EVALUATION REPORT

BIOMECHANICAL ASSESSMENT OF PHYSICAL REQUIREMENTS FOR TWO STRAP TIEDOWN SYSTEMS

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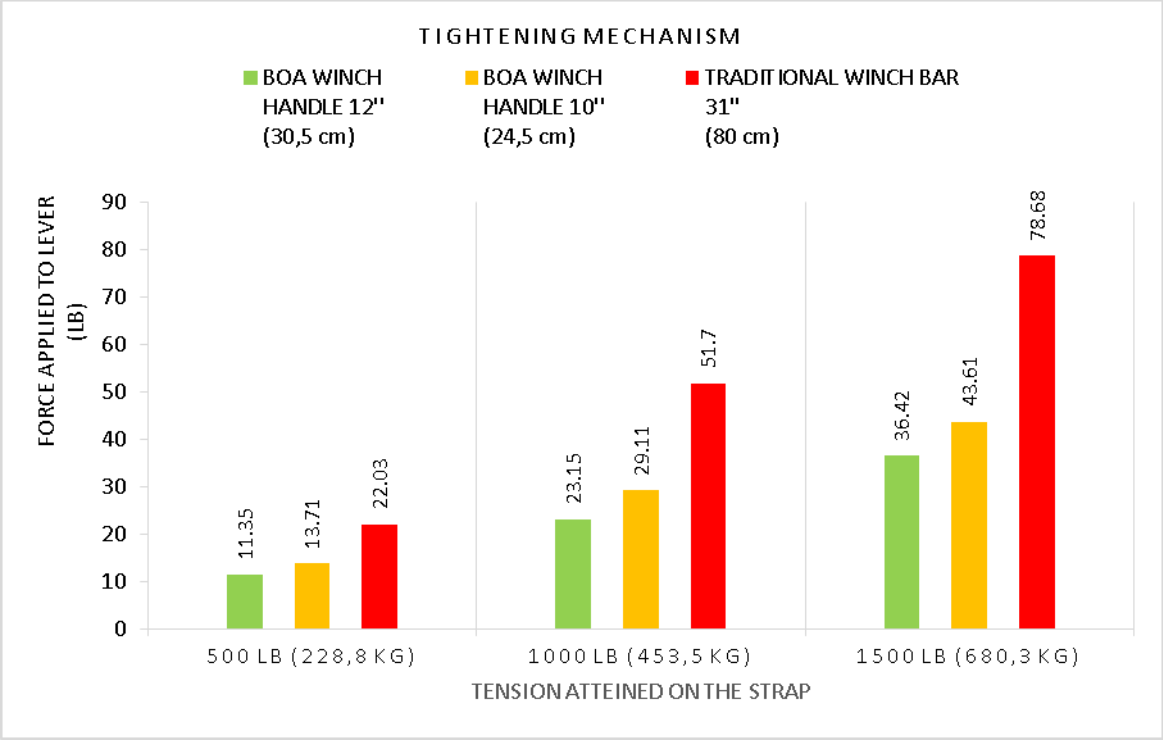
EVALUATION SUMMARY

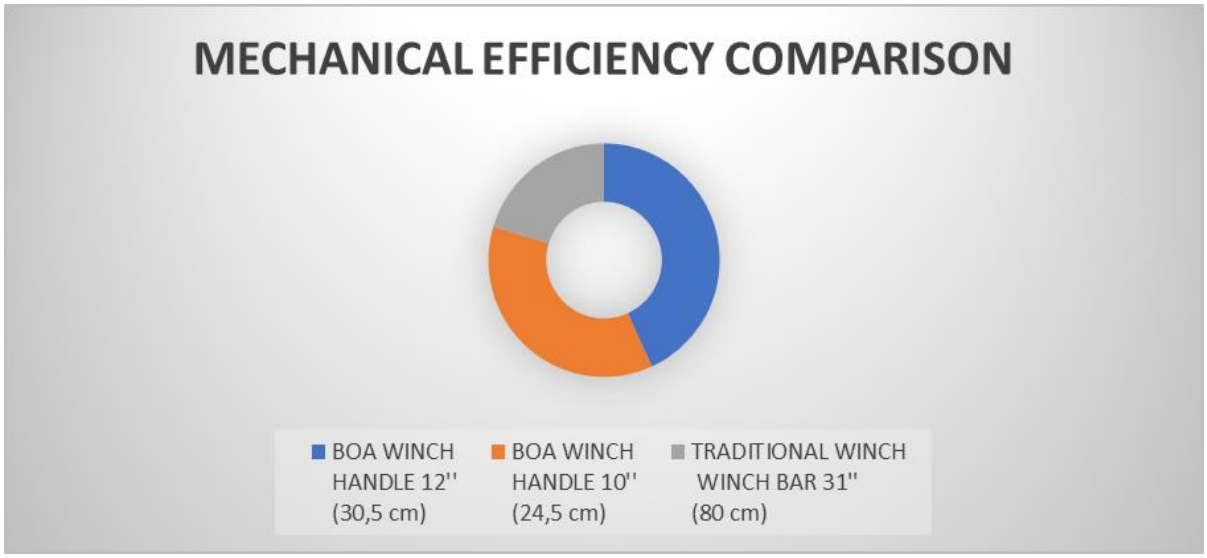
- The results of the biomechanical evaluation of the two strap tiedown systems (TRADITIONAL winch and BOA WINCH) show that the BOA WINCH system reduces the physical strain on the upper limbs and greatly improves the safety of tiedown manoeuvres.

- The BOA WINCH system with the 12" (30,5 cm) handle produces a tension on the tiedown strap that is 40 times higher than the force exerted by the worker on the handle, while the TRADITIONAL winch produces a tension on the tiedown strap that is only 20 times higher than the force exerted by the worker on the winch bar.



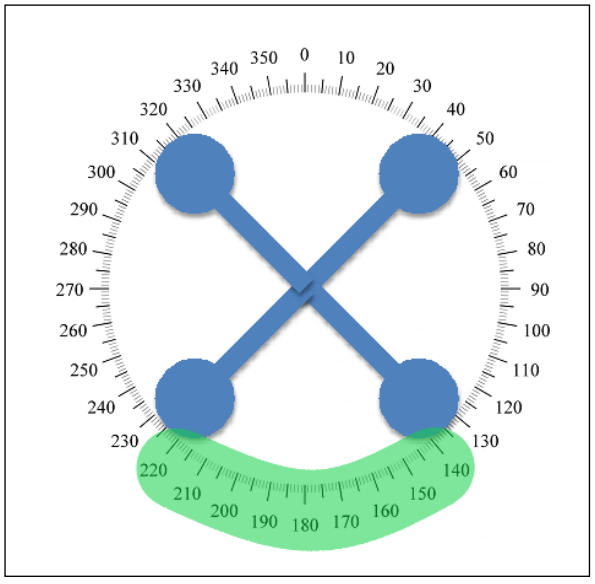
Forces required on the levers to achieve the three desired tensions

- The mechanical efficiency of the BOA WINCH system, which represents the ratio between the tension produced on the tiedown strap and the force applied to the lever, is twice as efficient as that of the TRADITIONAL winch. Therefore, the worker must only exert half the effort to apply the same levels of tension with the use of the BOA WINCH system. The use of the 12" (30,5 cm) handle also offers a greater gain in mechanical efficiency than the 10" (25,4 cm) handle.



Comparison of mechanical efficiency between types of levers

- The BOA WINCH system reduces the torque exerted on the lower back, shoulders and elbows during the tightening process. The optimal torque reduction area is attained when the crank handle is pushed on a dial positioned between 4 and 7 o'clock and the operators keep their arms extended. Therefore, during the final strap tightening process, tension should be applied by manoeuvring between 135° to 225° in order to optimize efforts.



The dial's optimal handle load

- The use of the 12" (30,5 cm) ratchet handle in the BOA WINCH system allows more than 90% of the normal population, men and women, to reach a tension on the strap of 1500 lb (680 kg) when the effort zone is optimized.

- The TRADITIONAL winch allows only a very small percentage (less than 20%) of the normal population, men and women, to reach a strap tightening force of 1500 lb (680 kg) by using the lever only in the low position (See Figure 10) with a greatly reduced range of movement of the upper limbs. This system is unfavorable for truckers who are smaller in build.

- When winding up a longer length of strap onto the mandrel, the TRADITIONAL winch requires a lot of effort to pre-tighten the strap. Between 50% and 70% of the tension exerted on the strap is lost after the system is locked. Considering the actual tension measured on the strap after the tightening manoeuvre, the mechanical efficiency, which represents the ratio between the tension produced on the tiedown strap and the force applied to the lever, loses more than 50% of its effectiveness during the manoeuvre. This loss of tension does not seem to be present in the BOA WINCH system since the mechanism does not allow any release of the tension exerted.

- The strap pre-tightening manoeuvres with the TRADITIONAL winch demonstrate the presence of an elastic tension that could induce rapid movement, also known as kickback in the industry, of the bar if the worker were to mishandle it. There is a risk of injury to the thorax and the head. This effect is also present when the cog wheel is being unlocked, where the risk of dropping the bar is even greater since it is held with only one hand. This elastic tension is not present with the BOA WINCH system since the tension is blocked continuously, when the BOA WINCH mechanism is loosened, there is no counter shock making the risk of an accident directly related to the lever is practically nil.

SYSTEMS	MECHANICAL EFFICIENCY AT 1500 LB (680.3 KG)	POPULATION ABLE TO PERFORM THE TASK (%)	LOSS OF TENSION DURING TIGHETENING PROCESS (%)	EASE OF USE WHILE SECURING A LOAD	RISK OF INJURY DURING USE
BOA WINCH HANDLE 12" (30,5 cm)	39,25	> 90	5 to 10	HIGH	LOW
BOA WINCH HANDLE 10" (25,4 cm)	33,03	> 70	5 to 10	HIGH	LOW
TRADITIONAL WINCH WINCH BAR 31.5" (80 cm)	18,48	< 20	50 to 70	MODERATE	HIGH

High level summary of the results obtained

RESEARCHER'S BIOGRAPHY

Denis Marchand has been a professor in the Department of Human Kinanthropology at the *Université du Québec à Montréal (UQAM)* since 1995. He teaches courses on the biomechanical and perceptual-motor aspects of human work in the master's program in ergonomics at UQAM. At the bachelor's level, he teaches courses in kinesiology and the prevention and treatment of musculoskeletal injuries. His professional expertise in the field focuses mainly on the ergonomic analysis of workstations and the design of ergonomic work tools.

Over the past 25 years, he has evaluated more than 200 workstations using quantitative tools. He is currently working on research projects funded by the IRSST on the evaluation of biomechanical parameters associated with the wearing of safety harnesses and on the evaluation of the physiological response to the wearing of individual protective clothing to enable the validation of new technologies developed for firefighters' clothing. Since 1997, he has supervised and graduated 21 students from the master's program in kinanthropology requiring a thesis. Most of these achievements have been financed by the IRSST or by private companies.

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1 INTRODUCTION

This specific mandate was carried out on behalf of 2T2 GROUP INC. It consisted of a biomechanical evaluation of the physical constraints associated with strap securing tasks, particularly on flatbed trailers.

Two tiedown systems were analyzed and compared, the TRADITIONAL winch using a 31.5" (80 cm) winch bar and the BOA WINCH system using a ratchet handle. For the BOA WINCH system, two handle lengths were evaluated, 10" (25,4 cm) and 12" (30,5 cm), which gave us three conditions to evaluate.

