Characteristics of physical exposure when undocking a half-size trolley from a flight galley

A comparison of undocking a half-size trolley with and without a directional lock mechanism on the wheels

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ABSTRACT

Objective: In the aviation industry, numerous physically strenuous job tasks are included in the job as a flight attendant causing a significant risk of musculoskeletal injury during their workday. Handling of the service trolley in particular is reported to be a key factor in regards to on-board injuries. Among reported strenuous job tasks is pushing and pulling the trolley to reposition in the galley. In addition, limited space often results in the wheels of the trolley interlocking with the galley (jamming), when pulling the trolley out from the galley (undocking), further complicating this job task. Therefore, a directional lock mechanism, which eliminates jamming, could easen the task of undocking.
This study ergonomically assessed the physical exposure when undocking a half-size trolley with and without a directional lock on the wheels. This was performed by evaluating the magnitude of the joint reaction force on the lumbar spine (L4/L5), the magnitude of the hand force when undocking the trolley, the duration spent with a flexion of the trunk which was categorised as an awkward working position as well as the frequency of the occurrence of jamming with no directional lock.
Method: The kinematic data required to assess the magnitude of the joint reaction force on L4/L5 as well as the duration of an awkward working position was obtained with the use of inertial sensor-based motion capture (Xsens MTw Awinda). To estimate the magnitude of the joint reaction force on L4/L5, the kinematic data, along with kinetic data obtained with the use of a force dynamometer (AMTI FS-6), were processed in AnyBody Modelling System. Furthermore, the kinetic data were used to address the magnitude of the hand force when undocking the trolley. The frequency of jamming was counted manually. The tests were performed in a lab with the subjects undocking the trolley 25 times with a directional lock (DL) and with no directional lock (NDL) while pulling at the force dynamometer attached to the handle of the trolley. To address the frequency of jamming, the tests included undocking the trolley 25 additional times without the force dynamometer, amounting to an undocking of the trolley 75 times in total. Thereto, to determine any potential significant differences, the two conditions were statistically analysed.
Results: The results failed to show a significant difference between the joint reaction force on L4/L5 with an anteroposterior shear force of 4.44 N/kg (.56 (SD)) and 4.87 N/kg (.30), mediolateral shear force of 0.56 N/kg (.15) and 0.48 N/kg (.32), and compression force of 19.59 N/kg (2.66) and 20.19 N/kg (1.63) for DL and NDL respectively. Regarding external force, the difference between DL and NDL were significant, with a value of 50.81 N(4.53) and 70.96 N (4.29) for DL and NDL respectively. Furthermore, addressing duration, DL reduced the time spent in an awkward working position significantly compared to NDL with a duration of 88.30 seconds/25 repetitions (17.46) and 203.42 seconds/25 repetitions (35.30) for DL and NDL respectively.
Conclusion: This study suggests that undocking a half-size trolley is not a physically strenuous job task and does not involve noticeable risk in regards to physical exposure. However, implementing a directional lock mechanism on the wheels of the trolley could make the task of undocking more convenient for flight attendants.

Key words: flight attendants – trolley – physical exposure – peak forces – Xsens – AnyBody Modelling System

1. Introduction

Handling of the trolley used in the aviation industry on board air crafts have shown to be a significant risk factor among flight attendants regarding musculoskeletal injuries (Griffiths and Powell, 2012); (Agampodi et al., 2009); (Lee et al., 2006a). In general, flight attendants have a median of 22 days away from work annually per employee due to muscoloskeletal disorders (Bureau of Labor Statistics, U.S.). Furthermore, a study by Mulay et al. (2019) showed that up to 87 % of flight attendants report muscoloskeletal symptoms.
Almost every reported on-board injury have been described to be associated with handling of the trolley (Agampodi et al., 2009). In general handling of the trolley accounts for 12 % of the service time during flight, resulting in highly repetitive work, which can cause severe physical stress, even with no heavy loading involved (Labaj et al., 2019); (Glitsch et al., 2007). The handling comprises of a frequent usage of 150 to 250 trolley movements (e.g. pulling) during a work shift on short- and medium-distance flights. Pulling accounts for 23 % of such movements whose duration is often in range of 4.3 s before coming to a halt (Glitsch et al., 2007). Furthermore, flight attendants report several strenuous work tasks regarding

