

HUMAN FACTORS ISSUES IN FIREARMS DESIGN AND TRAINING

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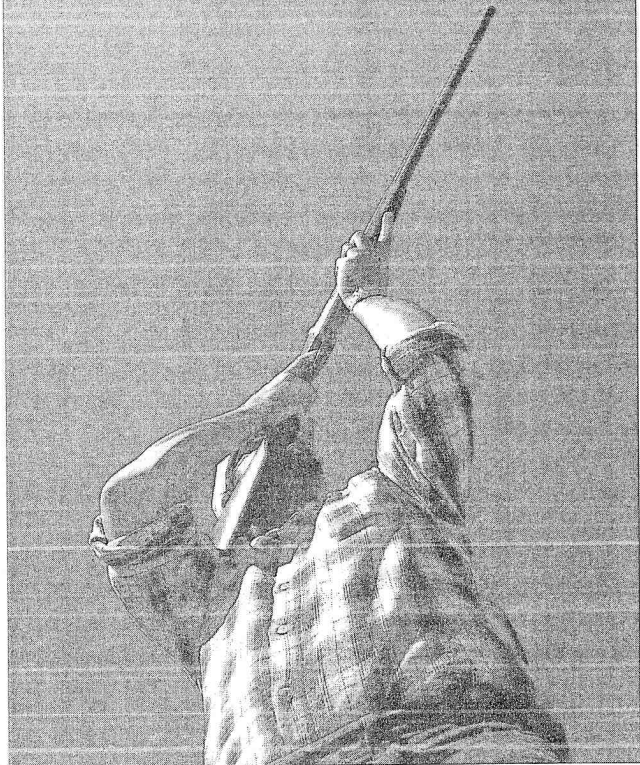
THUNDEROUS GUNSHOTS ECHOED along a mountainside just west of Pike's Peak on a warm Saturday in October 2003. Firing the many weapons were eight human factors specialists who had just attended the Human Factors and Ergonomics Society Annual Meeting in Denver. What were they up to and why?

Few of them had any previous experience in handling firearms. Essentially, these individuals were being trained in all aspects of handling, loading, aiming, and firing firearms by highly qualified trainers. The firearms included many different caliber single- and double-action semiautomatic pistols and revolvers, shotguns, and AK-47s, as well as fully automatic machine guns. This full day of shooting followed many hours of "dry fire" training during the previous day, in which participants had extensive practice with unloaded weapons. All of us were attempting to understand the human factors issues that pertain to firearms that people use and misuse.

This event came about because, along with firearms expert and author Paul Paradis, two of the authors (Hendrick and Hornick) had provided testimony in criminal cases to help juries decide if shootings were intentional or accidental. It appears that an increasing number of human factors experts are serving in such cases.

It is essential that those involved understand the characteristics of firearms relative to human capabilities and limitations. It also seems that society's escalating concern with handgun use offers an opportunity for the human factors/ergonomics (HF/E) discipline to render design guidance, especially for a new generation of firearms just beginning to evolve – guns with electronic brains that "know" their owners and that may not even incorporate mechanical triggers.

Firearms, unlike many tools, lack the standardization of design and training that could greatly reduce unintended injury and death.



This article is a product of the collective training and learning experiences of the authors, including during those days in October. Its purpose is to highlight some of the more obvious areas where HF/E research, principles, and existing knowledge could potentially improve the design and standardization of firearms and related safety training programs.

FEATURE AT A GLANCE: Guns are tools. Like any other tools, they can be either good or poor at achieving their purpose. Here we look at the design and operation of firearms from a human factors perspective. The unique nature of firearms manufacture, their history, and prolonged use brings to the fore several advantages of considering a user-centered perspective. Observations on standardization, the minimization of negative transfer, and the prevention of inadvertent use argue that the human factors/ergonomics community has much to contribute to the production of safe and effective future firearms.

