Don't Jump

The potential effects of jumping from heights

By William M. Montante

A STRAIGHT LINE may be the shortest distance between two points, but it is not necessarily the safest. Workers who drive or unload a transport truck or forklift, work around a loading dock on platforms or ladders, or perform any task designed so that it invites an opportunity to jump down may find it expedient, unavoidable or necessary to take that quick route down.

Regardless of the task, potential hazards, personal goals or levels of risk tolerance, what goes up does come down with increased risk for injury. Gravity is relentless and it remains unwavering and indifferent to personal well-being. Challenge the laws of gravity and Newtonian mechanics, and the outcome just might be grave. "Gravity is a relentless companion, both friend and foe, always on duty" (Gonzalez, 2004).

A Lesson from Sir Isaac Newton

Sir Isaac Newton, the brilliant and enigmatic 17th century British scientist who was sometimes slow to learn from his experiences, teaches a valuable hazard-awareness lesson. As the tale goes, he discovered gravity when he observed an apple falling from a tree. That may not have been the whole story, for another—perhaps tall—tale described his flash of insight in a slightly different light. Allegedly, the bystander reconstructed the scene as follows:

> The way I heard the story, Mr. Newton was riding in a surrey through an apple orchard. Wanting one of those juicy ripe red apples, he glanced around and not spying the landowner, jumped down from the seat, only upon landing to twist his ankle. He then uttered, to my amazement, a few choice English expletives that I theretofore heard only from the whiskey-soaked jowls of Bristol dockworkers. He then hobbled over and sat down against one of those apple trees, only to then again slip afoot, poor chap, and bump his head hard against said tree dislodging a ripened apple that, by Providence no doubt, fell and opportunely hit him squarely on the noggin. Such foul words again poured from the mouth of that respected scientist as he raised high his fist as if to challenge the tree-spirit for that rude and unwelcome thumping. He spoke aloud not aware of my presence, "Any more assaults on my body this day will put me in an early grave!" From that episode, the word *gravity* entered the English lexicon and Newton went on to explain mathematically why that apple fell and make several other monumental discoveries.

Now, the Rest of the Story

Building on those lingering painful memories, combined with other observations of the natural world, Newton ultimately derived his universally applicable laws of motion (USOE):

- **First law:** A body in motion tends to stay in motion unless acted upon by an unbalanced force (or a body at rest tends to stay at rest). Inertia is another way to describe this phenomenon. Imagine driving a car and abruptly slamming on the brakes (action). You feel your body continue to move forward (reaction), held in place by the (hopefully) buckled seatbelt's friction between body and car seat, and hands on the steering wheel. Without the unbalanced force, the occupant would remain in motion, until striking or being launched through the windshield, eventually succumbing to the inevitable force of gravity and/or the opposing force of some other fixed object.
- **Second law.** Force is equal to the mass of an object times its acceleration ($F = ma$). Imagine a bowling ball and a soccer ball dropped from the top of a tall building. Which ball would hit the ground with greater force and cause more damage? Common sense might suggest the heavier object. Not so. Gravity accelerates all objects at the same rate (about 32 ft/s^2), so both balls would hit the ground at the same time. The severity upon impact with the ground is a result of the different masses of the two balls. The greater the mass, the greater the force the object imparts on the ground (Figure 1). The third law then takes over.
- **Third law:** For every action there is an equal and opposite reaction. Imagine shooting a shotgun. The recoil kick the shooter feels is the reaction force upon the shotgun and his/her shoulder, which is equal and opposite in magnitude to the force that pushes the pellets. Other examples are a rocket launching, or blowing up a balloon and letting it go—equal and opposite reaction. When the bowling

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ball and soccer ball hit the ground, the ground reacts in kind, though in the opposite direction (Figure 2).

All three laws relate to varying degrees to this "don't jump" message, but the main concerns are the second and third laws—force being equal to mass times acceleration for the downward fall of the body, and that the ground reaction force (GRF) is equal and opposite to the force applied by the body striking the ground (Kwon).

Figure 1

Mass Affects Severity of Impact

What the Research Shows

As youngsters, playing, jumping, falling down and getting back up to do it all again are just part of the same game. Rarely are risk assessments or considerations of adverse consequences from jumping part of the thought process for having fun. Children do not realize that repetitive jumping actually improves the strength of their bones.

Bauer, Fuchs, Smith, et al. (2001) studied the effects of children jumping (drop landing or plyometrics) and reported that mechanical loading from physical activity, with both high forces and high loading rates, promoted bone growth and mineral density at the hip. Athletes who participate in high-impact activities, such as gymnastics, tend to have greater bone mineral density (up to 35% more) at the hip than runners, and at least 50% stronger than the average person. The Bauer, et al. research on children measured maximum GRF from jumping to be 6 to 10 times body weight, with roughly 80% of the resultant GRF dissipated by the hips and low back (Texas Woman's University). In gymnasts, however, the GRF can be as high as 18 times body weight (Seegmiller & McCaw, 2003). That partly explains why competitive gymnasts are typically small in stature, light in weight, strong in relation to height and weight, and young.

