DESIGNING FOR SAFE USE

100 PRINCIPLES FOR MAKING PRODUCTS SAFER

Michael Wiklund
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An introduction to safety

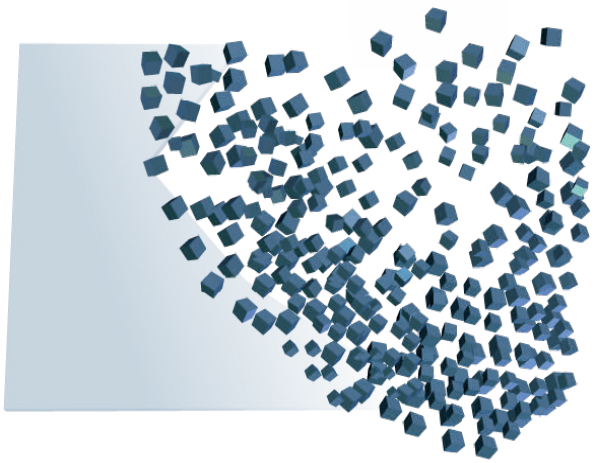
What is safety?

Safety is the result of many factors, including the way people think and behave, characteristics of the environment, and protections against hazards that might be present. In some cases, safety is something that can be objectively measured. In other cases, safety might be subjectively judged, as something being safe or unsafe.

See *Principle 5 - Include pads*

Objectively speaking, a motorcycle helmet offers some protection to a rider in many accident scenarios. The trauma that results in the event that a rider's helmeted head strikes the pavement is bound to be less than if the rider was not wearing a helmet. The added protection can be demonstrated using strain gauges, accelerometers, and X-rays, for example.

Subjectively speaking, a rider is likely to feel safer when wearing a helmet, regardless of whether he or she understands or even cares about the product's specific protective properties (e.g., force vectoring, absorption characteristics). Such is the nature of protective equipment—to be there when it is needed, and otherwise fade into the background or be invisible.



See *Principle 7 - Temper the glass*

For example, glass tabletops can be tempered so that, in the event that someone falls onto it, the glass breaks into lots of little bits, rather than dangerous shards. The fallen person need not be aware of the safety feature ahead of time to benefit from it when it matters most.

That said, people sometimes need to recognize hazards and take care to avoid them. This is the case when safety depends on someone reading a warning (e.g., "Keep hands away from moving gears") or donning a protective device (e.g., respirator). Therefore, safety is not always assured unless people participate in the process of staying safe.

See *Principle 96 - Make PPE available and usable*

Ultimately, product designers have a responsibility to protect the people who come into contact with the product. Users assume that all types of gadgets, devices, tools, equipment, systems, and the like are reasonably safe to use as intended—"reasonable" being the keyword.

But what does "reasonably safe" mean? What is the safety threshold between reasonably safe and not? This is for society and individuals to decide, and the decisions are closely tied to risk perception. If the goal were to achieve absolute safety, there would be no motorcycles, or cars for that matter. There would be no contact sports. There would be no knives with which to slice bagels in half. But, we routinely accept and take risks, including walking down a street that has manholes that we expect to be covered, but might not be.

The hypothesis of risk homeostasis[1] holds that people establish a threshold for themselves with respect to the amount of risk they will accept. This explains why an average skier might fly down the beginner's slope, yet take his or her time on the expert slope, therein accepting about the same risk of an injurious fall. Accordingly, we (society as a whole) tend to invest resources into making things safe enough that users are mentally comfortable with their risk exposure. In some cases, and due to personal standards of care and social norms, we accept considerable risk (e.g., riding a motorcycle), and in other cases, very little risk (e.g., undergoing LASIK eye surgery).

One more dimension of safety to consider is exposure. You assume no risk of head trauma due to a motorcycle accident if you never ride a motorcycle, excepting the case that one hits you. Likewise, you assume no risk of hand amputation due to operating a metal brake (i.e., a bending machine) if you never operate one. Therefore, individuals are already quite safe in view of all the hazards in the world. But, it is not always possible to control when an exposure might occur. Similarly, we cannot always count on people to have sufficient familiarity with hazards and proper precautions to be safe when unexpected exposures do occur. Therefore, designers have the sobering responsibility to make things as safe as practical and, in some cases, as safe as absolutely possible. Notably, the latter option requires what could be significant and essential financial investments (e.g., producing a table saw that includes a mechanism to instantly stop a saw blade if it comes into contact with one's skin). When safety features help bring risk into line with most users' acceptance thresholds, products may enjoy commercial success. Consider the rewards associated with designing for safe use: products can command a higher price, manufacturers can give themselves greater liability protection, and designers can feel good about their work.

