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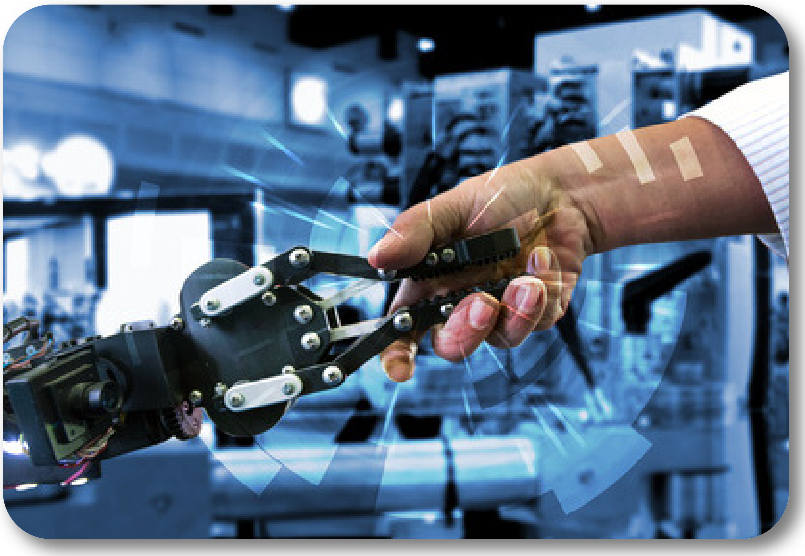

Prevention in the field of collaborative robotics

Synthesis of identified work at the international level

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comprendre les risques professionnels en Europe
understanding occupational risks in Europe

PREVENTION IN THE FIELD OF COLLABORATIVE ROBOTICS

SYNTHESIS OF IDENTIFIED WORK AT THE INTERNATIONAL LEVEL

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Glossary (terms with* in the text)

BGIA/IFA	Institute for Occupational Safety and Health of the German Social Accident Insurance, called IFA from 2010 (Germany)
CETIM	Centre Technique des Industries Mécaniques (France)
DGT	Direction Générale du Travail (France)
DGUV	Deutsche Gezetzliche Unfallversicherung (Germany)
DLR	Deutsches Zentrum für Luft- und Raumfahrt (Germany)
HSE	Health and Safety Executive (Great-Britai)
HSL	Health and Safety Laboratory (Great-Britain)
IFR	International Federation of Robotics
INRS	Institut National de Recherche et de Sécurité (France)
IRSST	Institut de Recherche Robert Sauvé en Santé et Sécurité du Travail (Quebec)
JNIOSH	National Institute of Occupational Safety and Health (Japan)
KAN	Kommission Arbeitsschutz und Normung (Germany)
MSDs	musculoskeletal disorders
TNO	Netherlands Organisation for Apllied Scientific Research
TUV	Technischer Überwachungs - Verein (Germany)
EU	European Union
OSH	Occupational safety and health

Contents

Preface

Collaborative robotics is a branch of industrial robotics which aims to develop robots capable of interacting with human beings in industrial processes. The human being and the robot thus share the same work area to carry out all or part of their tasks, whereas a "conventional" industrial robot is characterized by its physical remoteness and the fact that there is no collaboration with a human being.

Given the implications of collaborative robotics concerning changes in work organization, the work area and operator health and safety, but also the difficulty of its implementation, various actors, including OSH experts, have guided this technological development. This guidance has materialized in different ways depending on the country, taking the form of information, studies or guidelines.

In **France**, for example, in 2017 the Ministry of Labour published an OSH guide to the integration of collaborative robotics applications[1]. Produced by a working group bringing together representatives of industry, the users, inspection organizations and standardization experts, this guide aims to summarize the regulatory obligations of the various economic stakeholders and to propose a methodology for the implementation of risk analysis for collaborative robotics applications. It ends with a concrete case study illustrating the concepts mentioned earlier.

In **Germany**, the *Deutsche Gesetzliche Unfallversicherung* (DGUV) has published numerous documents relating to collaborative robotics, particularly on the issue of robot/human contacts. Among these, we can mention a document of recommendations[2] by the *Institute for Occupational Safety and Health of the German Social Accident Insurance Organization* (BGIA), published in 2009 and revised in 2011, which aims to provide a list of requirements for safely setting up work stations in a collaborative environment. However, the document remains focused on the issue of robot/human contacts which is covered by several studies[3] and which had led, in particular, to the introduction of contact thresholds in ISO/TS document 15066:2016, *Technical Specification providing guidelines for application of the EN ISO 10218-2:2011 standard*.