handling of the trolley including pushing and pulling (Lee et al., 2006a).
Pulling a fully loaded half-size trolley against an inclined surface have been shown to exceed recommended external force limits of 90-110N for pulling, exceeding the recommended limit even at a 0° gradient (Schaub et al., 2007); (Glitsch et al., 2004). In addition, the L5-S1 peak compression forces of pulling a half-size trolley at a 5° gradient was 2700N. This could in some cases exceed the recommended exposure limit (REL) for repetitive work, with compression forces larger than 2200-5400 relative to age, and shear forces larger than 700N being a significant risk factor regarding injuries to the lumbar spine. (Gallagher & Marras, 2012); (Jäger, 2018).
When addressing the job tasks of flight attendants it is also relevant to consider that the mean back flexion during pulling of a half-size trolley ranges between 12°-33° with an interquartile range of 7°-46°. The 95th percentile during pulling showed values above 60° (Glitsch et al., 2007). According to Meyers et al., (2000) back flexion of 30°-70° or trunk twisting of 20°-30° are classified as awkward postures and is categorised as a high risk task when addressing field work jobs. The odds ratio between a back flexion >45° and back disorders is 5.7, and 5.9 for lateral bending >20°, when compared to a neutral working posture (back flexion <20° and lateral bending <20°) (Punnett et al., 1991).
Pulling the trolley out from the galley (undocking) is performed in an even more restricted space than pulling the trolley during serving and is associated with an asymmetrical position including lateral- and forward bending. This can increase the risk of excessive forces applied to the discs of the lumbar spine (Jäger et al., 2013). This is supported by Griffiths & Powell, (2012), who showed that a high proportion of work incapacity due to musculoskeletal injuries for flight attendants is accounted for by constrained postures or repeated effort and movement.

Flight attendants report that undocking of the trolley is a strenuous job task (Lee et al., 2006b). This especially applies for a half-size trolley, which is fully loaded with drinks, weighing up to 60 kg, since the half-size trolley results in higher force components compared to a full-size trolley due to unfavorable stability conditions (Schaub et al., 2007). This is exacerbated in cases where the wheels rotate outwards during undocking, and causes interlocking between the trolley and the galley (jamming), particularly occuring during undocking of the half-size trolley (Appendix 1).

This issue and potential solutions seem highly relevant to investigate, since the overall work performance of flight attendants, as well as their physical and mental well being can be affected by this issue (Appendix 1). A directional lock for the wheels on the trolley would prevent interlocking and thereby potentially improve the working conditions for flight attendants.

1.1. Purpose of this study

The purpose of this study was to determine characteristics of physical exposure (magnitude, repetition, and duration), during undocking of a half-size trolley with a directional lock (DL) and with no directional lock (NDL) on the wheels. An estimation of the joint reaction forces on the lumbar spine (L4/L5) during undocking allowed for assessment of the magnitude of loading and a comparison to REL. In addition, measurements of hand force were compared to recommended external force limits for pulling for additional risk assessment regarding the magnitude of physical exposure. Furthermore, the rate of occurrences of jamming during undocking, represented the frequency of exposure to a potentially risky event. Lastly, the duration of holding an awkward posture as a result of undocking was quantified to determine the duration of this exposure.

1.2. Hypothesis

It was hypothesised that DL would significantly reduce the magnitude of the joint reaction force on L4/L5 and the magnitude of the hand force, as well as the duration spent in an awkward working position, when undocking the trolley from the galley, compared to NDL.

2. Method

2.1. Subjects

This study included 8 male participants, trained to handle jamming during undocking, who had a mean age of 27.63 years (6.35 (SD) 23-43 (min-max)), average height of 1.82 m (0.08 m), average body weight of 87.65 kg (19.12 kg) and had an average BMI of 26.32 (4.58). No subjects suffered from any musculoskeletal disorders prior to the testing. Due to the Covid-19 pandemic no educated flight attendants were recruited for this study.
Furthermore, due to Covid-19, precautions were taken to ensure a safe test environment. All subjects and researchers had to provide a negative Covid-19 test taken at a maximum of 72 hours prior to testing. Furthermore, face masks and gloves were worn by everyone in the lab at all times. In addition, thorough disinfection of all equipment was performed before and after each test.

