# Lessons from 35 years of PPE selection, evaluation, design and standardization

Jean ARTEAU

*Département de génie mécanique, École de technologie supérieure ÉTS*
*1100 ouest rue Notre-Dame, Montréal QC Canada H3C 1K3*

**Abstract.** To protect, personal protective equipment PPE shall be as safe as possible and always worn by all workers. The PPE user-friendliness is essential for an effective use. Even if PPEs are legally mandatory, employers and workers shall be convinced that a specific PPE is the one to be worn always by all workers for a task. Workers' psychophysical perceptions of comfort, interference with the tasks and safety when performing their tasks in a controlled environment similar to the real work environment, correlated with physical, mechanical, biomechanical and physiological measurements are a good tool for the global evaluation of PPE. The success is a combination of political involvement, joint employer-employee partnership, work and tasks analysis, risk assessment and independent evaluation based scientific methods.

**Keywords:** personal protective equipment, selection, evaluation, design, criteria

## 1. Context

Personal protective equipment PPE are mandatory by the laws and regulations. In Canada, laws, regulations and standards are linked by a legal process named incorporation by reference (Arteau 2015b). In Europe, PPE are made mandatory by the directives and the mirror national legislations (Council Directive 89/656/EEC and 89/686/EEC). To protect, PPE shall be as safe as possible and always worn by all workers (Arteau Giguère 1991, 1993). Therefore the effective use of PPE by workers in the workplace needs a detailed assessment. Even if PPEs are mandatory by the laws, employers and workers shall be convinced that a specific PPE is the one to be worn always by all workers for a task. The employers' expectations are that the selected equipment will be the correct one the first time and they will not have to pay again and again for inappropriate equipment. The workers' expectations are that equipment will be comfortable without interference with the tasks. Thus several criteria shall be met. Pitfalls are numerous and should be avoided.

From the major lessons learned, risk analysis (dangerous phenomenon, dangerous situations), criteria and strategies to achieve a successful implementation of a PPE program are presented. The criteria then a methodology are presented.

## 2. Criteria

In 1983, three basic evaluation criteria were developed: effectiveness, reliability and user-friendliness for the evaluation of a fall arrest harness (Giguère Arteau 1985;

Arteau Giguère 1991, 1993). A major conflict was identified: safety vs comfort. A PPE is worn 100% of the time while its effective use is less than 0.01% of the time when an accident occurs. The European Directive 89/686/CEE on PPE stipulates in articles *1.1.2.1 Highest level of protection possible* and *1.1.2.2 Classes of protection appropriate to different levels of risk* that a lesser protection can be completely acceptable and even desirable to favour an effective wearing. The standard EN 13921-2007 recommends "the reasonable balance between the gravity of the dangerous phenomenon, the protection, the constraint and the duration" (Desjardins-David Arteau 2011 and Arteau et al 2015b). This reasonable balance is summarized by the equation

*Global protection = P·N·D*
*where P: protection level*
*N: number of workers using the PPE*
*D: duration of effective use of the PPE / duration of the exposure.*

It is better to have a PPE with P=95% (1 injured person over 20 accidents) worn by N=100% during D=100% PND=95% than a P=100% worn by N=50% during D=50% PND=25%. To maximize PND, is needed an effective, reliable and user-friendly PPE. User-friendliness is defined as the facility of training, of use and of integration to the task as well as comfort during the normal execution of the task. This criterion is thus important to maximize N and D of our equation.

Later Desjardins-David expended the evaluation criteria (Desjardins-David Arteau 2011). This methodology is based on four categories of evaluation criteria with a process to evaluate and validate each of those criteria. The 4 categories are: Performance, Supplies, Physical comfort, and Psychological comfort. They are divided in 18 sub-categories. Performance: Efficiency, Reliability, Durability; Supplies: Availability, Accessibility, Cost, Maintenance, Durability; Physical comfort: Adjustment, Thermal Comfort, Freedom of movement, Interferences and Psychological comfort: Look, Conviviality. The Cost is also divided in: acquisition, maintenance, storage, replacement. The criteria are exhaustive with their conflicts and covering the different preoccupations of all actors in the industry. Therefore it is possible to make arbitration between the different possibilities and obtain a consensus from everybody involve in the PPE selection. It is also a very efficient methodology because each criterion needs to be evaluated and validated during the different steps. The methodology could be used to apply EN 13921-2007 (Arteau et al 2015b).

## 3. Methodology

Several PPE were evaluated (see references). The methodologies were designed to evaluate or to observe the performance, the physical comfort and the psychological comfort. For new equipment or a new application of an existing PPE, the performance was firstly tested in laboratory. New test methods were created for the vest-harness (Giguere Arteau 1985; Arteau Giguere 1991), for a wood pole fall arrest system (Arteau et al 1997) and then integrated in Canadian standards. Existing tests were modified to evaluate the performance of mountaineering PPE in new uses for arborists (Arteau et al 2008). When the performance was demonstrated, the user-friendliness could be evaluated by workers doing typical tasks in a controlled environment and giving their psychophysical perception on self-answered questionnaires. The experimental design compares a complete spectrum of

equipment (as examples Arteau et al 2019a, 2019b). Also each criterion is not always evaluated by only one test; the laboratory tests measure the mechanical strength and performance while the evaluation with workers in doing tasks measures the user-friendliness and the interaction PPE-worker.