More recently, in 2015, an information document was published by the DGUV[4]. More general in its approach, it summarizes the legislation and regulatory obligations, the incidence rate in the industrial sector and the functioning of the standardization bodies, and it deals specifically with the case of collaborative robotics in its Section 5 where basic OSH concepts are introduced.

In the **United Kingdom**, in 2012 the *Health and Safety Executive* (HSE) published a study[5] aiming to assess the protocols and the methodology used to introduce contact thresholds into

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1 "Guide de prévention à destination des fabricants et des utilisateurs pour la mise en œuvre des applications collaboratives robotisées" (2017), French Ministry of Labour - An English version should be available soon

2 "BG/BGIA risk assessment recommendations according to machinery directive - design of workplaces with collaborative robots" (2011), BGIA

3 "Kollaborierende Roboter - Ermittlung der Schmerzempfindlichkeit an der Mensch-Maschine-Schnittstelle" (2014), DGUV
"Entwicklung eines Kraft-Druck-Messgerätes zur Messung und Bewertung von Mensch-Roboter-Kollisionen" (2014), DGUV

4 "DGUV Information 209-74e - Industrial robots" (2015), DGUV

5 "Collision and injury criteria when working with collaborative robots" (2012), Health and Safety Laboratory (HSL)

the draft version of ISO/TS 15066. Moreover, within the framework of its HSE *Centre for Shared Research*[6] platform, the HSE has initiated a research project aiming to answer a number of key questions in order to improve safety in the implementation of collaborative robotics applications.

In the **Netherlands**, in 2016 the *Netherlands Organisation for Applied Scientific Research* (TNO) published an information document[7] summarizing a large quantity of research concerning the technical and social implications of robotics. The document is for the purpose of risk prevention, and describes the risks to be taken into account before the integration of a collaborative robotics application. It outlines the procedure to be complied with in order to ensure employees' safety. In this sense, it is fairly similar to the guide published by the *Direction Générale du Travail* (DGT: National Directorate of Labour) in France, although it does not precisely propose a methodology to be complied with.

In **Canada**, the OSH research institute *Institut de recherche Robert-Sauvé en Santé et en Sécurité du Travail* (IRSST) in partnership with the *Institut National de Recherche et de Sécurité* (INRS) in France has published a scientific report[8] giving occupational safety recommendations for working out collaborative applications. The report deals in particular with the use of safety functions at the robot level and their implementation in practical case studies. Accordingly, several companies were contacted to provide experience feedback concerning allowance for safety in the integration of collaborative applications in Quebec.

In **Japan**, in 2015 the *Japan National Institute of Occupational Safety and Health* (JNIOSH) published a note[9] describing the various risk prevention measures applicable to collaborative robotics. The objective for the JNIOSH is, ultimately, the publication of a Japanese guide concerning risk prevention in the use of collaborative robotics. The JNIOSH has also published various research work for the design of methods and tools to minimize the hazards involved in the use of collaborative robots[10].

On the **European Union** level, the Commission has published a brochure describing the EN ISO 10218-1:2011 and 10218-2:2011 standards, specifying the safety requirements for the integration of industrial robots and industrial robot systems, and aiming to describe all the important information contained in said standards, without necessarily offering a critical analysis of them.

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6 For further information: https://www.hsl.gov.uk/blog/2017/09/13/the-cobots-are-coming-but-will-they-be-safe/

7 "Emergent risk to workplace safety as a result of the use of robots in the workplace", TNO report (2016)

8 "Robotique collaborative – Evaluation des fonctions de sécurité et retour d'expérience des travailleurs, utilisateurs et intégrateurs au Québec", IRSST scientific report (2017)

9 "Global harmonization of safety regulations for the use of industrial robots - permission of collaborative operation and a related study by JNIOSH" (2015), JNIOSH, Tsuyoshi Saito & Toshiro Hoshi & Hiroyasu Ikeda & Kohei Okabe

10 "Proposal of Inherently Safe Design Method and Safe Design Indexes for Human-Collaborative Robots" (2005), Hiroyasu Ikeda & Tsuyoshi Saito
"Development of a normally closed type of clutch using magnetorheological suspension for safe torque control of human-collaborative robot" (2008), Tsuyoshi Saito & Hiroyasu Ikeda

Introduction

This note aims to summarize the main ideas stressed in various work carried out regarding collaborative robotics and the risk prevention measures that could be implemented. Although in these studies the stated objectives and expectations of the various market stakeholders may diverge, it turns out that the risks identified are largely the same. And yet, societal issues involving collaborative robotics and increased interaction with human beings are apparently not neglected.