2.2. Experimental Protocol

The experiment was performed in a mock-up galley environment. A galley was constructed in cut-out clipboards to portray the actual galley used in a short- medium distance passenger flight, Embraer E-Jet 195 aircraft, with the dimensions of 317 mm × 883 mm × 1050 mm (W × D × H) which can contain a full-size trolley twice the length of a half-size trolley (See *Figure 1A*). All trials of undocking the trolley was conducted with a carbon-composite half-size trolley with the standard dimensions of 301 × 405 mm × 1030 mm (W × L × H) and with a weight of 10.6 kg. Weight equivalent to the maximum possible loaded setting was added to the trolley during the trial to represent undocking a fully loaded half-size trolley, resulting in a total weight of 60 kg.

A prototype of a directional lock consisted of metal hinges mounted on the wheels of the trolley which eliminated jamming during undocking. See *Figure 1B*. A force dynamometer was mounted to the handle of the trolley, with a 3D-printed feature (See *Figure 1C*), to measure the force applied to the trolley by the participants during the task of undocking. The entirety of the setup is shown in *Figure 1D*.

Fig. 1. The test setup and custom designed constructions. (A) galley, (B) directional lock, (C) force dynamometer mount, (D) test setup.

Prior to the familiarisation trials and test trials the anthropometric measurements of the subjects were noted and saved in Xsens MVN Analyze Pro v. 2020.2. These measurements consisted of weight, body-, shoulder-, hip-, knee-, and ankle height as well as shoulder width, arm span, hip width and shoe length. The familiarisation trial consisted of 10 repetitions of undocking with no directional lock (NDL). Since the method of undocking a trolley varies among flight attendants no instructions regarding technique was given to the subjects besides that the hand of the subject was only allowed to be in contact with the force sensor. However, basic instructions regarding the pedal function of the trolley, the pulling distance, and not pull the handles at the top of the trolley, were verbally given before and during the familiarisation trial. Furthermore, the subjects were told not to alternate hands throughout the trial.

A cross-over design counterbalancing the sequence of performing DL and NDL trials across the subjects was chosen to eliminate any bias in relation to order effect during the two tests, with half of the subjects starting with DL and the other half starting with NDL.

For each test, the initiation consisted of the subject squatting with their palm facing the ceiling, followed by three rapid consecutive pronations of the hand, tapping the force sensor each time. This initiation was performed to synchronise the Xsens and force sensor recording. Each test then consisted of 25 repetitions of undocking with either DL or NDL. One repetition of undocking consisted of standing upright facing the galley, loosening the break, reaching for the force dynamometer on the trolley, pulling the trolley all the way out of the galley followed by standing upright in a neutral position. Following each repetition a researcher would dock the trolley until a total of 25 repetitions were completed. Furthermore, NDL consisted of 25 additional repetitions of undocking the trolley to quantify the frequency of jamming. This quantification was not performed for DL, since the function of the directional lock was to eliminate jamming completely, with this function being confirmed prior to the study. This quantification during NDL was performed without the force sensor. The participants had a break of two minutes after every five repetitions and five minutes between performing DL and NDL. In addition, a short pause of approximately 10 seconds after each repetition was held when the researcher was docking the trolley.

2.3. Measurements

Xsens MTw Awinda (Xsens Technologies B.C., Enschede, the Netherlands) was used for acquiring kinematic data as a .MVN file, containing joint angles, with a sampling frequency of 60Hz. This equipment consists of 17 inertial measurement units (IMUs) placed on different body segments with straps, in accordance with Karatsidis et al., (2017). Calibration of the Xsens MTw Awinda was performed with the 'N-pose + walk' approach and was deemed acceptable once the subject achieved a "Good" calibration according to software criteria. Furthermore, a visual inspection of the relation of body segments was implemented for verification purposes. AMTI's FS-6-250 force dynamometer (AMTI, Watertown, MA, USA) was used for kinetic data acquisition saved as a .MAT file, containing the external force output. Mr. Kick II (v. 2.03) software was used for this acquisition, with a sampling frequency of 2000Hz.

