A bnp PUBLICATION

MARCH 2007

Roofing Contractor

The Premier Magazine for Commercial and Residential Roofing and Insulation

INTERNATIONAL ROOFING EXPO

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SAFETY ADVICE: Suspension Trauma: Why and Why Not?

Posted: March 7, 2007

Suspension trauma (ST), also known as orthostatic intolerance, is a physiological disorder that results from restraining the human body motionless in a head-erect position for an extended period of time. It can affect many post-arrested fall victims, as well as some other individuals who spend extended lengths of time in suspension, such as riggers, sport climbers, cavers and fire or rescue personnel.

I am not a medical professional. My experience is restricted exclusively to designing and building personal fall protection systems and writing fall prevention/protection plans for the construction industry. This subject was originally researched in Europe as early as 1968, and it has garnered increased attention in this country in the past few years. In 2002, Paul Seddon produced a comprehensive study in England for the British Health and Safety Executive titled "Harness Suspension: Review and Evaluation of Existing Information," HSE 451-2002. His compendium of medical case studies and scientific research projects extensively documents his extensive experience working for the Industrial Rope Access Trade Association (IRATA). Many of his groundbreaking post-arrested-fall suspension analyses are considered required reading by authorities in the field of fall protection. However, there are ongoing worldwide debates concerning the pathology of harness suspension versus the trauma of harness arrest, and many point to differing test results regarding terminal impact forces generated by equal live and dead body weights. These lines of inquiry could provide significant insight into the increasing numbers of post-arrested fall injuries resulting from what is broadly described as "harness-induced trauma."

There is a powerful conflict brewing between various parties over the science and economics of the personal fall protection industry today. The rising injury rates of those who have arrested falls utilizing ANSI-standard deceleration devices in conjunction with full body harnesses testify to the ongoing problems of providing verifiably adequate fall protection around the world.

In 2003, another mechanical engineer researcher for the HSE, Harry Crawford, produced a paper titled "Survivable Impact Forces on Human Body Constrained by Full Body Harness." In this study, he searched existing fall-arrest literature to review the survivability of a fall in a personal fall arrest system (PFAS) and analyze relevant international medical and physiological opinions. His stated purpose was to evaluate European Nation (CEN) regulated standards including "the present 6kN (1,384 pound) maximum arrest force for a human subject wearing a full body harness on a free fall of up to 4m (13.12 feet)." It is important to note that these standards are not at all applicable to regulated maximum allowable terminal impact forces (TIF) in the United Kingdom or the United States.

His abbreviated conclusion from this study is that the deleterious physiological effects of an arrested fall in a full body harness would be significantly reduced if the TIF were limited to 4 kN (899 pounds). In the United States, OSHA mandates deceleration lanyards be limited to an ANSI-derived TIF of 1,800 pounds (8kN) for a 220-pound mass (100 kg) free-falling 6 feet (1.8 m). Crawford's conclusions favor an obvious belief that a 4 kN TIF would drastically reduce (if not substantially eliminate) the physiological damage a PFAS user encounters in any arrested fall. With a deceleration distance of less than a foot (and much of that recovered by the energy absorption system), the Dennington™ Harness produces a TIF significantly less that 900 pounds on a 220-pound fall victim, maintains vertical spinal orientation and virtually eliminates the slamming effect (or "jolt") described in his paper. It is my opinion, based on my field experience, that the technology developed for the Dennington Harness has the capability to exceed the minimum safety factors that Crawford proposed.

The PFAS industry will certainly continue to change as the science of fall arrest evolves, eventually replacing the market's standard deceleration devices with improved technologies. However, there is little argument that those individuals wearing standard full body harnesses today have the potential to become seriously injured or perhaps killed by the very device designed to prevent their deaths in an accidental fall. Also known as orthostatic intolerance (from "ortho" meaning "upright" and "static" meaning "motionless"), suspension trauma (ST) has a relatively short written history in the workplace. While the sport climbing community has had a passing knowledge of ST, it wasn't until the advent of OSHA's 1998 Fall Protection Standard mandating a personal fall arrest system (PFAS) that the American worker became increasingly exposed to prolonged, motionless, vertical suspension while awaiting a potential rescue.

The Mechanics of ST

The Dennington safety harness is designed to keep the fall victim in a vertical position and minimize terminal impact forces.

After succumbing to the initial 1,800-pound (8 kN) "slamming effect" delivered by a standard ANSI elongation deceleration (in conjunction with any rebound impacts), the victim's body is restrained in a semi-vertical orientation (orthostasis). The fact that the harness supports the suspended victim from his dorsal D-ring also adds to the deleterious effects on the circulatory system. The victim is often left hanging not in a true upright position, but slightly face-down on an incline of approximately 15 degrees to 20 degrees from true vertical, depending on his original pre-use fit test.

