations to this finding: 1) Our population may not have sufficient exposure contrast. Insufficient exposure data is a common obstacle in identifying associations between exposure and disorders (Liv, Mathiassen, and Svendsen 2011). As indicated by the results in Table 2, exposure to musculoskeletal shoulder load differed between work tasks and the majority of the contrast came from differences in preferred work positions in the aircraft baggage compartment. The contrasts were weakened because less than 10% had worked in the aircraft baggage compartment for more than 50% of a work year, only 187 (11%) of the baggage handlers had exclusively worked in the baggage sorting area during their employment, and none had exclusively worked in the aircraft baggage compartment or on the ground on the apron. As such, the variation in musculoskeletal shoulder load between baggage handlers is not substantial. Thus, seniority explains the observed accumulated musculoskeletal shoulder load between individual baggage handlers. This is supported by a high correlation between seniority and each of the four musculoskeletal shoulder load variables. 2) It is possible that our choice of modelling of musculoskeletal shoulder load may not have been ideal. We took this into consideration by applying four modelling approaches including both median and 90th percentile values and by additional analyses including 90th percentile abduction moment and compression force. 3) It is possible that even though accumulated musculoskeletal shoulder load is an important aspect in the development of subacromial shoulder disorder, acute load should also be included to assess the association between musculoskeletal load and subacromial shoulder disorder.

Applying AMS results

The study design of using one representative baggage handler to build the dynamical computer models may be criticized. However, averaging the movement pattern of, e.g., ten persons would probably not result in a movement pattern that was more representative of the movement pattern of baggage handlers in the airport, and the added value of this procedure would therefore be questionable. Moreover, specific
muscle strength of the persons would be unknown, as this would require scanning and reconstruction of
individual muscle volumes and physiological cross sectional areas in each person. Such an approach is
currently unrealistic. These considerations are a common issue within computer simulation of human
movement and we decided that a model based on one representative person was the best approach in the
present study. However, even if the measured work task specific loads are representative, the within work
task variation may still be larger than the between work task variation, resulting in load misclassification at
the individual level when representative within task loads are attributed to the individual person. This
problem, however, is not specifically related to computer simulated load assessment.

**Strengths and limitations**

Main strengths of our study are utilization of detailed self-reported information on employment
characteristics in combination with biomechanical estimations of the musculoskeletal shoulder load during
typical baggage handling working tasks. Our exposure, musculoskeletal shoulder load, is therefore closely
related to the actual work tasks that the individual baggage handlers have performed during their years of
employment. Another strength of our study is the availability of information on all confounders identified
using DAG methodology except for shoulder intensive sport activities. Also, we utilized a reference group
consisting of unskilled workers, which according to our data, showed a high degree of comparability with
the group of baggage handlers. Finally, we included an objective outcome of diagnoses and surgical
treatment registered in the Danish National Patient Register. Limitations of our study include the lack of
information on shoulder intensive sport activities which was identified as a confounder through DAG
methodology. The results may, therefore, be confounded if baggage handlers are more or less likely to do
shoulder intensive sport activities than the reference population. This would, however, only influence the
HR’s for the reference population. Furthermore, our definition of outcome probably included the most
severe cases of subacromial shoulder disorder restricted to only 135 cases of incident subacromial shoulder
disorder, which could influence the statistical power of the study. Finally, the chosen approach including only one individual in biomechanical estimations may be criticized.

In contrast to our hypothesis, biomechanically estimated shoulder load, which included information on both work task duration as well as shoulder load intensity, did not show a stronger association with subacromial shoulder disorders than seniority of baggage handlers. Exposure contrast was mostly due to a contrast in duration of shoulder loads whereas the contrast in intensity of shoulder loads was less pronounced. Future research exploring associations between musculoskeletal disorders and measures combining duration and intensity of musculoskeletal loads would benefit from study populations with greater exposure contrast in both duration and intensity of shoulder loads. Such study populations could also be utilised for study questions addressing the relative importance of acute and accumulated musculoskeletal loads in musculoskeletal disorders.

