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Lowering Back Injuries by Utilizing Self-Loaded Equipment for Adaptive Snow Sports

Elizabeth O Neill*

Department is Engineering Technology, State University of NY Buffalo State, New York, USA

Abstract

The revised 1994 National Institute for Occupational Safety and Health's NIOSH Lifting Equation (NLE) is widely used to assess the risk of injury to the spine by providing estimates of the Recommended Weight Limits (RWL) for hands. This adaptive snow-sports (skiing/snowboard) study uses the predictive equations to identify lifting situations that put adaptive instructors at risk (>2.0 LI) for lower back injuries during a routine lift of a sit-ski onto a chairlift. Using NIOSH lifting equation calculations, along with predictive equations of spinal loads using the trunk and pelvic flexion, have identified that under the RWL's calculated during our lifting activities, spinal loads exceed the recommended safe compression and shear force levels.

Keywords: Adaptive snow sports • Manual lift of sit ski • Twisting posture during lifting • Lower back injury during lift • Manual material handling

Introduction

The original survey data was collected to find, eliminate barriers and other issues may hinder people from participating actively in the sport (>3 times) along with any equipment issues they may have with adaptive snow-sports (skiing and snowboarding) used in the industry today. Through research collected during the 2018/2019 snow-sports season from various resorts across the United States, the study identified that manual lifting of adaptive sit-skis was a significant issue. Fifty-one percent of these instructors have been involved with the sport for >20 years [1]. They come from across the United States with variable years of experience in adaptive snow sports. Our survey data was collected from 85+ people that are adaptive snow sports instructors, participants and manufacturers, which including Professional Ski Instructors of America (PSIA) and Rehabilitation Engineering Society of North America (RESNA). Comparing statistical data to simplify the top three issues while comparing variables to identify other issues after cost, being number one, with data collected from both groups (participants and instructors). Many areas may have different or similar barriers to participation, but that will be discussed in the full report [2]. Many equipment problems have been compared to both groups as well, so we can identify what each group sees as a problem. Using the equipment issues and barriers to participation, categorized them for analysis, graphing the similar variables and compare them to what the instructors see as an issue versus the participants' view. We started to see trends after calculating some basic statistics. After removing the geographic information, started to see what issues/barriers are common to both groups. Identifying these similarities and common trends, we can seek out future solutions to these problems and improve the future of the adaptive snow-sports industry. The one major area for improvement was chairlift loading and unloading for both groups of people surveyed. They both identified this as an area that needed improvement [3].

Materials and Methods

Research

The first group surveyed was the adaptive snows sports instructors. The instructors identified equipment issues they saw regularly. They were asked to list the most frequent equipment issues or failures they witnessed from instruction. These could have listed multiple issues but to list the more frequent ones first. Helping categorize the most frequent issues with adaptive snow sports equipment. Instructors were also asked to list any barriers that they see to participation in adaptive snow sports [4]. These barriers were identified in another paper presented at American Society of Engineering Educators (ASEE) 2022 conference. Using similar categories, identified issues with participation, according to the second group surveyed. All survey questions were posed from the point of view of the two groups. This information was categorized using the code numbers for the instructor data collected.

***Address for Correspondence:** Elizabeth O Neill, Department is Engineering Technology, State University of NY Buffalo State, New York, USA; E-mail: Richardkhondowe467@gmail.com*

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After collecting data from thetwo groups, the study compared the groups and the issues that existed [5].

Comparing the equipment problems and barriers to participation in adaptive snow sports. This comparison further identified the hazards associated with adaptive instruction, manual lifting of a sit ski loading onto a chairlift. Further scrutinization of the lifting techniques using computer software was modeled to re-create the manual lift of a sit ski onto a chairlift. The limitations of the Jack software were no able to perform the tasks in a manner similar to the manual lift [6]. The trial of this computer model showed that it is impossible to re-create that type of manual lift. Showing that it was far from the traditional manual lifting methods used in industry today. All weight limits and lift techniques were not found in the computer database. Using the revised NIOSH lift equation identified this manual lift of an adaptive sit-ski poses a dangerous risk to those performing the task. The instructors are assuming a risk that they may not be aware exists [7].

All figures and tables below will be used to compare and analyze the two groups and compare the data respectively. Once this data identified the areas of risk. Calculations are done using NLE guidelines and identify the risks of lifting tasks required of adaptive snow sports instructors. Additional calculations using the same data was done for NLE verification (Ergonomics Plus, Jack Software) (Figure 1) [8].