Conditions evaluated in our study:

1- TRADITIONAL winch system with winch bar 31.5" (80 cm)
2- BOA WINCH system with ratchet handle 10" (25,4 cm)
3- BOA WINCH system with ratchet handle 12" (30,5 cm)

Figure 1. *TRADITIONAL winch system with winch bar*

***Figure 2**. BOA WINCH system with ratchet handle 10" (25.4 cm)*

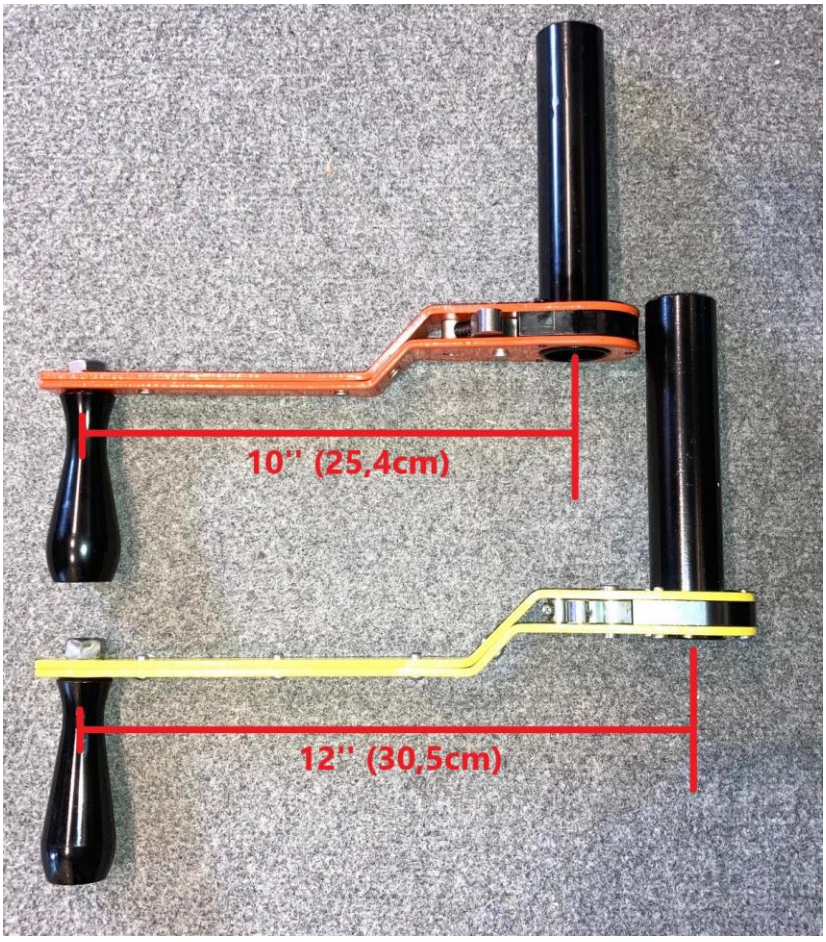


***Figure 3.** BOA WINCH ratchet handle 10" (25,4 cm) and 12" (30,5cm)*

These analyses made it possible to identify the levels of physical effort required for the main joints used during tiedown manoeuvres, i.e. the shoulders, elbows, wrists and lower back, as well as identify the situations that can cause risks of musculoskeletal injuries during these manoeuvres.

The video analyses were used to identify the postures used by the workers during load securing and, more specifically, during the tightening of the straps. A dynamometer made it possible to measure the forces exerted by the hands during these operations for both systems. These dynamometric measurements and the articular positions of each worker were used and modelled with 3D STATIC STRENGTH software to calculate the torque exerted on the joints.

Torque is defined as the power required to rotate a mechanism around a fixed point, often called a pivot. Torque, in relation to a given point, is a vector physical quantity and is usually expressed in Nm (Newton meter) or ft-lb (foot-pound).

In our study, this represents the power required to operate the winch lever (bar or handle) and to measure this value on four points of the human body: the wrist, the elbow, the shoulder and at the level of the lower back between the fifth lumbar vertebra and the first sacral vertebra (L5-S1).

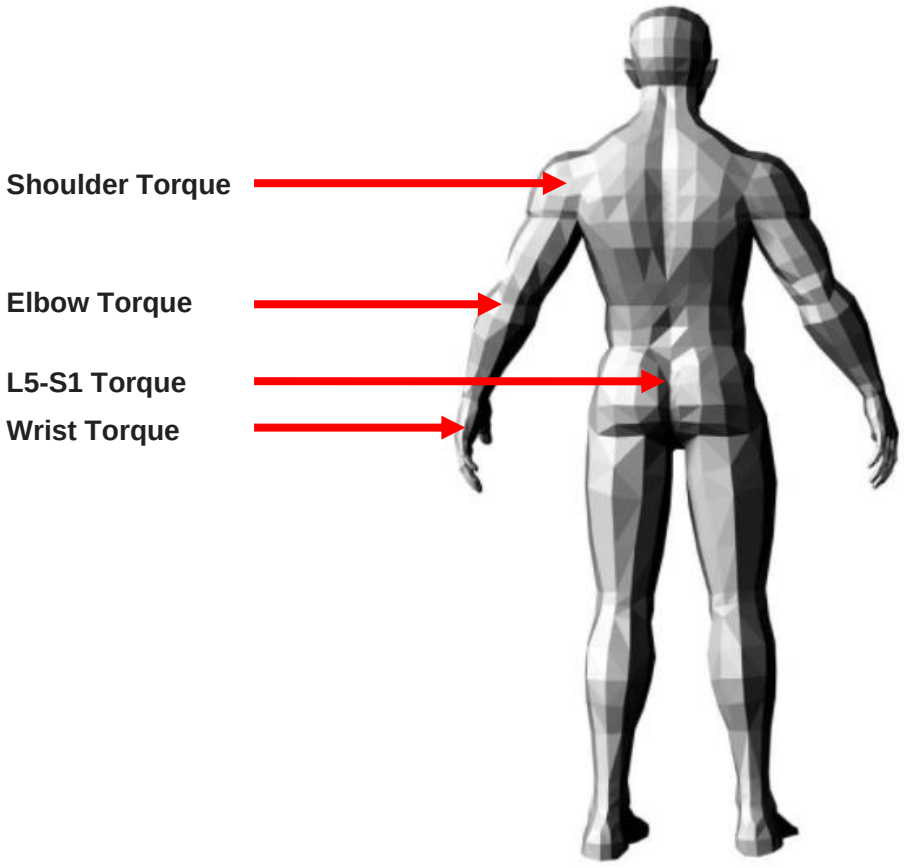


Figure 4. *Points for measuring torque on the human boy*

Tables and figures show the differences obtained between the two tiedown systems and the advantages of using a longer handle for the BOA WINCH. Ergonomic recommendations are also presented in order to optimize the positioning of the user during tiedown manoeuvres with the BOA WINCH system.

2. METHODOLOGY

2.1 *Assembly*

A load cell attached by means of 3" nylon straps was installed on a steel coil that was part of a load of steel coils loaded on a flatbed trailer. This load cell was connected to a digital display, cameras filmed the different working angles and a dynamometer measured the force on the handle or winch bar.

Figure 5. *MAC TRAILER MANUFACTURER flatbed trailer*

Figure 6. *Assembly installation and equipment positioning for different measurement recordings*

2.2 *Measuring the forces exerted on handles or levers*

Dynamometric measurements were taken during the evaluation of the two systems to determine the mechanical efficiency of the three conditions evaluated: a TRADITIONAL winch with a winch bar, a BOA WINCH winch with a 10" (25,4 cm) handle and a BOA WINCH winch with a 12" (30,5 cm) handle.

The forces exerted on the various levers were measured with a dynamometer (Shimpo 500 lb). A strap was used to attach the dynamometer to the handle of both the 10" (25,4 cm) and 12" (30,5 cm) handles of the BOA WINCH system or to the end of the 31.5" (80 cm) winch bar used for the TRADITIONAL winch. The forces exerted were measured when three tension levels; 500, 1000 and 1500 lb (227, 454 and 680 kg) were reached on the strap. The load cell was used to verify that these forces on the strap had been reached. The load cell used was a Zemic type S cell (5t) supplied by 2T2 GROUP INC.

An example of how to take a measurement with the TRADITIONAL winch when a force of 1000 lb (454 kg) is reached on the strap is shown in Figure 7. The levers were arranged horizontally, i.e. perpendicular to the winches, for the measured conditions. The force exerted solely by the weight of the levers (handles or winch bars) was also evaluated with the dynamometer.

Figure 7. *Example of the procedure used to evaluate the force exerted on the lever when three levels of strap tension are reached*

2.3 *Mechanical Efficiency*

To fully understand the scope of this study, it is important to understand what mechanical efficiency is. Mechanical efficiency is the ratio between the tension produced on the tiedown strap and the force applied to the lever (ratchet handle or winch bar). This measure of mechanical efficiency was calculated to compare the effectiveness of the two systems.

Lever force measurements were used to define the forces exerted by the operators hands when producing the three levels of tension with the two tiedown systems.

2.4 *Videos*

Two video cameras (GoPro Hero6) were used to optimize the identification of the articular angles in the upper limbs. Several strap tightening and loosening tasks were filmed for each participant. It was important to have a very realistic picture of the manoeuvres to be performed during the tests.

2.5 *Subjects*

Four people participated in the evaluation to check the possible effect of the operator's height and weight on the strap securing task. Three students and one experienced truck driver were present when the data collection was conducted.

Subjects were selected to obtain sizes representing the 5^{th}, 50^{th} and 95^{th} percentiles of the North American population. They were trained in tiedown manoeuvres by an experienced truck driver so that they could perform the manoeuvres in a compliant manner.

The table below shows the anthropometric characteristics of each subject.

Subject	Sex	Height		Weight	
		(m)	(ft)	(kg)	(lb)
1	M	1,83	6’	110,2	243
2	M	1,88	6’2’’	101,9	225
3	M	1,73	5’8’’	71,2	157
4	F	1,63	5’5’’	67	148

***Table 1**. Anthropometric characteristics of each subject*

2.6 *Measuring the forces exerted on the joints of the upper limbs*

The evaluation of the physical efforts associated with the use of these two tiedown systems was carried out using 3D STATIC STRENGTH PREDICTION software developed by researchers at the University of Michigan. This software makes it possible to calculate the rotational forces (torque) that are produced at the joints when a force is applied with the hands to a load or work tool.

By taking into account the articular positions and the forces that the hands had to exert on the lever, it was possible to calculate the articular torque required when reaching the three levels of tension measured for the study, i.e. 500, 1000 and 1500 lb (227, 454 and 680 kg)

This software also includes reference tables that enable it to establish, as a function of the articular torque obtained, the percentage of the normal (North American) population that would be capable of producing this level of effort for each joint.

These measures also made it possible to establish what percentage of the normal population would be able to perform the various tasks. These percentages were established for the joints of the upper limbs (wrists, elbows and shoulders) and the lower back (joint between the fifth lumbar vertebrae and the floor of the sacrum (L5-S1)).

The analyses carried out for the female subject give the percentages of the normal population for females, while those for the three male subjects give the percentages obtained for males only. In fact, the scientific literature shows that there are considerable differences between men and women in terms of their ability to produce articular torque. The results of the percentages presented for the three men vary only according to the different postures used to perform the tiedown manoeuvres.

Comparisons were made between the three tiedown conditions to demonstrate the differences. With the BOA WINCH system, the torque was evaluated for four dial positions (45°, 135°, 225° and 315°) during handle rotation movements (see Figure 8). The analysis of these four positions was intended to make recommendations for the optimal use of the BOA WINCH system.

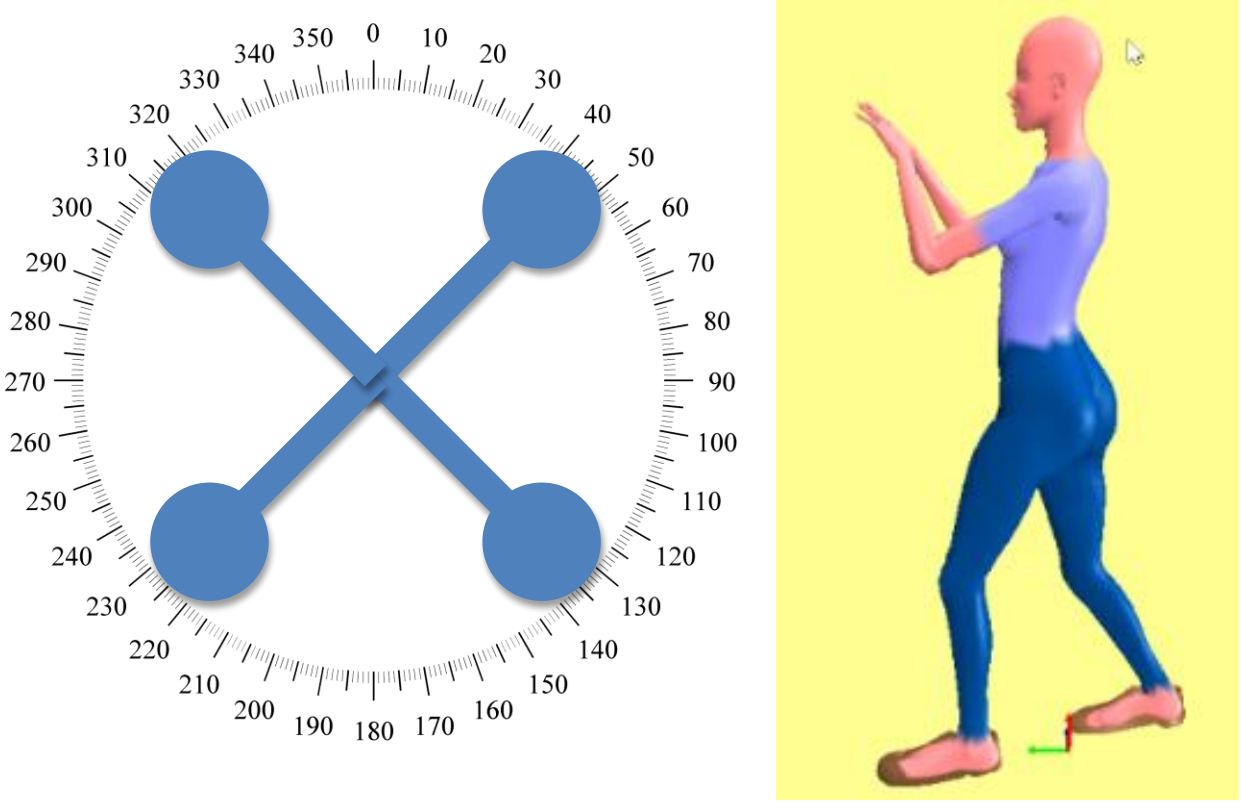


***Figure 8**. Representation of the four evaluated handle positions and the operator position for a (45°,135°, 225° et 315°) manoeuvre with the BOA WINCH system*

Figures 9 and 10 show examples of images that were used to analyze postures for both systems. The figures also show representations of a 3D humanoid and a view of a 2D sagittal plane (stick figure) where we can see the force exerted on the operator's hands which is represented by red arrows. These images were used to analyze the working postures for the different tiedown conditions.

