Effectiveness of personal protective equipment in working with pesticides – a systematic review

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Abstract. This paper presents the findings of an ongoing project developed in collaborations with SC Medinet HC Services SRL that addresses the occupational safety issues related to handling toxic substances, with emphasis on personal protective equipment in working with pesticides. INCDPM together with SC Medinet partner carried out an extensive literature review of existing published relevant materials, textbooks, journals, conference papers found in Science Direct Freedom Collection, Elsevier database, Web of Science - Core Collection, Springer Link Journals, that were processed with PRISMA method (Preferred Reporting Items for Systematic Reviews and Meta-Analyses).

1 Introduction

During their job, toxic substances can enter the body of the pesticide handling workers through four routes of exposure including dermal (skin), ocular (eyes), ingestion (mouth) and inhalation (lungs). Skin contact is the most common cause of pesticide poisoning for applicators and some pesticides enter the body through the skin quite readily. At the time of mixing, pesticides are more concentrated and the likelihood of injury is increased during this time. Exposure to hazardous chemicals in various sectors of use is a cause of occupational diseases. Skin diseases rank high in the list of occupational diseases, but typically these refer only to local effects caused by chemicals. In recent years, systemic dermal exposure under consideration of percutaneous absorption and personal protective equipment (PPE) has moved into the focus as well. Gloves represent the most widely used type of dermal PPE (against both local and systemic exposure), but other types of PPE, such as suits, aprons, boots and goggles are also used. Sometimes, protective creams are used instead of protective gloves or clothing [1].
Assumptions on the magnitude of the protective effect of PPE are generally based on considerations of the material used and the breakthrough times reported for specific chemicals. In this context, permeation of chemicals (i.e. transition of the chemical through the barrier itself on a molecular level) can be distinguished from penetration (i.e. transition of the chemical through needle holes, seams etc.) [2]. However, these terms are often used interchangeably in the literature. They are also very difficult, if not impossible, to separate

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in studies at workplaces. Apart from chemical permeation or penetration through PPE, several other factors are meanwhile acknowledged to have an impact on the effectiveness of dermal PPE, such as the specific scenario considered and the handling of PPE [3,4]. Overall, the effectiveness of dermal PPE can be affected by factors, such as:
- The properties of the PPE, also in combination with the properties of the substance: form/type of the PPE and material properties, e.g. glove length, material thickness [5]; use of new or already used PPE [6].
- Properties of a substance: State of the substance at process temperature; Volatility of the substance.
- Work tasks and processes: exposure pattern and dermal loading (aerosol, splashes, immersion etc.), type of application (e.g. direction in spray applications), use frequency and exposure duration, conditions of use, instruction and training of workers, compliance by workers [7].

From the above state-of-art we can see that influencing factors can be roughly categorised into operational conditions, task description and related parameters, substance parameters and user behaviour and training. And because parameters of these categories certainly have an effect on the exposure to pesticide itself and they can also influence the efficiency directly, the goal of the paper was to cover also the parameters representing the user behaviour and different levels of training, which is a novelty. We also include in this paper a list of the most important PPE used in working with pesticide.
The advantages brought by our approach are that the information gathered in the course of these studies may be used to develop a two-step model that can be applied for calculating final protection factors by implementing parameters representing the user behaviour and different levels of training.

2 Method

For this paper it was used The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) [1]. The PRISMA 2020 items are relevant for mixed-methods systematic reviews (which include quantitative and qualitative studies).
A literature search was conducted in ScienceDirect Freedom Collection, Elsevier database, Web of Science - Core Collection, Clarivate Analytics, Scopus, SpringerLink Journals. Keywords such as Personal Protective Equipment for pesticide, toxic substances in rodent control, Personal Protective Equipment for pesticides, pest control job hazard analysis were used to retrieve relevant studies which explicitly reported on Personal Protective Equipment for handling pesticides. The searches were limited to English and Romanian languages only. The PRISMA checklist was used to validate the research process [8]. In addition, a number of web pages were searched for "grey literature" such as project reports or other information. Examples are the web pages of TNO, HSE /HSL and the US EPA. Search strategies were similar to the one described above, however, had to be adapted due to the variable nature of the search engines available.
The titles and abstracts of the search results were screened independently by all authors with discrepancies discussed and resolved.
Articles were eligible for full-text screening if the title and/or abstract mentioned Personal Protective Equipment for handling toxic substances. Full-texts were screened for inclusion by all authors disagreements resolved by discussion. Research studies that made use of previously collected or administrative data were also acceptable if they satisfied other criteria. Studies were excluded if they were published before 2000.