KEYWORDS: weapons design, user performance, negative transfer, operational standardization, inadvertent shooting, instructor certification

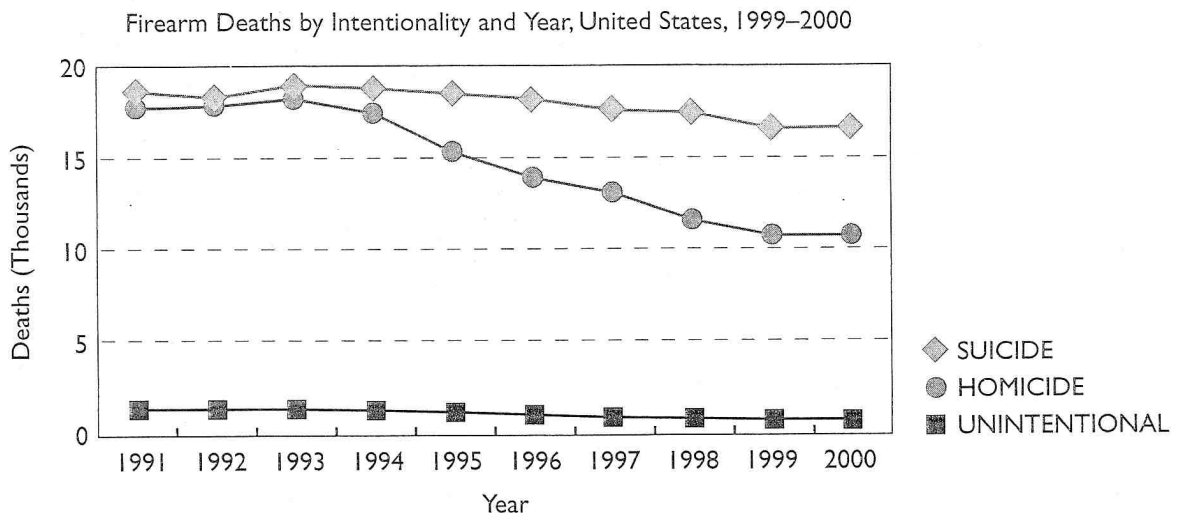


Figure 1. Death rates from firearms for the decade 1991–2000 in the United States. From National Safety Council (2003).

Overall Issues in Gun Design and Use

In modern society, firearms induce a variety of reactions and are the topic of much ongoing social, cultural, and political discourse. Here we do not engage in any part of this debate. Although we recognize and empathize with the various positions and perspectives that have been expressed (see Hancock, 2003), our sole purpose is the consideration of firearms from the viewpoint of their design and operation. Firearms are tools, and like any other tool, they have their characteristic advantages and disadvantages. In this article, we examine these attributes from a user-centered perspective.

The first thing to note about firearms is that conceptually, they are extensions of the hand. Compared with other contemporary hand tools, firearms produced by reputable manufacturers are often effective with regard to their intended purpose even when they are not truly user-friendly

in terms of human factors design criteria. When properly maintained and operated by a trained person highly familiar with a given firearm, the weapon can perform its intended purpose with reasonable accuracy and safety.

However, when viewed from a total systems perspective, a number of human factors design problems are evident that prevent the firearms from fully and safely achieving their purported goals. For example, it is often the case that people miss what they are aiming at. Similarly, in many cases, users inadvertently hit something other than their desired target, sometimes with fatal consequences. In signal detection terms, these events represent both high miss and high false alarm rates and attest to the impoverished utility and flawed design of some firearms purely as tools.