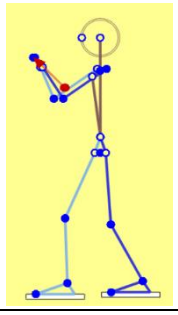
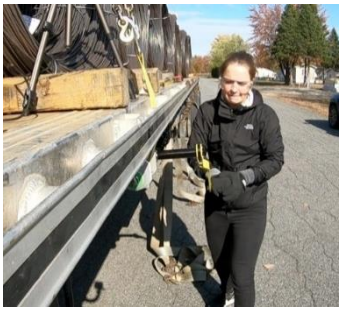
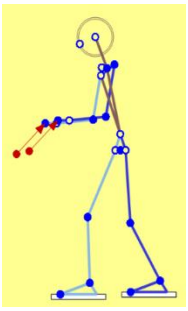
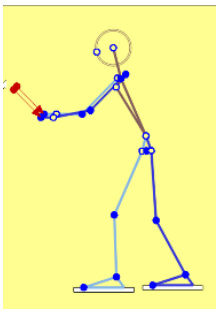
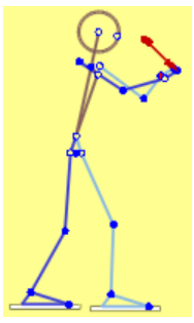
HANDLE POSITION	SIDE VIEW	UPPER VIEW	SAGITTAL PLANE 3D	SAGITTAL PLANE 2D
45°				
135°				
225°				
315°				

Figure 9. *Examples of working postures analyzed with the 3d static strength prediction program for the BOA WINCH*

For the movements performed with the TRADITIONAL winch, the torque was evaluated for the movement with the lever (winch bar) in the up and down position. Figure 10 represents the evaluated positions.

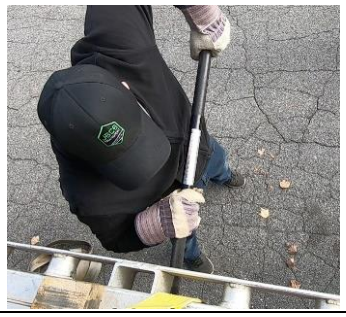
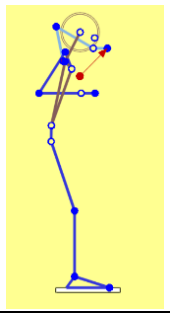
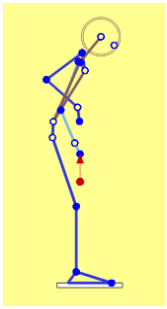
BAR POSITION	SIDE VIEW	UPPER VIEW	SAGITTAL PLANE 3D	SAGITTAL PLANE 2D
HIGH				
LOW				

Figure 10. *Examples of working postures analyzed with the 3d static strength prediction program for the TRADITIONAL winch*

2.7 *Limitations*

In order to carry out our study in a safe manner, we limited the measures taken for strap tensions varying from 500 to 1500 lb (454 à 680 kg). Normal working conditions are mostly below 1500 lb (680 kg). The use of winch bars with the TRADITIONAL winch is particularly dangerous when certain limits are exceeded. According to the results obtained, we can extrapolate that, for higher tensions, the values would remain proportional at least within the working load limit which is 5500 lb (2500 kg).

3 RESULTS AND DISCUSSION

3.1 *Dynamometric Force*

Table 2 and Figure 4 show the results of the dynamo metric measurements performed with the different systems to achieve the three target values of strap tension. The dynamometer measurements show that the TRADITIONAL winch requires twice the force to be applied to the end of the lever compared to the BOA WINCH with the 12" (30,5 cm) handle, while the winch bar of the TRADITIONAL winch is almost three times longer (31.5" (80 cm)).

The mechanical efficiency of the BOA WINCH system, which represents the ratio between the tension produced on the tiedown strap and the force applied to the handle, is twice as high as that of the TRADITIONAL winch. The worker must therefore apply half the effort to reach the same levels of tension on the straps with the use of the BOA WINCH system.

SYSTEMS	TENSION ON THE STRAP		FORCE APPLIED BY LEVER ONLY (NO APPLIED PRESSURE)		DYNAMOMETRIC FORCE		MECHANICAL EFFICIANCY
	(lb)	(kg)	(lb)	(kg)	(lb)	(kg)	
BOA WINCH handle of 10" (25,4 cm)	500	226,8	1,80	0,82	13,71	6,22	32,23
	1000	453,5	1,80	0,82	29,11	13,20	32,35
	1500	680,3	1,80	0,82	43,61	19,78	33,03
BOA WINCH handle of 12" (30,5 cm)	500	226,8	1,80	0,82	11,35	5,15	38,02
	1000	453,5	1,80	0,82	23,15	10,50	40,08
	1500	680,3	1,80	0,82	36,42	16,52	39,25
TRADITIONAL WINCH winch bar of 31.5" (80 cm)	500	226,8	2,47	1,12	22,03	9,99	20,41
	1000	453,5	2,47	1,12	51,70	23,44	18,46
	1500	680,3	2,47	1,12	78,68	35,68	18,48

Table 2. *Dynamometric values obtained when reaching three levels of tension on the strap*

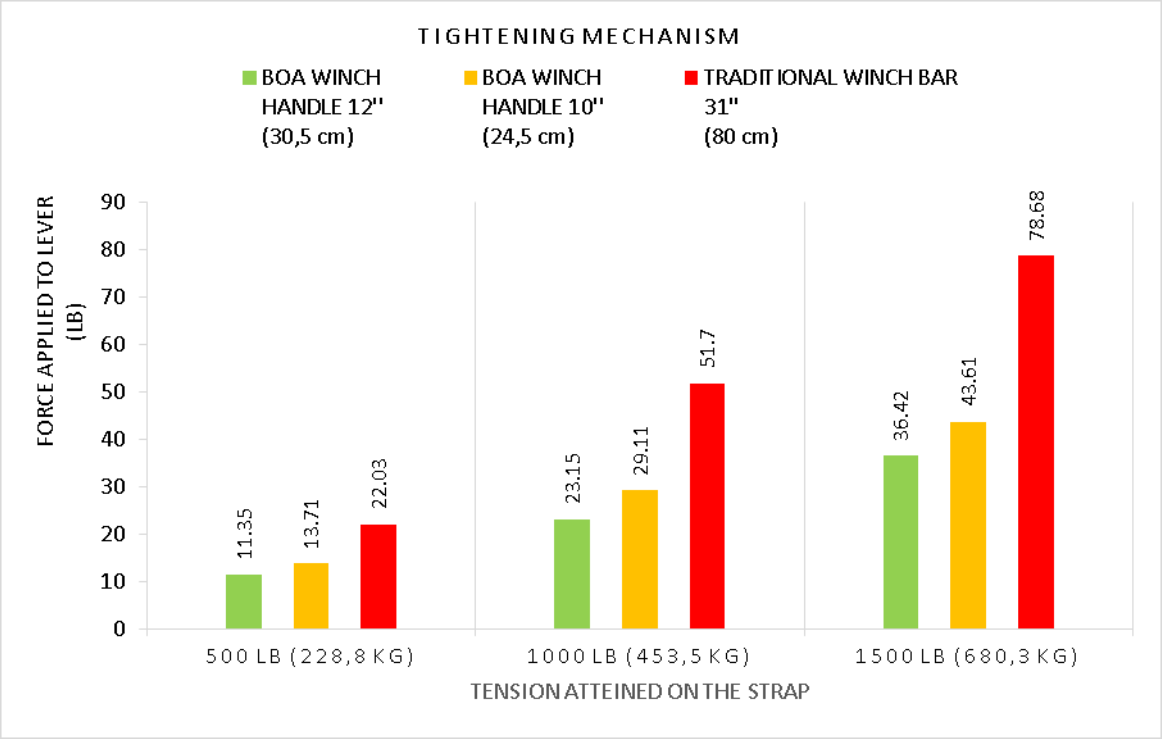


Figure 11. *Force required on the levers to achieve the three desired tensions*

The measurements presented in Table 2 also show that the mechanical efficiency of the BOA WINCH system is far superior to the TRADITIONAL winch. The BOA WINCH with its 12" (30,5 cm) handle has a mechanical efficiency of 39.12 compared to the TRADITIONAL winch that has a value of only 19.11 (see Figure 12).

The BOA WINCH system with the 12" (30,5 cm) handle gives a mechanical efficiency 2.05 times higher than the TRADITIONAL winch and the 10" (25,4 cm) handle gives a mechanical efficiency 1.7 times higher than the TRADITIONAL winch.

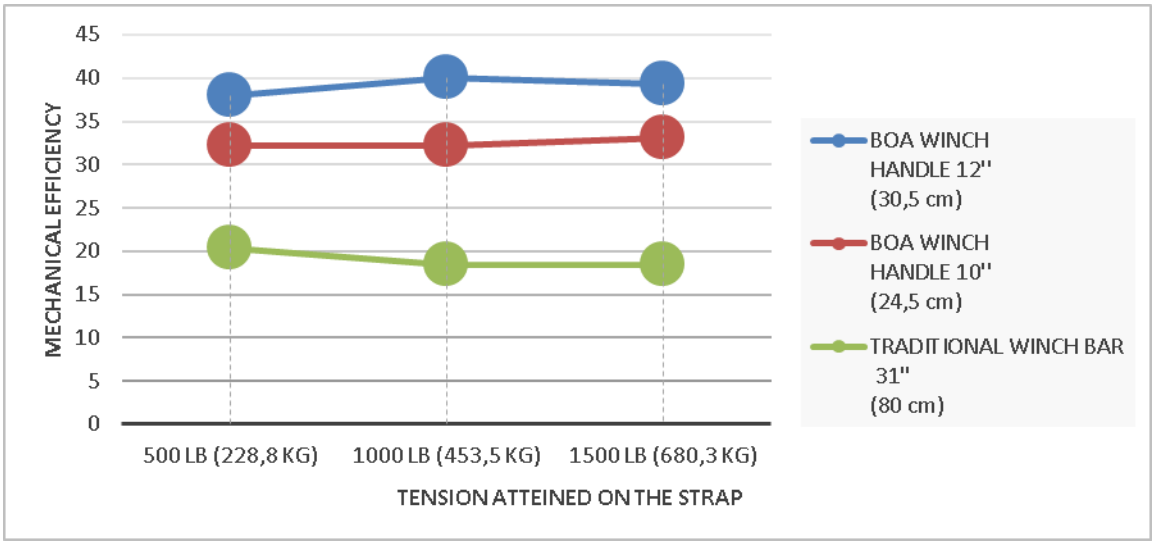


Figure 12. *Representation of the measured mechanical efficiency for the three systems according to the strap tension levels reached*