The hypoextension of the neck will often strain the large sternocleidomastoid muscle running from the clavicle to the back of the head. Over time, failure to resist the weight of the head may constrict the common carotid artery supplying blood to the brain. The slamming effect created by terminal impact forces of such a violent arrest can turn the nylon leg-loop straps of the harness into fierce tourniquets directly over the point where the femoral vein lies just below the skin at a "pulse point." A multitude of physical injuries and tissue constraints may result from even a properly fit-tested, standard full body harness involved in an arrested fall. My experience indicates that more than 75 percent of all harnesses worn on construction sites today are not properly sized and adequately fit-tested. Contractors untrained in the OSHA standards and inexperienced at designing site-specific PFA systems are prone to simply purchase extra-large harnesses for the entire crew.

A common case of harness-induced trauma (HIT) will depend on a host of external and internal conditions applied to and generated within the body of the arrested victim. Terminal impact postural orientation, pre-use fit adjustment, work clothing and tool belts, system components from the dorsal D-ring to anchor point, and the victim's conditioning all contribute greatly to the degree of HIT experienced. As Seddon's HSE report states, a full body harness can pose some obvious disadvantages for the victim of an arrested fall held in a vertical position: "Usually, the geometry of the harness is such that this causes the leg-loops or thigh straps to concentrate pressure at the inside thigh and/or the groin area, which can result in considerable discomfort. This, together with possible restriction of blood vessels in the legs, steep angle and lack of ability to move encourages venous pooling and onset of suspension trauma. A more horizontal position could be better from this point of view."

Over the next several minutes after the arrested fall, approximately 5 liters of the blood circulating through thousands of miles of the body's blood vessels begin to collect and infuse the tissues of both legs due to the gravitational force on the blood under the lowest pressure from the heart. By means of a "muscle pump," the femoral vein utilizes muscle compression against the leg bones to mechanically force venal blood up the legs. Likewise, with each beat of the heart, the waste-burdened venal blood passes through a series of tricuspid valves (about 20 cm apart), much like a series of canal locks, allowing the blood to "climb" in its return journey to the heart. With harness-induced pathology (HIP), the circulatory system begins to lose sufficient blood pressure to force the venal flow up the femoral veins and back to the heart against the unrelenting force of gravity.

The heart begins beating with low stroke volume, affecting the status of its own muscles and valves. The blood oxygen level drops to dangerous levels as the pulmonary artery is forced to circulate hemoglobin that has not been sufficiently enriched with oxygen by the lungs. Meanwhile, the blood's chemistry begins to alter and become acidic as waste byproducts begin to build up. As the tissues in the leg begin to infuse and swell, the ratio of blood solids to plasma increases, thickening the vascular blood and further reducing circulation. Other physical and neural syndromes also begin to increase as hypoxia (oxygen starvation) begins to affect critical organs. Many tell-tale symptoms arise as arterial and capillary flow is restricted to those organs being deprived oxygen. Peripheral numbness, auditory and/or visual hallucinations, shortness of breath, dizziness, nausea and profuse sweating are often common. The kidneys and liver are both critically dependent on a large and steady supply of oxygen-rich blood in order to remove contaminants and toxins from the body, and both of these organs can be early victims to hypoxic necrosis, or death due to oxygen starvation.

Once initiated, the condition typically worsens as the sensory nerves associated with blood chemistry and pressure send urgent, repeated signals to the brain to initiate an episode of temporary unconsciousness, known as a faint (or syncope). Under normal circumstances, this would cause the victim to fall into a prone position, which would naturally return the necessary blood volume back to the heart, lungs and brain as the pressures within the cardiovascular system equilibrate.

There are many ways in which individual faint victims fall. The brain switches off muscle control centers to the lower limbs first, causing what is often called a "wilting" or "casual" fall. The victim usually remains semi-conscious for the few seconds necessary to keep the upper torso semi-vertical and protect the head and neck using the arms to brace against the impact of the ground. This is intended to bring the skull in for a soft landing. In other cases, the victim resists the first insistent signals to faint until the entire body becomes rapidly disconnected and the victim falls to the floor in a rigid posture in what is often called a "keeling fall," often injuring the head and neck in the process. Usually within minutes, the typical faint victim regains consciousness (with some event memory loss) as blood volume returns to the heart and eventually recirculates to the brain and lungs. Although weakened, confused and sometimes embarrassed, the victim usually suffers no long-lasting ill effects if the fall itself causes no serious injuries.