Even if the target is hit, users remain highly variable in their performance and need considerable hands-on training

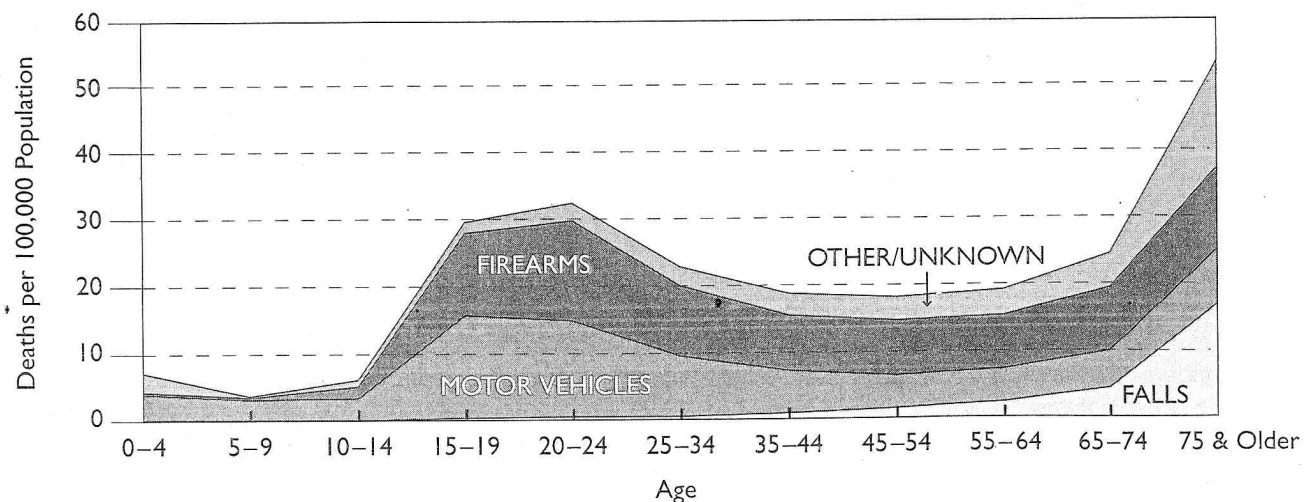


Figure 2. Age-adjusted death rates from traumatic brain injury by external cause and intentionality. Data for the United States 1989–1999. From National Safety Council (2003).

FIREARM CHARACTERISTICS AND HUMAN FACTORS IMPLICATIONS

Feature	Characteristic	Implication
Trigger pull or force	May range from 1 to 2 lbs. "hair trigger" to 12+ lbs.; will vary from hard to soft pull in double-action.	Low force can cause inadvertent firing; large force may make it difficult for small-stature people to use; variation between trigger pulls may induce inadvertent firing.
Handgrip	Vary considerably in size and shape for different purposes.	Fit should be personally made for optimal comfort, handling, and accuracy.
Sighting device	Generally two pieces, one at end of barrel and one at rear end of stock; different designs; some firearms with one sighting device on far end of barrel.	Variations in sighting devices cause negative transfer of training, resulting in initial loss of accuracy until user becomes familiar with sighting characteristics.
Magazine release (semiautomatic handguns)	Permits extraction of bullet container (clip). Vary widely in location and in direction of motion to activate release (up, down, forward, rearward, inward).	Important for disarming gun. Confusion about manner in releasing magazine can lead to accidental discharge. This is another negative transfer-of-training factor.
Bullet in chamber	Some semiautomatic handguns fire with the clip out if a bullet is in the chamber; others do not. Some chambers permit visibility of bullet, others do not.	Accidental discharge is possible when a user has released the clip and believes the firearm cannot be fired or that a bullet is not present.
Safeties	Not present on all firearms. Are intended to keep firearm from discharging if dropped. Some are automatically released when trigger is pulled (e.g. Glock 9mm). Inconsistent coding.	User may put the safety "on" but instead enable the firearm to fire. User may believe that a firearm is safe when it actually will discharge.

to improve their shooting accuracy to a satisfactory degree of competence. This initial assessment leaves aside incidents of misuse in which, for whatever reason; the firearm discharges accidentally or unintentionally and causes inadvertent damage (see Hendrick & Paradis, 2001; Paradis & Hendrick, 2001).

Factors Impeding Firearm Safety and Effectiveness

Given the problems of operation of these tools, it is not surprising that deaths and injuries from gunshot wounds (see Annett, Mercy, Gibson, & Ryan, 1995) represent a considerable fraction of all forms of accidental death and injury, at least in the United States (National Safety Council, 2003, and see Figures 1 and 2). Given these data, it is more than surprising that the power of ergonomics in design has not previously been brought to bear on this topic. Why is this?