In general, each country that has researched the issue of collaborative robotics endeavours to establish risk prevention methodologies and make them available to the various market stakeholders. However, it appears that this research is only in its early stages, and few works propose thoroughly suitable tools. Finally, some of these studies report on the current state of the market regarding the coverage of collaborative robotics in the installed industrial base and its incidence rate.

1. Overview: stated expectations, objectives and opportunities

For the manufacturers and market stakeholders who have expressed their views in the various reports and studies, collaborative robotics represents a range of interests and opportunities.

From the economic viewpoint, first, it provides a gain in flexibility for production facilities, improving the firm's competitiveness. In particular, a collaborative robot can take charge of low-value-added work while the human being focuses on work requiring greater expertise, thus finding a compromise between mass production and personalized high-quality production. Finally, a notable socio-economic aspect is the fact that the development and installation of these robots would make it possible to compensate for a shortage of labour due to demographic factors, marked by significant ageing of the labour force. Moreover, for some OSH experts[11], the collaborative robot is viewed as an opportunity with regard to assistance for disabled or ageing workers.

But the interest shown for collaborative robotics is not confined merely to this aspect. For manufacturers, it offers above all space saving in the workplace, enabling them to be freed from certain space constraints (enlargement of the premises, reorganization of production lines, etc.).

Furthermore, collaborative robotics is perceived as capable of improving the overall ergonomics of the workplace and thereby reducing the proportion of painful work in a worker's job and, in particular, limiting the risks of musculoskeletal disorders (MSDs), e.g. through assistance in carrying heavy loads.

To a lesser extent, collaborative robotics is presented as an advantage for corporate visibility and communications.

In the Canadian study by the IRSST, for example, one of the manufacturers questioned stressed that the use of a collaborative application was a showcase for the firm. This observation can be compared with the introduction of power-operated exoskeletons in the field of building and construction industry. The use of exoskeletons helps to reduce the painfulness of certain tasks, but also to convey a more attractive image of the job, thus making it possible to more easily recruit labour that has become scarce. An example is the Colas exoskeleton to assist asphalt rakers.

Lastly, an issue that could be defined as political is worth mentioning. Collaborative robotics is a growth market which could therefore become a strategic advantage and a source of creation of skilled jobs. Robot sales have increased in recent years and the proportion of sales of collaborative robots will grow constantly[12].

The need to have an interaction between humans and robots is one of the fundamentals of the "collaborative robot" concept according to the standards (cf. §3.2 of the NF EN ISO 10218-2 standard: *Robots and robotic devices — Safety requirements for industrial robots — Part 2: Robot systems and integration*). But on reading the publications one notes that this is seldom emphasized by the market stakeholders.

[11] "L'homme au travail et le robot : une relation à inventer", Hygiène et sécurité du travail - N°231 – June 2013

[12] Source © Statista: https://fr.statista.com/statistiques/565144/robots-industriels-ventes-mondiales/; Source "World Robotic Report 2016", International Federation of Robotics (IFR): https://ifr.org/ifr-press-releases/news/world-robotics-report-2016

Collaborative robotics is more than merely a change of space: it addresses the issue of work organization via networking. In Germany, for example, the DGUV* has noted a range of issues relating to new work organizations[13] due to expected technical developments with the transition to Industry 4.0. With this major change, namely the transition from separate work areas to a collaborative area for robots/humans, are the old forms of work organization still applicable? How can a balance be found between the new, more flexible forms of work and adequate social protection, whether at the level of occupational risk prevention or the compensation of accident victims?[14] In its position paper[15] dated February 2017, the DGUV* highlights the importance of allowing for the current changes in thinking regarding work regulations.

Along these general lines of thinking, there are an increasing number of questions regarding collaborative robotics, or again artificial intelligence. Apart from the question of the responsibility of the various economic actors (manufacturer, integrator, user and the robot itself) in the event of accidents, TNO*[16] raises other interesting points.

The main issue is protection of personal privacy, bearing in mind that robots are capable of storing information coming from their environment and thus storing data which could be private. The TNO report gives as an example the use of cameras, considered necessary for the robot to move in a hospital room but which, in contrast, become intrusive in the patient's everyday life.