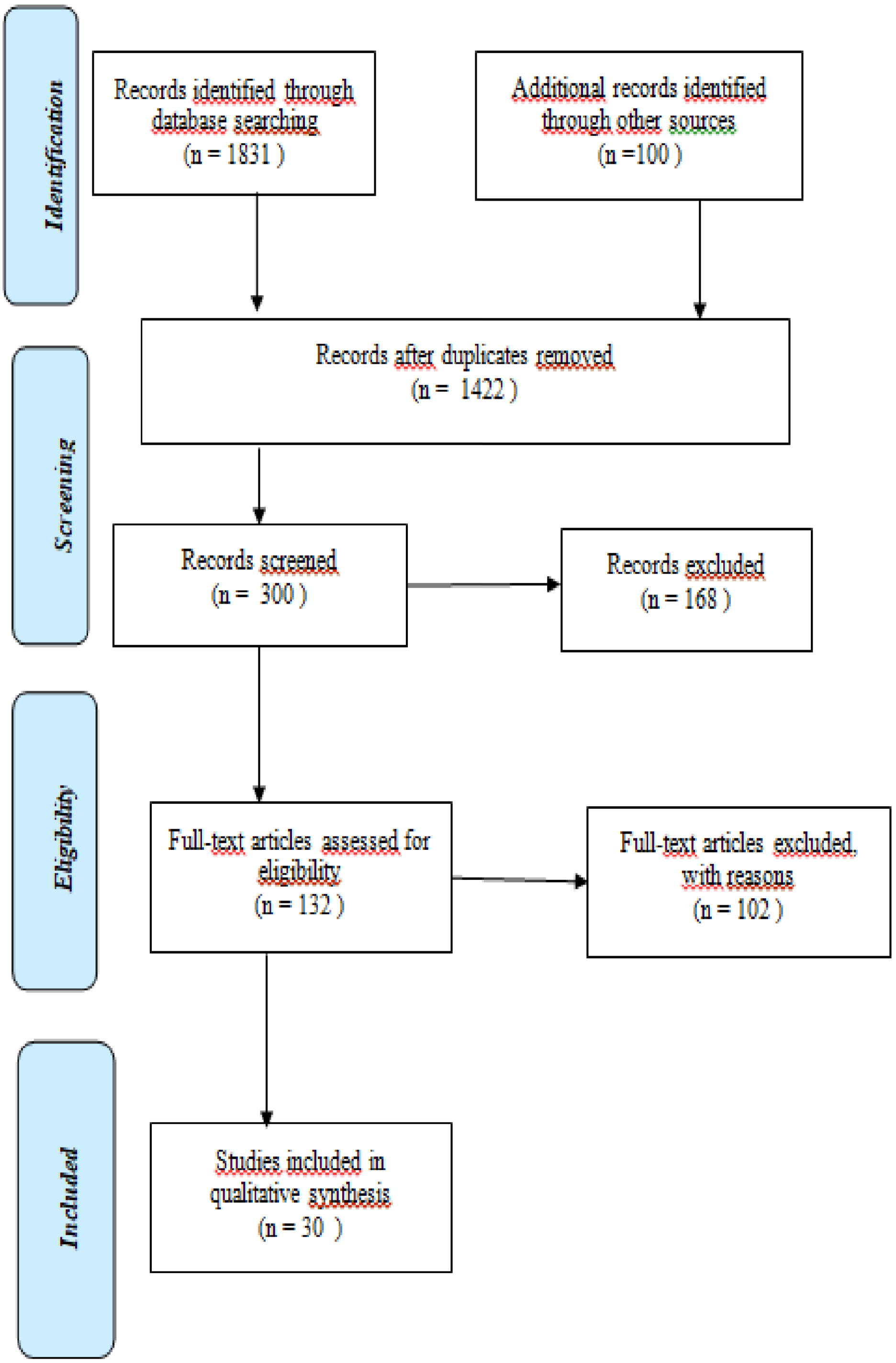

Fig. 1. PRISMA flow diagram

3 Results and discussion

The literature search yielded 1831 references, of which 132 articles were selected for full-text screening as specified by the inclusion criteria, and ultimately 30 were included in this review (Fig. 1).

