On the Safety of Mobile Robots Serving in Public Spaces

Identifying gaps in EN ISO 13482:2014 and calling for a new standard

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ABSTRACT

Since 2014, a specific standard was dedicated for the safety certification of personal care robots, which operates in close proximity to humans. These robots served as information providers, object transporters, personal mobility carriers, and security patrollers. In this article, we point out the shortcomings concerning EN ISO 13482:2014, which encompasses guidelines regarding the safety and design of personal care robots. In particular, we argue that the current standard is not suitable for guaranteeing people's safety when these robots operate in public spaces. Specifically, the standard lacks requirements to protect pedestrians and bystanders. The guideline implicitly assumes private spaces, such as households and offices, present the same hazards as in public spaces. We highlight the existence of at least three properties pertaining to robots' use in public spaces. These properties includes: 1) crowds; 2) social norms and proxemics rules and 3) people's misbehaviours. We discuss how these properties impact robots' safety. This article aims to raise stakeholders' awareness on individuals' safety when robots are deployed in public spaces. This could be achieved by integrating the gaps present in EN ISO 13482:2014 or by creating a new dedicated standard.

CCS CONCEPTS

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KEYWORDS

Insert comma delimited author-supplied keyword list, Keyword number 2, Keyword number 3, Keyword number 4

1 Introduction

It is increasingly common to have mobile robots at work in public spaces. Public spaces is defined as city venues accessible to the public. These venues include pedestrian paths, train and subway stations, airports, highways, parking lots, shopping malls, shops, and museums (Tonnelat, 2010). Robots discussed in this article are mobile service robots. These mobile service robots are characterized based on their functions, external designs and autonomy levels. These robots mainly serve as information providers, object transporters, personal mobility carriers, patrollers, tour guides and shop assistants.

In industrial environments, only professional operators are allowed to interact with robots. In public spaces, however, anybody could potentially interact with a mobile robot. As a consequence, the general public is at stake of facing potential dangers if safety measures were not properly implemented. Therefore, ~~users~~, pedestrians, and bystanders are exposed to potential dangers regarding mobile robots operating in public spaces. The terms pedestrians and bystanders are used to loosely define laypersons of any age, gender, physical and cognitive conditions who share the same vicinity with a mobile service robot (Scholtz, 2003).

Safety standards, conduct codes and regulations are crucial for building trust in new technologies and their successful implementations (Harper and Virk, 2010). This principal also applies to mobile service robots and their use in public spaces. According to the European Economic Area, robots to be traded must be CE (Conformité Européenne) marked. This signifies the robot has "[met] high safety, health, and environmental protection requirements"[1]. The CE certification ensures manufactured robots conform to the applicable European Union directives and harmonised standards, including the Machinery Directive 2006/42/EC. Since 2014, it is necessary for service robots to attain standards described in EN ISO 13482:2014. This document contains specific safety requirements regarding the use of personal care robots operating in close proximity to inexperienced laypersons in non-industrial environments. Before the introduction of EN ISO13482:2014, "ISO 10218 was the sole international standard pertaining to the safety requirements for robots and robot systems" (ISO/TR23482-2:2019).[2] EN ISO13482:2014 was meant to complement ISO 10218-1:2011, which contains safety requirements for industrial robots' operations. The guideline also expands and creates new markets for service robots (Jacobs and Virk, 2014). More specifically, guidelines under EN ISO13482:2014, a European harmonized standard, is based on the Machinery Directive (Directive 2006/42/EC). In other words, EN ISO 13482:2014 guidelines are in compliance with the Machinery Directive. Therefore, EN ISO 13482:2014 can facilitate the CE marking entitlement. In legal disputes, EN ISO 13482 serves as a guide to determine if a product was liable to fault.[3]

There are four aims in this article. Aim 1 highlights the hazards for pedestrians and bystanders overlooked in EN ISO 13482:2014. Aim 2 identifies hazards emerging from public environments. Aim 3 serves to protect robots from security threats to ensure users', pedestrians' and bystanders' safety. Aim 4 serves to broaden the range of psychological hazards that could derive from interactions with robots operating in public spaces. These hazards were not mentioned in EN ISO 13482:2014. We aim to raise the awareness on EN ISO 13482:2014's limitations pertaining to safety standards regarding service robots' operation in public spaces.

We will summarize and discuss EN ISO13482:2014's shortcomings with respect to its existing safety standards and relate these issues with pertinent state-of-the-art methods that could benefit the future research directions of service robots. Firstly, the safety requirements under the current standard encompass only the users but not the pedestrians and bystanders. Secondly, the current standard is not suitable for ensuring safety in public spaces. EN ISO13482:2014 takes into account safety issues related to outdoor and indoor physical environments including temperature and humidity fluctuations. The standard, however, does not consider crowds' fluctuations, social norms, proxemics rules and vandalism. These are non-physical properties that can cause hazards. Thirdly, the current standard fails to consider safety aspects pertaining to the cognitive/psychological hazards and the potential security threats deriving from interaction with robots serving in public spaces.

This article is organized into five sections. Section 1 provides an overview of EN ISO 13482:2014. Section 2, highlights the hazards and propose requirements for ensuring pedestrians' and bystanders' safety. Section 3, identifies and discuss hazards derived from public environments. Section 4, identifies the significance of robot security to ensure users', pedestrians' and bystanders' safety. Section 5, identifies potential psychological hazards and risks reduction measures.

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1 https://ec.europa.eu/growth/single-market/ce-marking_en

2 ISO 10218 (July 2011 edition) is the European standard that specifies the requirements and guidelines for inherently safety design, protective measures and information for the use of industrial robots. It describes the basic dangers associated with these robots and provides the requirements to eliminate, or adequately reduce, the risks associated with these hazards.

3 At the time of writing, EN ISO13482:2014 is under periodical review.

1.1 Overview of EN ISO 13482:2014

Table 1 summarize several existing standards for service robots. Ultimately, EN ISO 13482:2014 is *the* sole reference standard for personal care robots. By definition these service robots "contribute to the quality of life of users through direct interaction regardless of their attribute, age or gender (e.g. children, elderly persons, pregnant women)" (ISO/TR23482-2:2019). ~~Personal care robots include carrier robots, information carrying robots and assistant robots. Carrier robots are robots with footholds for standing passengers. Carrier robots can also be legged passenger carriers transporting passengers sitting on a monocycle or any wheeled vehicles. Information carrying robots include servant robots designed to fetch and carry tasks, provide information and entertain people. Assistant robots are those robots implemented with leg motion assistant devices or body weight supportive devices. Exoskeleton wearable robots are also assistant robots.~~

EN ISO13482:2014 contains safety requirements for three ~~robot~~ types of personal care robots. They include the mobile servant robot, the physical assistant robot and the person carrier robot. According to ISO/TR23482-2:2019, these robot types are the most commercialized robots in the market when the standard was published. The safety requirements delineated, however, is not specific and it could be applied to any personal care robot types. In EN ISO13482:2014, the first robot category includes servant robots that can serve and interact with humans. This includes "handling objects or exchanging information". Servant robots such as butlers, waiters, secretaries or receptionists serve people. The second robot category includes personal care robots that physically assist users. These robots provide "supplementation or augmentation of personal capabilities". These personal care robots include exoskeletons robots and other wearable robotic devices that can support the user's weight and can enhance the user's force. The third robot category includes robots designed to "transport humans to an intended destination". These are robots that can carry a single person or a small group. Carrier robots can also be legged passenger carriers transporting passengers sitting on a monocycle or any wheeled vehicles. These robots travel in in pedestrian areas at limited speed (ISO/TR23482-2:2019). There are also robots that serve dual functions, such as "person carrier robots handling objects and interacting with humans (hybrid of mobile servant robot and person carrier robot)" (ISO/TR23482-2:2019). If EN ISO13482:2014 needs to be applied to a hybrid robot, the right category should be determined based on the robot's intended purpose. "When a particular robot can belong to more than one type, the manufacturer chooses the robot type, intended use, conditions for use and limitation for use" (ISO/TR23482-2:2019). This article discusses robots that serve as servants and/or person carriers.