Words of encouragement

We encourage you to draw upon this book's principles for safe design to produce—yes—safer products. We also encourage you to draw guidance from other sources (particularly safety standards), use good professional judgment, and follow an iterative user-centered design process that includes user testing (also called usability testing).

1. "About Risk Homeostasis: A Theory about Risk Taking Behaviour." Gerald J.S. Wilde Ph.D., Professor Emeritus of Psychology, Queen's University, Kingston, Ontario, Canada, http://riskhomeostasis.org.

About the book chapters

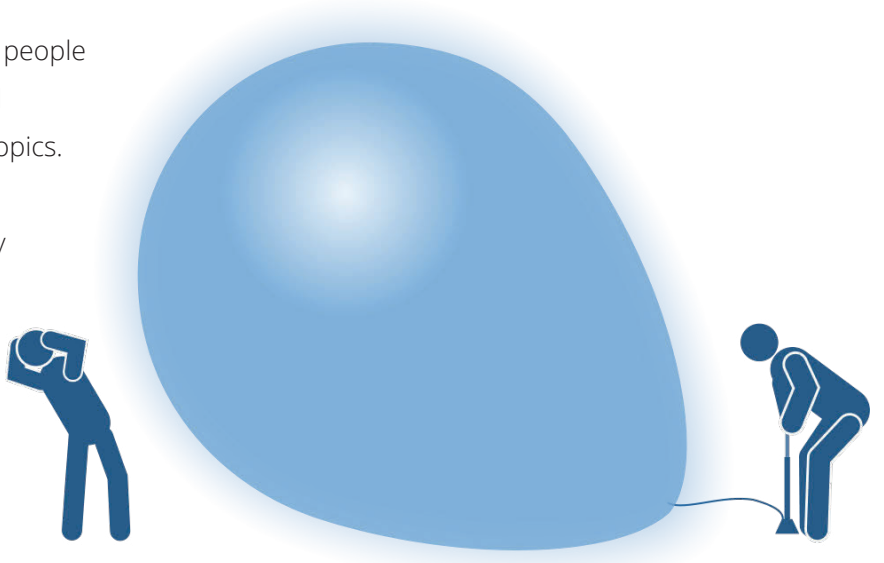
We crafted each of the "chapters" conveying design principles with the following criteria in mind:

- Stay focused on principles that pertain to how users interact with products and how users can be protected against harm.
- Provide some specific user interface design tips.
- Illuminate an aspect of designing safe products that either has broad application, is particularly important to certain types of products, and/or is simply interesting.
- Use photos of real products to illustrate some of our points.
- Make the chapter something we would like to read.
- Include important details that are central to understanding how to achieve safety with regard to the aspect of safety in discussion.
- Use our professional judgment and a synthesis of available information on a topic to make it more accessible to non-specialists.
- Include some "fun facts."
- Be artful.
- Add humor—primarily via graphical depictions—to an otherwise serious subject for the sake of reading enjoyment.

Each chapter is accompanied by an icon, meant to make each principle perhaps just a bit more memorable. On the next page is a small assortment of these icons.

As you delve into the chapters, you might notice that there was a lot to say in words about some topics, while other points were best communicated in a principally graphical manner. So, you will see stylistic variety among the chapters, and you will notice that some chapters are faster reads than others.

We acknowledge and applaud the fact that people with greater subject matter expertise could probably write a book on each of the 100 topics. But, we are pleased with our final product. We hope you enjoy the book and take away some important lessons.




SAFETY SEAL
EXPIRED
OFF
A
B
C
WARNING
PASSED
PASSED

About the exemplars

As “bonus content,” we have complemented the safe design principles with 10 exemplars of designing for safe use. Each exemplar is a showcase—an amalgam of safety features that we found in actual products. However, our renderings of hypothetical products are not intended to represent any actual products on the whole.