Our analysis of available published data shows that the data measuring PPE effectiveness are still scarce and correspond to a limited number of exposure scenarios. These data show that recommending the wearing of PPE does not always result in effective protection. Also, nearly all articles addressing the wearing of PPE, whether in exposure studies or PPE performance studies as such, have observed that a great many PPE field use conditions do not correspond to what is assumed in the regulatory provisions and its marketing authorisation. Preliminary hypotheses concern the influences of educational level, social status, working relations, and the availability of such equipment to workers.

Field observations show that actual wearing of PPE is well below stipulated recommendations, although it varies according to type of task. This is a widespread observation in studies where wearing practices are uncontrolled and addressing protective cover all use issues, even in European countries where conditions might seem to be the most favourable. [9] - [32].

A large number of studies was identified that can theoretically be used to derive an exposure reduction efficiency value. The highest numbers of datasets were identified for gloves and whole body garments. However, the range of efficiency values for each category of personal protective equipment is large and it is hardly possible to identify a reason, why certain studies lead to higher or lower efficiency results. The transparency of the various publications is often low, resulting in data gaps concerning PPE properties and the assessed scenario. It is often not known if the PPE in question can be considered appropriate for the situation and the assessed substance.

Only few publications evaluating the methodology of PPE efficiency were found, leading to mostly inconclusive results concerning sampling method and study design. However, as it is already known that variability in dermal exposure can be induced by different sampling methods, an influence on efficiency results seems likely. Additional variability can be added by different ways of evaluating the raw data. As an example the exposure data can be reported in different units (e.g. mg/cm^2, $mg/cm^2/h$) or differ concerning statistical evaluation (evaluation of single efficiency values to derive efficiency values vs. average exposures used for derivation of efficiency value). Thus, overall the available data are able to give a general idea on efficiencies that can be expected for certain types of PPE (Table 1).

In addition, various, isolated pieces of information about aspects influencing efficiency have been identified, such as:

- the challenge of exposure (deposit),
- personal behaviour or
- PPE characteristics (e.g. glove length, use status (old vs. new)).

However, a detailed differentiation and evaluation of the factors which are necessary to reach a specific efficiency value has not been possible. Thus, although isolated pieces of information could be identified a full understanding of the summarised efficiency values is not possible and comprehensive advice leading to a specified efficiency cannot be given.

One of the aspects that are essential for PPE efficiency is the ability to function as a barrier against a challenging substance. The material can be passed either on a molecular level by permeation or on a more macroscopic level, i.e. through pores, holes, damaged material, seams etc. by penetration. A number of studies focus on the evaluation of these barrier properties.

Regarding in vitro studies (with animal or human skin samples) dealing with permeation or penetration of chemicals through dermal PPE, no general conclusions on protection factors can be derived. The main reasons for this finding are that a) these studies do not reflect real-life work scenarios and b) barrier efficiencies identified in these study types differed vastly (0-100 %) - depending on: the respective material tested, the chemical investigated and the experimental set-up.

Table 1. Default effectiveness values for dermal PPE - gloves.

Effectiveness	Description	Context
Gloves		
80%	Chemically resistant gloves conforming to EN374	REACH (ECHA, 2012), ECETOC TRA (ECETOC, 2012)
90%	Chemically resistant gloves conforming to EN374 with basic employee training	
95%	Chemically resistant gloves conforming to EN374 with specific activity training; industrial users only	
90%	For challenges by a liquid	BPR, HEEG Opinion 9 (EC, 2010)
95%	When new gloves for each work shift are used	
95%	For challenges by a solid	

Table 2. Default effectiveness values for dermal PPE – protective clothing.