The sheer magnitude of the GRF comes in large part from the combined effects of the total mass-times-acceleration product of all the downward moving body segments—that is the total of all net muscle forces and the gravitational force acting at each instant of time from start to finish of the jump (Burnett; Kwon). It is doubtful that a person would survive unscathed beyond youth, or become a gymnast, if the human body did not adapt to those repetitive high-force impacts.

How does the body withstand repetitive impacts up to 18 times body weight and not break down more often? Repetitive shocks from impact landing cause microstrains or tiny fractures in the youthful, still growing, leg and hip bones that quickly heal, even stronger (Milgrom, Finestone, Levi, et al., 2000). This is similar to annealing a piece of metal.

However, risk for injury increases as people age, get more out of shape, and lose muscle mass, strength, flexibility and bone density. As adults, those microstrains continue to occur as people age and continue to purposefully or unavoidably jump down from heights. Adults simply do not heal as fast nor do the bones continue to strengthen. Just the opposite occurs. Add to that potential outcome the inevitable, mostly unavoidable, downgrading effects from the stress and fatigue of daily life, improper diet and similar factors, which further compromise bone density and muscle, tendon and ligament strength in the legs, hips and low back.

Abstract: *Jumping down from heights presents an injury potential. Gravity, in combination with fundamental laws of motion, imparts forces that can reach many times body weight. This article discusses the effects of jumping from heights.*

Several researchers have investigated impact forces from exiting a truck cab and the back of a box trailer (Fathallah & Cotnam, 2000; Fathallah, Gronqvist & Cotnam, 1999, 2000a; 2000b). This research shows that jumping from the cab seat level produced impact forces averaging 6 times—and as high as 12 times—the subject's body weight. Not surprisingly, the lowest impact forces occurred when drivers used available grab-rails in combination with steps. Although the cabs of most commercial vehicles are equipped with

Figure 2

Equal & Opposite Reaction

Force on Lower Back From Jumping

This is a simplified, assumption-laden example of the force imposed on the lower back when a 200 lb 6-ft-tall male jumps down from a height of 4 ft (1.25 m).

A driver jumps to the ground off a truck tailgate, at height *h.* When the driver's feet touch the ground, the driver's knees bend to absorb shock. The driver's body descends a further distance *b* as the knees bend. The following calculations give the average force, not the maximum shock-loading or cumulative effect, on the driver's lower back from the time the feet first touch the ground to the time when the driver is totally at rest.

Since the interest is the force on the lower back, the system to which Newton's second law is applied is the upper body.

1) Gravity (m_1g) pulls down on upper body.

2) The only rigid (actually semirigid) structure between the pelvis and upper body is the spinal column. Thus, it is this structure that applies an upward force, *F,* on the upper body to bring it to rest as the person lands. Newton's second law for the upper body:

$$F - m_1g = m_1a$$

Note that m_1 is the mass of the body above the vertebrae on which the force is calculated. Assuming we are low on the lumbar spine, referencing anthropometric data, we take $m_1 \approx 0.6$ m.

Assumption: the deceleration is uniform during the time the person is coming to rest. (It is this assumption that leads to *F* being the average force.) Then:

$$a = g\frac{h}{b} \text{ and } F = m_1g\left(1 + \frac{h}{b}\right)$$

Example 1: A Perfect Landing

m = 90 kg • h = 1.25 m • b = 50 cm = 0.5 m

Therefore $m_1 = 54$ kg

and

$$F = (54\text{ kg})(9.81\text{ m/s}^2)\left(1 + \frac{1.25}{0.5}\right) = 1{,}854\text{ N (or 417 lb)}$$

It should be noted that the acceleration normally will not be uniform (even for a perfect landing). This means the maximum force is significantly larger than the above number and is likely to be 30% larger (estimate). So:

$$F_{(max)} = 1{,}854\text{ N} + 30\%\text{ of }1{,}854\text{ N} = 2{,}410\text{ N (542 lb)}$$

Example 2: Poor Landing

In a poor or awkward landing, the driver will absorb the shock over a much smaller value of *b*. So take *b* = 0.30 m (could actually be even smaller). The above calculation can be repeated and this gives the average force:

F = 2,740 N (616 lb)

Then the maximum force is likely to be about 3,560 N (800 lb).

Note: *Based on information from M. O'Shea, Kansas State University, Department of Physics, via e-mail correspondence.*

A PowerPoint presentation and companion toolbox talk on this topic is available upon request. Contact the author at william.m.montante@marsh.com.

steps and handrails, drivers may bypass these aids and simply jump down. Surveys of driver practices report that 30 to 50% of drivers at least partially jump out of the cab or the trailer (Fathallah & Cotnam). Drivers may not be aware of the damage they are inflicting upon their bodies—and certainly they are not thinking about gravity or the laws of motion.

The Gravity of the Situation

Like Newton, people are sometimes slow to learn from experiences. Often, people choose to take risks because they are not aware of the potential for harm, or are in a hurry and do not take the time to assess risks and hazards, think about staying in control, or assess the consequences of actions. In addition, there may be situations where there is no easy way to get down from a height.