The problems related to society’s acceptance of collaborative robots must also be taken into account to the extent that such robots may be perceived as competitors in the job market, endangering human jobs. They could also lead to rejection in the event of accidents involving them, or else result in dehumanization of the workplace. Along the same lines, the KAN* warns about the risk of excessive humanization of robots, which, here again, could lead to a phenomenon of rejection according to some psychologists[17].

Moreover, again according to TNO*, the development of robotics raises various moral and ethical issues. Depending on how they are programmed, the robots could be led to make choices in certain situations, even if it means putting a person in danger to avoid putting a greater number of people at risk. In these circumstances, on what basis should these decisions be taken?

Finally, the last moral issue involved could be the rights of robots which, due to their constantly increasing independence and intelligence, could be granted rights similar to those of humans. It is therefore not surprising that the players involved in the development of collaborative robotics are endeavouring to find answers, especially in the legislative area.

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13 DGUV Kompakt, September 2017

14 Moreover, these generic questions also refer to the concept of the isolated worker, whether at home or in a co-working space.

15 “Industrie 4.0: Herausforderungen für die Prävention - Positionspapier der gesetzlichen Unfallversicherung“ (2017), DGUV

16 “Emergent risk to workplace safety as a result of the use of robots in the workplace”, TNO report

17 “Digitalisierung und industrie 4.0“, Kommission Arbeitsschutz und Normung (KAN) Kanbrief, 2017

2. Prospective occupational risks

So the development of collaborative robotics arouses a range of more or less clearly defined and precise expectations on the part of manufacturers, OSH experts and national authorities in the industrial, agricultural and medical fields. At the same time, these players have endeavoured to highlight the identified and prospective risks.

2.1. Risks of contact and crushing

By abolishing the boundary between robotized areas and the work areas of employees, collaborative robotics applications entail new risks related to robot/human contact, whether impacts or crushing.

These risks are especially high when the collaborative robots are not inherently safe. The study by the IRSST* highlights the fact that several of the collaborative robot systems observed use conventional industrial robots which have been adapted for collaboration. However, unlike these adapted industrial robots, robots designed from the outset for collaboration have inherent limitations (angular velocity lower than the velocity of conventional robots, smaller payloads, etc.) which can prevent some of the risks. And yet, these robots designed from the outset for collaboration are not necessarily inherently safe by the sign.

According to several studies[18], the risk of direct crushing or crushing against another rigid object is the main cause of accidents involving robots[19], which makes this question especially important.

2.2. Risks of MSDs*

Although it is expected that collaborative robotics will reduce risks of MSDs*, the IRSST* and INRS* have found that the change of work pace or intensity (e.g. the handling of heavier loads) can create new risks.

This group of risks due to closer interaction between robots and humans is especially significant in that the TNO* report emphasizes the need for a close human presence to assist the collaborative robot. The human being must still guide the robot (even though this task should disappear as a result of improvements in robot autonomy), and a human presence remains necessary to protect safety by supervising the robot. Finally, only a human being can ensure the general quality of a product or analyse the error diagnostics coming from the robot.

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[18] Chinniah Y (2016) Robot Safety: Overview of Risk Assessment and Reduction. Adv Robot Autom 5:139. .
Charpentier P. & Sghaier A. (2012). Industrial Robotics: Accident Analysis and Human-Robot Coactivity. Proceedings of the 7th International Conference on the Safety of Industrial Automated Systems, SIAS 2012, 11-12 October 2012, Montreal, Canada

[19] When speaking of the incidence rate, the term robot refers to collaborative and non-collaborative robots without distinction, but in the great majority of cases it is “conventional” industrial robots that are considered.

2.3. Risks related to the tool or the machined part

Publications, and especially the BGIA* study of 2011, also mention the risks related to the tool and the part machined or transported by robots in collaborative applications.

The French Ministry of Labour's guide specifies, for its part, that a dangerous tool should be secured by a guard or another equivalent means to be able to be used as part of a collaborative application.

2.4. Psychosocial risks

In addition to the physical risks, psychosocial risks have been identified by the IRSST* and INRS*. Stress related to the fear of dangerous or repeated contact with robots leads the worker to remain attentive to the robot's movements, entailing an extra effort of concentration and, ultimately, psychological risks. The fear of contact is only one of the potential sources of stress entailed by collaborative robotics.
The impression of dehumanization of work, fear of competition between robots and humans, or else a malaise faced with work shared between man and the machine are again mentioned as risk factors. Moreover, regarding the robot's appearance, excessive humanization and an excessively anthropomorphic appearance may lead to rejection by workers, according to some psychologists[20].