Effectiveness	Description	Context
Protective clothing		
50%	Non-professionals wearing long-sleeved shirt and trousers or skirt with shoes; no gloves worn	Biocides, HEEG Opinion 9 (EC,2010)
75%	Uncoated cotton coveralls; only for dry substances	
80%	Coated coveralls (coveralls designed to protect against spray contamination such as chemical protection clothing of type 6); e.g. spray application of insecticides (PT18), but may also be adequate for other scenarios for other PTs	
90%	Coated coveralls (coveralls designed to protect against spray contamination such as chemical protection clothing of type 6)	
95%	Impermeable coveralls; the challenge is 'considerable' (i.e. $\geq$ 200 mg in-use product/minute) on the whole of the body, not including the hands	
99%	Double coveralls, typically e.g. worn during spraying of antifouling products (long-sleeve, long-leg cotton coverall with a second coverall with a hood worn over the cotton coverall); outer coverall should be chemically resistant if exposure is to wet paint, spray mist or solvents	

HEEG Opinion 9 clarifies that using the default effectiveness values for gloves assumes "that the worker has a good occupational hygiene approach in his/her behaviour and uses, where appropriate, gloves with long sleeves to prevent exposure via the openings around the wrists. It is also assumed that gloves are taken off carefully, without touching the outside of the contaminated gloves with bare hands" (EC, 2010).
Similarly, ECETOC TRA assumes that 'specific activity training' (95% effectiveness for gloves) can only be considered in the industrial setting, but not for professional workers (ECETOC, 2012). The differentiation between the effectiveness levels in ECETOC appears to primarily reflect different levels of training/management. In contrast, HEEG Opinion 9 (EC, 2010) assumes a high level of training for all effectiveness values for gloves, the differentiation rather reflecting different states of a substance, with an additional input of new versus used gloves.
While the scope of default of effectiveness values for dermal PPE in the areas of chemicals (REACH) and biocides (BPR) shows some differences, the scientific basis of these default values and their justification is limited. In this context, an analysis of measured data on the effectiveness of dermal PPE at workplaces is considered helpful to substantiate or disprove the default values shown in Table 1. For example, dermal exposure measurements with and without dermal PPE can be used to derive values for the effectiveness of the dermal PPE in place. Most of such measurements were performed during the use of agricultural pesticides and non-agricultural biocides, such as antifouling products and wood preservatives. This fact in itself limits the resulting values to specific type of application and conditions of use (often spray or brush applications performed outdoors) and to specific substances (active substances are generally non-volatiles).

4 Personal Protective Equipment used in working with pesticide

4.1 Gloves

When handling hazardous substances, it is best to always wear unlined, elbow-length chemical-resistant gloves. The elbow-length protect worker's wrists and prevent pesticides from running down the sleeves into the gloves. Glove materials include:

- Natural rubber (latex) - only effective for dry formulations. Relatively Permeable.
- Nitrile - good protection for both dry and liquid pesticides. Moderately permeable.
- Butyl - good protection for both dry and liquid pesticides.
- Neoprene - good protection for both dry and liquid pesticides, not recommended for fumigants.
- Polyethylene
- Polyvinylchloride (PVC)
- Barrier laminates. Relatively impermeable.

The quality of construction and material before buying any glove must be checked because efficacy varies with the manufacturer. Protection increases with the thickness of the materials, but extra thick gloves may interfere with dexterity. Never use fingerless gloves. Never use leather or cotton gloves. These types of gloves can be more hazardous than no protection at all because they absorb and hold the pesticide close to the skin for long periods of time.

The proper glove use is as important as selection. The gloves must be check closely for holes by filling the gloves with air or clean water and gently squeezing. The gloves must be destroyed if any holes appear or wrapped in a plastic bag and put with an empty pesticide container for proper disposal. In the case of where the worker hands are reaching up (such as changing nozzles), turn glove cuffs up to form a cup to trap any liquid that runs down the arm. When finished spraying, the gloves must be washed with detergent and water before remove them. This way, will not contaminate the hands or the inside of the gloves when removed. After removing the gloves, the hands must be washed with lots of soap and water.

Not all glove materials will give the same level of protection. Some materials will last longer against certain types of pesticides and chemicals. They will be highly, moderately or slightly chemical resistant.

4.2 Body Covering

Regular work attire of long pants and a long-sleeved shirt, shoes, and socks are acceptable for slightly toxic (category III- Caution) and relatively non-toxic (category IV - Caution) pesticides. Many applicators prefer work uniforms and cotton coveralls that fit the regular-work-attire description and provide equal protection. Applicators should reserve one set of clothing for pesticide use only. Launder and store separately from all other clothing.