The most innovative aspects of EN ISO13482:2014 pertain~~s~~ to robots that maneuverer themselves autonomously, work among humans without hindrance and interact closely with humans, including physical contacts. Annex A in the standard contains hazard items resulting from the interaction with personal care robots. However, the list is not "all-inclusive". Hazards can span from battery change, to errors in localization and navigation. It is specified in the standard that other hazards may emerge from the robot's "particular design, intended use or reasonable foreseeable misuse" (EN ISO13482:2014). In order to facilitate designers and other stakeholders, ISO/TR23482-2:2019 supplements EN ISO13482:2014 by providing clarifications on the definition of personal care robots, on the differences with other types of service robots and on risk assessment and reduction. It includes also specific examples for users on how to apply the standard. According to ISO/TR23482-2:2019, personal care robots is a subgroup of the service robots family. This subgroup is further divided into household and medical robots. Household robots include autonomous vacuum cleaners and mowing robots. Medical robots are robots designed to facilitate disease diagnosis, treatment and monitoring. The standard distinguishes service robots from industrial robots and autonomous vehicles. Autonomous vehicles are used on public roads with speed limits greater than 20 km/h (ISO/TR23482-2:2019). Industrial robots are used in industrial automation. Finally a further document exists, ISO/ TR 23482-1:2020, which describes test methods to ensure personal care robots' conformity to ISO13482's safety requirements (ISO/TR 23482-1:2020).

So far, many robots have been certified and obtained CE mark with EN ISO 13482:2014. They include guide robots,[4] delivery robots,[5] walking assistant robots[6], and wheel-based humanoid robots[7].

Table 1. Standards for non-industrial robots

Robot type	Reference
Standards for personal care robots	ISO 13482 Robots and robotic devices - Safety requirements for personal care robots (ISO 13482:2014)
	ISO/DTR 23482-1 Robotics - Application of ISO 13482 - Part 1: Safety-related test methods
	ISO/TR 23482-2 Robotics - Application of ISO 13482 - Part 2: Application guide
Standards for service robots	ISO 19649 Mobile robots – Vocabulary
	ISO 18646-1 Robotics - Performance criteria and related test methods for service robots - Part 1: Locomotion for wheeled robots
	ISO 18646-2 Robotics - Performance criteria and related test methods for service robots - Part 2: Navigation
	ISO/CD 18646-3 Robotics - Performance criteria and related test methods for service robots - Part 3: Manipulation
	ISO/CD 18646-4 Robotics - Performance criteria and related test methods for service robots - Part 4: Wearable robots
	ISO/CD 22166-1 Robotics - Part 1: Modularity for service robots - Part 1: General requirements

1.1.1 Concerns about EN ISO 13482:2014

Since its release in 2014, there have been concerns among scholars regarding the scope and contents of EN ISO 13482:2014. According to Scassellati (Cole, 2014), the release of the standard was premature and hazardous because at the time of its publication, there was little knowledge on the risks and opportunities of care regarding robots' usage. "We don't have a clear understanding of the basic science behind human-robot interaction[s], the roles care robots should play, the kind of support [we] should provide, [and their] impact on users" (Cole, 2014). A critical review of EN ISO 13482:2014 states the standard lacks semantic clarity and a precise definition regarding the care robot. Moreover, robots categories in the standard is confusing and could lead to legal consequences (Fosch Villaronga, 2014).
In a subsequent work on person carrier robots, (Fosch Villaronga and Roig, 2017) propose a regulatory framework, which consists of safety as well as legal and ethical aspects. With respect to our study the main difference is the methodology used. The authors framed their analysis drawing on already defined principles derived from the RoboLaw project (www.robolaw.eu), namely: liability, safety, privacy, integrity, dignity, autonomy, data ownership, ethics and justice. In our study, we based our analysis on the properties emerging from the characteristics of the robot operating environment, that is public spaces. Other studies focused on specific technical aspects, highlighting shortcomings with respect to ISO13482:2014. For instance, (Gwon et al., 2019) deal with verification and validation. In particular, the authors studied the stability evaluation system of a carrier robot in an experiment with a wheelchair driving in three different conditions with ramps and obstacles. The authors point out the lack of a test evaluation technology and certification system for verification and validation of a robot stability in ISO13482:2014. Likewise, (Kim et al., 2017) address the determination of the protective stop function of mobile service robots, an aspect which is currently missing in ISO13482:2014. In the cost function, the authors included physical as well as mental safety aspects (i.e. comfort distance between the robot

4 (https://www.nsk.com/company/news/2017/press0404a.html

5 https://news.panasonic.com/global/topics/2016/45099.html

6 https://pressreleasejapan.net/2018/01/26/honda-walking-assist-device-receives-ec-certificate-medical-device-directive-mdd-utilizing-jqa-iso-13482-certification/

7 https://www.iso.org/news/Ref2169.htm .

and the human). (Guiochet et al., 2017) and (Salem et al., 2015) point out the lack of concerns for risks related to cognitive (psychological) hazards in ISO13482:2014.
With respect to existing research papers, in our study we perform a broader analyses of ISO13482:2014 and propose a more general overview of safety requirements. The next section identifies the negative consequences affecting pedestrians and bystanders due to the insufficient protection guidelines in EN ISO 13482:2014.

2 On bystander's safety

Humans have at least five roles in their relationships with robots. In human-robot interactions (H-RIs), each individual can be a supervisor, an operator, a teammate, a mechanic/programmer, or a bystander (Yanco and Drury, 2004; Scholtz, 2003). The terms pedestrian and bystander are used to loosely define a laypersons of any age, gender, physical and cognitive conditions "co-existing in the same environment as the robot" (Scholtz, 2003). A pedestrian or bystander is not necessarily a trained person on robots' operations and they can be unaware of the robot's presence and its actions. This level of H-RIs differs from users and operators, who are willing and able to use the robot. Operators exercise the knowledge on the robot's functions and they implicitly accept any associated operational risks. Pedestrians and bystanders relate to robots only through their simultaneous presence with the robot in the same physical space. For example, a pedestrian can encounter a robot while walking down the corridor. A bystander standing in a queue can encounter a robot when it passes by. Interactions between bystanders and the robot are limited. It is difficult for designers to address a bystander's role with the robot (Scholtz, 2003). The main challenge is to evaluate and communicate information to the bystander in order "to make [them] comfortable with robots in their environment" (Scholtz, 2003).

EN ISO 13482:2014 does not contain requirements to ensure pedestrians or bystanders' safety. All modalities of H-RIs defined in EN ISO 13482:2014 are between the user (in some cases the operator) and the robot. Pedestrians and bystanders (including animals) are excluded in EN ISO 13482:2014 except in collision cases when they are considered as "safety-related objects".[8] This is an inadequacy in the standard because collision is not the only form of interaction between pedestrians and bystanders with the robot. Individuals can interact with a robot when the robot is simply navigating or when it is stationery.