2.5. Risks related to remote controls, cybersecurity and maintenance

The improving autonomy of collaborative robots also creates certain risks related to controls, management and remote reprogramming. Malicious reprogramming or reprogramming by unauthorized personnel is probably the most important problem.

> ***Note that the subject of cybersecurity*** is covered by draft ISO standard 22100-4 *Guidance to machinery manufacturers for consideration of related IT-security (cyber security) aspects*, which can be added to other standards, in particular ISO 27001 *Security techniques - Information Security Management Systems* and ISO 27032 *Security techniques - Guidelines for cybersecurity*, which deal with information technologies.

The control of robot programming is therefore an important issue emphasized by the IRSST*, TNO* and DGUV*[21] which describe in detail preventive measures relating to this risk and discuss the precautions to be taken within the framework of remote diagnosis systems supplied with the robots.

Generally, it must be ensured that reprogramming, a change in or a rearrangement of the functions of an automated system does not generate risks. For this reason an assessment must be made of the impact of these changes. Moreover, maintenance itself is a source of numerous accident risks which must be taken into account. It usually requires that the automated system be in an operating mode in which the safety systems are partially inoperative, thereby endangering the operators in charge of these tasks.

[20] Kanbrief, 2017, Kommission Arbeitsschutz und Normung (KAN) https://www.kan.de/fileadmin/Redaktion/Dokumente/KAN-Brief/de-en-fr/17-2.pdf

[21] DGUV Information 209-74e - Industrial robots (2015). DGUV

2.6. Regulatory risks

The TNO* report considers that a risk is constituted by the fact that the legislation and regulations are unable to adapt to developments in robotics and digitization. The proposed illustration concerns autonomous vehicles, an innovation without a clear regulatory or normative framework. The regulatory risk can be considered as an obstacle to innovation, since a new type of solution proposed by a manufacturer is not in conformance with the regulations because it is not covered by them.

> ***This point of view could be tempered*** by the report following the recent impact study on the Machinery Directive[22] which shows precisely that it is not considered as an obstacle to innovation. The essential health and safety requirements (EHSRs) remain applicable and usable. On the other hand, it is true that the interconnections between the various European regulations may create a grey area requiring clarifications, such as the example given by TNO* of automated tractors which are covered by neither the Machinery Directive nor the Tractors Directive 2003/37/EC. It is therefore manufacturers' responsibility to ensure that they do not create dangerous situations by paying very special attention to the various risks created by these new technologies. Inspiration could be drawn from the relevant EHSRs of other regulations, even if they are not necessarily directly applicable to them.

3. Risk prevention methods proposed by the various stakeholders

Some of the publications consulted describe certain risk prevention methods in order to ensure safety in the use of collaborative robotics applications. These may take the form of tools, proposals within the framework of work organization, or else scientific research to contribute to standardization work.

3.1. Proposed tools and methods

The major reference framework on which risk prevention is based, and which is often mentioned, is the standards. The standards referred to are, for example, ISO 10218-1&2 *Robots and robotic devices - Safety requirements for industrial robots*, but also ISO 12100 *Safety of machinery - General principles for design - Risk assessment and risk reduction*, ISO 13849-1 relating to the performance levels of safety functions, ISO 13855 on the *Positioning of safeguards with respect to the approach speeds of parts of the human body* and EN 349 on *Minimum gaps to avoid crushing of parts of the human body*.

One notes, moreover, in the replies to the TUV*[23] survey, carried out with 15 manufacturers, 14 integrators and 5 user companies in Germany and Austria, that industrial firms assign great importance to certification issues in the development of collaborative robotics. In particular, they emphasize the importance of certification during the production and integration, but also, where applicable, the reprogramming of collaborative robots.

[22] Document of the Technopolis agency available on the European Commission's website: http://ec.europa.eu/docsroom/documents/25661

[23] "Sicherheit in der Mensch-Roboter-Kollaboration" (2016), TUV & Fraunhofer Austria

Secondly, the approach recommended by all the publications is risk analysis. In most of the documents, it is accompanied by check-lists of the major risks and weaknesses to be taken into account. The study by the IRSST* and the guides published by the TNO* and DGUV*[24] propose detailed lists to assist the designers and integrators of automated units. In France, we can mention the *Centre technique des industries mécaniques* (CETIM) which has set up the IDAR tool, a "risk analysis method which is based on a functional description of the equipment and, especially, on an analysis of the operator's activity throughout the life cycle of such equipment"[25].