Exemplar 1
Car seat

Exemplar 2
Blood glucose meter

Exemplar 3
Tractor

Exemplar 4
Stepladder

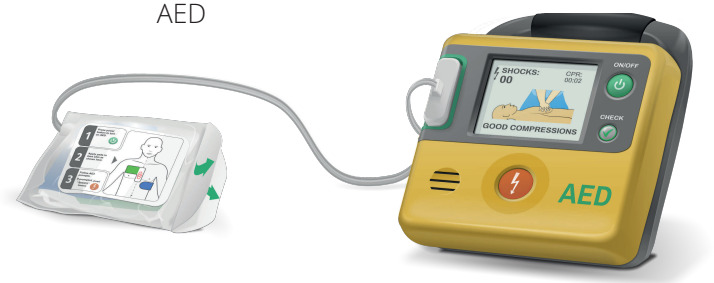
Exemplar 5
Anesthesia machine

Exemplar 6
Chainsaw

Exemplar 8
Steam iron

Exemplar 7
Medication blister pack

Exemplar 9
AED



Exemplar 10
Stretcher

IMPORTANT: We are not endorsing actual products that have one or more of the cited safety features. A particular product's safety must be judged holistically and in view of test data, such as what might be collected through tests involving the given product and its intended users. Even then, there is a need for post-market surveillance to determine if a thoroughly tested product actually performs safely in the real world.

About the endnotes

The endnotes section, which you will find at the back of the book, lists the sources of quoted material and related content that you might wish to access directly. We tried to stay on the correct side of the fine line between referencing sources for uncommon and highly specialized information versus what many people would consider to be common knowledge.

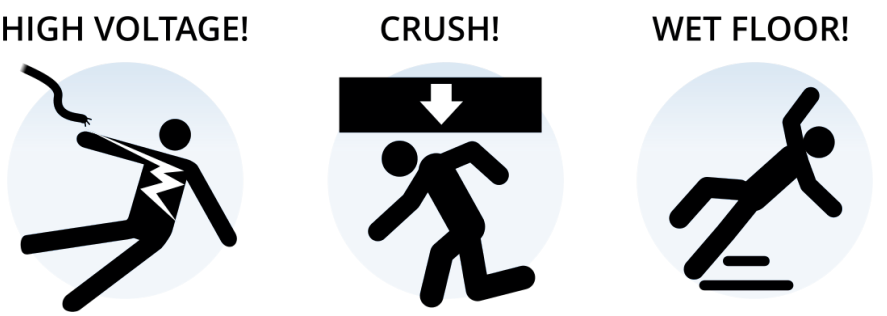
This section also presents credits to the individuals and organizations that generously gave us permission to use their photographs. All other photos were our own or did not require permission.

In conclusion...

A message from SAM (Safety Action Model)

I know what you're thinking: that I look really familiar. That's because you've seen me in lots of warning signs and instruction sheets, giving you a heads-up when there is a hazard in the midst and you need to be cautious.

Some of my classic appearances include:



I show up on many pages throughout this book, helping to identify hazards, which inform principles of designing for safe use. It's my job and I love what I do.

So, don't worry about me. I'm a professional model—technically an Isotype[2]—and it's my job to be exposed to hazards and graphically suffer injuries so that people can stay safe.

My hope, and the hope of the authors of this book, is that our content helps drive efforts to make products as safe as possible so that real people do not suffer the type of real-life consequences that I only experience on paper.

2. "The History of Symbols." Graphic Design History, Designhistory.org, 2012, www.designhistory.org/Symbols_pages/isotype.html.

Acknowledgments

We have numerous colleagues, teachers, friends, family, and others to thank for supporting our book project. Their support took many forms, such as guiding us to be creative, sharing ideas on how to depict safe and unsafe scenarios, commenting on draft content, delivering food and beverages to our workstations, enduring the many hours that we spent on the project rather than socializing with them, and inspiring us to do our best.

PRINCIPLE 1

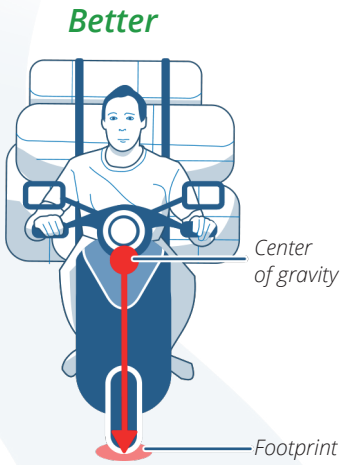
Provide stabilization

Principle

Prevent products from tipping over or falling on someone by adding stabilizing features or securing them to their surroundings.