Lack of standardization. One probable reason for this overall problem is the industry-wide lack of standardization. It is estimated that there are on the order of 200 million handguns in the United States alone. This inventory varies across so many structural and functional attributes that it is simply

impossible to specify any hard and fast rules as to their modal design and operation. The table above presents a general summary of some of the major human factors features of interest.

A number of human factors design problems are evident that prevent the firearms from fully and safely achieving their purported goals.

Although most firearms do adhere to basic design guidelines such as trigger placement and the location and direction of movement of various parts and controls, enough differences exist so that individuals are often unable to operate a novel firearm without instruction or significant familiarization time. Moreover, the differences between the design of various types and classes of firearms (for example, semiautomatic handguns vs. revolvers, or shotguns vs. assault rifles) can be dramatic, especially with regard to the placement and operation of key features such as the magazine release, action, and mechanical safeties. Sighting systems, for instance, vary enormously, as do

the number and type of safeties incorporated into the weapon. Additionally, almost none of the controls themselves give a clear indication of their intended purpose to a novice user.

Some firearms are antiques and may be even hundreds of years old. Others are recently manufactured and may or may not have had the benefit of some form of human factors input. In addition to this historic variation, firearms may take the form of revolvers, semiautomatic handguns, machine guns, rifles, and shotguns. Unfortunately, even this categorization represents only gross taxonomic differentiation, and other divisions by factors such as caliber are equally valid. Variability is further complicated by the wide variety of weapons using the same type of ammunition (see Figure 3). Into this welter of variability comes a relative intransigence of manufacturers to any form of cross-company standardization. Generally, the result is a societal sector of activity in which tool design has restricted commonalty, when commonalty is a major factor in promoting safety.

Lack of training transfer. One obvious human factors concern that emerges immediately from this cross-firearm variability is the problem of transfer of training. In the firearms world, even similar-looking and, in a fundamental sense, similarly operating weapons have radically different control configurations. For example, on some semiautomatic handguns, the magazine release control may require individuals to push either up, down, forward, backward, or even inward in order to activate the release. There is no standardization on different firearms as to the position of this activator; neither is it color-coded, nor on occasion is it obviously visible! Yet releasing the magazine is one of two crucial safety steps required to ensure the firearm itself is unloaded.

The differences between the design of various types and classes of firearms can be dramatic.

On other models, the user has to pull the trigger as part of the process of breaking the firearm down for cleaning, an action that has resulted in many accidental shootings. Similar design concerns are evident in safeties that are installed to ensure the firearm does not discharge inadvertently. Indeed, this primary line of safety defense against inadvertent use is similarly without standardized function or structure.

Not all weapons have manual safeties; in fact, some firearms manufacturers intentionally design their products without such devices. On those that do have safeties, sometimes when a red spot is showing, this means the safety is activated – in other words, the weapon will *not* fire – whereas on others, this can mean *exactly the opposite*. On revolvers, the cylinder release, which must be used in the unloading process, may require the user to push up (Dan Wesson firearms), push forward (Smith and Wesson firearms), pull back (Colt firearms), or push in toward the center of the frame (Ruger).



Figure 3. These highly varied firearms share one commonality: They all use the same type of ammunition.

Changing between firearms can be a confusing experience, and the problem of regression to previously learned response habits under stress is a crucial issue given the context in which some firearms are employed. Herein lies a rich area for HF/E research to determine a recommended standardized design for safeties and cylinder releases.

It is not only across firearms that negative transfer occurs. Using a semiautomatic handgun in the double-action position, the user might need 12 lbs of pull to activate the trigger, and yet, when the very same gun is in the single-action position, the shooter may need only 5 lbs of pull in order to fire it. To make matters worse, some handguns fire only in single-action mode (e.g., M1911A1 Government Model – Colt, Smith and Wesson, Springfield Armory, etc.), whereas others fire only in double-action mode (e.g., all semiautomatic handguns manufactured by Glock). This can well mean an accidental discharge when the individual is surprised by this within-weapon or between-weapon difference – again, particularly in highly stressful or threatening situations.