However, little documentation illustrates this risk prevention approach with cases of integration. Apart from the French Ministry of Labour which proposes a concrete industrial case study in its guide, from preliminary research to identification of the need through to its implementation, we can mention the BGIA*[26] institute which gives an example of application of the risk analysis recommendations for a theoretical industrial situation.

Finally, there are performance aids for the validation of collaborative robot systems. The IRSST* mentions, *inter alia*, the development of solutions "for measuring the maximum force and pressure in the event of collisions with a robot in order to assist with assessment of the risks related to these machines before designing the work station[27]".

One may also refer to the tests carried out by the sensor manufacturer SICK, again in the field of measurement of contact forces, or the European research project COVR aiming to develop a validation protocol for collaborative robotics[28].

3.2. Work organization

Some publications stress the importance of work organization in the implementation of risk prevention.

Operator training is emphasized by both the IRSST* and TNO*.
Likewise, there are specific developments concerning the management of safety parameters and robot program parameters to prevent any accidental or inappropriate change. It is recommended that access to any program modification should be protected via a password, or an equivalent means, accessible only to authorized personnel. The guides also stress the importance of life cycle management of the robot's software, and the robot management plan in order to take into account the risk involved in changes made to the robot system.

Another point to watch, which could be likened to both ergonomics of the work task and preparation of the work station, is the fact of making the robot's trajectory as predictable as possible for the operator, in order to facilitate possible obstacle avoidance. A publication by the KAN*[29], highlighting an American study[30], showed that robot movements allowing effective

[24] "DGUV Information 209-74e - Industrial robots" (2015), DGUV
[25] "Enjeux relatifs aux applications robotiques collaboratives", CETIM, (2017)
[26] "BG/BGIA risk assessment recommendations according to machinery directive – design of workplaces with collaborative robots" (2011), Institute for Occupational Safety and Health of the German Social Accident Insurance Organization (BGIA)
[27] Huelke M. and Ottersbach, J. (2012), How to approve Collaborating Robots – The IFA force pressure measurement system, Paper presented at the Safety of Industrial Automated Systems (SIAS) conference, Montreal, Quebec, Canada, pp. 204-209
[28] These studies were the subject of a presentation at the October 2017 meeting of ISO/TC 299 WG3.
[29] "Digitalisierung und industrie 4.0" Kommission Arbeitsschutz und Normung (KAN) KANBRIEF, 2017
[30] For further information: https://pdfs.semanticscholar.org/cc 34/6f721bcf6c30340ce0a 670297552116ca19b.pdf

interaction and pleasant work for the human being were those which were the most predictable for the operator.

If several trajectories are capable of ensuring the same function, it is necessary to program trajectories that the operator can anticipate in order to optimize collaboration and increase productivity. In the case described, the most direct trajectory is not the most appropriate, but a trajectory exaggerating the movement in one direction in order to facilitate anticipation. Rather than the theoretically optimal trajectory in terms of production, the objective is to program optimized movements for human perception. "The better [the collaborative robot] signals its intentions to the human beings in its environment, the more trust they are able to have in it".

3.3. Scientific research and research programmes

Various academic and scientific studies have contributed to thinking about the safety of collaborative robotics systems. For example, the ISO/TS 15066 guide, which supplements the ISO 10218-1:2011 and ISO 10218-2:2011 standards, bases its establishment of contact thresholds on a 2014 German study (*Experimental assessment of pain thresholds in major parts of the human body due to mechanical exposure in human/machine interface*). A fairly similar study, moreover, was carried out in Japan in 2005[31], under the aegis of the JNIOSH*, based on a sample of nine adult males in good health. The objective is once again to identify the consequences of robot/human contact depending on the speed and force developed by the robot, or again, the angle of contact. The results of the Japanese study are less advanced than those of the German study, because it was less ambitious. It is therefore the German study which now serves as a reference.

However, this study raised some criticism, notably by the HSE*[32] which identified problems of methodology and findings. The HSE considers, in particular, that the study:

- cannot take into account individual variability, which is potentially infinite, in the reaction to contact;
- does not sufficiently take into account psychological factors (stress) and organizational factors (work rate, carrying heavy loads, etc.) which can cause variations in risks of contact and their perception; and
- focuses on thresholds for a single contact but does not consider the frequency of contact.

Finally, the HSE regrets that the tests were carried out on static persons and not on persons in movement, which could change the findings.