Know your center of gravity

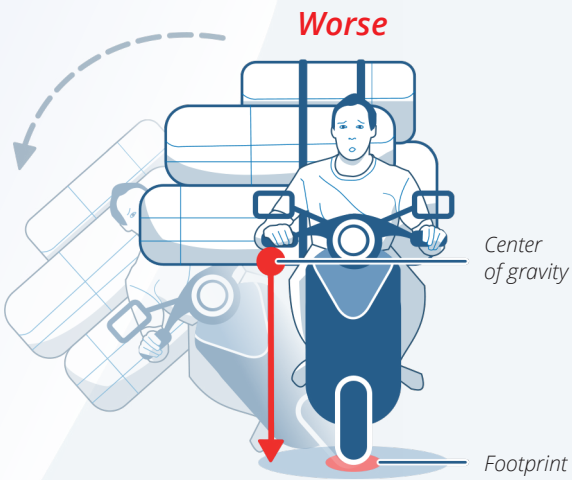
Toppling objects can cause injury as well as property damage. Consider the consequences of a parked motorcycle falling onto a bystander, a ladder falling sideways with a house painter aboard, and a chest of drawers pitching forward onto a toddler who is climbing it to fetch a toy (see *Principle 63 - Childproof hazardous items*). An object is naturally stable when its center of gravity is within its footprint rather than outside of it. Move the center of gravity beyond the footprint (i.e., beyond the area of support) and the result is instability plus the potential to tip over. It also helps to keep the center of gravity low so that applied forces, such as the centrifugal force acting on a riding lawnmower turning sharply, do not overcome the stabilizing forces.



The motorcycle is stable because the center of gravity is within the motorcycle's footprint.

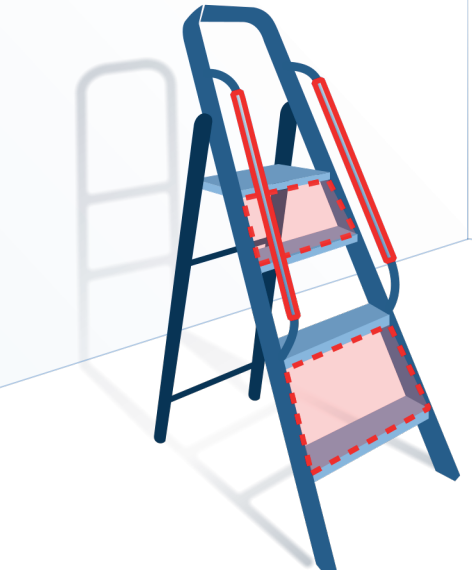
Tip-overs are no joke

Between 2000 and 2013, the US Consumer Product Safety Commission reported that product tip-overs and/or instability led to 430 deaths. They also reported that tip-overs caused an average of 38,000 injuries requiring emergency department visits per year during the period of 2011 to 2013. Most of those injuries (56%) were caused by furniture tip-overs. The most common injuries were contusions, abrasions, and internal organ damage. The most commonly injured body part was the head, followed by the legs, feet, and toes. Children between the ages of 1 month and 10 years accounted for 84% of the reported deaths.[1]



The motorcycle is unstable and prone to tipping over because the center of gravity is outside the motorcycle's footprint.

Never go beyond your footprint



When you add a person into the mix—such as one standing on a stepladder—the key is to keep the person reasonably centered within the footprint, rather than extending past it. In the case of stepladders, railings (see *Principle 32 - Provide a handrail*) help to do this as does making the steps narrower as the height increases. A crossbar-type of hand hold also encourages safe positioning.

Training wheels increase a bicycle's footprint, which helps children keep their balance.

Stability improves as you enlarge an object's footprint without changing other physical variables (e.g., height, weight). That is why an office chair with a five-leg base is inherently more stable than one with a four-leg base.

To prevent tip-overs and still handle heavy loads, lift trucks and cranes have outriggers that extend to increase their footprints so that they remain under the entire apparatus's center of gravity. Outriggers of a sort are also used to stabilize the top of some roofing ladders.

Cranes use extensions (outriggers) to increase the crane's overall footprint and create added stability.

If you cannot keep an item's center of gravity within its footprint, or if forces might overturn the object, then some kind of retention or hold-down device might help. Common examples are brackets and tethers used to keep ovens and chests of drawers/ bookshelves from toppling forward.

PRINCIPLE 2

Make things easy to clean

Principle

Reusable products should be designed to facilitate easy and effective cleaning, sterilization, and/or disinfection.

Clean up nicely

Perhaps the biggest risk associated with things becoming dirty is exposure to chemical and/or biological agents. That's why the food and medical industries have standards for cleanliness and even sterility.