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Table 1: Participant characteristics of baggage handlers and non-baggage handlers in 2012, Copenhagen Airport Cohort

<table>
<thead>
<tr>
<th></th>
<th>Baggage handlers</th>
<th>Non-baggage handlers</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>1688</td>
<td>1973</td>
<td></td>
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**Register-based factors**

**Age**
- Median (Q1-Q3): 31 (25-36) vs. 34 (26-40), <0.001 (Wilcoxon Rank Sum test)
- Age distribution:
  - <30, n (%): 800 (47) vs. 753 (38), <0.001 ($\chi^2$-test)
  - 30-44, n (%): 759 (45) vs. 899 (46)
  - 45-59, n (%): 129 (8) vs. 313 (16)
  - ≥60, n (%): 0 (0) vs. 8 (0)

**Educational level**
- Elementary school, n (%): 691 (41) vs. 884 (45), <0.01 ($\chi^2$-test)
- High school, n (%): 232 (14) vs. 284 (14)
- Vocational education, n (%): 676 (40) vs. 675 (34)
- Higher education, n (%): 89 (5) vs. 130 (7)

**Shoulder lesion or injury before employment, n (%):**
- 30 (2) vs. 33 (2), 0.81 ($\chi^2$-test)

**Self-reported factors**

**Body mass index**
- <18.5, n (%): 1 (0) vs. 9 (0), <0.001 ($\chi^2$-test)
- 18.5-24.9, n (%): 611 (36) vs. 661 (34)
- 25.0-29.9, n (%): 812 (48) vs. 897 (45)
- ≥30.0, n (%): 249 (15) vs. 368 (19)

**Smoking**
- Never, n (%): 653 (39) vs. 661 (34), <0.01 ($\chi^2$-test)
- Past, n (%): 559 (33) vs. 702 (36)
- Current, n (%): 466 (28) vs. 595 (30)

**Physical activity**
- Sedentary, n (%): 164 (10) vs. 260 (13), <0.001 ($\chi^2$-test)
- Low, n (%): 577 (34) vs. 714 (36)
- Medium, n (%): 680 (40) vs. 705 (36)
- High, n (%): 248 (15) vs. 268 (14)

**Have you used lifting equipment**
- Never or almost never, n (%): 360 (21)
- Less than half of the time, n (%): 453 (27)
- Half of the time or more, n (%): 424 (25)

1 Information on use of lifting equipment was only collected among baggage handlers.
Table 2: Exposure contrast between the three work tasks: baggage sorting area, on the apron on the ground, on the ground in the aircraft baggage compartment. Exposure estimates are based on AnyBody Modeling System™ measurements of the median or 90th percentile musculoskeletal shoulder load of the right arm during a representative work cycle with a 15-kg work load.

<table>
<thead>
<tr>
<th>Task</th>
<th>Abduction moment</th>
<th>Compression force</th>
<th>Supraspinatus force</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median (p10-p90)</td>
<td>Median (p10-p90)</td>
<td>90th percentile (p10-p90)</td>
</tr>
<tr>
<td><strong>Baggage sorting area</strong></td>
<td>16.7 Nm (4-43)</td>
<td>1125 N (599-2220)</td>
<td>65 N (4-211)</td>
</tr>
<tr>
<td></td>
<td>21 Nm (10-62)</td>
<td>1006 N (501-2996)</td>
<td>70 N (0-281)</td>
</tr>
<tr>
<td></td>
<td>12 Nm (1-43)</td>
<td>1356 N (571-2308)</td>
<td>74 N (5-205)</td>
</tr>
<tr>
<td></td>
<td>17 Nm (2-23)</td>
<td>1013 N (726-1357)</td>
<td>51 N (6-147)</td>
</tr>
<tr>
<td><strong>On the apron on the ground</strong></td>
<td>21 Nm (10-62)</td>
<td>1006 N (501-2996)</td>
<td>70 N (0-281)</td>
</tr>
<tr>
<td><strong>On the apron in the aircraft baggage compartment before 2004</strong></td>
<td>6 Nm (1-28)</td>
<td>1524 N (905-2322)</td>
<td>64 N (15-177)</td>
</tr>
<tr>
<td></td>
<td>10 Nm (2-31)</td>
<td>1063 N (520-1677)</td>
<td>106 N (4-131)</td>
</tr>
<tr>
<td></td>
<td>20 Nm (12-44)</td>
<td>1700 N (1290-2660)</td>
<td>79 N (44-131)</td>
</tr>
<tr>
<td></td>
<td>8 Nm (2-21)</td>
<td>1372 N (683-1935)</td>
<td>25 N (1-57)</td>
</tr>
<tr>
<td></td>
<td>24 Nm (2-35)</td>
<td>2545 N (1127-4428)</td>
<td>34 N (0-323)</td>
</tr>
<tr>
<td><strong>On the apron in the aircraft baggage compartment after 2003</strong></td>
<td>4.5 Nm (1-19)</td>
<td>1096.5 N (536-1589.25)</td>
<td>22.75 N (3.75-81)</td>
</tr>
<tr>
<td></td>
<td>8.5 Nm (1.25-25.75)</td>
<td>712.75 N (410.5-1465.5)</td>
<td>43.75 N (1-112.25)</td>
</tr>
<tr>
<td></td>
<td>13.25 Nm (4.25-36.75)</td>
<td>1012.75 N (446-1879.5)</td>
<td>25 N (1-57)</td>
</tr>
<tr>
<td></td>
<td>18.75 Nm (4.25-53)</td>
<td>1515.25 N (834.5-3112.5)</td>
<td>12.25 N (0-119.75)</td>
</tr>
</tbody>
</table>