Another German study relating to contacts with robots currently being carried out by the *Berufsgenossenschaft Holz und Metal* (BGHM, the insurance organization for the wood and metal sector), in conjunction with the Fraunhofer Institute, is due to be completed in March 2018[33]. It focuses on quasi-static contacts in order to determine pain thresholds. The initial results seem to show that the thresholds thus obtained are lower than those proposed in ISO/TS 15066.

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31 "Measurement of human pain tolerance to mechanical stimulus of human-collaborative robots" (2005), Tsuyoshi Saito & Hiroyasu Ikeda

32 "Collision and injury criteria when working with collaborative robots" (2012), Health and Safety Laboratory (HSE)

33 This study was the subject of a presentation at the October 2017 meeting of ISO/TC 299 WG3.

The HSE* has planned to set up in 2017 and 2018 working groups[34] with industrial firms to review joint research projects on cobots, thus facilitating a transition to collaborative robotics. The project should answer questions relating to good practices in the area of safety, ways of improving the standards relating to collaborative robotics, or again the conduct of risk assessment.

Finally, among the numerous studies on collaborative robotics (cf. Appendix: Examples of research work related to occupational risk prevention in the field of collaborative robotics), we may mention the robot-arm airbag project carried out by the German DLR* with a view to cushioning the effect of contacts with a human being, or again the American study mentioned earlier concerning robot movements (cf. §3.2). Finally, in October 2017 the INRS* published an overview of the prevention of risks related to the use of robots and physical assistance devices[35].

4. Current state of the collaborative robotics market

Some of the publications examined offer criteria for assessing the current state of the market, whether regarding the coverage of collaborative applications in the installed industrial base, or the identified incidence rate.

4.1. Coverage of the installed industrial base

There is a lack of information concerning the quantity and use of collaborative robotics applications in companies. The IRSST* study, which included a field survey part, showed that collaboration in the companies visited involved merely sharing the work area during production. Moreover, only four companies out of the twenty or so contacted in Quebec had operational collaborative applications.

In Japan, the JNIOSH* carried out surveys via questionnaires[36] with various stakeholders, in particular 36 manufacturers and 14 users. It highlighted the manufacturers' fear of not being able to integrate collaborative robots. In particular, the persons questioned admit they do not have a good knowledge of the safety standards and procedures applicable in the field of collaborative robotics. Despite this, 15 producers and five users say they plan to use collaborative applications either to transfer parts and tools or to control production operations.

> ***Despite the limited information provided*** by these studies, there is real momentum behind the policy of integration of collaborative robotics applications, as also shown by the *World Robotic Report 2016*.[37]

[34] These working groups have been set up within the framework of the HSE's Centre for Shared Research. For further information: https://www.hsl.gov.uk/blog/2017/09/13/the-cobots-are-coming-but-will-they-be-safe/

[35] Atain J.J. & Sghaier A. (2017). "Les robots et dispositifs d'assistance physique : états des lieux et enjeux pour la prévention". INRS

[36] "Global harmonization of safety regulations for the use of industrial robots - permission of collaborative operation and a related study by JNIOSH" (2015), National Institute of Occupational Safety and Health (JNIOSH), Tsuyoshi Saito & Toshiro Hoshi & Hiroyasu Ikeda & Kohei Okabe

[37] Source: "World Robotic Report 2016", International Federation of Robotics (IFR): https://ifr.org/ifr-press-releases/news/world-robotics-report-2016

4.2. Identified incidence rate

Incidence rate statistics remain rare and hard to interpret. This is because the figures do not necessarily refer to the same type of accidents, and in particular they do not concern collaborative robotics applications specifically but robotics applications in general.

In a 2012 article by Charpentier & Al.[38], reference is made to a study that analysed the EPICEA[39] data bank and identified 31 robot-related accidents in France between 1997 and 2010. There we learn, for example, that:

- 65% of the accidents concerned operators and 35% concerned maintenance workers;
- 26% of the accidents were fatal and 68% caused severe injuries;
- In 19% of accident cases, access to the robot was protected by fixed guards;
- In 26% of cases, access was restricted by removable guards;
- In 16% of cases, the guards were insufficient.

Most accidents were therefore apparently due to deficiencies at the access security level (safety shunts, misuse or poor installation, etc.).

The TUV* guide also proposes some incidence rate statistics based on figures from the Austrian accident insurance organization (*Allgemeine Unfallversicherungsanstalt,* AUVA) and the DGUV*.