While equipped with a full body harness and restrained in a near-vertical post-arrested posture below an anchor point, the suspended victim may enter the faint cycle as described, but the victim is denied the ability to enact a relaxed fall into a prone recovery posture. The faint signal is repeated by the brain multiple times, but with no recovery signals in response, each faint becomes deeper and initiates more rapidly. While the general syncopal mechanism is identical for most of us, the physiological effects and the depth of unconsciousness vary between individuals. As a result, many suspended victims may endure multiple, debilitating faint cycles, incurring brain death within as little as 10 to 15 minutes, depending on multiple environmental and physiological factors. Another individual exposed to these same conditions may result a variety of effects from serious debilitation to no significant symptoms at all.

Why Do Some Avoid ST?

Why is it often common for a suspended fall victim or aerial worker to avoid the onset of ST symptoms entirely? What mechanisms are either in play or eliminated to allow this person an extended period of time without suffering the serious symptoms and often lethal effects of ST? IRATA records indicate more than 5.8 million suspended work-hours are logged by qualified climbers without any reports of ST. The most likely explanation is obvious. In these cases there is sufficient venal blood volume returning from the lower extremities to the heart to prevent the syncope cycle signal from being sent to the brain. In addition, many individuals demonstrate a greater tolerance than others to the onset of suspension trauma. (For example, NASA tests indicate that women have a slightly greater tolerance to orthostasis than men.) I have also read a report that implied that a well-conditioned individual (such as an astronaut or an Olympic athlete) may succumb to ST symptoms earlier than the overweight, poorly conditioned average man on the street. The study's tilt-table research implied that the athlete's body has been conditioned to an immediate 1:1 supply/demand ratio by his cardiovascular system, while the out-of-shape individual is conditioned to functioning without an ample oxygenated blood supply.

Mark Dennington explains the benefits of his Dennington Harness at a demonstration at Barksdale AFB in Bossier City, La. After jumping, he completed the presentation in the harness. The entire hang time was 45 minutes.

While I am not a physician or EMT, it seems evident to me that an individual of average weight without a medical history of heart disease, lung disease or defects to the circulatory system who is adequately hydrated and whose glucose levels are sufficient will tend to resist the onset of ST symptoms, under identical conditions, longer than one who is not. External environmental stress factors, such as extreme heat or cold, can also play a large part in the ability of the body to fend off ST. Any ancillary blood loss from the vascular system will reduce overall blood volume and affect the heart's stroke volume, hastening the onset of ST. Therefore, anyone who has survived an arrested fall without bruises, contusions, lacerations or compound fractures with internal bleeding due to the slamming effect or rebound impacts will have a substantial advantage over someone else who exhibits cardiovascular blood loss.

In his study, Seddon details a 1968 harness testing program conducted at the Wright-Patterson Air Force Base orthostatically suspended test subjects in parachute harnesses for up to 30 minutes. Four of the five subjects exhibited no appreciable symptoms beyond mild discomfort, while the fifth victim fainted for a minute and become semi-conscious for 3 to 5 minutes. It would be important to note that none of these volunteers were dropped in a 6-foot free-fall and exposed to a terminal impact force, creating extensive harness-induced trauma. This test was more indicative of a work-positioning suspension rather than a post-arrested fall suspension. Seddon goes on to quote research studies of fallen mountain climbers who, once their fall was arrested, survived periods hanging free that lasted from a half an hour to eight hours. While they were rescued alive, all eight later died. They survived from a half an hour to 11 days.

Many cases have been recorded of fallen climbers who survived long periods of post-arrested falls without any post-rescue mortality. A significant factor in a rock climber's survival of an arrested fall involves the equipment. The climber is often within reach of his dynamic, kernmantle lead, or belay line, which has contributed to a portion of his shock absorption. This line can serve as a survival aid, if he can reach it to rig a relief step, or ascend or traverse to another point of refuge. Not all occupational falls involve the use of a lifeline and rope-grab device. Sometimes the worker becomes suspended with no structure or self-rescue line within reach, such as a lanyard off of a beam anchor or a self-retracting lifeline attached to his dorsal D-ring. This victim requires immediate rescue before becoming symptomatic.

The Dennington Harness

The Dennington safety harness reduces the terminal impact forces of a fall with specially designed bungee shock absorbers.

At 60 years of age, I have made over two-dozen voluntary demonstration jumps while wearing a Dennington Harness with its patented three-point bungee deceleration device. I have suffered no slamming effects or rebound impacts and haven't broken a single capillary yet. I have conducted three consecutive jumps (in separate harnesses) in a brief four-hour period and continued to hang suspended for yet another 45 minutes demonstrating self-rescue and survival techniques. In all 26 of my demonstrations, I have never observed the slightest symptom of suspension trauma, nor have I been unable to fully enact self-rescue procedures. The typical symptoms of pre-syncopal ST include:

• Breathlessness (followed by hyperventilation).