1Mean of loading/unloading baggage carts, loading baggage containers, and unloading baggage containers.  
2Loading/unloading baggage carts.  
3No extending belt loader.  
4Extending belt loader available. Values are weighted mean of use of extending belt loader (75%) and no use of extending belt loader (25%). Sitting was not feasible when using extending belt loader.
Table 3: Association between musculoskeletal load and subacromial shoulder disorders, Copenhagen Airport Cohort, 1994-2012

<table>
<thead>
<tr>
<th>Cases</th>
<th>Person-years</th>
<th>IR</th>
<th>HR (unadjusted)</th>
<th>HR (adjusted1)</th>
<th>HR (adjusted2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accumulated median abduction moment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-baggage handlers</td>
<td>64</td>
<td>27041</td>
<td>237</td>
<td>1.01 [0.60;1.71]</td>
<td>0.79 [0.45;1.38]</td>
</tr>
<tr>
<td>Lowest (&lt; 80 Nm)</td>
<td>18</td>
<td>7750</td>
<td>232</td>
<td>1.00 (ref)</td>
<td>1.00 (ref)</td>
</tr>
<tr>
<td>Medium (80-213 Nm)</td>
<td>18</td>
<td>7981</td>
<td>226</td>
<td>0.97 [0.50;1.86]</td>
<td>0.79 [0.41;1.54]</td>
</tr>
<tr>
<td>Highest (&gt; 213 Nm)</td>
<td>35</td>
<td>7730</td>
<td>453</td>
<td>1.93 [1.09;3.40]</td>
<td>1.20 [0.65;2.24]</td>
</tr>
<tr>
<td><strong>P-value (Type 3 Wald-test)</strong></td>
<td></td>
<td></td>
<td></td>
<td>0.01</td>
<td>0.25</td>
</tr>
</tbody>
</table>

| **Accumulated median compression force** | | | | | | |
| Non-baggage handlers | 64 | 27041 | 237 | 1.02 [0.60;1.71] | 0.79 [0.45;1.38] | 1.01 [0.59;1.73] |
| Lowest (< 5531 N) | 18 | 7742 | 232 | 1.00 (ref) | 1.00 (ref) | 1.00 (ref) |
| Medium (5531-14624 N) | 18 | 7949 | 226 | 0.97 [0.51;1.87] | 0.80 [0.41;1.55] | 0.93 [0.48;1.78] |
| Highest (>14624 N) | 35 | 7770 | 450 | 1.93 [1.09;3.40] | 1.20 [0.65;2.24] | 1.72 [0.97;3.07] |
| **P-value (Type 3 Wald-test)** | | | | 0.01 | 0.26 | 0.06 |

| **Accumulated median supraspinatus force** | | | | | | |
| Non-baggage handlers | 64 | 27041 | 237 | 0.96 [0.57;1.60] | 0.73 [0.42;1.27] | 0.95 [0.56;1.61] |
| Lowest (< 266 N) | 19 | 7723 | 246 | 1.00 (ref) | 1.00 (ref) | 1.00 (ref) |
| Medium (266-725 N) | 19 | 8005 | 237 | 0.96 [0.51;1.82] | 0.78 [0.41;1.55] | 0.91 [0.48;1.73] |
| Highest (>725 N) | 33 | 7733 | 427 | 1.72 [0.98;3.03] | 1.05 [0.56;1.99] | 1.53 [0.86;2.72] |
| **P-value (Type 3 Wald-test)** | | | | 0.04 | 0.37 | 0.16 |