## 4. Results

### *4.1 The vest-harness*

The vest-harness evaluation showed that the performance (efficiency) seems to be demonstrated by a dynamic drop test of the vest-harness fit on a rigid mass and then on articulated manikin, the test methods in harness CSA EN ISO standards. But when the comfort in suspension was tested by several human subjects having different anthropometry, the vest-harness did not maintain suspended ectomorphic and endomorphic subjects. The biomechanical interaction human–harness was shown only with humans because an articulated manikin represents one somatotype. The efficiency is more than mechanical strength. A pass at all criteria is mandatory (Giguere Arteau 1985; Arteau Giguere 1991).

### *4.2 Horizontal lifelines HLL*

Horizontal lifelines HLL as fall arrest system were used in steel erection at a large scale for the first time in 1988 (Arteau 1991; Arteau Lan 1993; Arteau Lan Corbeil 1994). Their efficiency and mechanical strength were demonstrated by laboratory tests and field tests. Based on these results workers could be confident to use them. The great success of HLL was largely a consequence of their user-friendliness and lack of interference with the tasks.

The HLL allows the worker great mobility while minimizing his involvement in two actions, attaching and detaching himself during an entire work sequence on a bay or a complete wall. The degree of activity defined as being the number of action performed by a worker to make a protective system effective is very small compared to the traditional harness-lanyard-anchor system.

The HLL system represents savings as compared to the net with respect to price and maintenance cost. Ironworkers and riggers can carry out maintenance by evaluating the condition of the cables, and by repairing the anchor struts as needed, because all these system components are made of materials with which the workers are familiar. Nets made of synthetic fibers, however, deteriorate rapidly under the action of ultraviolet light and require periodic laboratory tests. At the end of the work, the HLL system is disassembled and reused.

Since the HLL system is installed by the first workers (the connectors) and remains in place, it is used by the other ironworkers (i.e., bolters and welders), and is rented to the other firms such as those installing the steel deck, pouring the concrete, and doing the painting. In addition, the perimeter cables are integrated into the guardrail. The lack of obstruction in the center of the bay allows bolts and tools to be carried from the ground or a lower floor and raised directly. Since the HLL is supported at a height of 0.8 m from the upper flange, it is used as a handrail and a reference point to provide better balance for the ironworkers. Furthermore, workers feel safer, feel more secure moving around, their production improves, and they tire less quickly. Similar benefits were observed with billboards (Lan et al, 1994, 2004)

### *4.3 Wood pole fall arrest system*

In Quebec, electric distribution lines are aerial lines attached to wood poles. The distribution network on wood poles extends on more than 97.000 km and is made of 2.500.000 poles to serve 2,8 million customers. Linemen climb poles with spurs penetrating the wood while they are supported by work positioning pole strap attached to a belt. Falls could occur. Several fall arrest systems exist. In combination with the pole strap, they choke around the pole and stop the fall. A proposed system was tested for its efficiency, reliability and user-friendliness (Arteau et al 1997). The test protocol based on the criteria (section 2) gave a complete answer. But the proposed system failed on efficiency, reliability and user-friendliness.

### *4.4 Climbability and hardness of woodpoles*

As written in 4.3, wood poles are largely used for electrical distribution and telephone lines, around 3.000.000 wood poles. Several wood species and preserving treatments harden the poles. The hardness of the poles became a contentious question. 1.500.000 poles are used jointly by the electricity company and by a major telephone company; the basic cost of the poles was $6\times10^9$ cdn dollars ($4\times10^9$ Euro). During the project, pole hardness, gaff penetration, deceleration (impact), muscle activity and hardness perception were measured. A strong correlation with a coefficient of determination of 95% was observed between impact by the gaff penetration during descent and the linemen's perception of hardness (Beauchamp et al 1999). The pole hardness issue was solved. The workers' perceptions are reliable. As possible, independent physical, biomechanical or physiological parameters will be measured to correlate the workers' perception. (For further results, consult all references on climbabiliy). This project was possible because of the involvement of the two companies.

### *4.5 Working at height and fall protection for arborists*

Fall protection has made large progress in Quebec. The arborists had difficulties to integrate fall protection in their work: firstly, a great variability of trees; secondly, unfruitful trials to create systems by combining PPEs not necessarily compatible used in construction, industry, rescue, climbing, mountaineering, speleology. The efficiency and the reliability were evaluated by mechanical tests done in laboratory. The user-friendliness evaluations were performed in controlled environment in urban forests and parks of the city of Montreal (Arteau et al 2007, 2015a). A harness was designed. The mechanical efficiency and compatibility of equipment was tested. Several systems were evaluated for their user-friendliness in many environments allowing the users to select the ones most suitable in a precise context. A similar project was done for rebar installers (Arteau et al 2008, 2019a, 2019b).

## 5. Conclusion

The reviews of many cases illustrate the reasons behind successes and failures during the last 35 years. The involvement from the higher management and from the worker representing associations is essential. Selection criteria were validated. Workers' psychophysical perceptions of comfort, interference with the tasks and

safety when performing their tasks in a controlled environment similar to the real work environment, correlated with physical, mechanical, biomechanical and physiological measurements are a good tool for the global evaluation of PPE. Certain projects were not carried out because of political or managerial decisions external with the applicants of the projects. The success is a combination of political involvement, joint employer-employee partnership, work and tasks analysis, risk assessment and independent evaluation based scientific methods.

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