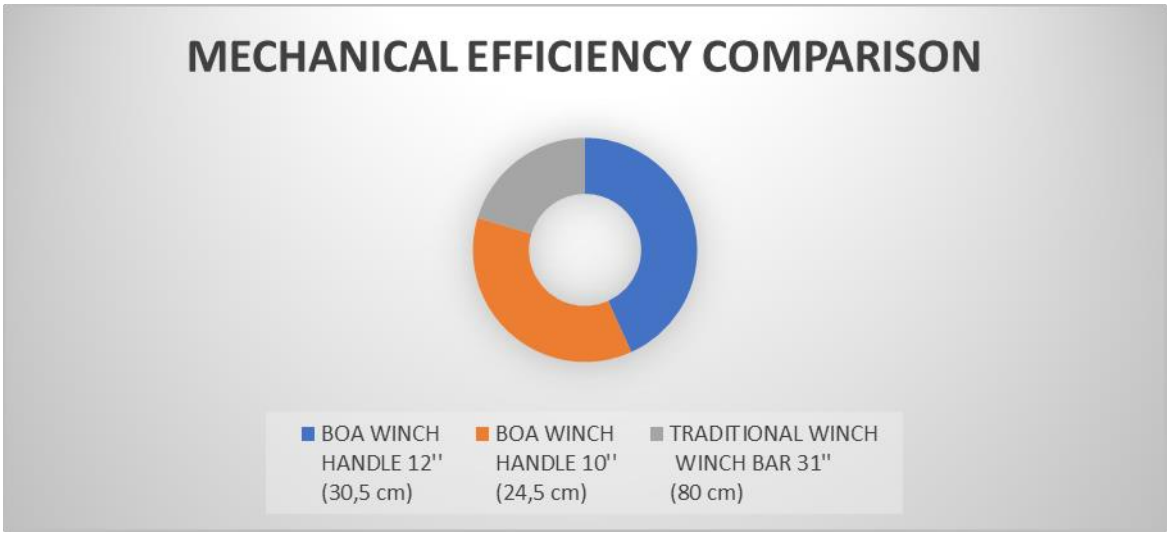


Figure 13*. Representation of the measured mechanical efficiency for the three systems according to the strap tension levels reached*

The superior mechanical efficiency of the BOA WINCH is explained by the use of its gear system that multiplies the force thanks to its worm gear system at a ratio of 22:1.

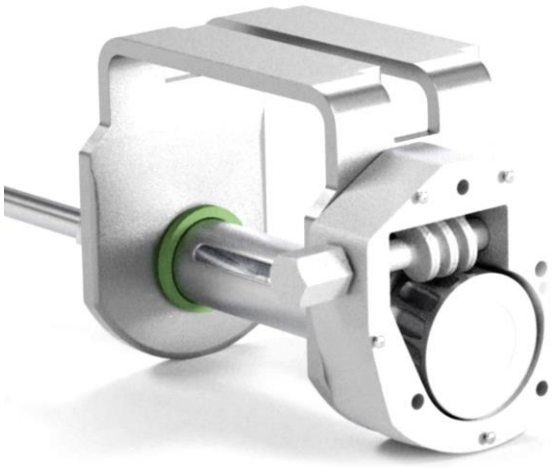


Figure 14. *Worm gear system used by the BOA WINCH*

3.2 *Tension lost during initial tightening with the TRADITIONAL winch*

When tying down using a long length of strap on the mandrel, i.e. when securing low loads, it is difficult to achieve effective pre-tightening of the excess strap on the mandrel with the TRADITIONAL winch.

Indeed, before being able to apply real tension to the load, the winding of the excess strap requires pre-tightening which must be completed by the repetitive use of back-and-forth movements with the winch bar to succeed in progressively removing the strap slack before reaching safe tension levels to stabilize the loads on the trailer.

These movements carried out with the TRADITIONAL winch require a lot of effort and energy to carry out the initial pre-tightening and to remove slack from the strap. The main disadvantage is that the worker must apply significant force that is not maintained by this system.

The difference between the force exerted and those maintained on the strap during pre-tightening is considerable (see Figure 15). According to the results obtained, only one third of the force exerted on the strap would be retained after the system is locked. Between 50% and 70% of the tension on the strap is lost while locking the cog wheel (see Figure 16).

Considering the actual tension exerted on the strap after the tightening manoeuvre, the mechanical efficiency of the TRADITIONAL winch would lose more than 50% of its efficiency (see Figure 17).

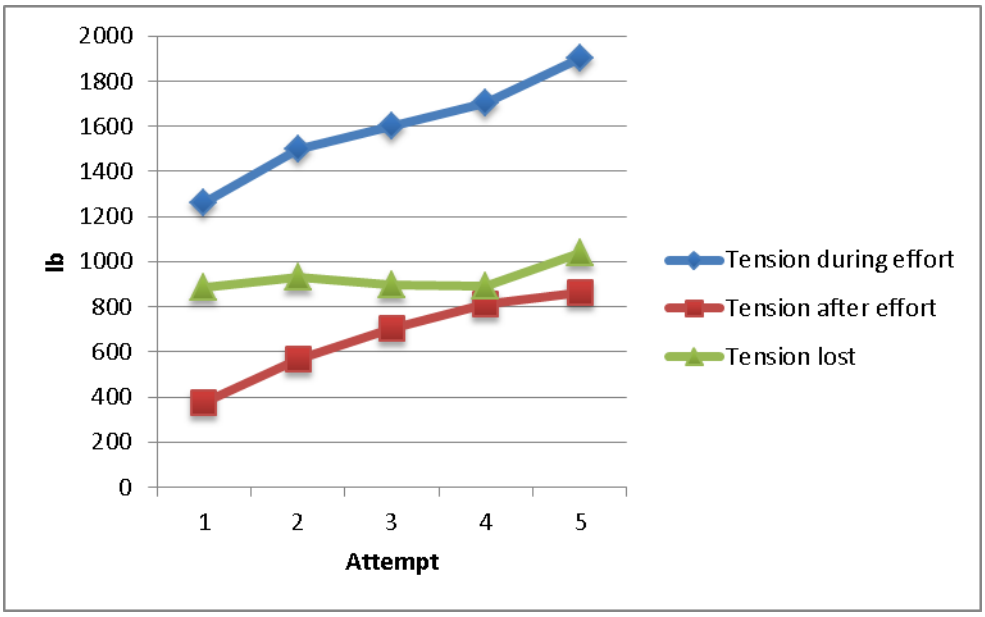


Figure 15. *Representation of the tensions measured during the initial tightening of a strap with the TRADITIONAL winch*

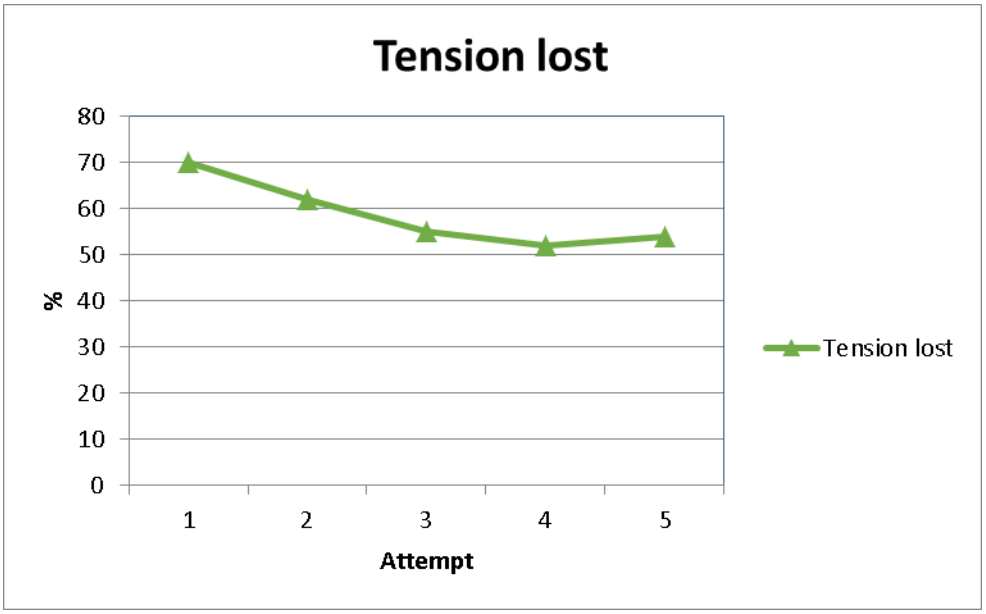


Figure 16. *Representation of the percentage of tension lost during the initial tightening of the strap for each attempt with the TRADITIONAL winch. Refer to Figure 15*

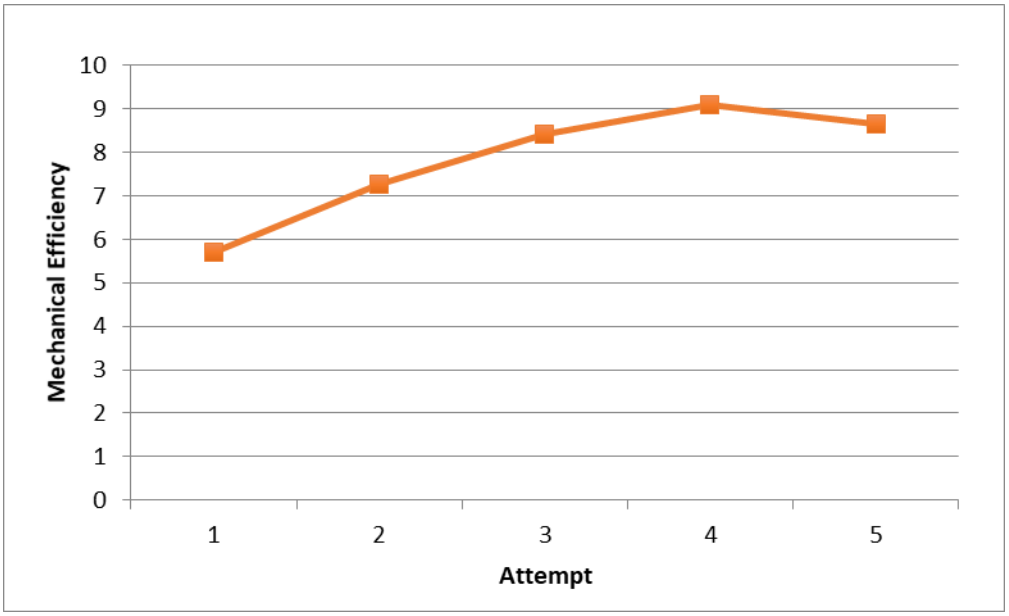


Figure 17. *Representation of the actual mechanical efficiency obtained when the strap is initially tightened during each attempt with the TRADITIONAL winch*

In terms of safety at work, the strap pre-tightening manoeuvre with the TRADITIONAL winch demonstrates the presence of this elastic tension which could induce a rapid rise of the bar if the worker were to drop it.

Because the high forces on the bar require workers to hold it close to their body to be able to perform these manoeuvres successfully, the possibility of it hitting the thorax or the head is omnipresent. Given the mass and the speed that the bar could reach, the risk of fracture and/or concussion seems possible during this manoeuvre.

This effect is also found when unlocking the TRADITIONAL winch. The risk of injury and mishandling the bar is even greater in this situation since the bar is held with only one hand while the second hand has to deactivate the sprocket wheel system that blocks the winch. A very large force must be applied downwards with the hand opposite the one holding the bar while the other releases the locking mechanism.

On the other hand, the effect of elastic tension loss during pre-tightening of the BOA WINCH is very small because the tension is applied gradually and constantly. Furthermore, there is no counter-shock effect when tightening or disengaging the BOA WINCH since the tension is almost instantaneously reduced to zero during the unloading manoeuvre due to the worm gear mechanism. When the BOA WINCH mechanism is loosened, there is no counter shock making the risk of an accident directly related to the lever is practically nil.

***Figure 18**. Posture used by the worker when unlocking the TRADITIONAL winch*

3.3 *Articular torque with* BOA WINCH

Figure 19 shows the different postures used by the 5’5’’ and 148 lb (1,63 m and 67 kg) person. The representation of the stick figure also demonstrates the orientation of the forces exerted on the hands for the four dials evaluated. The orientation of the forces exerted in the 45° and 135° dial positions demonstrates that it is possible to use the weight of the segments to help produce these forces. For the other two dial positions (225° and 315°), the muscles involved in these positions must provide tension to support the weight of the segments and the external force that must be developed in the hands to ensure handle movement.

In order to facilitate the identification of problematic situations, a series of tables are available that present the articular torque as well as the percentages of the normal population that would be able to make these efforts.