Aside from causing contamination, filth can make labels and warnings illegible, make surfaces slippery when wet, and interfere with mechanical motion. For example, consider the following scenarios:

- A poorly located warning label could be obscured over time by soot from a machine's exhaust pipe or by clippings from a mower's discharge chute.
- A greasy handle could lead someone to lose his or her grip while lifting a heavy object.
- Gears contaminated by dirt could fail to mesh properly, possibly leading to a dramatic mechanical failure or perhaps a motor overheating.

Accordingly, manufacturers of reusable devices should ensure that devices facilitate easy and effective cleaning, as well as any necessary disinfection or sterilization.

Toppings no one ordered

Easy cleaning should also be a priority in the food industry. Restaurants and establishments serving a high volume of customers typically use several devices to help expedite food prep in the kitchen. Unfortunately, some of these devices can have nooks and crannies that harbor guck and unwanted bacteria.

In July 2017, a McDonald's employee was fired after he tweeted pictures of an ice cream machine drip tray filled with mold (see image on left).[1]

FDA and reprocessing

Sobering to those who have undergone or will undergo a related examination, the US Food and Drug Administration (FDA) recently compelled manufacturers of minimally invasive devices, such as duodenoscopes, to develop designs and cleaning procedures to prevent cross-patient contamination.

After a series of illnesses—and in a few cases, deaths—occurred due to accumulated bacteria, the FDA ordered three duodenoscope manufacturers in the US (Olympus, Fujifilm, Pentax) in 2015 to conduct postmarket surveillance studies so the FDA could better understand how duodenoscopes are reprocessed in real-world settings.[2] In a statement to *USA TODAY*, the FDA said it is studying the problem and collaborating with manufacturers to determine whether the cleaning protocols can be revised, or whether obstacles to thorough cleaning require an entire redesign of the scopes themselves. Meanwhile, it is "important for these devices to remain available" because of their "lifesaving" ability to detect and treat potentially fatal digestive disorders.[3]

Based on the duodenoscope-related incidents and studies described above, the FDA updated their guidance on reprocessing medical devices in healthcare settings in 2017.[4]

Ways to make things easy to clean

Eliminate or minimize seams, crevasses, and places for fluids and materials to collect.

Ensure that people can reach areas that require cleaning, and that it is easy to find and access areas that require cleaning.

Use material finishes (e.g., lacquer, plastic coating, anodizing) that enable thorough cleaning without degradation.

Use a color that will make grime visible, highlighting when a device requires cleaning.

Eliminate or minimize the need for special cleaning apparatus, materials, and solutions, but make them readily available if they are necessary.

Eliminate or minimize the need for item disassembly and reassembly in order to clean it.

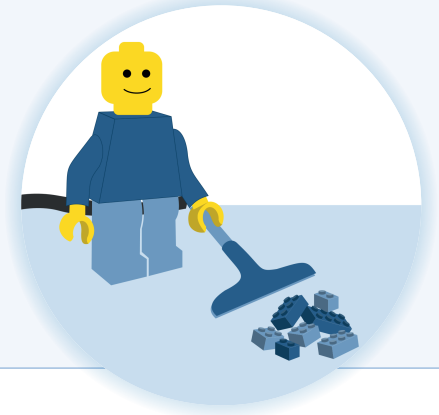
Convey proper cleaning procedures via instructions, a quick reference guide, a checklist, and/or on-product labels.

PRINCIPLE 3

Eliminate small parts from kids' products

Principle

When designing products that will be used near or by children, eliminate small, loose parts or objects that could cause choking.



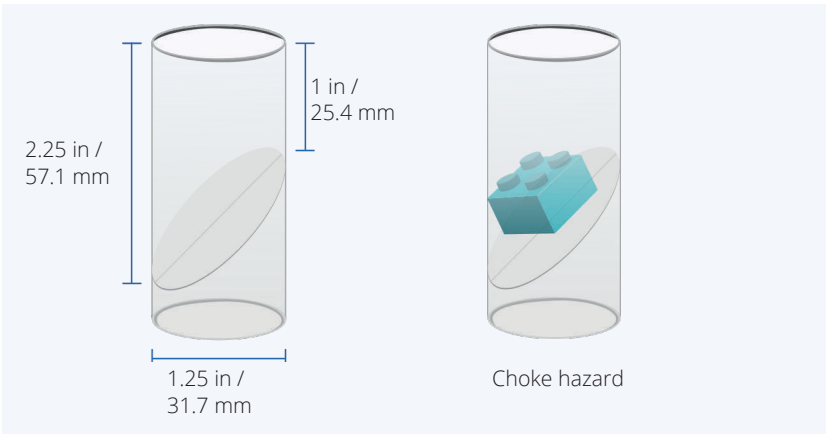
The Small Parts Regulations

Anyone who has small children or who has been around small children knows that children will put almost anything in their mouths. But, loose, small parts are a hazard to young children. That was the evidence-based conclusion drawn by the US Government that led to the Small Parts Regulations - Toys and Products Intended for Use by Children Under 3 Years Old, 16 CFR Part 1501 and 1500.50-53, which is enforced by the US Consumer Product Safety Commission (CPSC).[1]