2.4. Data analysis

Initially, each .MVN file was HD-processed in Xsens MVN Analyze Pro (v2020.2), before being cut to exclude all data prior to the synchronisation of Xsens and Mr. Kick II. The HD-processing function improves the quality of the motion capture data, since the software has information about the location and orientation of each segment prior to, during and after each time frame (Xsens MVN User Manual, 2019). To maintain the synchronisation of the motion capture data and external force data, the amount of frames from the synchronisation to a visible initiation of undocking in the .MVN file were noted and discarded.

For the purpose of addressing the magnitude of the forces acting on the body during the trials the two .MVN files for each subject were divided into five additional files, each containing five undockings. Each file was exported as a .BVH file to ensure compatibility with AnyBody Modelling System (AMS).

The force data, sampled at 2000Hz, was converted from μV to N in MATLAB, using a conversion matrix from the AMTI FS-6 User Manual (AMTI FS-6 User Manual), and was resampled to match the sampling frequency of the Xsens recording of 60Hz before being exported as a .txt file compatible for including an external force during the inverse dynamics analysis in AMS. Furthermore, the force data was exported as an .xlxs file where the resultant force vector was calculated to investigated the external forces involved in undocking of the trolley. The H5-files obtained from the inverse dynamics analysis were exported to MATLAB where the shear- and compression forces of L4/L5 were extracted with the purpose of statistical analysis being performed in SPSS (v27) and Microsoft Excel 365 (v16.0.11929.20762).

For calculating the duration of time spent in awkward working positions the undivided .MVN files were exported as an .xlxs file, containing all joint angles with a reference to a vertical plane. From these joint angles, the number of frames with a back flexion of >30° and a trunk twisting of >20° was counted and divided by the sampling frequency, providing information regarding time spent in an awkward working position.

2.5. Statistical analysis

Multiple failures in the kinematic- and inverse dynamics analyses were encountered due to high sensitivity in the muscle recruitment solver of the model within the AMS software. Due to this, data of only four subjects were included in the statistical analysis when addressing the magnitude regarding joint reaction forces. Therefore, the number of dependent variables exceeded the number of subjects included in the statistical analysis if only a single one way Repeated Measures Multivariate Analysis of Variance (one way RM MANOVA) was conducted, resulting in insufficient residual degrees of freedom. To accommodate this problem, two one way RM MANOVAs were conducted.

The first one way RM MANOVA was conducted to evaluate the estimated mean peak forces of DL and NDL. The undocking of the trolley with the two different wheel mechanisms functioned as a within-subject factor with two levels (DL and NDL) and the peak forces as dependant variables. This test focused on the magnitude of ergonomic evaluation and showed the effect of a directional lock mechanism on three measures, anteroposterior- (AP) and mediolateral (ML) shear force, and proximodistal compression force. Data used for the purpose of analysis were normalised by body weight (N/kg), while data that are visually presented are non-normalised, for the purpose of a comparison to absolute values for REL.

To address the duration aspect of ergonomic evaluation as well as the magnitude regarding external forces, another one way RM MANOVA was conducted upon the kinematics recorded with Xsens MTw Awinda (Xsens Technologies B.C., Enschede, the Netherlands) and the external forces recorded with AMTI's FS-6-250 force dynamometer (AMTI, Watertown, MA, USA). The time spent in an awkward working position, measured in seconds, as well as the external peak forces, measured in newton, functioned as dependent variables while the two conditions functioned as the independent variable consisting of two levels.

Assumptions such as outliers, multicollinearity and normal distribution were assessed through boxplot and Q-Q plot inspections as well as Pearson correlation and Shapiro-Wilk's test of normality. These were all met.
Follow-up univariate tests were conducted upon finding significant differences.

To address the event of jamming, a one sample T-test was conducted. This test aimed to examine if the percentage of events of jamming during NDL was statistically significant different from zero, which represents the hypothesised mean of jamming during DL.
To account for any family-wise errors due to multiple tests a Holm-Bonferroni adjusted α-level was used.