A colour code makes it easy to visualize situations that can be problematic when the percentage of the population capable of performing the task decreases considerably.

The values highlighted in green indicate that more than 80% of the normal population would be able to make these efforts.

The values highlighted in yellow indicate that only 50% to 79% of the normal population would be able to make these efforts.

The values highlighted in red indicate that less than 50% of the normal population would be able to make these efforts.

3.3.1 Subject study #4: Woman of 5'5'', 148 lb (1,63 m, 67 kg)

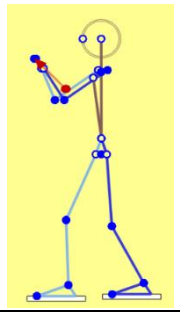
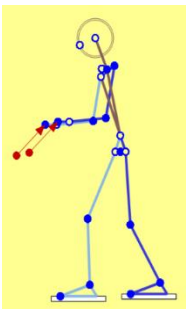
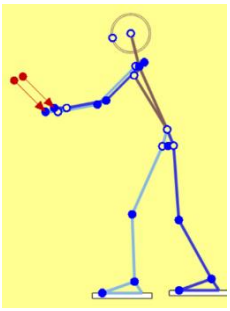
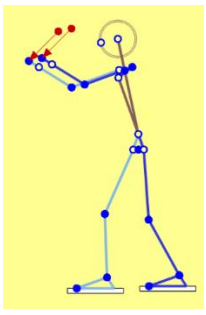
HANDLE POSITION	SIDE VIEW	UPPER VIEW	SAGITTAL PLANE 3D	SAGITTAL PLANE 2D
45°				
135°				
225°				
315°				

Figure 19. *Representation of the postures used by the 5'5'', 148 lb (1,63 m, 67 kg) person according to the four handle positions used for the torque analyses*

Tables 3 to 6 show the articular torque obtained for the four dials of the BOA WINCH system.

Based on the results obtained, the efforts performed in the 45° and 135° dial positions with the 12" (30,5 cm) handle can be achieved by a high percentage of the population for the three levels of strap tension. For the 45° dial position, the torque exerted on the upper limbs and lower back are very low and more than 93.2% of women would be able to produce a tension of 1500 lb (680 kg) on the tiedown strap.

Similar results were obtained for the 135° dial position. These results suggest that the BOA WINCH system allows smaller sized people to easily tighten the straps with movements where the handle would be pushed on a dial positioned between 4 to 7 o’clock.

The percentages of the normal population drops significantly when the movements are produced in the other two dial positions (225° and 315°) and the tensions required on the strap are greater than 1000 lb (454 kg). The grip of the handle finds itself away from the body with efforts to be produced against gravity. The values in the red zone indicate that few women would be able to produce a tension of 1500 lb (680 kg) on the tiedown strap using these working positions.

	500 LB (228,8 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-0,5	-0,37	99,7	-0,4	-0,3	99,7	-0,4	-0,3	99,7	-0,3	-0,22	99,7
Elbow	-3,4	-2,51	100	-2,8	-2,07	100	-2,9	-2,14	100	-2,5	-1,84	100
Shoulder	0	0	98,9	0,6	0,44	99,2	-1,2	-0,89	99,1	-0,7	-0,52	99,3
L5-S1	-16,5	-12,2	99,5				-15,9	-11,7	99,5			

	1000 LB (453,5 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-0,8	-0,59	99,2	-0,7	-0,52	99,7	-0,7	-0,52	99,5	-0,6	-0,44	99,8
Elbow	-6,4	-4,72	99,9	-4,7	-3,47	100	-5,2	-3,84	99,9	-3,9	-2,88	100
Shoulder	7,3	5,38	95,9	9	6,64	97,7	4,5	3,32	97,5	5,7	4,2	98,4
L5-S1	-20,6	-15,2	99,3				-19	-14	99,4			

	1500 LB (680,3 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-1,2	-0,89	98,1	-1	-0,74	99,4	-1	-0,74	99,4	-0,8	-0,59	99,5
Elbow	-9,2	-6,79	99,7	-6,4	-4,72	99,9	-7,8	-5,75	98,8	-5,5	-4,06	99,9
Shoulder	14,1	10,4	89,2	16,9	12,5	94,8	10,7	7,89	93,2	13	9,59	96,5
L5-S1	-24,4	-18	99,2				-22,5	-16,6	99,3			

Table 3. *Torque on the wrist, elbow, shoulder and L5-S1 according to the various levers in dial 1 (45°)*

	500 LB (228,8 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	1,3	0,96	99,3	1,3	0,96	99,5	1	0,74	99,4	1	0,74	99,5
Elbow	3,5	2,58	99,2	3,9	2,88	99,4	2,7	1,99	99,3	2,8	2,07	99,5
Shoulder	-3	-2,21	99,8	-2,6	-1,92	99,9	-2,9	-2,14	99,9	-2,7	-1,99	99,9
L5-S1	-6,9	-5,09	99,7				-10,6	-7,82	99,7			

	1000 LB (453,5 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	3	2,21	94,5	3	2,21	96,4	2,3	1,70	97,9	2,3	1,70	98,2
Elbow	9,5	7,01	90,4	10,6	7,82	93,1	7,9	5,83	96,4	7,9	5,83	97,1
Shoulder	-3,1	-2,29	99,5	-2	-1,48	99,7	-2,2	-1,62	99,8	-2,2	-1,62	99,8
L5-S1	16,5	12,17	97,2				7,8	5,75	98,7			

	1500 LB (680,3 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	4,6	3,39	79,4	4,6	3,39	86,4	-1,5	-1,11	91,4	3,8	2,80	92,6
Elbow	15,1	11,14	60,5	16,8	12,39	70,6	-6,2	-4,57	80,3	13,7	10,10	84,4
Shoulder	-3,1	-2,29	98,6	-1,3	-0,96	99,5	-6,2	-4,57	99,6	-1,6	-1,18	99,6
L5-S1	38,2	28,17	86,5				28,7	21,17	93,1			

Table 4. *Torque on the wrist, elbow, shoulder and L5-S1 according to the various levers in dial 2 (135°)*

	500 LB (228,8 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-1,7	-1,25	97,9	-1,7	-1,25	98,9	-1,4	-1,03	98,7	-1,4	-1,03	99,2
Elbow	-9	-6,64	99,8	-9,2	-6,79	99,8	-7,9	-5,83	99,9	-7,9	-5,83	99,9
Shoulder	-23,1	-17,04	92	-23,4	-17,26	94,3	20,5	15,12	95,7	-20,5	-15,12	96,8
L5-S1	-79	-58,27	93,8				-75,1	-55,39	94,7			

	1000 LB (453,5 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-3,4	-2,51	82,8	-3,4	-2,51	92,9	-2,7	-1,99	91,8	-2,7	-1,99	96,3
Elbow	-16,9	-12,46	97,7	-17,4	-12,83	98,6	-14,1	-10,40	99,2	-14,2	-10,47	99,4
Shoulder	-41,4	-30,54	30,4	-42,1	-31,05	42,3	-34,5	-25,45	60,9	-34,8	-25,67	69,1
L5-S1	-105,6	-77,89	86				-91,3	-67,34	89,8			

	1500 LB (680,3 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-5	-3,69	47,1	-5	-3,69	76	-4,2	-3,10	67	-4,2	-3,10	86,2
Elbow	-24,3	-17,92	89,1	-24,9	-18,37	93,5	-21,1	-15,56	95,6	-21,1	-15,56	96,8
Shoulder	-58,5	-43,15	1,1	-59,4	-43,81	3,3	-50,8	-37,47	8,4	-50,8	-37,47	15,5
L5-S1	-130,3	-96,10	74,3				-118,8	-87,62	80,9			

Table 5. *Torque on the wrist, elbow, shoulder and L5-S1 according to the various levers in dial 3 (225°)*

	500 LB (228,8 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-2,3	-1,70	96,4	-2,3	-1,70	97,1	-1,9	-1,40	97,8	-1,9	-1,40	98,2
Elbow	-10,1	-7,45	99,4	-10,5	-7,74	99,6	-9,1	-6,71	99,7	-9,1	-6,71	99,8
Shoulder	-21,3	-15,71	93,5	-22	-16,23	95,2	-18,9	-13,94	96,6	-18,9	-13,94	97,5
L5-S1	-84,8	-62,55	90,9				-75,6	-55,76	93,5			

	1000 LB (453,5 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-4,7	-3,47	66,5	-4,7	-3,47	73,2	-3,7	-2,73	82,6	-3,7	-2,73	86,2
Elbow	-19,5	-14,38	90,5	-20,4	-15,05	93,9	-16,8	-12,39	96,6	-16,8	-12,39	97,5
Shoulder	-35,9	-26,48	47,9	-37,1	-27,36	58	-30	-22,13	74,1	-30	-22,13	80,7
L5-S1	-137,2	-101,19	64,2				-115,4	-85,11	78,5			

	1500 LB (680,3 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-6,9	-5,09	19,7	-6,9	-5,09	28,3	-5,8	-4,28	40	-5,8	-4,28	49
Elbow	-28,3	-20,87	57,2	-29,6	-21,83	69,9	-25,5	-18,81	79	-25,5	-18,81	84,5
Shoulder	-49,5	-36,51	6,6	-51,5	-37,98	12,3	-42,5	-31,35	25,5	-42,5	-31,35	36,5
L5-S1	-185,9	-137,11	29,7				-159,7	-117,79	49,3			

Table 6. *Torque on the wrist, elbow, shoulder and L5-S1 according to the various levers in the dial 4 (315°)*

3.3.2 Subject study #3: Man of 5'8'', 157 lb (1,73 m, 71,2 kg)

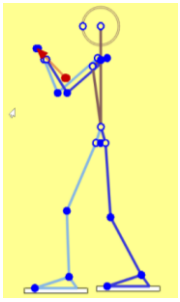
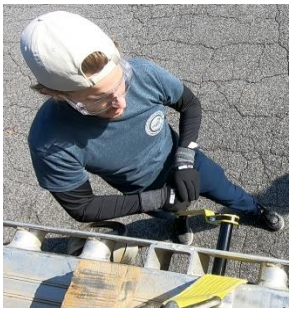
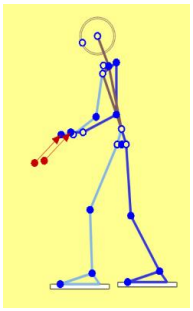
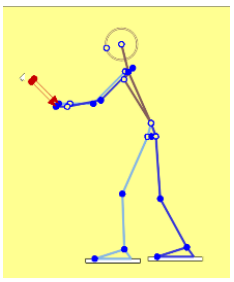
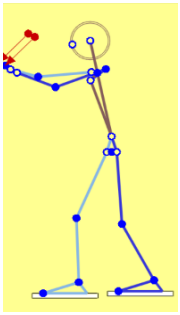
HANDLE POSITION	SIDE VIEW	UPPER VIEW	SAGITTAL PLANE 3D	SAGITTAL PLANE 2D
45°				
135°				
225°				
315°				

Figure 20. *Representation of the postures used by the 5'8'', 157 lb (1,73 m, 71,2 kg) person according to the four handle positions used for the torque analyses*

Tables 7 to 10 show the articular torque obtained for the four dials. For an average-sized person, the results show that the efforts made in the 45° and 135° dial positions with the two handles can be achieved by a high percentage of men. This is true for the three levels of tension exerted on the strap.

The percentages of the normal male population drop significantly when the movements are produced in the other two dial positions (225° and 315°) with the 10” handle and the tensions to be produced on the strap approach 1500 lb (680 kg). Once again, we note that the 12" (30,5 cm) handle increases the percentage of men capable of producing these efforts.