The next subsection identifies potential hazards for pedestrians and bystanders during their physical and non-physical interactions with mobile robots. These issues were identified based on the latest research developments in robot engineering. These research developments include odometry sensors for motion sensing; LiDAR sensors and RGB-D cameras for visual sensing; force/torque sensors for impact detection; and artificial skin for contact sensing (Kruse et al., 2013; Mitsch et al., 2017). There are also aspects concerning robot operations. This include H-RIs during robot navigation (Ali, et al 2019); reactive obstacle avoidance (Huber et al., 2019); human motion probabilistic modelling (Charalampous, 2016; Pohler et al., 2019), and contact recognition (Khoramshahi and Billard, 2019;Haddadin, et al., 2017).

2.1 Safety requirements for bystanders and pedestrians

2.1.1 Interactions involving physical contacts

An unprecedented aspect of EN ISO13482:2014 is the set of safety guidelines regarding the physical interactions between humans and robots. These guidelines, however, pertains only to very limited categories of physical interactions involving the user. These categories include forces applied to the human body (lifting a person from the bed), continuous contacts (transporting a person) and cooperative contacts (handling of an object).

8 Only in ISO/TR 23482-2:2019 there are explicit references to possible hazards with bystanders and pedestrians. On the contrary, iIn the checklist of hazards contained in Annex 1 of EN ISO 13482:2014 Annex 1, there is no reference to pedestrians nor bystanders.

Robots' presence in public environments opens new interaction possibilities with pedestrians and bystanders. Unlike collisions between these individuals with the robot, foreseeable interactions include swiping, pushing and tapping. These intentional or unintentional interactions can originate from both the human and the robot. Unfortunately, there are no safety requirements thus far regarding these forms of contacts.

Robots are programmed to execute active or passive intentional physical contacts with humans. Active physical contacts are aimed at inducing a reaction from an individual. In noisy and crowded environments, it is more effective to communicate using physical contacts compared to audio or visual interfaces. A recent study proposed an unconventional solution for improving efficiency and safety during navigation based on intentional physical contacts (Shrestha et al., 2015). They contemplate the possibility of inducing a bystander to move aside by means of a physical contact with a robot. Another group suggests predicting bystanders' reactions from a robot's touch (Shrestha et al., 2018). This is achieved by correlating different contact points on the human body (i.e. upper arm, lower arm, upper back and lower back), with the force generated from the robot and the direction of the individual's response. These results confirmed that the human reaction is consistent with the direction of contact force when the robot's arm touches the individual.

Passive physical contacts take place when no reaction from humans is sought. For instance, a robot is programmed to "swipe" a person. A robot's swipe is defined as a harmless sideways movement in order to contact an individual's body. For example, a robot "utilizes forearm contact to create space for itself and to act as a safety buffer, during very close or congested navigation interactions" (Kamezaki et al., 2018). Indeed, there might be situations in which stopping might not be the best option with respect to safety and efficiency (Shrestha et al., 2015). This is attributed to the fact that a frozen robot becomes an obstacle for others (Trautman, et al. 2015) and fails to accomplish its task. Likewise, human-to-robot intentional physical contacts occur when humans purposefully touch the robot to cause reactions (active response) or without the intention to trigger a movement/behaviour in the robot (passive response).

Human-to-robot physical contacts can be further categorized as inoffensive, when the intentions are good, and offensive, when the intentions are malicious such as vandalism. Offensive interactions will be addressed in Section 4. Moreover, unintentional contacts take place when physical contacts between robots and humans are inevitable. The same occurs when unintentional human-to-human contacts are inevitable in everyday life. For instance, inadvertent physical contacts occur in a bottleneck situation or while standing in a queue. Sometimes moving away or freezing in order to minimize contacts, may be more disruptive and dangerous. As a result, a robot may be programmed to touch and accept contacts as to minimize the risks of injuries.

Reciprocal touch communication between robots and humans focused on two types of sensing abilities. They are hard contact sensing through stiff covers connected to inner sensors and soft contact sensing through skin-like soft sensors covering the robots' body (Argall and Billard, 2010). Although there is a large amount of research in this area, unfortunately robots cannot distinguish between voluntary and involuntary touch (Khoramshahi and Billard, 2019). However, service robots' proprioceptive capabilities are context independent. For example, LiDAR data gathered from a child running on sidewalk is interpreted as a movable obstacle with a known velocity. An elderly losing balance and falling over a robot, is interpreted as a collision. The collision could be avoided if a robot was to assist the falling individual. To accomplish such discriminations, robots, should have sensors that can discriminate unintended events and contacts. Potentially, this could be achieved similar to how large datasets are integrated in computer vision. This occurs when visual data is collected frame by frame in order to distinguish different visual inputs from the surroundings.

As highlighted above, researchers are exploring and testing unconventional forms of physical interactions involving pedestrians and bystanders. It is important to start addressing the aforementioned safety aspects. Based on Annex 1's hazard checklist in EN ISO13482:2014, Table 2 contains a general list of hazards deriving from new forms of interactions involving bystanders and pedestrians.

It should be noted that there might be differences in people's attitude when they engage with robots. For instance there are people willing to interact and even to touch robots. On the other hand, there are people who prefer to avoid, ignore, or resist robots. A study found out that prior experiences with robots, as well as pet ownership positively affects proxemics by reducing the distance between robots and people (Takayama and Pantofaru, 2009). Furthermore, robots' morphologies significantly affect how children perceive robots. The study found people's the perception on robots is related to the levels of anthropomorphism and social presence the robots convey (Barco et al., 2020). Interestingly, children relates to anthropomorphic robots with a higher level of intimacy compared to zoomorphic robots. People's attitudes toward robots depend on many intrinsic factors that is robot-specific. Intrinsic factors include the robot's motion, appearance, embodiment, gaze, speech, posture, social conduct, or any other robot dependent attributes. Extrinsic factors pertain to the individual's age, cultural background, and prior experiences with robots.

There is heterogeneity in attitudes from pedestrians and bystanders toward robot working in public spaces. Therefore, unlike being in the industrial or professional setting, it is not possible to exclude robots' interactions to specific categories of people. One promising solution would be to apply universal design principles. It is important to note that these principles are different from those proposed by (Matsuhira et al., 2008; Elara, Rojas and Chua, 2014) for designing inclusive spaces for robots. Neither do we mean designing more usable interfaces for facilitating disabled or elderlies to interact with robots, as proposed by (Ferati, Murano and Giannoumis, 2018) with respect to self-driving cars. Instead, we propose to extend the concept of universal design to make the robot universally acceptable to all individuals, independent of intrinsic and extrinsic factors regarding H-RIs. A promising solution is to implement universal acceptance, which is to make the robot adaptable to the person interacting with it. Specifically, we propose to alternate the robot's behaviour including its prediction models, motion control, speech and proximity according to the person's age, gender and cultural background. This could be achieved by using physiological and behavioural metrics to understand a persons' comfort level before bringing the robot to close physical proximity to humans (Lasota, Fong and Shah, 2017).

Currently, adaptive and individualized robot-mediated technology has been developed for many robot applications in various sectors including health, education, and home (Ahmad, Mubin and Orlando, 2017). A recent robot navigation algorithm has been developed to classify pedestrians' personalities such as aggressiveness, anxiousness and shyness, that could be determined based on based on their movements (Bera, Randhavane, and Manocha, 2017). It is important to note that users might be unintentionally exploited as a result of interacting with robots that are capable of adapting to users (Sanobari et al., 2019). The study explored the ethical implications resulting from robots' social interaction techniques aiming to change human moods and behaviours. Moreover, privacy concerns should be particularly considered when relying on interfaces to detect people's physiological parameters. This topic will be further discussed in Section 5.