3. Results

The estimated peak shear- and compression forces (normalized by body weight) was analysed using a one way RM MANOVA to determine the effect of a directional lock mechanism on the wheels on the shear- and compression forces of the lumbar spine (L4/L5). The differences between DL and NDL were not statistically significant on the combined dependent variables, $F(3,1)=.478$, $p=.756$; Wilks' $\Lambda=.411$; partial $\eta^2=.589$, but showed a large effect size. Undocking a half-size trolley during DL showed an AP shear force of 4.44 N/kg (.56), a ML shear force of 0.56 N/kg (.15) and a compression force of 19.59 N/kg (2.66). Undocking a half-size trolley during NDL showed an AP shear force of 4.87 N/kg (0.30), a ML shear force of 0.48 N/kg (0.32) and a compression force of 20.19 N/kg (1.63). No further univariate tests were conducted.

The second one way RM MANOVA was aiming to determine the effect of the directional lock mechanism as time spent in awkward working positions as well as the external forces involved during undocking. Undocking a half-size trolley during NDL showed the largest amount of time spent in an awkward working position (203.42 seconds/25 repetitions (35.30)), equal to 8.13 seconds pr. repetition, compared to time spent in an an awkward working position during DL (88.30 seconds/25 repetitions (17.46)), equal to 3.53 seconds pr. repetition. Furthermore, undocking during NDL showed the highest external force (70.96N (4.29)) compared to the external force during undocking with DL (50.81N (4.53)). The differences between DL and NDL were statistically significant on the combined dependent variables, $F(2,5)=182.950$, $p<.001$; Wilks' $\Lambda=.013$; partial $\eta^2=.987$. Follow-up univariate tests were conducted and showed that both time spent in awkward working positions ($F(1,6)=88.33$, $p<.001$; partial $\eta^2=.936$) and external forces involved in undocking the trolley ($F(1,6)=429.86$, $p<.001$; partial $\eta^2=.986$) were statistically different depending on the condition. The average time spent in an awkward working position as well as the average peak hand force for one repetition during DL and NDL is visualised in *Figure 2*.

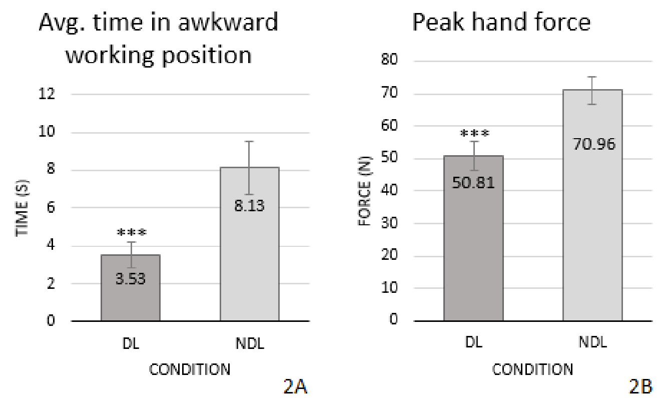

Fig. 2. (A) Average time in awkward working position during DL and NDL.
Fig. 2. (B) Peak hand force during DL and NDL. (*** = p≤.001).

Table 1 shows that none of the subjects exceeded the REL of 700N in AP and ML peak shear forces during neither DL or NDL.

Table 1. Peak AP and ML shear forces of L4/L5 during DL and NDL, REL and number of times these were exceeded.

Peak shear forces							
Subj. #	Shear AP (DL)	Shear AP (NDL)	Shear ML (DL)	Shear ML (NDL)	REL	Exceeded (DL)	Exceeded (NDL)
5	398N	353N	57N	53N	700N	0	0
6	567N	636N	99N	34N	700N	0	0
7	562N	523N	62N	45N	700N	0	0
8	325N	402N	70N	93N	700N	0	0

Table 2 shows that none of the subjects exceeded their individual age and gender dependant REL in peak compression forces during neither DL or NDL.