	500 LB (228,8 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-0,6	-0,44	99,8	-0,5	-0,37	99,8	-0,5	-0,37	99,7	-0,4	-0,30	99,7
Elbow	-3,8	-2,80	100	-3,2	-2,36	100	-3,3	-2,43	100	-2,9	-2,14	100
Shoulder	-0,7	-0,52	100	-0,1	-0,07	100	-1,9	-1,40	100	-1,5	-1,11	100
L5-S1	-18,4	-13,57	100				-17,8	-13,13	99,8			

	1000 LB (453,5 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-0,8	-0,59	99,4	-0,7	-0,52	99,7	-0,5	-0,37	99,6	-0,4	-0,30	99,8
Elbow	-5,8	-4,28	100	-4,5	-3,32	100	-3,3	-2,43	100	-2,9	-2,14	100
Shoulder	4,1	3,02	99,8	5,4	3,98	99,8	-1,9	-1,40	99,9	-1,5	-1,11	99,9
L5-S1	-20,6	-15,19	99,8				-17,9	-13,20	99,8			

	1500 LB (680,3 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-1,4	-1,03	99,5	-1,1	-0,81	99,5	-1,2	-0,89	99,7	-1	-0,74	99,7
Elbow	-10,4	-7,67	100	-7,2	-5,31	100	-8,6	-6,34	100	-6,3	-4,65	100
Shoulder	14,5	10,69	99,6	17,4	12,83	99,6	10,8	7,97	99,7	13,2	9,74	100
L5-S1	-25,4	-18,73	99,8				-23,7	-17,48	99,8			

***Table 7**. Torque on the wrist, elbow, shoulder and L5-S1 according to the various levers in the dial 1 (45°)*

	500 LB (228,8 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12'' - Flexed elbow					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	1,4	1,03	99,6	1,4	1,03	99,5	1,2	0,89	99,6	1,2	0,89	99,7
Elbow	0,9	0,66	100	1,7	1,25	100	0,5	0,37	100	1,1	0,81	100
Shoulder	-6,1	-4,50	99,9	-5,1	-3,76	100	-5,6	-4,13	99,9	-4,7	-3,47	100
L5-S1	-18,5	-13,64	99,8				-20,9	-15,42	99,8			

	1000 LB (453,5 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	3,5	2,58	96,8	1,4	1,03	97	2,7	1,99	98,4	2,7	1,99	98,5
Elbow	3,9	2,88	100	4,2	3,10	100	2,8	2,07	100	4,7	3,47	100
Shoulder	-9,8	-7,23	99,8	4,2	3,10	99,9	-8,4	-6,20	99,9	-7,1	-5,24	100
L5-S1	-1,5	-1,11	99,9				-8	-5,90	99,9			

	1500 LB (680,3 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	5,3	3,91	95,2	5,3	3,91	88,9	4,4	3,25	93,7	4,4	3,25	93,9
Elbow	6,7	4,94	99,8	10,9	8,04	100	5,3	3,91	100	8,7	6,42	100
Shoulder	-13,1	-9,66	99,6	-11,4	-8,41	99,9	-11,5	-8,48	99,7	-9,9	-7,30	99,9
L5-S1	13,3	9,81	99,9				6,2	4,57	99,9			

***Table 8**. Torque on the wrist, elbow, shoulder and L5-S1 according to the various levers in dial 2 (135°)*

	500 LB (228,8 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-2	-1,48	99	-2	-1,48	99,2	-1,7	-1,25	99,3	-1,7	-1,25	99,4
Elbow	-7,2	-5,31	100	-10,5	-7,74	100	-6,2	-4,57	100	-9	-6,64	100
Shoulder	-23,3	-17,19	99,5	-26,5	-19,55	99,5	-20,5	-15,12	99,7	-23,3	-17,19	99,8
L5-S1	-94,1	-69,40	97,8				-89,9	-66,31	98,1			

	1000 LB (453,5 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-4	-2,95	94,3	-4	-2,95	95,7	-3,2	-2,36	97	-3,2	-2,36	97,6
Elbow	-13,3	-9,81	100	-19,4	-14,31	99,9	-10,9	-8,04	100	-15,9	-11,73	99,9
Shoulder	-40,5	-29,87	93,7	-46,7	-34,44	100	-33,8	-24,93	97,4	-38,8	-28,62	97,7
L5-S1	-120,7	-89,02	95,4				-110,3	-81,35	96,5			

	1500 LB (680,3 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-5,8	-4,28	80,9	-5,8	-4,28	85,9	-4,9	-3,61	89	-4,9	-3,61	91,8
Elbow	-18,9	-13,94	100	-27,8	-20,50	99,6	-16,1	-11,87	100	-23,6	-17,41	99,8
Shoulder	-56,5	-41,67	70	-65,4	-48,24	100	-48,5	-35,77	84,7	-56	-41,30	85,9
L5-S1	-145,4	-107,24	91,5				-133,1	-98,17	93,7			

Table 9. *Torque on the wrist, elbow, shoulder and L5-S1 according to the various levers in the dial 3 (225°)*

	500 LB (228,8 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-2,7	-1,99	98,6	-2,7	-1,99	98	-2,2	-1,62	99,1	-2,2	-1,62	98,7
Elbow	-8,8	-6,49	100	-11,7	-8,63	100	-7,5	-5,53	100	-10	-7,38	100
Shoulder	-23,6	-17,41	99,5	-23,9	-17,63	99,7	-21,2	-15,64	99,7	-21,5	-15,86	99,8
L5-S1	-95,9	-70,73	97,3				-87,3	-64,39	97,9			

	1000 LB (453,5 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-5,5	-4,06	89,3	-5,5	-4,06	82,9	-4,4	-3,25	94,7	-4,4	-3,25	91,6
Elbow	-16,7	-12,32	99,9	-22,3	-16,45	99,6	-13,6	-10,03	100	-18,2	-13,42	99,8
Shoulder	-38,6	-28,47	94,8	-39,1	-28,84	97,4	-32,7	-24,12	97,7	-33,1	-24,41	98,8
L5-S1	-149,5	-110,27	89,1				-128,6	-94,85	93,4			

	1500 LB (680,3 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-8	-5,90	63,7	-8	-5,90	47	-6,7	-4,94	78,7	-6,7	-4,94	66,9
Elbow	-24	-17,70	99,6	-32,1	-23,68	97,7	-20,3	-14,97	99,8	-27,2	-20,06	98,9
Shoulder	-52,4	-38,65	77,5	-53,2	-39,24	88,2	-45,5	-33,56	88,3	-46,1	-34,00	94,1
L5-S1	-199,3	-147,00	72				-174,4	-128,63	81,8			

***Table 10**. Torque on the wrist, elbow, shoulder and L5-S1 according to the various levers in dial 4 (315°)*

3.3.3 Subject study #2: Man of 6'2'', 225 lb (1,88 m, 101,9 kg)

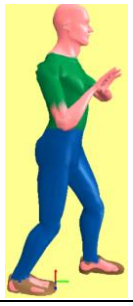
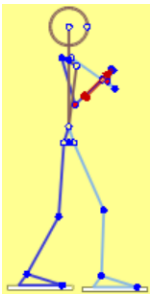
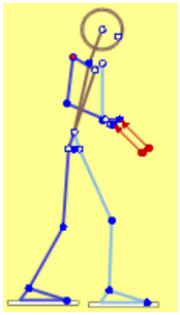
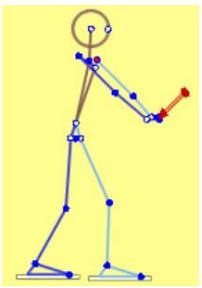
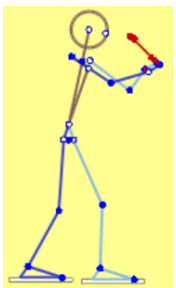
HANDLE POSITION	SIDE VIEW	UPPER VIEW	SAGITTAL PLANE 3D	SAGITTAL PLANE 2D
45°				
135°				
225°				
315°				

Figure 21. *Representation of the postures used by the 6'2'', 225 lb (1,88 m, 101,9 kg) person according to the four handle positions used for the torque analyses*

Tables 11 to 14 present the articular torque obtained for the four dials. For a tall person, the forces performed in the 45° and 135° dial positions with the two handles can be achieved by a high percentage of males in the population for all three levels of strap tension. The results with both handles remain in the green zone where more than 80% of men are capable of producing these efforts. These results confirm that the direction of the forces exerted in the 45° and 135° dial positions allow the weight of the segments to be used to produce part of the force to be exerted on the handle. This helps to reduce the torque exerted on the joints.

Once again, the percentages of the normal population drop significantly when the movements are produced in the other two dial positions (225° and 315°) with the 10" (25,4 cm) handle and the tensions to be produced on the strap approach 1500 lb (680 kg). Since these positions require the operator to exert forces against gravity, the torque become higher. The results obtained with the 12" (30,5 cm) handle show that it helps to reduce the articular torque and increases the percentage of men capable of producing these efforts.

	500 LB (228,8 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-2,9	-2,14	99,6	-0,6	-0,44	99,6	-0.8	0,74	99.6	-0.5	0,74	99.7
Elbow	-2,4	-1,77	100	-2,6	-1,92	100	-1.9	0,74	100	-2.6	0,74	100
Shoulder	-2,8	-2,07	100	2,5	1,84	99,9	-4.2	0,74	100	0.9	0,74	100
L5-S1	-19,3	-14,23	99,8				-18.6	0,74	99.8			

	1000 LB (453,5 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-1,7	-1,25	99.4	-0,9	-0,66	99.6	-1,4	-1,03	99,5	-4,4	-3,25	99,6
Elbow	-5,6	-4,13	100	-2,5	-1,84	100	-4,3	-3,17	100	-18,2	-13,42	100
Shoulder	-5,8	-4,28	99.7	12,1	8,92	99.8	2,4	1,77	99,9	-33,1	-24,41	99,9
L5-S1	-23,6	-17,41	99.8				-21,9	-16,15	99,8			

	1500 LB (680,3 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-2,5	-1,84	99,2	-1,1	-0,81	99,5	-2,1	-1,55	99,3	-1	-0,74	99,6
Elbow	-8,5	-6,27	100	-2,5	-1,84	100	-7	-5,16	99,3	-2,5	-1,84	100
Shoulder	13,9	10,25	98,3	21,1	15,56	99,6	9,9	7,30	99,8	16,6	12,24	99,8
L5-S1	-27,6	-20,36	99,7				-25,6	-18,88	99,8			

Table 11. *Torque on the wrist, elbow, shoulder and L5-S1 according to the various levers in the dial 1 (45°)*

	500 LB (228,8 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12'' - Flexed elbow					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	0,3	0,22	98,8	1,4	1,03	99,5	0,2	0,15	99,2	1,1	0,81	99,7
Elbow	0,1	0,07	100	1,2	0,89	100	0	0,00	100	0,4	0,30	100
Shoulder	-7,4	-5,46	99,9	-4,3	-3,17	100	-6,3	-4,65	100	-4	-2,95	100
L5-S1	-32,2	-23,75	99,7				-34,5	-25,45	99,7			

	1000 LB (453,5 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12'' - Flexed elbow					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	0,7	0,52	85	3,6	2,66	96,4	0,5	0,37	93,4	2,8	2,07	98,3
Elbow	1,1	0,81	99,8	6,7	4,94	100	0,7	0,52	100	4,5	3,32	100
Shoulder	-15,1	-11,14	99,9	-6,9	-5,09	100	-12,1	-8,92	99,9	-5,8	-4,28	100
L5-S1	-16,5	-12,17	99,9				-22,7	-16,74	99,8			

	1500 LB (680,3 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12'' - Flexed elbow					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	1	0,74	96,5	5,6	4,13	85,9	0,9	0,66	98	4,6	3,39	92,5
Elbow	2,1	1,55	99,1	11,7	8,63	99,8	1,6	1,18	99,8	9,2	6,79	99,9
Shoulder	-22,2	-16,37	99,3	-9,2	-6,79	100	-18,6	-13,72	99,7	-8	-5,90	100
L5-S1	-2	-1,48	99,5				-9,2	-6,79	99,7			

***Table 12**. Torque on the wrist, elbow, shoulder and L5-S1 according to the various levers in the dial 2 (135°)*

	500 LB (228,8 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-1,2	-0,89	98,8	-2,3	-1,70	98,4	-1,1	-0,81	99,1	-2	-1,48	98,9
Elbow	-8,5	-6,27	100	-13,6	-10,03	100	-7,4	-5,46	100	-11,9	-8,78	100
Shoulder	-28,7	-21,17	98,8	-33,8	-24,93	99	-25,8	-19,03	99,3	-30,3	-22,35	99,4
L5-S1	-89,9	-66,31	97,6				-86,1	-63,50	97,9			

	1000 LB (453,5 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-2,4	-1,77	90,5	-4,5	-3,32	89,4	-1,9	-1,40	95,3	-3,6	-2,66	94,5
Elbow	-16,2	-11,95	100	-25,6	-18,88	99,9	-13,2	-9,74	100	-21	-15,49	100
Shoulder	-48,8	-35,99	83,8	-58,2	-42,93	85,7	-41	-30,24	93	-48,8	-35,99	93,9
L5-S1	-116,4	-85,85	94,7				-106,1	-78,26	96,1			