Figure 1. Lift load limits initially was focused on participants in adaptive snow sports.

All data initially was focused on participants in adaptive snow sports and was not focused on the two issues that were uncovered. Once aligning the equipment issues side by side, it was apparent that lifting issues were a larger problem. Even participants identified lift/loading as a problem even though they did not participate in the process. Looking at lift issues more closely, the equipment problems that exist, and the barriers to participation [9]. The study observed pictures and video, identifying lift loads as a primary hazard to all adaptive snow-sport instructors. After finding NLE and using field measurements, research uncovered that the risk for a lower back injury was at or above 2.5. Sometimes even over 3.0; over the NLE recommended lift index of <1.0 for all manual lifts. According to the NIOSH revised lifting equation, all jobs should be designed to achieve 1.0 risk index or less. It was time to look at the adaptive snow-sports manual lifted equipment used in industry and how it was designed [10]. Another survey would be needed to follow up on lifting issues identified in our initial research. Verifying these issues and see who may have suffered injuries using this manual loaded equipment (Figure 2).

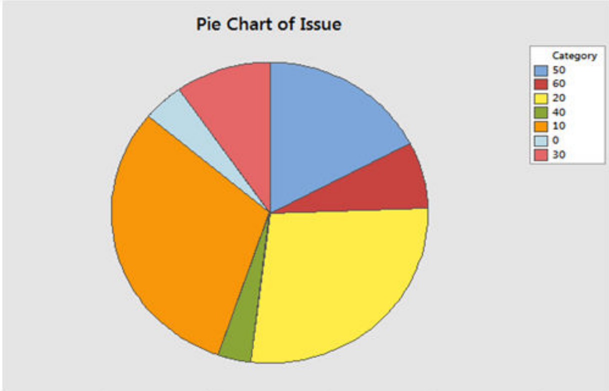

Figure 2. The equipment problems according to adaptive instructors.

Equipment issues according to instructors are shown above. Categories are number 60 with shock problems/failures, 50 binding problem/failures, 10 is cost of equipment, 40 is tether problem/failures, 30 is outrigger problem/failures, 20 is lift problem/failures, 0 is comfort problem/failures where most are related to the seat. Which is a problem that has been recently solved by offering custom foam seat bases for those who own their own equipment? Foam bases are available for the infrequent renter as well [11]. Improving the base foam while adding additional pieces for the seat bases of sit skis as needed (Figure 3).

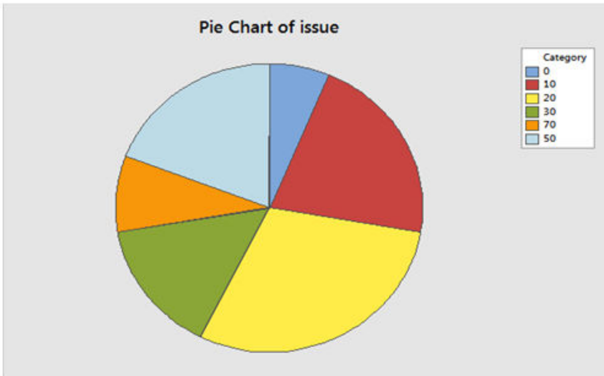

Figure 3. This pie chart shows the equipment issues according to adaptive participants.

This above pie chart above shows the same equipment issues as stated above just according to the participants. So they have a higher rating for comfort (seating and all components) based on the red 10 category. Which again, is an issue that has been solved in the past few years [12]. Comfort has come a long way for seating on sit skis. Second is lift issues, number 20, which pertains to loading/unloading, number 50 is third with binding failures, number 30 is outrigger problems/failures, number 70 is not having enough or too many different instructors since there is not a set number available. We can see the problems comparing the two groups directly since certain issues such as tethers would directly involve the instructor, not a participant. Having a follow up survey to assist in manual lift injuries that may have not been discovered in this initial survey [13].