To apply moderately toxic (category II - Warning) or highly toxic (category I - Danger or Danger-Poison) chemicals, it must be wear a clean, dry protective suit that covers the entire body from wrists to ankles. The sleeves must be long enough to wear over gloves. Openings, such as pockets, should be kept to a minimum. Protective suits are one- or two-piece garments, such as coveralls, and should be worn over regular work clothes and underwear. Protective suits may be disposable or reusable and are available in woven, nonwoven, coated and laminated fabrics. Since pesticides can work their way through clothing fibres, the degree of protection increases as one moves from woven to nonwoven and from coated and laminated fabrics. The manufacturer's label must be read for specific information related to care and intended use. Good quality construction, proper fit, and careful maintenance or disposal are also important.

Woven fabrics provide a barrier of fabric and air between the wearer and the pesticide but the effectiveness of the barrier depends on the specific properties of the fabric. Tightly woven, cotton twill offers better pesticide protection than other woven fabrics. Cotton coveralls are a sensible choice for general use because they are comfortable, lightweight, readily available, reusable, and affordable. They reduce the risk of dermal exposure to pesticides in dust, granule, or powder form but they do not protect the wearer against spills, sprays, or mists and are not recommended for use with liquid pesticides. Cotton coveralls may be reused if washed properly.

Nonwoven fabrics have a random orientation of fibres which do not allow direct paths through the material. Coveralls of nonwoven fabrics are less comfortable than coveralls made of woven fabric and precautions should be taken to avoid heat stress situations. Most nonwoven suits are disposable; they should be discarded after eight hours of use.

Uncoated nonwoven fabrics are convenient for use with pesticides in dust, granule, or powder form. They do not protect the wearer against spills, sprays, or mists and are not recommended for use with liquid pesticides and should not be worn when using chlorinated hydrocarbons.

Fabrics can be made more resistant to pesticide penetration by laminating fabric layers and/or by applying chemical coatings. Chemical - resistant protective suits of coated or laminated fabrics are a must if the worker will be in a mist or spray that would wet his clothing. Coated and laminated fabrics resist water penetration, but not all of these fabrics qualify as chemical resistant. Chemical-resistant suits are recommended when handling highly toxic (category I) pesticides.

4.3 Apron

When repairing or cleaning spray equipment and when mixing or loading it is important to wear a chemical-resistant apron. This is a good practice for all pesticides and is essential for pesticides of category I and II toxicity. Aprons offer excellent protection against spills and splashes of liquid formulations, but they are also useful when handling dry formulations such as wettable powders. Aprons can be easily worn over other protective clothing and are comfortable enough for use in warm climates. Choose an apron that extends from the neck to at least the knees. Some aprons have attached sleeves. Nitrile, butyl, and neoprene offer the best protection. PVC and natural rubber are also available.

4.4 Boots

When handling or applying moderately or highly toxic pesticides it must be weared unlined chemical-resistant boots which cover your ankles. Nitrile and butyl boots appear to give the best protection. Do not use leather boots. If chemical-resistant boots are too hot to wear in warm climates or too difficult to put on, try wearing chemical-resistant overboots with washable shoes (such as canvas sneakers or layered socks.) Remember to put your pant legs outside the boots, otherwise the pesticide can drain into the boot. Wash boots after each use and dry thoroughly inside and out to remove all pesticide residue. Use them only for pesticide applications. It is wise to keep two pair of boots on hand in case of accidental contamination. Wash socks and canvas sneakers worn under chemical-resistant boots just like you would pesticide contaminated clothing.

4.5 Google or face shield

Whenever the chemical could possibly contact the workers eyes it must be wear a shielded safety glasses; a full-face respirator; snug-fitting, non-fogging goggles; or a full-face shield. Safety glasses with brow and side shields are acceptable for low exposure situations. Always wear goggles or full-face respirator when pouring or mixing concentrates or working in a highly toxic spray or dust. In high exposure situations when both face and eye protection are needed, a face shield can be worn over goggles. Clean them after each use. Be careful of the headband; it is often made of a material which readily absorbs and holds chemicals. Have several spares and change them often or use a chemical-resistant strap. If possible, wear the strap under your head covering.