CPSC states, "This regulation prevents deaths and injuries to children under three from choking on, inhaling, or swallowing small objects that they may 'mouth.' It bans toys and other articles that are intended for use by children under three and that are or have small parts, or that produce small parts when broken."

How do I know if a part is too small?

A part is too small for incorporation into a product intended for young children if it fits completely into a specially-designed test cylinder specified by the CPSC that is often referred to as a "choke test cylinder"[2] (shown on the right). The cylinder is a simple model for a 3-year-old child's expanded throat. If an item fits into the cylinder and is not on a list of exempt items per CPSC (e.g., buttons, chalk, barrettes), it is considered a choking hazard and banned because it could possibly fit down a young child's throat and create a blockage.



The choke test cylinder models a 3-year-old child's expanded throat (left). If an item fits completely in the cylinder, it is considered a choking hazard (right).

Keeping up with the big kids

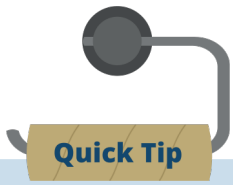
The challenging fact is that children under the age of 3 often play in the same space as older children who have playthings with small parts that are not subject to the CPSC regulation. Also, there are likely to be plenty of small objects in the environment (e.g., coins, keys, pen caps) that are not toys and could also pose a choking hazard. Still, the regulation helps protect young children from the parts of the products intended explicitly for their use.

This symbol must be added to CE-marked toys that contain small parts that are unsuitable for children less than 3 years.[3]

So, manufacturers of young children's products have their "marching orders." No product shall, as an integrated whole or as a separated portion thereof, fit entirely into the simple and clever choke test cylinder. Meanwhile, those designing and manufacturing products for older children and adults should be mindful that their products could get into the hands and mouths of little ones. Therefore, manufacturers should avoid producing unnecessarily small parts that are loose or might become loose. In general, manufacturers should take care to "childproof" products (see *Principle 63 – Childproof hazardous items*).

Here are some ways to prevent small parts from becoming a hazard:

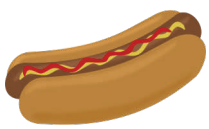
- Permanently tether small parts, like a gas cap to a car's filter port or pens to the desk at a bank.
- Make small parts slightly larger than absolutely necessary so that they do not fit in the choke test cylinder.
- As might be required already, place a warning on the product package to indicate that a plaything intended for older children, for example, is not intended for use by children 0-3 years of age (see symbol above).



Quick Tip

If you are looking for a home-test and do not have a choke test cylinder, some suggest using an empty toilet paper roll. Its diameter is slightly larger than the choke test cylinder, enabling you to err on the side of caution.[4]

Examples of choking hazards

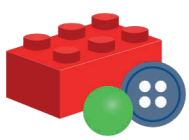


Hot dogs

A hot dog becomes a serious choking hazard to young children because it is "just the right size and consistency to perfectly block the airway."[5]

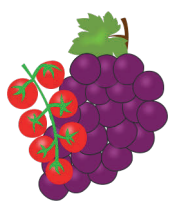
Marbles

Marbles intended to be enjoyed by older children are a choking hazard to young children.[1]



Small objects

Small objects (less than 1.5" in diameter) are reported as particularly hazardous. Such objects include buttons, coins, balls, and building blocks.[6]



Fruit

Cherry tomatoes and grapes can be a hazard, which is why they should be quartered before feeding them to young children (and yes, tomatoes are a fruit).[7]

PRINCIPLE 4

Limit sound volume

Principle

If a product can generate loud sounds ≥ 85 decibels,[1] which can cause temporary or permanent hearing loss or cause severe discomfort, it should incorporate volume-limiting features.