| **Accumulated 90th percentile supraspinatus force** | | | | | | |
| Non-baggage handlers | 64 | 27041 | 237 | 1.07 [0.63;1.83] | 0.83 [0.47;1.46] | 1.06 [0.61;1.83] |
| Lowest (< 874 N) | 17 | 7736 | 220 | 1 (ref) | 1 (ref) | 1 (ref) |
| Medium (874-2357 N) | 19 | 7982 | 238 | 1.08 [0.56;2.08] | 0.85 [0.44;1.66] | 1.03 [0.54;1.99] |
| Highest (>2357 N) | 35 | 7743 | 452 | 2.04 [1.14;3.64] | 1.25 [0.67;2.34] | 1.82 [1.01;3.28] |
| **P-value (Type 3 Wald-test)** | | | | 0.01 | 0.31 | 0.06 |

| **Seniority as baggage handler** | | | | | | |
| Non-baggage handlers | 64 | 27041 | 237 | 0.98 [0.58;1.65] | 0.75 [0.43;1.32] | 0.97 [0.57;1.67] |
| Lowest (0-4 years) | 18 | 7490 | 240 | 1.00 (ref) | 1.00 (ref) | 1.00 (ref) |
| Medium (5-12 years) | 19 | 8357 | 227 | 0.94 [0.50;1.80] | 0.77 [0.40;1.48] | 0.90 [0.47;1.72] |
| Highest (> 13 years) | 34 | 7614 | 447 | 1.84 [1.04;3.25] | 1.13 [0.60;2.11] | 1.64 [0.92;2.93] |
| **P-value (Type 3 Wald-test)** | | | | 0.02 | 0.29 | 0.08 |

IR: incidence rate per 100,000 person-years; HR: hazard ratio. Adjusted1: adjusted for confounders (age, educational level, calendar year, pre-employment shoulder injury and use of lifting equipment). Adjusted2: adjusted as 1 with the exception of age.
Table 4: Results of sensitivity analyses testing associations between additional measures of musculoskeletal load and subacromial shoulder disorders, Copenhagen Airport Cohort, 1994-2012

<table>
<thead>
<tr>
<th></th>
<th>Cases</th>
<th>Person-years</th>
<th>IR</th>
<th>HR (unadjusted)</th>
<th>HR (adjusted1)</th>
<th>HR (adjusted2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accumulated 90th percentile abduction moment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-baggage handlers</td>
<td>64</td>
<td>27041</td>
<td>237</td>
<td>1.00 [0.59;1.68]</td>
<td>0.77 [0.44;1.34]</td>
<td>1.00 [0.58;1.70]</td>
</tr>
<tr>
<td>Lowest (&lt; 213 Nm)</td>
<td>18</td>
<td>7632</td>
<td>236</td>
<td>1.00 (ref)</td>
<td>1.00 (ref)</td>
<td>1.00 (ref)</td>
</tr>
<tr>
<td>Medium (213-573 Nm)</td>
<td>17</td>
<td>8075</td>
<td>211</td>
<td>0.89 [0.46;1.73]</td>
<td>0.69 [0.35;1.36]</td>
<td>0.85 [0.44;1.65]</td>
</tr>
<tr>
<td>Highest (&gt;573 Nm)</td>
<td>36</td>
<td>7754</td>
<td>464</td>
<td>1.94 [1.10;3.41]</td>
<td>1.19 [0.64;2.19]</td>
<td>1.73 [0.97;3.09]</td>
</tr>
<tr>
<td><strong>P-value (Type 3 Wald-test)</strong></td>
<td>0.01</td>
<td></td>
<td></td>
<td>0.16</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td><strong>Accumulated 90th percentile compression force</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-baggage handlers</td>
<td>64</td>
<td>27041</td>
<td>237</td>
<td>1.07 [0.63;1.83]</td>
<td>0.83 [0.47;1.47]</td>
<td>1.08 [0.62;1.87]</td>
</tr>
<tr>
<td>Lowest (&lt; 11,512 N)</td>
<td>17</td>
<td>7740</td>
<td>220</td>
<td>1 (ref)</td>
<td>1 (ref)</td>
<td>1 (ref)</td>
</tr>
<tr>
<td>Medium (11,512-31,178 N)</td>
<td>20</td>
<td>7979</td>
<td>251</td>
<td>1.14 [0.60;2.18]</td>
<td>0.90 [0.47;1.73]</td>
<td>1.09 [0.57;2.08]</td>
</tr>
<tr>
<td>Highest (&gt;31,178 N)</td>
<td>34</td>
<td>7742</td>
<td>439</td>
<td>1.98 [1.11;3.54]</td>
<td>1.22 [0.65;2.28]</td>
<td>1.78 [0.98;3.21]</td>
</tr>
<tr>
<td><strong>P-value (Type 3 Wald-test)</strong></td>
<td>0.02</td>
<td></td>
<td></td>
<td>0.40</td>
<td>0.10</td>
<td></td>
</tr>
</tbody>
</table>