It is important to realize that the laws of motion apply just as well to the human body as they do to the motion of planets, a rocket blasting off from a launch pad, and cars, planes or any other object that moves slower than the speed of light. When jumping from a height (even a short distance) the pull of gravity, as noted, accelerates body mass downward. Rapidly traversing the distance, the feet first, hopefully, make contact with the ground, which then reacts equally in the upward, opposite direction to resist the body's downward motion.

The resultant GRF vectors up through the feet to the legs, hips and finally is dissipated in the lower back. Muscles, tendons and ligaments along that thrust line absorb some of the shock, yet in turn suffer cumulative wear and tear. These forces transmitted through the lower body combine to impose a shock loading of anywhere from 4 to 12 times body weight—or as noted up to 18 times for gymnasts.

Now let's consider the math. If a person weighs 200 lb, the impact load on the lower body can be more than 800 lb and upwards to 2,400 lb, with every jump. The sidebar at left offers a simplified example of the calculations.

It is also important to remember that the magnitude of GRF and the potential for damage depend largely on how a person lands (i.e., where the center of pressure is under the feet); whether landing occurs with one foot or two, flatfooted or heel-first; whether the body compresses upon landing to absorb the shock; the type of shoes worn; how hard the ground is; whether handrails/steps are used; and several other factors. One study reported that during walking, when leg muscles became fatigued, there was a decrease in flexibility and reaction time, and strains to the tibia increased by about 30% (Milgrom, et al., 2000). Fatigue is certainly a risk factor relevant to truck drivers and most industrial workers. A fatigued driver who must or chooses to jump down from a trailer is at even greater risk for injury. That reality should be sufficient reason to take the time to perform stretching exercises before starting work and throughout the workday.

To further reinforce the rationale for this "don't jump" message, studies by Fathallah, et al. (2000a) showed that when jumping from the seat of a tractor-trailer cab, the impact load on the body, measured by a force-plate, was 7 or more times body weight; from floor level, 5 to 6 times; and from the bottom step, only 1 to 1.5 times body weight (Figure 3). These statistics should make it clear that before making that leap, the closer (lower) the body's center of mass (center of gravity) is to the ground, the better. Forklift drivers should also heed this message when they jump down from the vehicle seat, as should warehouse workers when they choose to jump down from a dock rather than take the longer way and use the stairs. For added perspective, studies by shoe manufacturers Saucony and Z-Tech report heel impact forces ranging from 3 to 3.5 times body weight (Birnbaum, 1999).

Figure 3

Impact Load on the Body

Level 1: Seat—7 or more times your body weight

Level 2: Floor—5 to 6 times your body weight

Level 3: Bottom step—1 to 1.5 times your body weight

Bottom Line

From the perspective of workers' compensation claims, injuries resulting from exiting and jumping from trucks and from heights represent a significant, controllable source of loss. Fathallah, et al. (1999) referenced a 1986 study of workers' compensation claims where of 16 major injury categories, "slips/falls—elevation" ranked fifth in both frequency and cost of claims. Within that major category, "highway vehicles" was one of 49 subcategories that accounted for 8% of all falls and 7% of total dollar costs. The average cost of falls from highway vehicles was 60% higher than the average cost from all subcategories and 56% higher than the average manual materials handling claim.

A decade later, the impact had not changed. "The average cost of a 'fall from a highway vehicle' claim between 1993 and 1995 was about twice as high as the average cost for 'all claims (and twice as much for all manual materials handling claims)'" (Fathallah & Cotnam, 2000). Controlling overexertion/strains from manual materials handling might be the perennial priority for general industry and construction, but when gravity pulls the human body downward at $32\ \text{ft/s}^2$, the outcome is often substantially more severe and, thus, deserves priority attention.

A case in point comes from the author's experience with a beverage industry insurance captive, where in a recent year strain-from-jumping claims were only 2% of total claims and 4% of incurred costs. However, one such claim involving a leg fracture had cost the captive more than $250,000 in workers' compensation indemnity and medical payments. The net percentage of jumping-from-height claims might seem small in comparison to other categories; nevertheless, it represents a controllable loss exposure—one for which effective controls are known, available and relatively inexpensive (Photos 1 and 2). Similarly, and likely more cost effective, would be to conduct periodic education, training and coaching of personnel exposed to or prone to jumping from heights. Simply knowing that with each jump, gravity and GRF combine to strain the body with forces ranging from 4 to 12 times body weight should be sufficient to open eyes and change habits. The message is as clear as gravity is relentless:

- Learn from the observations, laws and the painful experiences of Newton. Do not learn the hard way and end up a statistic.
- Reduce the cumulative wear and tear on the body.
- Take the time to take the few extra steps.
- If jumping down cannot be avoided, a person should first get as low or close to the ground as possible (e.g., sit on the edge and jump from a seated position). In all cases, use handrails, handholds, steps and a three-point contact—but whenever possible simply do not jump. ■

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Trailer modifications can ease entering and exiting. Photo 1 (top) shows handholds and retractable steps. Photo 2 (bottom) shows trailer side door entry step and handhold.