Table 2. Hazards to pedestrians/bystanders involving physical interactions

No.	Hazard item	Hazard analysis		
		Hazard	Potential consequences	Notes
	Physical contacts between robots and bystanders	Hazardous robot shape	Physical	Covered in EN ISO 13482:2014 Clause 5.6
		Hazardous physical contacts (robot-to-human)	Physical	Covered in EN ISO 13482:2014 Clause 5.10.9
		Hazardous human reactions to a robot's touch	Physical	New

		Hazardous robot reactions to a human's touch	Physical and psychological	New (see also Section 5)
		Physical contacts with robot parts not intended for touch	Physical	EN ISO 13482:2014 clause 5.10.9
		Physical contact with human parts not intended for touch	Physical and psychological	New (see also section 5)

In line with ISO13482:2014, risk assessments shall be performed when there are foreseeable intentional or unintentional interactions between pedestrians and bystanders with robots. With respect to the hazards listed in Table 2, we propose possible solutions regarding robots' safety designs. A few examples of detrimental interactions between pedestrians and bystanders with robots are delineated in italics in the next sections.

2.1.1.1 *Hazardous human reactions resulting from a robot's touch*

An example of a hazardous human reaction resulting from a robot's touch is when *a pedestrian or a bystander does not expect a touch from the robot and reacts by suddenly moving sideways.* The robot's inability to foresee the individual's reaction as to timely adjust its behaviour could injure the person. These injuries are often induced on lower body parts. The robot could rolled over the person's feet or injure the person's hand or arm.

There are cases where it is possible for the robot to predict human reactions (Shrestha et al., 2015). However, data are needed in order to support the notion that robots can reliably predict and react to human reactions. A study has been done to remediate the aforementioned issue (Charalampous et al. 2016). The researchers attempt to enhance the robot's responsiveness by integrating trained data into the robot based on patterns of predictive human behaviours. Nonetheless, any cognitive solutions pertaining to the robots' sensing and recognition system could lack contextual data, leading to wrong estimations. These scenarios occur when there is a lack of training data for different human populations or when individuals behave unexpectedly. Therefore, unexpected bystanders' reactions should always be taken into account, as well as differences concerning their age, gender, and health status. To avoid collisions due to unexpected human reactions, it is recommended to cover the robot with soft materials in structures where the robot could potentially contact with individuals. The use of contact sensors and compliant reactive strategies could further reduce the associated risks in order to reduce impact forces and harm.

2.1.1.2 *Hazardous robot reactions resulting from a human's touch*

The following are examples of human interaction with service robots implemented with state-of-the-art proximity, contact sensing, and cognitive capabilities, as described in section 2. Examples of hazardous robot reactions resulting from a human's touch are: *1) A person intentionally swipes onto a robot, embedded with artificial skin, while it is moving in a crowded corridor. The robot stops abruptly and collides with a pedestrian following from behind.*
2) A robot is standing still next to a group of people and a bystander presses the robot's arm with the intention of requesting its service. The robot is not build to accept such external commands. Its proximity sensors interpret the touch as an unexpected collision and moves in the opposite direction, colliding with a group of bystanders. 3) A person intentionally pushes an autonomous servant robot aside in order to pass by. This activates the robot's force sensing system and the robot moves away from the individual. However, it collides with a nearby pedestrian who unexpectedly accelerates towards the robot.

ISO13482:2014 includes only scenarios when trained users interact with a robot with known intentions. As mentioned previously, the standard did not include scenarios when pedestrians and bystanders physically interact with a service robot. For robots to react in a safe and meaningful manner with pedestrians and bystanders, robots should be able to distinguish between inoffensive vs. offensive contacts, as well as, intentional or unintentional actions. However, these are challenging issues in robot engineering. A recent study improves the operator's safety in the industrial setting by implementing sensors in the robot that can differentiate between unexpected collisions from voluntary contacts with humans (Haddadin, De Luca, Albu-Schäffer, 2017). These proprioceptive sensors can distinguish between cooperation and collisions forces. Yet, it is challenging to create proprioceptive sensors that can distinguish different types of physical contacts. Ideally these sensors should be able to detect collisions, eliminate false positives and react in a timely manner to any unexpected human contacts. Thus far, there are no published studies regarding robots that can appropriately react to unexpected situations involving bystanders and pedestrians.

2.1.1.3 *Robot's physical contact with the incorrect human body part(s)*

An example when a robot contacts the incorrect human body part could be due to *calibration errors in the robot. It signals the bystander to step aside by touching the bystander's head instead of the shoulder.* Potential hazards due to errors in touching the wrong body part(s) should be included in the hazards checklist since intentional robot-to-human physical contacts do occur. These errors could cause physical dangers, pain or injuries in sensitive areas including the head or intimate body parts. Moreover, such errors from the robot can cause psychological hazards in individuals, which include embarrassment, stress or discomfort. For these reasons, it is important for service robots to distinguish humans according to age, gender, and health conditions as to ensure safety during H-RIs.

Service robots should be implemented with sensing systems that can distinguish and identify different human body parts regardless of height, size, and gender. There should also be trained algorithms for processing different sensory input, including situational awareness and age group specific behaviours. For example, a service robot such as delivery robots and autonomous wheelchairs should be able to distinguish behaviour patterns between adults, children and the elderly. According to car accidents data, it is crucial to take into account children's behaviour patterns based on their age groups (Schwebel, et al 2012). Robots need to be equipped with protective surfaces including shells, bumpers and covers to protect individuals when unexpected collisions occur. These safety compliances are similar to those involving human-human collisions. Some studies analysed collisions in relation to pain thresholds for adults (Muttray, A. et al 2014; Park, M. Y. et al, 2019) and others studies confirmed children as vulnerable populations (Fujikawa, T. 2013). However, the field has yet to agree on injury criteria and safe operational standards with service robots.

2.1.2 **Non physical robot-human interactions**

At least five scenarios can occur when robots and humans co-locate (Huttenrauch and Eklund, 2004). Both parties can pass by, follow, approach, touch or avoid one another. Other scenarios can occur when a robot navigates in public spaces and these situations do not involve physical interactions with the individual. For example, both parties can stop, overcome and cross by one another. Nevertheless, even when the robot is immobile, its presence can affect pedestrians' and bystanders' behaviours and feelings. Hazards caused by these forms of non-physical interactions could affect pedestrians' and bystanders' physical and psychological safety. According to Annex 1 in EN ISO13482:2014, we grouped some of these hazards in Table 3 under the item "hazards due to lack of human awareness". None of these hazards were included in EN ISO 13482:2014.

Table 3. Hazards to pedestrian involving non-physical interaction

No.	**Hazard item**	**Hazard analysis**		
		Hazard	**Potential consequences**	**Notes**
1	Hazards due to lack of human awareness	Lack of social awareness in the robot control system	Physical and psychological	
2		Lack of legibility of robot intentions	Physical and psychological	
3		The level of perceived safety elicited by the robot on the	Psychological	

		bystander/pedestrian is not acceptable		

In line with EN ISO13482:2014, risks assessments shall be performed for these forms of non-physical interactions. We propose possible solutions regarding safety designs based on hazards listed in Table 3. A few examples of detrimental interactions between pedestrians and bystanders with robots are delineated in italics in the next sections. Prospective safety hazards will be addressed in Section 5.