IR: incidence rate per 100,000 person-years; HR: hazard ratio. Adjusted1: adjusted for confounders (age, educational level, calendar year, pre-employment shoulder injury and use of lifting equipment). Adjusted2: adjusted as 1 with the exception of age.
Copenhagen Airport Cohort
N=69,175

Baggage handlers
N=3,473

Reference group
N=65,702

Baggage handlers meeting criteria
N=3,047

Random sample of references
N=2,427

Baggage handler respondents
N=2,089

Reference group respondents
N=3,660

Baggage handlers transferred to reference group
N=329

Baggage handlers
N=1,760

References
N=1,989

Diagnosed before employment or insufficient information on work exposure from baggage handlers
N=88

References not included in survey and baggage handlers not alive April 2012, no permanent residence in Denmark, not aged 25-75 years, or had requested research protection.

N=63,701

Non-respondents
N=1,725 (31.5%)
**Fig 2:** Example of the process of combining Anybody Modelling System information on shoulder joint compression force with information on work task percentage time to assess accumulated shoulder joint compression force during a three year employment in the airport.

<table>
<thead>
<tr>
<th>Employment Year</th>
<th>Questionnaire Information on Work Task Percentage Times</th>
<th>AMS Information on Work Task Specific Median Shoulder Joint Compression Forces</th>
<th>Questionnaire Information and AMS Information Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>100% in baggage sorting area</td>
<td>Baggage sorting area median value = 1125 N</td>
<td>1.0 x 1125 N</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 2</td>
<td>50% in baggage sorting area</td>
<td>Baggage sorting area median value = 1125 N</td>
<td>0.5 x 1125 N</td>
</tr>
<tr>
<td></td>
<td>25% on ground on apron</td>
<td>On ground on apron median value = 1006 N</td>
<td>+ 0.25 x 1006 N</td>
</tr>
<tr>
<td></td>
<td>15% in baggage compartment in kneeling position</td>
<td>Kneeling in baggage compartment median value = 1372 N</td>
<td>+ 0.15 x 1372 N</td>
</tr>
<tr>
<td></td>
<td>10% in baggage compartment in sitting position</td>
<td>Sitting in baggage compartment median value = 1700 N</td>
<td>+ 0.1 x 1700 N</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 1109.0 N</td>
</tr>
<tr>
<td>Year 3</td>
<td>25% in baggage sorting area</td>
<td>Baggage sorting area median value = 1125 N</td>
<td>0.25 x 1125 N</td>
</tr>
<tr>
<td></td>
<td>25% on ground on apron</td>
<td>On ground on apron median value = 1006 N</td>
<td>+ 0.25 x 1006 N</td>
</tr>
<tr>
<td></td>
<td>30% in baggage compartment in kneeling position</td>
<td>Kneeling in baggage compartment median value = 1372 N</td>
<td>+ 0.3 x 1372 N</td>
</tr>
<tr>
<td></td>
<td>10% in baggage compartment in sitting position</td>
<td>Sitting in baggage compartment median value = 1700 N</td>
<td>+ 0.1 x 1700 N</td>
</tr>
<tr>
<td></td>
<td>10% in baggage compartment in stooped position</td>
<td>Stooping in baggage compartment median value = 1065 N</td>
<td>+ 0.1 x 1065 N</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 1220.65 N</td>
</tr>
</tbody>
</table>

Accumulated shoulder joint compression force = 3535.45 N