Table 2. Peak compression forces of L4/L5 during DL and NDL, individual peak REL based on age and gender, and number of times these were exceeded.

Peak compression forces					
Subj. #	Peak (DL)	Peak (NDL)	REL (Age & gender)	Exceeded (DL)	Exceeded (NDL)
5	1809N	1631N	5400N	0	0
6	2577N	2591N	5400N	0	0
7	2185N	2090N	5400N	0	0
8	1305N	1533N	4000N	0	0

Table 3 shows that four out of eight subject's peak hand forces exceeded the REL 1-2 times during NDL and no REL were exceeded during DL by any subjects.

Table 3. Peak hand forces during DL and NDL, and number of times REL (110N) were exceeded.

Hand forces				
Subj. #	Peak (DL)	Peak (NDL)	Exceeded (DL)	Exceeded (NDL)
1	57N	129N	0	2
2	60N	141N	0	2
3	50N	97N	0	0
4	60N	84N	0	0
5	62N	110N	0	1
6	87N	109N	0	0
7	66N	132N	0	2
8	54N	79N	0	0

The one sample T-test showed that the mean percentage of jamming occurences during NDL (74.50 (8.80)) were statistically significantly different from zero (95 % CI, 67.14 to 81.86), $t(7)=23.947$, $p<.001$, $d=8.467$.

4. Discussion

4.1. Main results

The frequency of jamming during NDL showed to be significantly different from DL with a frequency rate of 74.5 %, showing that flight attendants are exposed to this event often during the task of undocking. However, the estimated peak shear- and compression forces showed no significant differences between DL and NDL, which do not correspond with our hypothesis, that DL would significantly reduce the magnitude of the joint reaction forces on L4/L5 compared to NDL. The magnitude of undocking a half-size trolley during NDL resulted in a peak shear- and compression force of 4.87N/kg and 20.19N/Kg, respectively, which amounts to a peak shear- and compression force of 426.86N and 1,769.65N for a person with the body weight of 87.65kg equivalent to the mean of the subjects in this study. This does not come close to the REL for a 27-28 year old male, equivalent to the mean of the subjects in this study, of 700N and 5400N for shear- and compression forces, respectively (Gallagher & Marras, 2012); (Jäger, 2018). Considering flight attendants being a female dominated occupation (Lee et al., 2006b) neither is the REL exceeded even when assuming female flight attendants the same age as our subjects have an average weight of 87.65 kg. For male flight attendants ≥50 years of age, the REL would have been exceeded 0, 5, 0, and 0 times during DL and 0, 8, 0, and 0 times during NDL for subject 5, 6, 7 and 8, respectively. For female flight attendants ≥50 years of age, the REL would have been exceeded 1, 10, 5, and 0 times during DL and 0, 10, 5, and 0 times during NDL for subject 5, 6, 7, and 8, respectively. This suggests that undocking a fully loaded half-size trolley is only a task which involves a risk in terms of magnitude of exerted force applied to the lumbar spine in case the flight attendants are ≥50 years.

The average peak hand force during DL was 50.81N, while the average peak hand force during NDL was 70.96N. Comparing the value for DL and NDL to the recommended external force limit of 90-110N, this limit is not exceeded. Furthermore, the Canadian Centre for Occupational Health and Safety (CCOHS) has similar recommendations, presenting a force limit of 110N for horizontal pulling, when the pulling is performed primarily with arm and shoulder muscles, with arms fully extended. The CCOHS recommends that this limit should not be exceeded in any work situation. As seen in *Table 3*, four subjects exceeded the recommended force limit of 110N for hand force during NDL at least one time suggesting that performing the task of undocking during NDL could pose a risk in relation to muscular injury in some cases.

The time spent in an awkward working position during DL was 3.53 seconds for each task of undocking, while this duration was significantly higher with 8.14 seconds during NDL. The task of undocking did not result in any noticeable trunk twisting, why the entire duration spent in an awkward working position was a result of the subjects having a back flexion of ≥30° (Meyers et al., 2000). This shows that DL reduces the time spent in an awkward working position by 59.2 % compared to NDL.