2.1.2.1 *Hazards due to the robot's lack of social awareness during navigation*

A robot unaware of social norms during navigation is potentially hazardous to the community. *For instance, in countries that operate under left-hand traffic, a mobile robot cuts across the right lane instead of staying on the left or cuts corners when turning at intersections can cause potential dangers to pedestrians or bystanders.* In this scenario, the mobile robot is endowed with human capabilities. Imaging data can be collected in various forms. They can be collected either in point clouds, in proximity sensors based on classified cluster detection capabilities (Yan, Z., et al 2017) or as labelled data for deep learning (Völz, B., et al 2016). Robots implemented with these data collection capabilities are able to detect expected human behaviours in motion patterns. These motion patterns are established based on the probability distribution of possible pedestrians' travel velocities encountered under different situations (Charalampous et al. 2016). However, a robot's lack of consideration for social norms can cause traffic perturbations and increase collision probabilities with pedestrians. Likewise, a robot violating personal space, for instance, while standing in a queue or during navigation can cause distress in pedestrians and bystanders.

Social rules are defined as accepted behavioural patterns when groups of people, communities or societies interact (Bicchieri, Muldoon and Sontuoso, 2018). Adherence to social norms is particularly important for robot navigation in public spaces. For instance, depending on the cultural context, a navigation robot travelling down a hallway needs to keep itself to either the right or the left lane (depending on the cultural context). Proxemics is the study of humans' space management during interpersonal communication (Hall, 1963). A typical example is the distance we keep when we talk to strangers. Indeed, there are robots that do not violate personal spaces (Nakauchi and Simmons, 2002). Moreover, there are systems to capture pedestrians' personality traits as to predict their future positions in order to generate motions that are comfortable to people (Bera et al., 2017). According to the study, the use of psychological traits can improved pedestrians' prediction accuracy in the long run.

Both social norms and proxemics can vary depending on the cultural context. Signs or texts are used to kindly remind people to adhere to rules that are specific to certain countries. These rules are established to ensure people's safety, to smooth crowd flow and to respect cultural habits. Specific examples include signs or texts to remind people to keep left or right in train stations during rush hours or to keep social distances in public areas under specific situations. Given the fact that social norms are loosely specified and culture-dependent, there are robotic wheelchairs implemented with motion planners that are capable of learning social norms by observing pedestrians and incorporating observations into its motion planning (Johnson and Kuipers, 2018).

The importance of adhering to proxemics and social norms are widely acknowledged in the robotics literature regarding navigations and human-robot interactions (Pacchierotti, Christensen, and Jensfelt, 2006; Takayama and Pantofaru, 2009; Kruse et al., 2013; Joosse et al., 2013; Rios Martinez et al., 2015; Lasota, Fong and Shah, 2017). Socially-aware navigation is defined as the robot's ability to take into account social norms and proxemics rules during operations. It allows a robot to navigate naturally, comfortably under stress-free conditions. Most importantly, this type of navigation is meant to respect accepted cultural conventions (Kruse et al., 2013). Socially-aware navigation is intended to reduce collision possibilities, and to reduce pedestrians' and bystanders' stress and discomfort. In order to execute socially-aware navigation, it is necessary to endow robots with perceptual and cognitive systems to detect and predict pedestrians' and bystanders' behaviours. The goal is to incorporate social norms and proxemics rules in motion planning. The cost-benefit trade-offs between safety and progress are important factors to consider. Frameworks have been recently proposed for socially-aware navigation such as the use of topological maps and social norm learning (Johnson and Kuipers, 2018).

2.1.2.2 *Hazards due to the lack of clarity in the robot's intentions*

The following is an example when the robot's intentions are unclear to the pedestrian. *A pedestrian walks down a narrow one lane-corridor with the robot approaching in the opposite direction. In this situation, the pedestrian does not know whether the robot will stop. If the robot stops, the pedestrian does not know if the robot has stopped for him/her because another person is close approaching. The pedestrian is also unsure about the robots' plans and when these plans will be executed.*

It is important to consider what information is needed to make pedestrians and bystanders comfortable when encountering robots (Scholtz, 2003). In the example above, the robot's intentions are unclear to the pedestrian. This can result in physical and psychological hazards, such as collisions and distress respectively. Ideally, the robot's intentions need to be conveyed transparently during human-robot interactions. Intensions transparency is crucial to promote trust in robots during H-RIs (Boyce et al., 2015; Wang, Pynadath, and Hill, 2016; Winfiled and Jirotka 2018). When a robot is self-explanatory, the users can be confident about what the system will do and why (Mueller, 2016). Understanding and disclosing robots actions and intentions ensure safety during H-RIs (Floyd and Aha 2016; Habibovic et al., 2018).

These issues are currently investigated in studies concerning the interactions between pedestrians and robots. For instance, a crowd guide robot was deployed to conduct evacuation protocols through sound and light communications (Boukas, E., et al 2015). The guide robot can also communicate with pedestrians and driverless vehicles (Rothenbücher et al., 2016). It has been demonstrated that pedestrians' and bystanders' understanding of the robot's intentions increases safety during robot navigation (Lichtenthäler, Lorenzy and Kirsch, 2012). In an experimental study, pedestrians crossing the zebra have access to communicate with an autonomous vehicle implemented with an interface to communicate its intentions. Results showed this increases the pedestrians' safety and comfort compared to pedestrians who interact with the autonomous vehicle without this interface implemented (Habibovic et al., 2018). In a similar study, a driverless car prototype was implemented with eyes to allow eye contact with pedestrians. This allows the pedestrians' to quickly make the correct decisions when crossing the street (Chang et al., 2017). However, errors, physical and psychological hazards could result from under or over trusting the robot's "intelligence" system. (De Graaf et al., 2017). Transparency helps to align pedestrians' expectations with robots' capacities. This is to avoid hazards related to over relying on the robot or having false expectations on the robot's yielding capacities. For example, pedestrians can take for granted that robots will always stop or yield in their presence.
There is no reference in EN ISO 13482:2014 regarding transparent interactions with respect to users, pedestrians and bystanders. The standard contains only guidelines, which assume the wrong decisions and actions from the autonomous robot do not harm users. Recommendations from the standard are also insufficient to address the issues related to transparency. For instance, the standard suggests increasing the robot's sensing capacity to ensure its reliability. The standard also suggests constraining operation scenarios or adding physical protections to the robot. This is to ensure safety when robots made the wrong decisions. Indeed, transparency could mitigate certain risks due to the robot's wrong decisions. Transparency allows users to react more appropriately before incorrect decisions or actions occur. These corrective actions can occur in a shared-control setting, or if the person is the robot programmer. In a transparent AI-learning based system, the user can be notified if there was insufficient data to make proper decisions.

Communicating the robot's intentions also implies designing appropriate user interfaces. EN ISO 13482:2014 takes into account possible hazards deriving from user interfaces design. However, the standard is concerned with interfaces' usability and content. For instance, the interface signals the robot status through command devices such as the on/off power switch or fault detection devices. Although, these are all important features as status warnings, they do not satisfy the transparency requirement, which requires the disclosure of the robot's intensions.