One hardly need mention that the absolute differences in trigger force between weapons also causes considerable problems. These vary from “hair triggers,” which can accidentally discharge simply from the action of picking up the handgun, swinging it into position, and automatically exerting pressure on the grip and trigger to overcome inertia and bring the gun to a halt (e.g., see Hendrick & Paradis, 2001, for an actual case example), to excessive trigger pressure, whereby individuals with smaller hands must struggle to activate the trigger with concomitant loss of muzzle control, which can be a particular problem for female users (see Hebert, 2000).

Clearly, there are many tool issues that cry out for the application of known ergonomic, human-centered design principles. In addition, HF/E research is needed to determine whether there should be a generalized standard or different standards for handguns designed for different purposes (e.g., home defense vs. law enforcement). For example, given the range of expected users, what is the optimal trigger force for both single- and double-action firearms, and what should the trigger travel distance be to enable accuracy while avoiding unintentional firing, particularly under high-stress conditions? Whether any such innovations and improvements could be enacted given the present industry conditions is an exercise in both political and marketplace forces.

"I didn't know the gun was loaded." Perhaps the leading cause of accidental discharge of firearms is not knowing whether or not it is loaded. When the varieties of firearms of a similar type are observed from an HF/E perspective, this is not surprising. When the magazine of a semiautomatic handgun is removed, there can still be a bullet in the chamber. Yet, unless users actually pull the slide back and peer into the chamber (something they can be expected *not* to do consistently because of the effort involved, particularly untrained persons), there is no visible indicator of a bullet in the chamber on most (but not all) semiautomatic handguns.

In the case of revolvers, the back of the cylinder often is covered, and in front, the bullets generally are recessed. As a result, with a dark-colored bullet, when the user looks at the front of the cylinder, he or she may think there are no bullets in the cylinder. Also, untrained users often mistake which is the next position on the cylinder to fire. This situation is highly problematic because individuals who do not deal with or handle firearms are likely to be totally unaware of this design issue, which is one of the primary precursors of the accidental misuse of firearms.

Firearms Injuries

When considering injuries associated with firearms, one inevitably thinks about gunshot wounds and shooting fatalities, which are the most serious forms of damage (see Figure 2, page 6). However, these are not the only types of injuries that can occur while operating firearms.

As part of the design of most semiautomatic handguns, the slide automatically retracts to expel the spent cartridge and then automatically loads the next cartridge into the chamber as it returns to its original position. This procedure is powered by the same explosive expansion of gas that propels the bullet down the barrel; this expulsion-reload sequence is accomplished extremely quickly and with a great deal of force. If the user has any part of the hand or face directly behind this return mechanism, it may be struck with great (indeed, explosive) force.

This situation is exacerbated by the fact that many of the surfaces on the moving parts of these guns (such as the slide assembly) are sharp and angular and can easily produce cuts and abrasions. Even when everything works properly, burns

often occur as a result of the expulsion of hot gas from the rear or action of the weapon. Additionally, some weapons have a hammer design that can abrade or pinch the hand during firing. Such force is enough in certain weapons to result in injury to the hand or face, including the possibility of blinding eye damage or finger amputation. Similarly, in some revolver designs, the gases that extrude the bullet from the barrel also escape from the gap on the front side of the revolving chamber. A finger placed too far in front of this area can be seriously burned and further damaged by the physical forces involved.

These are only a few examples of the ways that specific designed-induced injury can occur. Finger injuries are also associated with the act of loading as well as trapping actions inside the trigger guard itself.

If the firearm as a tool can benefit from an overall human factors reevaluation, then consideration of the physical ergonomics of firearm design also is a necessity.