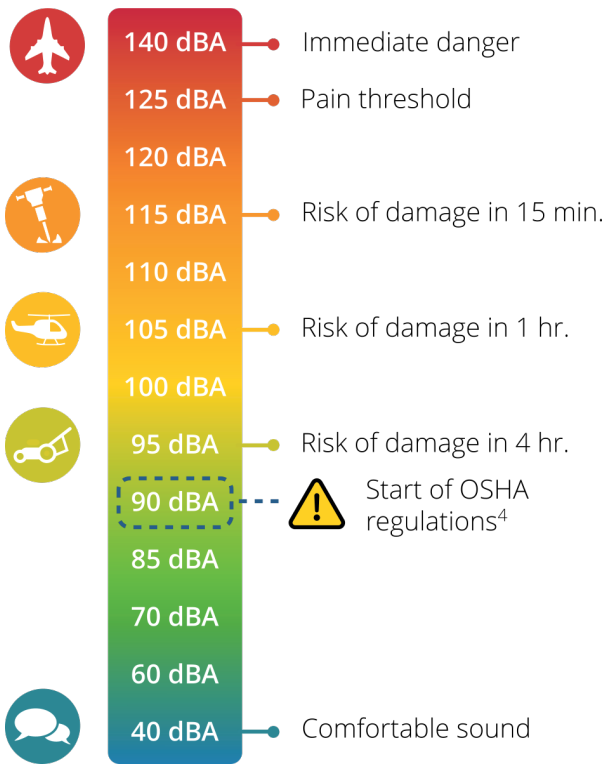
Can you hear me?

Generally speaking (or perhaps shouting), loud sounds are bad for ears. Just as looking into the sun too long can damage one's eyes (causing a condition called solar retinopathy),[2] being exposed to a very loud sound, or even moderately loud sound continuously, can damage the sensitive structures in the inner ear—sometimes permanently. The damage is termed Noise-Induced Hearing Loss (NIHL).[3] This explains why some artillery corps veterans have hearing loss. It also explains why folks who work around loud machinery are encouraged, or even required, to wear hearing protection. Not only can loud sounds lead to hearing loss, loud sounds can also arguably be annoying and disrupt communication.

What generates loud sounds?

Components striking or rubbing against each other, vibrating components, pressurized gas escaping through a nozzle, and cooling fans commonly cause loud sounds that can damage hearing over time.

The US Occupational Safety and Health Administration (OSHA) has established guidelines for occupational noise exposure. The PEL (Permissible Exposure Limit) is based on noise level and exposure time. According to OSHA, hearing damage can occur due to exposure to an 90 dBA sound (e.g., the level of a power lawnmower) for 8 hours per day. The standard also indicates that exposure time should be reduced by half with each noise level increase of 5 dBA.[4,5] So, even being exposed to a very loud sound for a short period of time can cause hearing damage. For example, a nearby lightning strike producing a clap of thunder registering 120 dB can cause permanent hearing loss.[6]



Permissible Noise Exposures. When users are exposed to sound levels that exceed the levels presented above, and sound-reducing controls cannot be utilized, users should make use of personal protective equipment to reduce sound levels to permissible sound levels.[5]

Protection against loud sounds

Wearing Personal Protective Equipment (PPE), such as ear plugs and ear muffs, can protect wearers against hearing loss. So can moving far away from the source. Product developers can also help by designing products to be quieter, either by lowering the amount of sound energy a product generates, or by muffling it. Here are some options:

- Reduce collision forces (that would otherwise produce a very loud sound)[7]
- Add padding that absorbs sound (i.e., passive noise cancellation)[7]
- Dampen the sound with a counteracting waveform (i.e., active noise cancellation)[8]
- Emit sound away from the user

When these sound energy reduction methods are not practical, you can:

- Encase the sound emitter (i.e., create a barrier to prevent sound escaping
- Add a muffler (i.e., silencer) that absorbs some of the sound energy, as in the case of an automobile with an internal combustion engine emitting high-pressure exhaust gases[9]

If it is impossible to reduce the product's sound to an acceptable level, warn users about the noise-related hazard, direct them to wear PPE (see *Principle 96 - Make PPE available*), and indicate the potential harm if they do not heed the warning.

Note that making a product too quiet can also be dangerous. For example, the sound of an engine helps pedestrians detect an approaching vehicle. Therefore, electric or hybrid cars that are nearly silent are sometimes difficult to detect, especially if a pedestrian is visually impaired. It is 40% more likely for a pedestrian to be struck by a "silent" car than by one with a noisy engine.[10]

Noise cancellation

Noise-canceling headphones are a great tool for reducing the consequences of constant exposure to loud sounds, such as those experienced by private pilots in single engine aircraft. Noise-canceling headphones work by using a microphone to detect ambient sounds, and then using electronics in the ear piece to generate noise-canceling waves that are 180° out of phase with the ambient noise waves, effectively "erasing" the ambient sounds.[8] Manufacturers now also apply noise-canceling technology that reduces noise at the source, eliminating the need for people to wear noise-cancelling headphones or hearing protection.