Results and Discussion

Ergonomists, safety, and health professionals have significant research in proper lifting techniques applying NLE and third-party research companies. Epidemiological studies have identified Manual Material Handling (MMH) and lifting activities as risk factors for Low Back Pain (LBP), which can lead to injury. NIOSH considered the compression force of the L5-S1 as the only critical stress factor when determining the RWL while the posterior anterior shear forces on the lumbar intervertebral discs during lifting activities likely act as a risk factor for LBP. The NLE is widely used worldwide by occupational health practitioners to assess the risk of LBP [14]. Bending and twisting 90 degrees while lifting any sit ski (mono ski, bi ski) can drastically increase back injuries using any lifting technique. Therefore, using NLE for a given lifting activity, even if the RWL proposed to control the L5-S1 compressive force, it remains unclear if the shear forces are in safe limits. Adding the risk of bending while twisting was confirmed by a follow up survey associated with this study in Phase II. This issue is no surprise to instructors that must twist 90 degrees to access the handle holds on a sit ski. Your ski boots are forward, but your trunk and pelvis flexion angled to grab the 125-150 U.S. pound equipment, including the participant that is approximately 7"-8" off the ground. Once the lift is upward, the sit-ski must be lifted 14-20" then pulled back onto the chairlift seat. This motion found to not only exceed the NLE guidelines, but the twisting of the trunk flexion adds a higher risk for lower back injuries during these activities [15].

Using data from the international journal of industrial ergonomics 47, in lifting activities involving moderate to high forward trunk flexion the estimated RWL generates L5-S1 spine loads exceeding the recommended limits. The data for a small load of only 45 pounds, that has similar lifting height (10"), and vertical movement (16") with trunk flexion of 90 degrees and pelvic flexion angle of 35 degrees has a compression load of 4752 N and shear load 1421 N. This is beyond the NLE safe lift limits of 3400 N compression load limit, and 1000 N of shear load limit. The only way to eliminate these hazards would be to re-engineer the equipment to be self-loading. Self-loading equipment exists on the market today and eliminates the need for such motions during the loading of a sit ski on a chairlift. Figure 1 shows the picture of self-loading a sit ski. This would also lead to participant independence [16]. A practice of adaptive snow sport instruction, according to the PSIA adaptive snow-sports instruction manual. Although this concept is not always taught regardless of cognitive and physical ability. Engineering issues/problems were re-visited during Phase II followed up the survey and verified that the practice of adaptive snow sports included LPB risks of bending and twisting during loading [17].

Once again, elimination by redesign would be the solution to reduce lower back injuries in adaptive snow sports. The NLE uses multipliers in calculations that show the levels of risks of certain lifting tasks. These multipliers can be found in NIOSH lifting equation application manual 1994. They are based on the measurements taken from loads of the lift (split into 2 for both instructors), horizontal multiplier, vertical multiplier, distance chairlift heights for a distance of lift, asymmetric frequency (angles), frequency of lift and coupling which is taken from handholds on the sit skis. These calculations will be included in the full report for an examination. Multipliers originally used in NLE are shown in Table 1.

Original Multipliers		
HM	1.00	1
VM	0.83	0.98
DM	0.91	0.91
AM	0.71	0.71
CM	1.00	1
FM	0.95	0.95

Table 1. Shows multipliers originally used in nle.

The multipliers were calculated at the origin of the lift and the end of the lift for the Ergonomics Plus software. Ours were only done at the origin and maybe why our calculations are a little different in lift index calculations. The significant risk index of all calculations over >1.0 would benefit from re design, according to NIOSH. Noted that NLE is one tool in a comprehensive effort to reduce lower back pain and disabilities. Taking into consideration that other research efforts have made significant contributions as well. The identified research from Arjmand shows the angle of pelvis and trunk flexion should be considered in these calculations as well. NIOSH even mentions that biomechanical analyses may be required to assess physical stress on joints accurately. The lifting equation does assume that the friction underfoot is stable, which is snow, and on ski/snowboard equipment is not. It does not take into consideration environmental conditions such as extreme cold/heat, lifting from a kneeling position, lifting unstable objects, lifting while pulling/pushing, or lifting at high speed (CDC). These items would likely elevate the stress on the body during lifting. The lifting Index can be used to evaluate the relative magnitude of the physical stress of a job. The higher the LI is to 1.0, the smaller the fraction of people capable of safely sustaining that level of activity. The LI can be used to prioritize ergonomic re design. Identifying those tasks as posing a higher risk for LI that are >1.0. The goal is to design all lifting jobs is to be under an LI of 1.0. Acknowledging that calculations for an adaptive instructor are >2.0 LI without other considerations such as trunk and pelvic flexion stressors, the goal is to eliminate this job task by supporting self-loading equipment. The NLE failed to adequately control spine compression and shear loads in lifting during moderate trunk forward flexion. Supporting the health and safety of adaptative instructors, who are mostly volunteers, should be the goal of all industry partners (Table 2).