Action in Context

Although it is clear that firearms as tools can be greatly improved (and not merely by the attempt to standardize controls), an overwhelming human factors concern relates to the conditions of operation. Firearms are inherently dangerous. Even when they are not in use, it is advisable to keep them under lock and key and to assume automatically that any weapon is loaded. That being said, it is possible to promote safer use through training and familiarization.

Implementing a mandatory handgun safety training requirement in order to purchase a firearm could greatly reduce the number of accidental shootings.

Additionally, some research has been conducted on the possible benefits of designing weapons that recognize authorized users and will operate only for them. These so-called smart guns may have a great deal to offer in terms of safety if certain technological and reliability issues are resolved (see Weiss, 1995, and Wirsbinski, 2001, for more complete discussions of smart guns). In the context of recreational shooting, the overarching theme must be safety. If enjoyment is the aim, then prevention of untoward events must be the prime goal. However, in the United States and some other countries, handguns are carried by both police and civilians for self-defense, and in this context, other factors come to prominence (Klein, 1992).

Many human factors interventions can lead to the improvement of the design of a tool, but firearms, like many vestigial technologies, will be around in their various forms for a long time. Given that century-old weapons are still in circulation and – more important – that 100-year-old firearm designs are still in use and manufacture (e.g., the Browning M1911 .45 automatic is used by many elite law enforcement

and military units, and the Browning M2 .50 machine-gun is still the primary heavy machine gun of the U.S. military), one should anticipate that such prolonged life spans for particular firearms will continue into the future. This means that firearms differ radically from virtually all other modern technologies whose rapid development renders older versions quickly obsolete. Rather like vintage cars, older firearms are collected for their historic value, but there is also a very active and sometimes illegal market in usable firearms, whatever their age.

Another deficiency in current training is the failure to adequately teach about the nature of high stress and how it affects the operator.

This concatenation of circumstances means that even if significant design improvements were enacted today, their effect could easily take decades to be fully felt. This concern does not mean that we should not try. Right now, an opportunity does exist to promote ergonomically designed firearms for the future. In particular, a new generation of smart guns, including fully electronic handguns, is being developed by major handgun manufacturers. Various methods exist or are under development for identifying the user, including both mechanical magnetic and electronic means (and see Weiss, 1995; Wirsbinski, 2001).

Issues in Training

If one cannot change the tool to have an immediate effect on firearms safety, one must retrench to the human factors professional's second line of defense: training. From the authors' collective experiences, particularly that of Paul Paradis, in investigating hundreds of accidental shootings, almost all were found to have occurred with persons who either had never taken a formal firearm safety course or had taken the course many years ago and it consisted of questionable content. The 2003 HFES Annual Meeting workshop alluded to in the beginning of this article provided first-hand experiential support for the importance of handgun safety training to those attending (see Figure 4). Participants were greatly impressed by what they learned, especially previously unknown facts about handgun design and safe firearms handling, along with all the safety techniques and procedures that they did not know prior to that training.

It is evident that although the right to own weapons in the United States is jealously guarded, the necessity for a comparable level of training is not as visible. It is sad but true to note that no training is required in most states to purchase a firearm. This state of affairs is lamentable, especially considering that the learning curve on firearm operation is so steep. We believe that implementing a mandatory handgun

safety training requirement in order to purchase a firearm could greatly reduce the number of accidental shootings – particularly if the quality of the training was high. Unfortunately, much improvement also is still needed with respect to both training content and training instruction.

Content issues. Currently, the National Rifle Association (NRA) provides the most widely available courses in handgun safety (see NRA, 1991). However, the NRA's safety course for handguns intended for self-defense in the home did not come into existence until 2000. Thus, most of the tens of thousands of people who had handgun training prior to 2000 were not adequately trained in the safe use of home-defense firearms.

Although it contains much excellent content, even the current NRA 2000 "Personal Protection in the Home" course has areas in which we feel improvement is still needed. One such area concerns the requirement to qualify only with a single handgun; exposure to a variety of handguns is important to appreciate their differences in design and operation. Paradis and Hendrick (2001, 2003) have investigated numerous unintentional shooting cases in which familiarity with the characteristics and safety features of one handgun were incorrectly assumed by the user to characterize the handgun involved in the incident.