Incidence rates in Austria and Germany - 2011-2014					
	2011	**2012**	**2013**	**2014**	**Fatal (over the period)**
Austria	10	17	12	15	0
Germany	107	72	119	151	2

Source: AUVA/DGUV

Of the two fatal accidents in Germany, the last one occurred in 2015 when an operator was crushed against a rigid object during a maintenance phase. This type of serious accident also occurred twice in Quebec during the modification of automated machinery programs (CNESST, 2004; CNESST, 2002).

According to the TNO* guide, since 1997 the United States has recorded 25 serious accidents involving robots, including 20 fatal accidents - a figure to be compared with the 4,679 fatal accidents which occurred there in 2014 alone.

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Appendix: Examples of research work related to occupational risk prevention in the field of collaborative robotics

Category	Description	Country	Reference
Risk prevention	Review of existing situation	France	Atain J.J. & Sghaier A. (2017). "Les robots et dispositifs d'assistance physique : états des lieux et enjeux pour la prévention". INRS
Safety/Contact	Airbag to cushion contacts	Germany	http://www.dlr.de/rmc/rm/en/desktopdefault.aspx/tabid-11890/20893_read-48688/
Safety/Contact	Speed control system	Japan	T. Saito & H. Ikeda, "Development of a normally closed type of clutch using magnetorheological suspension for safe torque of human-collaborative robot" (2008). JNIOSH.
Safety/Contact	Touch sensors to prevent contact	Germany	Fritzsche, M., Elkmann, N. and Schulenburg E. (2011) Tactile sensing: A key technology for safe physical human robot interaction, Paper presented at the 6th ACM/IEEE International Conference on Human-Robot Interaction (HRI), Lausanne, Switzerland, pp. 139-140
Cybersecurity	Protection of digital systems	France	Pietre-Cambacedes, L. et al. (2015) Cybersécurité des installations industrielles – Défendre ses systèmes numériques, France : Cépaduès
Risk analysis	Recommendation	United States	Murashov, V., Hearl, F. and Howard, J. (2016) "Working safely with robot workers: Recommendations for the new workplace", Journal of Occupational and Environmental Hygiene, 13 (3), D61-D71
Risk analysis	Paper	Germany	Schubert, J. (2015) Challenges and new ways for the risk assessment of Cyber physical systems, Paper presented at the Safety of Industrial Automated Systems (SIAS) conference, Königswinter, Germany, pp. 24-26
Risk analysis	Description of uses	France	Daille-Lefèvre, B., Dequaire, E., Roignot, R. et Fadier, E. (2015) "Acheter une machine : comment décrire les usages attendus?", Hygiène et sécurité du travail, (239), 70-73
Risk analysis	Transition from a conventional application to a collaborative application	Canada	Fryman, J., Arbor, A. and Matthias, B. (2012) Robotic Industries Association, Safety of Industrial Robots: From Conventional to Collaborative Applications, Paper presented at the Safety of Industrial Automated Systems (SIAS) conference, Montreal, Canada, pp.198-203
Risk analysis	Risk identification	Canada	Fujikawa, T. et Kubota, M. (2012) Evaluation of Injury Level and Probability for Risk Assessment of Mobile Robots, Paper presented at the Safety of Industrial Automated Systems (SIAS) conference, Montreal, Quebec, Canada, pp. 180-185
Risk mitigation	Risks during maintenance operations	Canada	Jocelyn, S. (2012) Identification et réduction du risque pour les interventions de maintenance et de production sur des presses à injection de plastique en entreprises, Mémoire de maîtrise, Polytechnique Montréal, Canada
Incidence rate	Paper on the robotics-related incidence rate in France	France	Charpentier, P.et Sghaier, A. (2012) Industrial Robotic: Accident analysis and Human-Robot Coactivity, Paper presented at the SIAS (Safety of Industrial Automated Systems) conference, Montreal, Canada, pp. 170-175
Psychological risk	Stress due to close human-robot presence	South Korea	De Graaf M.M.A. et Ben Allouch, S. (2013) The relation between people's attitude and anxiety towards robots in human-robot interaction, Paper presented at the IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), Gyeongju, Korea, pp. 632-637
Programming-related risk	Human risks in programming	United Kingdom	Glagowski, T., Pedram, H. and Shamash, Y. (1992) "Human factors in robot teach programming", In M. Rahimi and W.Karwowski (publishers), Human robot interaction, pp. 16-47. London, England: Taylor & Francis

Thematic Note

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