For non-users, EN ISO 13482:2014 considers possible hazards attributed to individuals who are unaware of the robot's presence. Installing acoustic emitters or lights to warn non-users of potential hazardous situations can increase the individual's awareness of the robot's presence and avoid possible collisions. However, signalling the robot presence is different from communicating its intentions and making decisions understandable by non-experts. Referring to the example given in the beginning of section 2.1.2.2, it is important to let a pedestrian know that the robot has stopped for him/her. In order to implement transparency during the robot's interactions with bystanders and pedestrians it is necessary to endow the robot with appropriate contact, visual and audio interfaces. Contact interfaces include joysticks, buttons and artificial hands. Visual interfaces include text displays, lights, gestures, robot appearances, and body movements. Audio interfaces include sound and voice devices. These interfaces can be used to convey implicit (robot motion) and explicit (voice outputs) messages. A haptic interface has been tested and developed for implementing transparency during pedestrian-robot interactions (Che, Okamura, Sadigh, 2018). The system communicates a mobile robot's intentions through implicit and explicit signals to a pedestrian. Through respect and simple collision avoidance, the system reduces users' effort and increases trust in the robot. In public spaces, however, bystanders' protection should not be based only on safeguarding protective measures (Che, Okamura, Sadigh, 2018). A robot's inherent safety design should also be incorporated into the bystanders' protection guidelines.

There are technical requirements to mitigate risks associated when the robot's intensions are ambiguous. When designing autonomous robots for operating in public spaces, we recommend taking into account robots' interactions with pedestrians and bystanders. Based on the concepts from (Scholtz 2003), certain aspects should be made transparent and understandable by pedestrians and bystanders. We propose to incorporate aspects such as status, service availability, direction indication, succeeding/presumptive moves and individuals' awareness as to clarify a robot's intention to pedestrians and bystanders. Status includes errors/malfunctions in the robot and situations that requires stand-by or stand-on based on the robot's operating status. Service availability is determined by the robot's operation availabilities, whether it is free or occupied. Direction indication is the robot's physical movements such as turning, heading strait or backwards. Succeeding/presumptive moves signifies what the robot will do next. Individual awareness requires the robot to inform pedestrians and bystanders its actions resulting from signals received.

3 Hazards emerging from public spaces

EN ISO 13482:2014 does not contain any restrictions, or special requirements for deploying personal care robots in public spaces. The standard recommends individuals to consider the robot's limits, the limits emanating from the environment, and the usage context. The standard, however, does not explicitly distinguish between robots operating in private and public spaces. In our opinion, the standard overlooks hazards when robots operate in public spaces. EN ISO13482:2014 consider only general aspects when designing safety guidelines for robot operating in public spaces. For instance, the standard contains guidelines regarding the presence of objects and obstacles to be avoided. It also draws attention to the physical qualities of indoor and outdoor spaces, such as snow, dust, water, slopes, steps and uneven ground, which are important safety aspects to consider. However, the standard lacks at least three important aspects regarding the use of robots in public spaces. These aspects include crowd density, implicit social rules and people's misbehaviours. Crowd density or their fluctuations often occurs in public spaces. There are implicit rules in the society, such as social norms and proxemics rules governing people's social behaviours and interactions. The most difficult aspect to control or predict are people's malicious intentions and they can be life threatening. In the next subsection, we will discuss these public spaces' properties and how they affect safety. Our focus is on autonomous and semi-autonomous servant/person carrier robots and their hazards for people in public spaces. We do not distinct between users and pedestrians, since these hazards concern all individuals.

3.1 Crowd density

Public spaces can become crowded. An environment is crowded when its density is above 4 people per square meter for a moving crowd and 2 people per square meter for a static crowd[9]. Population density in public spaces has not been considered as a source of hazards in EN ISO 13482:2014. Although EN ISO 13482:2014 acknowledges the presence of pedestrians and bystanders and referred to them as "safety related object[s]". It does not take into account people's specific attributes, namely the possibility of density variations during rush and non-rush hours.

High pedestrians and bystanders density requires special technical features to ensure safe and efficient robot operations (Moussaïd et al., 2010). These features include the ability to monitor and recognize crowd formations. The robot needs to react rapidly to changes in crowd dynamics in a safe and socially compliant manner. Failure to cope with these aspects may bring about new hazardous situations, such as obstructing crowd flow, creating unnecessary crowd movements or disrupting crowd organisation.

3.2 Social and proxemics rules

People tend to behave socially in public spaces. They move and interact with others by respecting social norms and proxemics rules. Moreover, it is typical for humans to attribute social features to objects, including robots, treating them as social actors/agents (Reeves and Nass, 1996). Humans do anthropomorphize robots. Anthropomorphism involves a person making attributions of human likeness toward a nonhuman object. As a result, humans may expect robots to behave socially (Takayama and Pantofaru, 2009). As pointed out in section 2.1.2.1, the EN ISO 13482:2014 does not include navigation requirements for individuals that are socially aware of their environment. According to the standard, the human beings present in the environment should be treated as "safety-related objects" namely as objects to be avoided, likewise animals.[10]

Concerning navigation and localization, EN ISO 13482:2014 recommends the robot to avoid any pre-known "safety-related obstacles". This serves to mitigate risks associated with unacceptable collisions and mechanical instabilities. The standard states the robot should stop when it detects a human, a safety-related object, in a protective stop space. The amendment in ISO/TR 23482-2:2019 indicates human entry into a protective stop space is not the only criteria for a robot to stop when it encounters a human. In addition to stopping, a robot should adjust its speed with respect to the distance or the relative speed of an obstacle. The EN ISO 13482:2014 considers hazards derived from a robot's navigation errors. It also considers hazards related to humans who are unaware of the robot's presence. For example, a robot's silent operation can increase the risks of collisions. However, the standard fails to acknowledge humans as *living beings*. Humans should not be perceived only as dynamic obstacles, but also as social entities (Rios Martinez et al., 2015). In reality, humans are more than "objects" present in the environment. Humans obey to social norms and they may react to the robot's presence (Che, Okamura and Sadigh, 2018). More importantly, humans have expectations concerning how themselves and others should adhere to social norms. When designing navigation robots for use in public spaces, we need to consider the physical and the social aspects of operative environments. Disregard for social norms and proxemics rules can be a source of hazards, as discussed in section, 2.1.2.1.

3.3 Vandalism

In private spaces, such as factories, domestic environments, and health care facilities humans and robots collaborate with one other. In public spaces, however, people's intentions towards robots may not be always benevolent. In public spaces, people's malicious acts are almost unavoidable especially vandalism. Indeed, robots risk being attacked (Salvini et al., 2014; Brscić et. al. 2015; Keijsers and Bartneck, 2018; Romero, 2018). In fact, most autonomous service robots operating in public spaces interact closely with people. These robots, however, are unsupervised, making vandalism difficult to prevent. Robot vandalism represents a hazard for users, bystanders, and the environment. Therefore, it

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9 https://www.qub.ac.uk/safety-reps/sr_webpages/safety_downloads/event_safety_guide.pdf.

10 Quite interestingly, EN ISO 13482:2014 characterises animals as live creatures in much more details than humans. This is evident by the variety of cases taken into account of collisions with robots, such as: "animal biting the robot; trampling the robot, fleeing the robot in fear; animal shock or distress due to the presence of the robot".

is important to implement safety requirements in robots design to prevent vandalism and malicious acts with similar intents. Evidently, EN ISO 13482:2014 does not include safety requirements to protect robots from vandalism and this issue will be addressed in the next section.

4.0 Hazards deriving from security threats to robots

There are hazards that can compromise robots' safety that are not due to malfunctions, accidents or misuse. These hazards derive from intentional harmful acts including robots abuse. Safety measures should protect a robot from damages caused by people and the surrounding environment. Security measures should prevent people and the surrounding environment from disturbing a robot's operation (Kirschgens et al., 2018). Safety and security are both interrelated issues. Therefore, safe robot operations require the prevention of security threats to robots (Kirschgens et al., 2018).