Another deficiency in current training is the failure to adequately teach about the nature of high stress and how it affects the operator physically, perceptually, and emotionally (see Hancock & Desmond, 2001) and how each of these factors can lead to accidental shootings. Again, the majority of cases of accidental shootings we investigated have involved high-stress situations (Hendrick & Paradis, 2001). We have also mentioned other areas for improvement, such as a lack of standardization of what constitute the fundamental principles of pistol marksmanship across even the various NRA firearms courses, never mind others; and the inappropriate

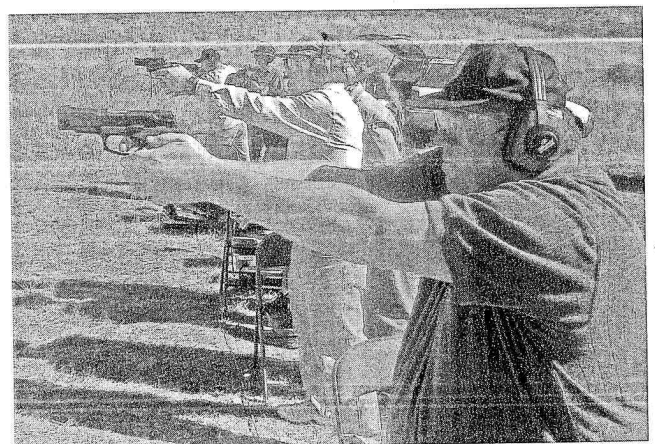


Figure 4. The first author is shown shooting under the direction of firearms expert and coauthor Paul Paradis at the firearm safety training course in Colorado, October 2003. Note the establishment of the firing line for safety.

biomechanical positioning advocated in the 2000 "Personal Protection in the Home" course manual (see Paradis & Hendrick, 2003, for further discussion).

Instructor selection, training, and certification. At present, a macroergonomic deficiency of handgun training programs is the system of instructor selection, training, certification, and recertification. There is no standardization of instructor training programs, and the content around the country varies widely. Similarly, there is no formal system of instructor selection, certification, and recertification. The methods for developing and implementing effective selection, training, and proficiency certification systems are well known in the human factors and industrial and organizational psychology professions and could be implemented as part of the NRA training programs or separate systems.

Unlike in the human factors/ergonomics discipline, there is no national professional association of firearm instructors. If one were to exist, it could help to raise the standards of both firearms instruction and the quality of handgun safety programs. We believe establishing such a professional association could have a positive impact on handgun safety training.

Summary and Conclusions

Whatever side of the gun debate one is on, one has to begin from the realities of the present circumstances. The current state of affairs is that many millions of weapons of greatly varying age are already in circulation. Although the contemporary application of HF/E principles may serve to help refine and shape future firearms, such as the new generation of smart guns, it can do little to reengineer the present inventory. In such a circumstance, the primary user-centered response strategy is structured training.

The aphorism that "guns don't kill people – people do" is insufficient to the case, given that in many circumstances, it is untrained individuals who find themselves the subject of prosecution and persecution for the incorrect use of a poorly designed tool. Inadvertent damage causing death and injury is equally possible using a one-ton metal vehicle or a one-ounce metal bullet. However, at present in the United States, it is far more likely that the latter will be prosecuted while the former will, in some sense, be seen as less blameworthy (Hancock, 2005). Each may be the result of the misuse of a less-than-optimal tool, but society treats these human-tool interaction failures in radically different ways.

We do not pretend to possess all the answers to such complex issues as these, or indeed to solve the moral conundrum as to our science's involvement in weapons production in general (see Hancock, 2003). However, our primary purpose here is to bring to readers' attention the fact that firearms are tools and therefore ought practically to be the subject of human factors concern and user-centered design requirements, including associated firearms training systems. How and where such inputs may exert an impact await future developments.

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