lift situations (min) and max is 100 lbs.	Load (weight split for 2 loaders)	RWL	Weight	Lifting index	Ergonomics calculator plus origin LI
Lift 1 (132 lbs.)	66.13	26.05	Pounds	2.54	2.52
Lift 2 (154 lbs.)	77.16	26.05	Pounds	2.96	2.94
Lift 3 (175 lbs.)	88.18	26.05	Pounds	3.39	3.36
Lift 4 (198 lbs.)	99.2	26.05	Pounds	3.81	3.78
Average lift (165 lbs.)	82.67	26.05	Pounds	3.17	3.15

Table 2. Lifting calculations NIOSH *vs.* ergonomics plus calculator.

All multipliers that were used from the NIOSH revised lift application manual to find the Recommended Weight Limit (RWL)=load constant × HM × VM × DM × AM × FM × CM. Those multipliers deal with different locations of the body during a lift. The horizontal location of the object relative to the body, vertical location of the object relative to the floor, distance moved vertically, asymmetry angle or twisting movement, frequency and duration of lifting activity, and coupling quality of the person's grip on the object. On page 29 of the NIOSH manual, the research originally considered the hand to container coupling good since it has handles or a form of handholds on the adaptive sit ski models. After further investigation, the notes on Page 30 of the NIOSH manual, number 5; for bulky objects and slippery surfaces, and the decision tree for coupling quality on Page 32; it is apparent that our situation classifies as poor. The coupling quality decision tree, Figure 4 from the NIOSH revised lifting application manual. It clearly states our coupling quality should be poor from the unstable load and bulky object being lifted. Meaning our multiplier should be 0.90 instead of 1.0 since the object is bulky and loose. Now using that revision to the coupling multiplier in calculations these results in the lift indexes are approaching and exceeding 3.0 according to the revised lift index per the application manual. The jack software (pmpcorp.com) also calculated similar results based on these revised coupling multiplier (Figure 4 and Table 3).

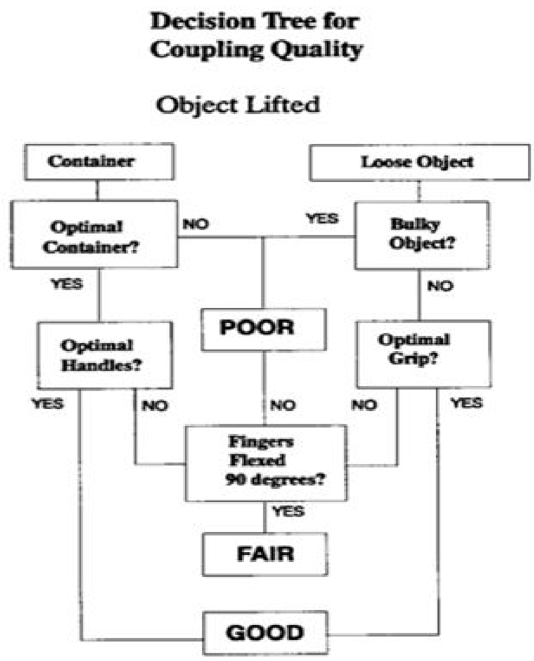

Figure 4. Decision tree for coupling quality.

Lift situations (min) and max is 100 lbs.	Load (weight split for 2 loaders)	RWL	Weight	Revised lifting index calculated and using jack software	
Lift 1 (132 lbs.)	66.13	23.45	Pounds	2.82	2.93
Lift 2 (154 lbs.)	77.16	23.45	Pounds	3.29	3.42
Lift 3 (175 lbs.)	88.18	23.45	Pounds	3.76	3.91
Lift 4 (198 lbs.)	99.2	23.45	Pounds	4.23	4.39
Average lift (165 lbs.)	82.67	23.45	Pounds	3.53	3.66
Load split for 2 people	**LC**	**RWL**	Kilograms	**Lift index calculated**	
Lift 1 (60 kg) shared 2	30	10.57	Kilograms	2.84	
Lift 2 (70 kg)	35	10.57	Kilograms	3.31	
Lift 3 (80 kg)	40	10.57	Kilograms	3.78	
Lift 4 (90 kg)	45	10.57	Kilograms	4.26	
Average (75)	37.5	10.57	Kilograms	3.55	

Table 3. Revised niosh lift index coupling multiplier of 90.