	1500 LB (680,3 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-3,5	-2,58	66,7	-6,5	-4,79	66,2	-2,9	-2,14	80,8	-5,5	-4,06	79,7
Elbow	-23,3	-17,19	100	-36,6	-26,99	99,8	-19,7	-14,53	100	-31,1	-22,94	99,9
Shoulder	-67,1	-49,49	43,2	-80,4	-59,30	46,7	-58	-42,78	65,9	-69,3	-51,11	68,8
L5-S1	-140,6	-103,70	90				-128,5	-94,78	92,6			

***Table 13**. Torque on the wrist, elbow, shoulder and L5-S1 according to the various levers in dial 3 (225°)*

	500 LB (228,8 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-3	-2,21	97,9	-3	-2,21	97,2	-2,6	-1,92	98,7	-2,6	-1,92	98,2
Elbow	-9,7	-7,15	99,9	-13,5	-9,96	100	-8,3	-6,12	100	-11,9	-8,78	100
Shoulder	-21,7	-16,01	99,4	-25,6	-18,88	99,6	-20	-14,75	99,6	-23,6	-17,41	100
L5-S1	-112,5	-82,98	95				-105	-77,44	96			

	1000 LB (453,5 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-6	-4,43	81,8	-6	-4,43	75	-4,9	-3,61	91,2	-4,9	-3,61	87,5
Elbow	-18,7	-13,79	99,3	-24,7	-18,22	99,7	-15,2	-11,21	99,7	-20,4	-15,05	99,9
Shoulder	-32,4	-23,90	96,1	-39	-28,76	97,3	-28,2	-20,80	98	-33,8	-24,93	98,6
L5-S1	-162,4	-119,78	83,3				-143	-105,47	89,1			

	1500 LB (680,3 KG)											
	BOA WINCH + HANDLE 10''						BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-8,8	-6,49	44,3	-8,8	-6,49	32,2	-7,4	-5,46	64,9	-7,4	-5,46	54,2
Elbow	-27,1	-19,99	96,2	-35	-25,81	98,8	-22,9	-16,89	98,3	-29,9	-22,05	99,4
Shoulder	-42,3	-31,20	85,3	-51,3	-37,84	89,9	-37,4	-27,58	92	-45,1	-33,26	94,5
L5-S1	-208,4	-153,71	63,3				-185,4	-136,74	74,3			

Table 14. *Torque on the wrist, elbow, shoulder and L5-S1 according to the various levers in dial 4 (315°)*

3.4. Articular torque with the TRADITIONAL winch

Figure 22 shows the postures used by the 5'8'', 157 lb (1,73 m, 71,2 kg) person according to the two positions used for the torque analysis: the beginning of the movement (bar up) and the end of the movement (bar down).

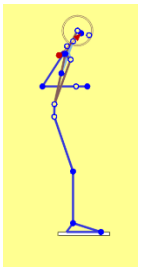
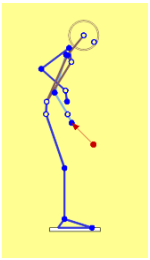
BAR POSITION	SIDE VIEW	UPPER VIEW	SAGITTAL PLANE 3D	SAGITTAL PLANE 2D
HIGH				
LOW				

Figure 22. *Representation of the postures used by the 5'8'', 157 lb (1,73 m, 71,2 kg) person according to the beginning of the movement (bar up) and the end of the movement (bar down)*

Table 15 presents the results obtained for the strap securing manoeuvres with the TRADITIONAL winch. It is noted that the beginning of the movement is particularly difficult for an average sized worker. The percentages of males in the normal population drop significantly when the movements must produce strap tensions approaching 1000 lb (454 kg).

Very few smaller-build workers would be able to reach a tension of 1500 lb (680 kg) with this system. In the high position, this worker needs to jump in order to be able to lower their shoulders and transfer their body weight onto the bar, which increases the risk of accidents during these manoeuvres. The poor posture of the wrist and elbow at the start of the movement explains why it would be impossible for this worker (0% of the normal

population) to produce this force. Without this jump over the bar, it would be impossible for the worker to produce the force necessary to move the lever down. This system seems to be disadvantageous for people of a smaller build.

	500 LB (228,8 KG)											
	TRADITIONAL WINCH - High position						TRADITIONAL WINCH - Low position					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	4,1	3,02	72,8	-0,5	-0,37	99,8	2,3	1,70	98,6	-0,1	-0,07	99,9
Elbow	22,4	16,52	97,1	-4,4	-3,25	100	9,6	7,08	100	-2,9	-2,14	100
Shoulder	14,3	10,55	99,3	2,6	1,92	100	28,5	21,02	97,5	6,5	4,79	100
L5-S1	31,8	23,45	99,8				-64,2	-47,35	99,4			

	1000 LB (453,5 KG)											
	TRADITIONAL WINCH - High position						TRADITIONAL WINCH - Low position					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	10,5	7,74	0,3	-0,5	-0,37	99,8	5,5	4,06	85,4	-0,1	-0,07	99,8
Elbow	52,5	38,72	1,1	-4,4	-3,25	100	22,6	16,67	100	-2,9	-2,14	100
Shoulder	47,9	35,33	76,9	2,6	1,92	100	69,2	51,04	59,4	6,5	4,79	100
L5-S1	130,4	96,18	92,5				-45,1	-33,26	98,3			

	1500 LB (680,3 KG)											
	TRADITIONAL WINCH - High position						TRADITIONAL WINCH - Low position					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	15,9	11,73	0	-0,5	-0,37	99,8	8,3	6,12	50,3	-0,1	-0,07	99,8
Elbow	79,8	58,86	0	-4,4	-3,25	100	34,4	25,37	99,9	-2,9	-2,14	100
Shoulder	78,5	57,90	20,9	2,6	1,92	100	106,3	78,40	9,2	6,5	4,79	100
L5-S1	220	162,26	27,6				50,6	37,32	87,4			

Table 15. *Torque on the wrist, elbow, shoulder and L5-S1 using TRADITIONAL winch in high and low lever positions*

Figure 23 shows the postures used by the 6'2'', 225 lb (1,88 m, 101,9 kg) person according to the two lever positions used for the torque analysis with the TRADITIONAL winch: the beginning of the movement (bar up) and the end of the movement (bar down).

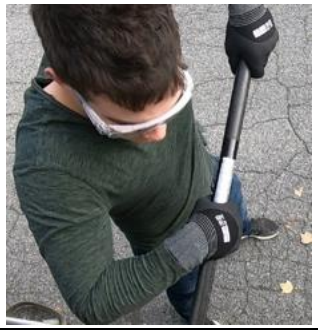
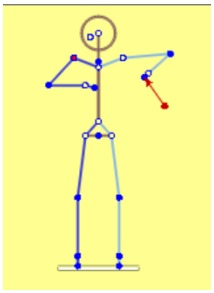
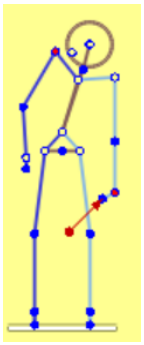
BAR POSITION	SIDE VIEW	UPPER VIEW	SAGITTAL PLANE 3D	SAGITTAL PLANE 2D
HIGH				
LOW				

Figure 23. *Representation of the postures used by the 6'2'', 225 lb (1,88 m, 101,9 kg) person according to the beginning of the movement (bar up) and the end of the movement (bar down)*

Table 16 presents the results obtained for strap securing manoeuvres with the TRADITIONAL winch for a larger sized person. It is also noted that the beginning of the movement still seems difficult even for a taller worker. The percentages of the normal population drop significantly when the movements performed from a high position must produce strap tensions approaching 1000 lb (454 kg).

	500 LB (228,8 KG)											
	TRADITIONAL WINCH - High position						TRADITIONAL WINCH - Low position					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	6	4,43	68,6	-0,3	-0,22	99,7	3,8	2,80	82	-0,4	-0,30	99,7
Elbow	-21,7	-16,01	95,4	-1,7	-1,25	100	17	12,54	99,9	-1	-0,74	100
Shoulder	15	11,06	98,5	-10,6	-7,82	100	40,7	30,02	99	-1	-0,74	99,9
L5-S1	35,6	26,26	99,9				-101,4	-74,79	98,8			

	1000 LB (453,5 KG)											
	TRADITIONAL WINCH - High position						TRADITIONAL WINCH - Low position					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	14,7	10,84	5,1	-0,3	-0,22	99,7	8,7	6,42	10	-0,4	-0,30	99,9
Elbow	-54,2	-39,98	6,1	-1,7	-1,25	100	39,4	29,06	76,6	-1	-0,74	100
Shoulder	37,8	27,88	28,6	-10,6	-7,82	100	95	70,07	73,3	-1	-0,74	99,9
L5-S1	94,5	69,70	95,7				-71,3	-52,59	51,3			

	1500 LB (680,3 KG)											
	TRADITIONAL WINCH - High position						TRADITIONAL WINCH - Low position					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	22,6	16,67	2	-0,3	-0,22	99,7	13,3	9,81	3	-0,4	-0,30	99,7
Elbow	-83,7	-61,73	3	-1,7	-1,25	100	59,8	44,11	6,7	-1	-0,74	100
Shoulder	57,8	42,63	5	-10,6	-7,82	100	144,6	106,65	16,8	-1	-0,74	99,9
L5-S1	148,2	109,31	56,9				90,5	66,75	16,8			

***Table 16**. Torque on the wrist, elbow, shoulder and L5-S1 using TRADITIONAL winch in high and low lever positions*

Figure 24 shows the postures used by the 6', 243 lb (1,83 m, 110,2 kg) person, according to the two lever positions used for the torque analysis: the beginning of the movement (bar up) and the end of the movement (bar down).

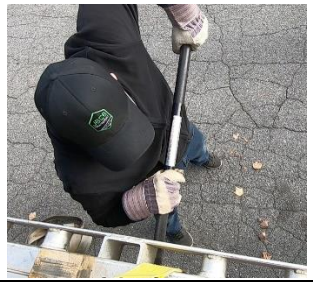
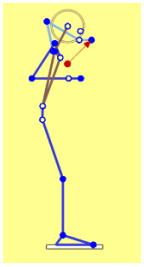
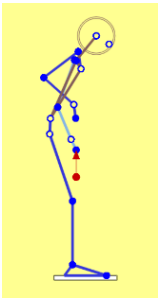
BAR POSITION	SIDE VIEW	UPPER VIEW	SAGITTAL PLANE 3D	SAGITTAL PLANE 2D
HIGH				
LOW				

Figure 24. *Representation of the postures used by the 6', 243 lb (1,83 m, 110,2 kg) person according to the beginning of the movement (bar up) and the end of the movement (bar down)*

Table 17 presents the results obtained for the strap securing manoeuvres with the TRADITIONAL winch. Even for an experienced worker, the beginning of the movement seems particularly difficult. The torque exerted on the wrist and shoulders are very high in the high position. The percentages of the normal population drop significantly for these two joints.

	500 LB (228,8 KG)											
	TRADITIONAL WINCH - High position						TRADITIONAL WINCH - Low position					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-6,3	-4,65	51,9	-0,5	-0,37	99,8	2,1	1,55	98,9	-0,1	-0,07	99,9
Elbow	-22,8	-16,82	100	-4,4	-3,25	100	7	5,16	100	-2,9	-2,14	100
Shoulder	-19,6	-14,46	40,4	2,6	1,92	100	3,9	2,88	96,3	6,5	4,79	100
L5-S1	-24,9	-18,37	99,9				-65,6	-48,38	99,4			

	1000 LB (453,5 KG)											
	TRADITIONAL WINCH - High position						TRADITIONAL WINCH - Low position					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-14,8	-10,92	25	-0,5	-0,37	99,8	5,5	4,06	86	-0,1	-0,07	99,8
Elbow	-53,5	-39,46	100	-4,4	-3,25	100	19,8	14,60	100	-2,9	-2,14	99,9
Shoulder	-46,1	-34,00	26	2,6	1,92	100	76,9	56,72	44,2	6,5	4,79	100
L5-S1	118,3	87,25	95,4				-49,8	-36,73	98,6			

	1500 LB (680,3 KG)											
	TRADITIONAL WINCH - High position						TRADITIONAL WINCH - Low position					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-22,5	-16,60	5	-0,5	-0,37	99,8	8,3	6,12	49,1	-0,1	-0,07	99,9
Elbow	-81,4	-60,04	100	-4,4	-3,25	100	30,2	22,27	100	-2,9	-2,14	100
Shoulder	73,4	54,14	5	2,6	1,92	100	117,8	86,88	20,8	6,5	4,79	100
L5-S1	202,9	149,65	40,3				53,1	39,16	89,4			

Table 17. *Torque on the wrist, elbow, shoulder and L5-S1using TRADITIONAL winch in high and low lever positions*

4. RECOMMENDATIONS

The BOA WINCH system considerably reduces articular stress on the upper limbs and increases the percentage of people capable of carrying out load securing strap tightening operations when compared to the TRADITIONAL winch.