PRINCIPLE 5

Include pads

Principle

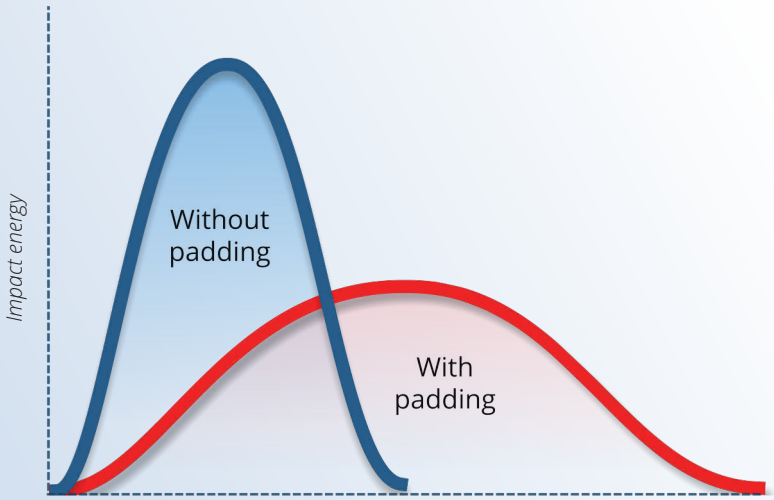
Add padding to protect users from forceful and/or repeated impacts.

Pain, bruises, sprains, and broken bones be gone!

Padding reduces the potential for immediate and cumulative trauma. At least that is the idea behind incorporating padding into many products. However, the padding must be designed properly to ensure it delivers the intended level of protection.

A motorcycle helmet's hard shell is an important defense against the superficial effects of blunt trauma such as abrasions and lacerations. However, it is the helmet's internal padding that diminishes the peak forces applied to the brain—forces that could otherwise cause more severe and lasting injuries. The internal padding extends the amount of time the head (and the brain within) has to accelerate or decelerate depending on the impact scenario, with milliseconds sometimes making the difference between lesser versus greater harm.[1] The idea is to reduce peak forces by dissipating them over a wider area and longer period of time.

Impact force with and without padding

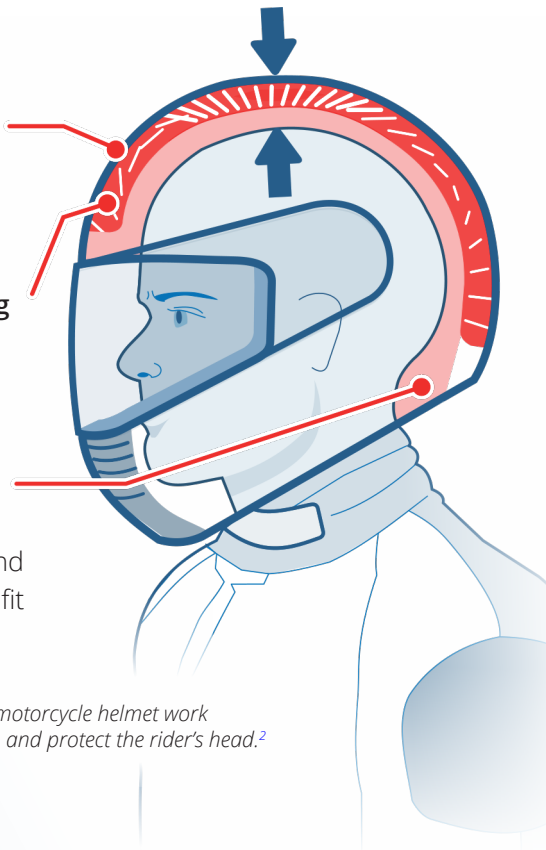


Padding slows down the impact force, spreading the force over a longer period of time and reducing the peak force.[1]

Rigid outer shell
Protects against abrasions and lacerations

Impact-absorbing foam liner
Absorbs most of the impact/force

Interior padding
Absorbs the remaining force and provides a secure fit



Multiple layers inside a motorcycle helmet work together to absorb force and protect the rider's head.[2]