In this era where Internet and cyber systems are prevalent, robots are usually interconnected with other robots and external services. Robots implemented with sensors can acquire a great amount of data from people and the environment. Physical and cyber-attacks could seriously compromise robots' safety, affecting users and bystanders. Some scholars believe that robots could be used to commit crimes and they call for countermeasures to resolve this problem (Sharkey, Goodman and Ross, 2010). Several studies demonstrate robots used in the industrial and the service sectors are vulnerable to attack (Maggi et al. 2017; Kirschgens et al., 2018; De Marinis et al., 2018). Unfortunately, this security issue has been overlooked or underestimated in the ISO13482:2014. It is common for robot designers and manufactures to hastily launch their products without giving adequate considerations to security (Kirschgens et al., 2018). Moreover, manufacturers are often inept in dealing with vulnerability reports'. The following subsections will address two types of security threats. 1. Attacks that hack the robot's control system software, exploiting the robot's internal vulnerability. 2. Attacks that vandalize the robot's sensors and actuators, exploiting the robot's external vulnerability.

4.1 Hazards due to internal vulnerabilities

This subsection describes attacks exploiting the robot's internal vulnerabilities. This includes hacking the robot's control system software through wireless or remote accesses. By definition, hacking is 'the activity of using a computer to access information stored on another computer system without permission, or to spread a computer virus' (Cambridge Oxford Dictionary Online). It is the most common threat exploiting the robot's internal vulnerabilities. Robot hacking is a criminal act. Robot hackers access a robot without permission to steal information, control the robot, spread a virus, or accomplish other malicious activities. Hackers can also access the robot control system by taking advantage of external vulnerabilities including the use of USB ports (Maggi et al., 2017). The most frequent attacks, however, are done via communication networks. Nowadays, most robots are implemented with standard networking and computing components adaptable to many applications. As a result, robots are often subject to security vulnerabilities when their computer networks are hacked (Akdemir et al., 2010).

The Robot Operating System (ROS) is a very popular set of software frameworks used in research and industrial applications (Dieber et al., 2020). Few studies have highlighted its security vulnerabilities. A group of researchers demonstrated the ease in hacking a robot programmed with ROS by controlling the system remotely from the Internet. Hackers can obtain the robot's data if they were able to access its sensors and control its actuators. Moreover, the ROS allows the hacker to infect the robot with subtle bugs to induce strange behaviours in the robot (De Marinis et al., 2018). There are disadvantages to standardizing a robot's operating system. Implementing a universal robot operating system could lead to large-scale cyber-attacks (Sharkey, Goodman, and Ross, 2010). Another study experimented with various models of industrial robots in a laboratory setting. The study demonstrates hackers can manipulate these robots through various means. Hackers can modify the robot's controller and its calibration parameters. They can also manipulate the robot's user-perceived status and its actual status. Furthermore, hackers can modify the robot's task logic to control its movements (Maggi et al., 2017).

The Robot Security Framework (RSF) is a comprehensive guideline to perform security assessment in robotics. It was written based on four layers including physical, network, firmware and application that are relevant to robotic systems. These layers were divided into aspects, which contain methods to ensure security (Vilches et al., 2018). Concerns about cyber attacks are widespread and acknowledged (Greenberg, 2016; UNESCO, 2017; Broadbent, 2017; Taurer et al., 2019). Hacked computers,[11] chatbots, dolls,[12] pace makers,[13] and other systems are frequently reported in the news. ISO13482:2014, however, ignores attacks exploiting personal care robots' internal vulnerabilities. The term "hacking" was never mentioned. EN ISO13482:2014 defines user interfaces as command devices including joysticks, operator control panels, voice and gesture recognition systems. The standard provides requirements to protect against cyber attacks. It prohibits 'unauthorized use of controls or parameter changes, even through remote access' in order to avoid 'unintended personal care robot starts or moves'. The standard requires to use of passwords, key cards or fingerprints when accessing a robot's user interface. Depending on the user, the standard also suggests reducing access levels to a robot's user interface. The main concern is that the user can gain unintentional access to the operator's control device by pressing the wrong buttons. When manufacturing and designing manual control devices, the standard requires measures to prevent unintended operations.

In general, EN ISO13482:2014 lacks measures to protect personal care robots against cyber attacks. IEC 62443 is a series of standards for ensuring information technology (IT) networks security (ISA/IEC 62443). It provides measures to prevent cyber threats in Industrial Automation and Control Systems (IACSs) used in industrial organizations. Although IEC 62443 applies to IT network security in the industrial sector, there should be safety guidelines comparable to IEC 62443 as to protect personal care robots form cyber threats. It is worth highlighting that IEC 62443 is not present in the normative references list provided in EN ISO 13482:2014, that is among the documents normatively referenced and indispensable for its application.

The hazards resulting from attacks against a personal care robot can seriously affect users' and bystanders' safeties. A hacked robot can be remotely turned into a "cyber and physical weapon", causing dangers to humans. This happens if the personal care robot was to serve people in a public space, such as an airport (Giaretta et al., 2018). Other hazards to robot users include the "denial of service". This can be a limping person who was denied walking support from a hacked service robot (Akdemir et al., 2010). Severe hazards include exploiting vulnerable individuals (Giaretta et al., 2018) and turning a robot into a criminal tool (Torresen, 2018; Sharkey, Goodman, and Ross, 2010). Therefore, we include "security hazards exploiting personal care robots' internal vulnerability" in the hazards checklist. Table 4 include two types of hazards in this regard. They are privacy violations and robot behaviours alteration with malicious intents. With the emerging 5G technologies, allowing real time data exchange among devices is imperative to protect robots from hackers.

Table 4. Security hazards exploiting personal care robots' internal vulnerabilities

No.	Hazard item	Hazard analysis		
		Hazard	Potential consequences	Notes

[11] https://www.witn.com/content/news/Greenville-city-computers-shut-down-after-virus-attack-508373251.html

[12] https://www.bbc.com/news/av/technology-31059893/what-did-she-say-talking-doll-cayla-is-hacked

[13] Hamlyn-Harris JH. 2017. Three reasons why pace-makers are vulnerable to hacking. In: TheConversation.https://theconversation.com/three-reasons-why-pacemakers-are-vulnerable-tohacking-83362

1	Security hazards due to internal vulnerability	Hacking robot database for stealing information/sensitive data (privacy violation)	Psychological safety	
2		Hacking the robot control system for altering the robot behaviours (behaviours violation)	Physical and psychological safety	

4.2 **Hazards due to external vulnerability**

Robots are designed to execute their actions based on information they received from the environment and the people they serve. In this regard, robots are tangible objects and could suffer from external vulnerabilities, including vandalism. Vandalism is defined as "the crime of intentionally damaging the property belonging to other people" (Cambridge Oxford Dictionary Online). In robotics, vandalism can occur when a robot's sensor or its external surface is maliciously damaged. Vandalism can also occur through cyber attacks. For instance, a robot could be order to crash against the wall when its control system is hacked.