• Profuse sweating and hot flushes (dehydration).

• Paleness and tingling sensations in the extremities (vasoconstriction).

• Increasing pulse rate (followed by low pulse rate).

• Period of high blood pressure (followed by low blood pressure).

• Nausea and cramping.

• Dizziness, disorientation and confusion.

• Loss of peripheral vision (colors fade to grey).

• Fainting.

I always conduct a self-assessment (heart rate, respiration rate, blood pressure) after every demonstration jump and have not observed any standard deviations, beyond the expected elevated levels after strenuous work. Staying well hydrated and loaded with carbs is always important for any climber. After the demonstrations, I always disassemble the demonstration scaffold, load the equipment trailer and drive another 4 to 5 hours to my next destination without any debilitating effects.

The Dennington Harness not only reduces TIF to 800 pounds or less, it also limits the maximum total fall distance to a 6-foot maximum, as mandated in the original OSHA Fall Protection Standard. The integral lanyard on the Dennington Harness is 5 feet long with an additional 12-inch loop to back up the approximately 8-inch elongation of the bungee system during arrest. I weigh 210 pounds, and the bungee cords on my harnesses are sized and constructed according to my medium weight classification As measured in my demonstrations, the total distance from anchor while post-fall suspended in a Dennington Harness is approximately 10 feet, while a standard safety harness leaves the fall victim approximately 18 feet from the anchor point. The harness is also currently being manufactured in a version with a 4-foot, 6-inch lanyard for taller ironworkers to eliminate any possibility of striking the lower decking in a typical steel framed building under construction.

For those post-arrested-fall (PAF) victims who never succumbed to ST, the ability to perform a half-dozed survival maneuvers while suspended after a fall may prove to be the difference between a jolting experience and a fatality. Many of those who survived a brief suspension after impact may have been able to do so purely on their own superior circulatory system. Some may have had the advantage of a nearby lifeline with which they could tie a foot loop in which to stand and relieve leg loop pressure on the femoral vein. Perhaps they had sufficient line to rig a “hammock-style” suspension system, raising both legs perpendicular to the spine.

After an arrested fall, those with a physical structure accessible nearby may be able to seek temporary refuge until technically rescued, but many victims are left suspended, spinning helplessly in mid-air. While waiting for rescue, suspended victims can exercise the “muscle pump” in their legs by executing leg lifts and toe points to promote sufficient circulation and prevent a syncopal cycle from initiating. These techniques are purely defensive tactics and must be exercised continuously until their suspension is concluded. The pain induced and the energy required to repeat these prophylactic procedures will rapidly exhaust the strength of an arrested fall victim. Time is the enemy after any successfully arrested fall. The victim is only half-rescued at that point. A prompt rescue is imperative if the victim is to survive any period prolonged suspension.

Preventing ST

There is no doubt that there is much left to be discovered about the variables resulting in suspension trauma deaths. Any statements which I make concerning personal fall arrest are based on my own experience and training, and not on any degree in engineering or any certification by an accredited organization. It is, in my opinion, becoming quite apparent with the increased employer compliance to OSHA’s Construction Fall Protection Standards (1926.500) that the National Institute of Occupational Safety and Health and the Bureau of Labor Statistics, in conjunction with the Center To Protect Workers’ Rights, should confer in order to develop a cooperative injury/fatality recording system to clearly identify such post-arrested-fall suspension accidents. A comprehensive program for analyzing the direct, indirect and root causes for these cardiopulmonary injuries should be instituted. Follow-up investigations could also be conducted to determine if the post-rescue patient care and emergency medical treatment properly addressed the nature of this unique problem. In this way, designers and constructors of personal fall arrest and rescue systems would have the necessary criteria to develop a truly site-specific fall protection and rescue plan, which would best eliminate or mitigate the conditions which contribute to ST. We also need much more specific, voluntary data from the industries with members who don and doff harnesses on a daily basis. Arrested falls in full body harness occur many more times on sites around the world than is generally recorded.

Victims of suspension trauma fall from roofs, building structures, towers, tanks, chimneys, power poles, cranes, aerial lifts and a thousand other anchor points while performing a million daily tasks. It is an occupational disease of growing proportion with little known about its diagnosis and less about its prevention. In years to come, there will be further medical research into orthostatic intolerance. Much of this study will improve the techniques we use to arrest a human fall.

In the meantime, it is up to each individual employer to meet his general duty to implement a site-specific fall prevention and protection program. This may only be accomplished by making a good faith effort to educate, enact and enable employees in the safest methods of arresting a fall when wearing a full body harness. Workers should be trained and experienced to resist the onset of suspension trauma until they are promptly rescued according to a site-specific rescue plan.