The results of the measurements carried out with the BOA WINCH system suggest that the final tightening of the straps should be carried out in a working position that optimizes the transfer of the weight of the upper limbs and trunk to the grip of the tightening handle. Figure 26 presents the recommended posture in order to reduce joint stress to the upper limbs and back as much as possible. This working position would allow more than 90% of the normal female and male population to be able to produce high tension (1500 lb (680 kg)) on the tiedown straps with the BOA WINCH system.

The back-and-forth movements of the handle for the final tightening should be made between the dial positions of 4 to 7 o'clock with the arms extended. The ratchet handle allows the force to be exerted only during the push.

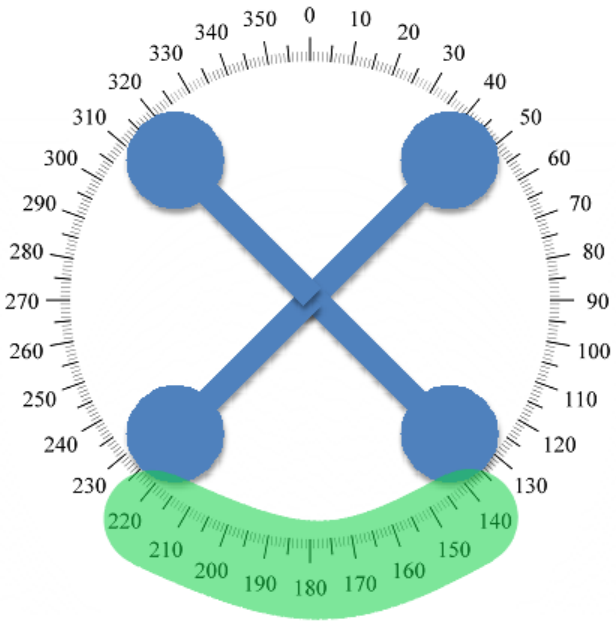


Figure 25. *Quadrant for optimal effort applied on handles*

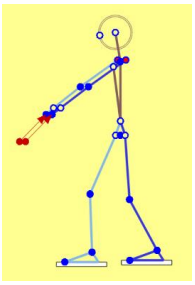
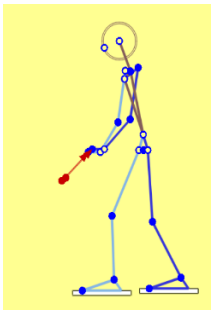
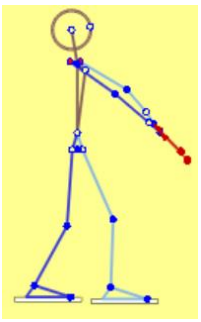
HANDLE POSITION	SIDE VIEW	UPPER VIEW	SAGITTAL PLANE 3D	SAGITTAL PLANE 2D
135°				
135°				
135°				

Figure 26. *Representations of the recommended posture at the start of the handle thrust. this movement of the handle should be done on a dial positioned between 4 and 7 o'clock with arms extended*

Tables 18 to 20 show the torque exerted on the wrist, elbow, shoulder and L5-S1 when using an ergonomic posture to achieve strap tightening with the 12" (30,5 cm) handle. The results of the Table 18 suggest that the use of this posture would allow a very high percentage (over 85%) of the normal female population to achieve high levels of tension on the strap.

	1000 LB (453,5 KG)					
	BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	0,2	0,15	97,8	0,5	0,37	99,4
Elbow	0,6	0,44	95,9	1,2	0,89	98,4
Shoulder	-1,7	-1,25	99,4	-1,1	-0,81	99,6
L5-S1	33,4	24,63	93,6			

	1500 LB (680,3 KG)					
	BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	0,4	0,30	92,8	0,8	0,59	98,6
Elbow	1,7	1,25	85,2	2,6	1,92	95,2
Shoulder	1,1	0,81	98,6	2	1,48	99,4
L5-S1	56,9	41,97	85,8			

Table 18. *Torque on the wrist, elbow, shoulder and L5-S1 for a short person*

	1000 LB (453,5 KG)					
	BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	0,3	0,22	99,1	1,1	0,81	99,6
Elbow	0,4	0,30	99,9	3,1	2,29	100
Shoulder	-4,2	-3,10	99,6	-1,3	-0,96	100
L5-S1	2	1,48	99,9			

	1500 LB (680,3 KG)					
	BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	0,6	0,44	97,4	1,9	1,40	98,9
Elbow	1,6	1,18	96,2	6,2	4,57	100
Shoulder	-2,1	-1,55	98,6	3,1	2,29	99,9
L5-S1	28,6	21,09	99,5			

Table 19. *Torque on the wrist, elbow, shoulder and L5-S1 for an average person*

	1000 LB (453,5 KG)					
	BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-1,2	0,15	98,3	0,2	0,15	99,7
Elbow	-3,5	0,44	99,9	-1,6	-1,18	100
Shoulder	-10,6	-1,25	99,7	-9,7	-7,15	100
L5-S1	12,4	24,63	99,8			

	1500 LB (680,3 KG)					
	BOA WINCH + HANDLE 12''					
	LEFT SIDE		POPULATION	RIGHT SIDE		POPULATION
AREA	(Nm)	(lb-ft)	(%)	(Nm)	(lb-ft)	(%)
Wrist	-0,7	-0,52	99,6	-0,5	-0,37	99,1
Elbow	-2,7	-1,99	100	-2,5	-1,84	100
Shoulder	-12,1	-8,92	99,9	-12,1	-8,92	100
L5-S1	-7,5	-5,53	99,9			

***Table 20**. Torque on the wrist, elbow, shoulder and L5-S1 for a tall person*

5. APPENDIX: Industry-related report

In analyzing a study conducted by IHSA from March 2020 on injuries in the trucking industry, it is interesting to note that a high percentage of injuries are caused by excessive efforts that cause the user to exceed their capabilities. In addition, a high percentage of injuries are caused to the back and the shoulders.

Top 5 Most Common Parts of Body Injured Rate Group 570												
Year	BACK, INCLUDING SPINE, SPINAL CORD, N.E.C.		MULTIPLE BODY PARTS		SHOULDER, INCL. CLAV.,SCAP., AND TRAP. MUSC. IF SHLDR. MENT.		KNEE(S)		ANKLE(S)		Total for Top 5	
	Count	% of Total	Count	% of Total	Count	% of Total	Count	% of Total	Count	% of Total	Count	% of Total
2015	232	12.1%	201	10.5%	164	8.6%	129	6.7%	119	6.2%	845	44.1%
2016	244	11.5%	214	10.1%	217	10.3%	163	7.7%	155	7.3%	993	46.9%
2017	316	15.6%	285	14.1%	187	9.2%	144	7.1%	108	5.3%	1,040	51.4%
2018	295	13.7%	326	15.2%	185	8.6%	163	7.6%	146	6.8%	1,115	52.0%
2019	270	12.5%	235	10.9%	176	8.1%	159	7.4%	168	7.8%	1,008	46.7%

Table 21. https://www.ihsa.ca/pdfs/statistics-research/2019/injury-performance-data/rate-group-570.pdf *(page 11)*

Top 5 Most Common Parts of Body Injured Rate Group 570												
Year	BACK, INCLUDING SPINE, SPINAL CORD, N.E.C.		MULTIPLE BODY PARTS		SHOULDER, INCL. CLAV.,SCAP., AND TRAP. MUSC. IF SHLDR. MENT.		KNEE(S)		ANKLE(S)		Total for Top 5	
	Count	% of Total	Count	% of Total	Count	% of Total	Count	% of Total	Count	% of Total	Count	% of Total
2015	232	12.1%	201	10.5%	164	8.6%	129	6.7%	119	6.2%	845	44.1%
2016	244	11.5%	214	10.1%	217	10.3%	163	7.7%	155	7.3%	993	46.9%
2017	316	15.6%	285	14.1%	187	9.2%	144	7.1%	108	5.3%	1,040	51.4%
2018	295	13.7%	326	15.2%	185	8.6%	163	7.6%	146	6.8%	1,115	52.0%
2019	270	12.5%	235	10.9%	176	8.1%	159	7.4%	168	7.8%	1,008	46.7%

Table 22. *https://www.ihsa.ca/pdfs/statistics-research/2019/injury-performance-data/rate-group-570.pdf (page 13)*

Based on the results of this study, the torque exerted on the lower back and upper limb joints are considerably reduced when using the BOA WINCH in comparison to the TRADITIONAL winch when performing tiedown manoeuvres. This reduction in effort suggests that a significant number of injuries can be avoided by using a more effective tool. In addition, since the number of injuries increases with the age of truck drivers (see Table 23), it would be more advantageous to use the BOA WINCH to allow these workers to continue their careers without injuries for longer periods of time.

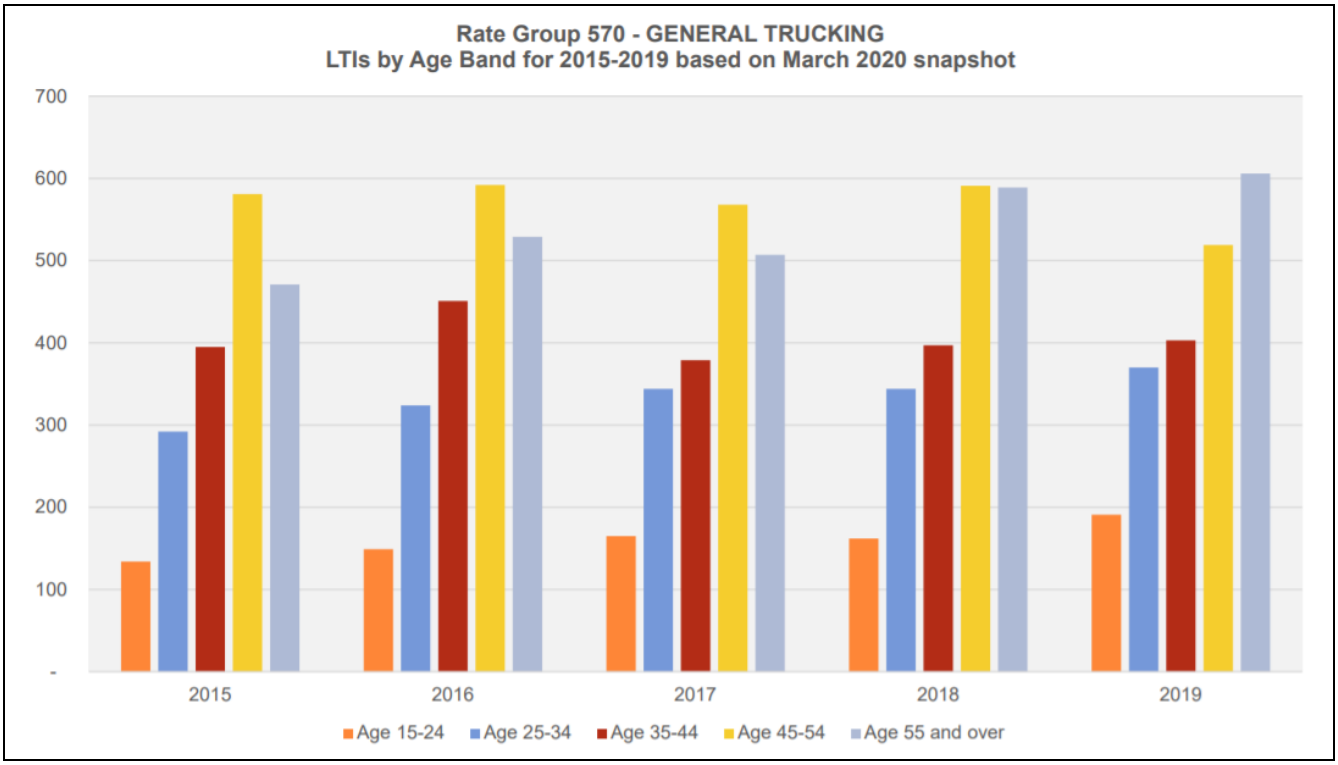


Table 23. *https://www.ihsa.ca/pdfs/statistics-research/2019/injury-performance-data/rate-group-570.pdf (page 19)*