The hair and skin on your neck and head must be protected too. This is most important in situations where exposure from overhead dusts or sprays is possible, such as hand-spraying uphill or when flagging for aerial applications. Chemical-resistant rain hats, wide brimmed hats, and washable hard hats (with no absorbing liner) are good. In cool weather, chemical-resistant parkas with attached hoods are a good choice. If the attached hood is not being used, tuck it inside the neckline so that it will not collect pesticides. Do not use cotton or felt hats; they absorb pesticides.

Disposable gloves or shoe covers should be used only once for a very short-term task, and then discarded. First wash the PPE, and then remove them by turning them inside out. Then dispose of them properly.

4.6 Respirators

Respirators protects from inhaling toxic chemicals. The label tells if a respirator is required. Consider wearing one during any lengthy exposure with a high risk of pesticide inhalation. Always wear a respirator while mixing or filling highly toxic pesticides. Applicators who will be constantly exposed to small amounts of moderately toxic pesticides for a day or several days, should also wear a respirator. Air-purifying respirators remove contaminants from air by filtering the air. In the majority of situations where a pesticide applicator will need a respirator, an air-purifying respirator will provide adequate protection. These respirators will not protect the applicator from all airborne pesticides, such as fumigants, and are not to be used when the oxygen supply is low. The pesticide label will specify which type of respirator must be worn.
Air-purifying respirators can be categorized into four styles; cup-shaped filters, full or half-face piece style with cartridges, full or half-face piece style with a canister and the powered air-purifying respirator. The filtering face piece respirator, must be worn when the pesticide label requires one and when the risk of inhaling pesticide dusts, powders, mists, aerosols, or sprays is present. These cup-style dust/mist-filtering respirators are usually made of stiff fabric that is shaped like a cup. It is worn on the face and covers the nose and mouth and filters out dusts, mists, powders, and particles. Pesticide handlers must wear cup-style or cartridge-style dust/mist-filtering respirators. A respirator that also removes vapours must be worn if the pesticide label requires it and when there is a risk of inhaling gases or vapours. Respirators with full or half-face face piece and have one or more cartridges that contain air-purifying materials can meet this requirement. This face piece style also comes with a large canister that contains more air-purifying materials than a cartridge does. This style must seal tightly against the face. A fit test is necessary before using a cartridge or canister respirator for the first time.
Pesticide applicators will be given directions on the label for the proper respirator and cartridge. Organic vapour (OV)-removing cartridge respirators will list a choice of either an N, R or P filter or prefilter. Respirator filters/prefilters will be designated as "N" (meaning no oil resistance), "R" (oil-resistant for 8 hours) or "P" (oil-proof, may last longer than 8 hours). This means that "R" and "P" respirators assure that oils will not degrade filter efficiency. Respirator cartridges will have an efficiency designation of 95, 99 or 100. A type 95 is 95% efficient while a type 99 is 99% efficient and the type 100 is the most efficient and equivalent to the old HEPA filter. The type 100 respirators will be designated "HE" (high efficiency) and will be used with powered air-purifying respirators.

5 Conclusions

Our analysis of available published data shows that the data measuring PPE effectiveness are still scarce and correspond to a limited number of exposure scenarios. A large number of studies was identified that can theoretically be used to derive an exposure reduction efficiency value. The highest numbers of datasets were identified for gloves and whole body garments. However, the range of efficiency values for each category of personal protective equipment is large and it is hardly possible to identify a reason, why certain studies lead to higher or lower efficiency results. Also, nearly all articles addressing the wearing of PPE, whether in exposure studies or PPE performance studies as such, have observed that a great many PPE field use conditions do not correspond to what is assumed in the regulatory provisions. Preliminary hypotheses concern the influences of educational level, social status, working relations, and the availability of such equipment to workers. Field observations show that actual wearing of PPE is well below stipulated recommendations, although it varies according to type of task. This is a widespread observation in studies where wearing practices are uncontrolled and addressing protective cover all use issues, even in European countries where conditions might seem to be the most favourable. There is, however, evidence confirming that in studies in which PPE wearing practices are uncontrolled, PPE does not always fulfil the protective role attributed to it in marketing authorisation procedures. Analysis of the available literature shows that many gaps exist between work safety in theory and the complexities of real practical conditions. These gaps are all sources of risk for people. It is important to take them into account and include them in regulations concerned with preserving the health of workers.

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