Projecting the size of this effect to a realistic scenario, undocking nine trolleys, as on board a short- medium distance passenger flight, amounts to a reduction of 41.49 seconds with DL. However, despite the reduction of time spent in an awkward working position of 59.2 %, both undocking with DL and NDL is considered a high risk task in regards to back disorders, with DL reducing the exposure to this risk.

However, according to Nourollahi et. al 2018, long term activity with awkward posture for 20 min or more can lead to physical fatigue, and 5-20 min of constant trunk flexion can lead to soft tissue changes. The task of undocking the trolley during DL or NDL does not come close to this duration, indicating that neither poses any risk in regards to low back pain. Furthermore, this task is unlikely to be performed by the same flight attendant each time, since there will always be more than one present in the cabin during a flight (Arbejdsmiljørådet for Luftfart, 2016).

This reduces the exposure to time spent in awkward working positions as a result of undocking during a workday even further.

4.2. Methodological considerations

As mentioned in *Test setup & equipment* the mount to attach the force sensor to the trolley was 3D-printed in a strong plastic material. However, during testing, the material snapped in half two times due to excessive force application, in order to unjam the wheels. This might have caused some of the subjects to be more careful in regards to how they would undock the trolley, resulting in reduced peak values for the force application to the handle. Furthermore, the subjects were instructed only to be in contact with the force sensor, not pull the handles at the top of the trolley, and not to support their weight on the galley or trolley. Doing so, as possible in an ecological setting, could result in a reduced spinal load and a more comfortable working position or ease the task of unjamming, as this allows for more individual freedom when performing the task.
The galley was constructed from cut-out clipboards, allowing for slight deformation of the galley, which would not be the case in an ecological setting, since the galley would be made of welded aluminum. This deformation allowed for the subjects to unjam the trolley by forcefully rotating the wheels 180° outwards. In addition, the subjects used in this study were not educated flight attendants, which could result in a different movement pattern when undocking compared to an experienced flight attendant. The tests were all performed at a 0° gradient. However, this is not true to a real life setting, since food and drink services sometimes begin while ascending resulting in the flight attendants having to undock the trolley against an inclined surface. Even when the plane is at "flight-level", this task would still be performed against an incline. (Arbejdsmiljørådet for Luftfart, 2016). Therefore, performing the test at a 0° gradient, the results will be underestimated compared to an ecological scenario.

4.3. Statistical considerations

Due to the failures in the kinematic- and inverse dynamics analyses in AMS only data from four subjects were used in the one way RM MANOVA regarding shear- and compression forces on L4/L5. This resulted in a very small sample size with a corresponding lack of residual degrees of freedom if all dependent variables were to be considered jointly in one multivariate test. Therefore, multiple multivariate tests were needed, which increased the risk of family-wise errors. However, the differences in time and external peak forces during DL and NDL showed such a low p-value ($p<.001$) that the Holm-Bonferroni adjusted α-level made no difference to the interpretation of the results.

5. Conclusion

In spite of the high frequency of jamming during NDL compared to DL the study did not observe a significant reduction of magnitude of the joint reaction force on L4/L5 during DL compared to NDL. Furthermore, no thresholds regarding lumbar spinal load were exceeded for neither DL or NDL.
In addition, the magnitude of the hand force was significantly reduced during DL compared to NDL. The recommended force limit of 110N for the hand force during pulling was exceeded by 50 % of the subjects during NDL, however, only seven times in total for all 200 repetitions performed. This suggests that undocking a trolley from a galley is not a task, which in general should be considered as risky in regards to exposure to magnitude.

The duration of the awkward working position was significantly reduced during DL compared to NDL. Despite this beneficial trend, undocking a trolley from the galley during NDL one time would result in an unnoticeable time spent in an awkward working position. This indicates that undocking a trolley from a galley is not a task, which should be associated with much risk in regards to back disorders as a result of an awkward working position.

In general, this study suggests, that undocking a half-size trolley from a galley is not a physically strenuous job task and does not involve noticeable risk in regards to physical exposure. Therefore, a directional lock mechanism on the wheels of the trolley is relevant to implement due to convenient purposes rather than a solution to reduce the physically strenuous job tasks flight attendants are exposed to during a work day.

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