Of course, there is a cost involved to that but the risk of instructor injury should outweigh that cost now that this research has uncovered these facts. According to the NIOSH lifting application manual, all experts agree that anything above a 3.0 lift index, all workers at an increased risk for a lower back injury. The lift index results reveal that all instructors are at a high risk of injury during any of those manual lifts. Jack software simulation allowed us to somewhat evaluate the lifting techniques. Without even taking into account of the bending and twisting that is involved with lifting of a sit ski onto a chairlift. The Jack software provided limits that are all below any lift scenarios analyzed. This study accounted for the NIOSH calculations by using the jack model and found similar results. The Jack software program uses origin of the lift, and destination of the lift in the calculations. Similar to the ones by ergo plus software utilized to verify our calculations in Figure 6. Although, the Recommended Weight Limit (RWL) was slightly lower 22.57, than calculated results of 23.45 U.S. pounds. The limitations of current software could not reproduce the bending, squat, twist the figure while picking up a load/sit ski together with another instructor. This study conducted more data calculations with the Jack software modeling and found that for the tasks of lifting and lowering in the manual handling limits, shown in Table 4 below. All loads that are recommended for different percentages of females and males (50, 90, 5 percentiles) all results are far too low for any tasks of manual lifting and loading of a sit ski.

Lift/Lowering task	% Capable	Lift limit	Lowering limit	% of population find loads too heavy
Male 1	0.9	18 lbs.	22 lbs.	10 % of Males
Male 2	0.75	27 lbs.	31 lbs.	25% of Males
Male 3	0.5	35 lbs.	42 lbs.	50% of Males
Female 1	0.9	13 lbs.	13 lbs.	10 % of Females
Female 2	0.75	18 lbs.	18 lbs.	25% of Females
Female 3	0.5	22 lbs.	20 lbs.	50% of Females

Table 4. Lift/loads limits from Jack software analysis.

The Jack software program will allow you to manipulate the human figures for just about any scenario for one human using a workplace design but not necessarily for an adaptive snow sports sit ski lift. Since our populations were greater than 40 years of age and health factors is unknown, using this software was very difficult for our population. These issues were only the first of many that the study had with the Jack software. There is no consideration for age, and asymmetry taken into consideration when bending, squatting to grab a load for a lift. Which makes a difference since most current information showed that it would have an impact on the data collected on our population of adaptive instructors. The Jack software will not allow two figures to share a load which is in all our lift scenarios. A team lift could not be considered using the Jack software. It was extremely difficult, to get any useful simulations from this computer model due to those limitations.

Knowing that fact, removing these manual lifted sit ski models, should just be a formality at this point to adaptive programs around the world. Safety should be their top priority and incorporating these changes would protect the future of adaptive instructors nationwide.

Conclusion

NIOSH experts agree that all workers will be at an increased risk of a work related injury when performing highly stressful lifting tasks, anything exceeding 3.0 lift index. Furthermore, they state that all jobs should be designed to achieve 1.0 risk index or less. If this is not that case, then the task should be redesigned immediately. No other alternative other than, replacing manual loading with self loading equipment, exists at this time to eliminate the risk of a lower back injury to an adaptive snow sports instructor. This is a liability for all adaptive snow sport programs in the world today. It is a serious issue that needs to be examined further immediately. RESNA has agreed to form a committee in response to this research. Collectively both parties need to address these concerns at all levels to protect adaptive instructors from injury. Adaptive programs should look into removing or replacing all manually lifted sit skis from their inventory. These should be considered high risk and not used for lessons where manual loading is involved. Manufacturers' future designs should replace all manually lifted sit skis models; to safely load sit skis onto a chairlift in the future. Adaptive snow sports is an area that continues to evolve and since it is relatively new, these changes only allow it to be safer for those teaching students in this capacity. It would also allow a larger spectrum of people that could possibly teach the sport to others. It could potentially prolong their ability to stay as an instructor when removing any manual lifting from that methodology. Making it a little easier on all those involved with teaching adaptive snow sports.

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