Robots could suffer from other forms of external vulnerabilities in addition to vandalism. As mentioned previously, a robot could have its external devices such as USB ports or its RJ-45 ports hacked (Maggi et al., 2017). As a result, the perpetrator gains access to the robot's data. A robot can suffer from external vulnerabilities even if it's not physically damaged, this can occur if its emergency stop button or sensors was manipulated. According to the Machinery Directive 2006/42/EC, the emergency stop button needs to be easily accessible in case of need. A robot could suffer from external vulnerabilities if the use of the emergency stop button was abused. It is challenging to prohibit the use of the emergency stop button since anyone can stop an autonomous robot at will. Furthermore, hackers can gain control of the robot if the robot's external sensors were hacked (Akdemir et al., 2010). Hacking external devices is not the only method to inflict external vulnerabilities on a robot. A robot is externally vulnerable if sticks, paints or tapes obstruct the robot's sensors. These external vulnerabilities are different from vandalism, since they are not meant to damage the robot, but to compromise its behaviours. Malicious users can also perceive the robot as an "agent" rather than an "object". Attacks can range from pushes to verbal assaults (De Angeli, Brahnam, Wallis, and Dix, 2006). A few scholars have referred to such abusive behaviours as bullying (Salvini, 2014; Keijsers and Bartneck, 2018). Robots are often bullied since they cannot retaliate (De Angeli 2006). Moreover, autonomous robots with human-like features can increase humans' propensity to exhibit aggressive behaviours towards them. A study investigates the origins of aggressive behaviours towards robots (Keijsers and Bartneck, 2018). They found a negative correlation between human aggressions towards the robot and the degree of robot dehumanization. Another study focused on children assaulting robots in public spaces. These assaults include physically and verbally abusing the robot (Brscić et al, 2015). A statistical model was developed to predict children's abusive behaviours towards the robots' control system. This model was successfully tested in a shopping mall with a real robot. Vandalism and bullying can negatively impact personal care robots tasks efficiencies, as well as the safety of users and pedestrians. However, these events could be mitigated if individuals were to increase their exposure to robots. This is known as the "novelty-routine effect" which will be further discussed in Section 5.

Awareness of robots' vulnerabilities protects robots from abuse, which robot designers often overlooked. A study proposed design solutions to protect robots from various attacks (Akdemir et al., 2010). Another study describes ethical principles concerning responsible robotics (Boden et al. 2017). The authors discuss whether robots should be endowed with self-defence capabilities such as built-in taser shocks to defend themselves against theft or vandalism. According to the authors, "a robot should never be armed to protect itself since human safety is more valuable than that of machines".

The term vandalism has only been mentioned twice in EN ISO13482:2014. Vandalism was vaguely defined in the standard as the possibility to start or move the robot by an unauthorized person. Robot designers and manufacturers should bear in mind they should not only protect robots from misuse, but also from abusive behaviours such as vandalism. Protecting the robot components against abusive behaviours should be part of safety risks assessments. These protective measures serve to prevent acts of hacking the robot control system, damaging sensors and stealing robot parts. Other protective measures include implementing verbal or emotional interfaces, alarms, security cameras and avoidance behaviours in the robot (Brscić et. al. 2015). Ideally, the most effective means to prevent vandalism would be to educate the public regarding proper robot usage.

We suggest to implement the new hazard item 'security hazards due to external vulnerabilities' in EN ISO13482:2014. Table 5 illustrates security hazards resulting from external vulnerabilities in robots used in public spaces.

Table 5. Security hazards due to robots' external vulnerabilities

No.	Hazard item	Hazard analysis		
		Hazard	Potential consequences	Notes
1	Security hazards due to external vulnerability	Vandalism: damaging the robot or its components	Physical and psychological safety.	
2		Bullying, compromising the robot behaviours by exploiting external properties (behaviour violation)		

5.0 Psychological safety

Existing protocols emphasize the importance of implementing safety measures to protect humans from physical harms during H-RIs. Robots can also inflict psychological harms on humans, which is often over-looked (Lasota, Fong and Shah, 2017). Since the human mind and the body are intimately linked, injuries inflicted on the body can negatively impact the human psychology. Our distinction is purely functional and relates to classifying and identifying potential hazards that are harmful to the human psychology during human-robot interactions. These hazards relate to the person's cognitive and emotional health.

Psychological safety measures ensure "stress-free and comfortable" human-robot interactions (Lasota, Fong and Shah, 2017). Psychological hazards can cause discomfort, stress and fear in an individual.
In robotics, psychological hazards have been addressed in the framework of occupational safety (Horton et al., 2018). In the industrial sector, the workers' mental stress can be attributed to poor ergonomic devices and cognitive burdens resulting from non-usable interfaces. Boredom caused by repetitive tasks can also cause mental stress (Hudson and Bethel, 2018).

Psychological safety can be at stake in various contexts, with any robot types, ranging from industrial to humanoid robots. Psychological hazards, caused by physical as well as cognitive interactions with robots can result in mental stress in professional users and bystanders. For instance, a user touching or being touched by a robot can feel discomfort and fear. A pedestrian can be stressed when walking next to a robot with a scary appearance or a robot exhibiting unexpected or unsafe movements. Moreover, poor ergonomics and operability inflicted to a robot user can also cause mental stress. Perceived or subjective safety can result in psychological hazards during interactions with robots (Lasota, Fong and Shah, 2017). Perceived safety can be defined as 'the user's perception of the level of danger when interacting with a robot, and the user's level of comfort during the interaction' (Bartneck et al. 2009). This is different from certified safety, which is safety that has attained the standards for certification (Fosch Villaronga, 2017). There are neither standards nor regulations for mitigating hazards linked with perceived safety (Fosch Villaronga, 2017). Perceived safety is a hazard since it may compromise the robot's optimal performance due to the user's anxiety.

Other psychological hazards can emerge when the interface between humans and robots are constantly evolving. The British Standard on ethical robot design categorized psychological hazards under "ethical harms". This encompasses "anything likely to compromise [the] psychological and/or societal and environmental well being" (BS 8611:2016). The list of psychological hazards in the standard extents beyond stress, fear and discomfort. It includes 'embarrassment, anxiety, addiction, deception, humiliation [and] being disregarded' (BS 8611:2016). The list was further expanded in the European Parliament report on recommendations to the Commission on Civil Law Rules on Robotics (European Parliament, 2017). It incorporates "emotional connection" or "emotional attachment", as new psychological hazards due to the widespread robots use in vulnerable groups including children, the elderly and the disabled. Furthermore, these robots were design to harbour social capabilities designed for companionship, education, and entertainment. The emotional response and the social bond between humans and robots during interaction may emotionally impact individuals including vulnerable groups in three ways (Malle and Scheutz, 2016). 1. Third parties, including hacker can access or control a robot to obtain personal and confidential information. 2. Users can suffer from loss and grief if they establish an emotional bond with robots who serve as robotic pets. 3. It is dangerous for individuals to over invest their trust on the robot's "intelligence".

A major obstacle to mitigate psychological hazards is individuals' perceived safety on robots. It is a subjective method to determine hazards robots can create and how the hazards are manifested. Human perceptions and expectations concerning robots do fluctuate (Bartneck et al., 2009) As discussed in Section 2.1.1, there are extrinsic and intrinsic factors affecting people's attitude towards robots.

The novelty/routine effect, based on the level of people's exposure/familiarity to robots, is an extrinsic factor that can influence the perceived safety on robots. This concept has been investigated in people's engagement levels towards service robots. According to several studies, the novelty effect decreases after prolonged interactions (Pacchierotti et al., 2006 and Hutternrauch et al., 2002). Robots gain user's acceptance as a consequence of use (Dario et al., 1999). The effect of anthropomorphism decreases when humans get acquainted with robots (Lemaignan et al., 2016). The novelty/routine has important effects on human robot interactions, because increased familiarity with a robot can mitigate stress or non-acceptance during humans' initial interactions. However, from a safety standpoint, we argue that the novelty/routine effect cannot be considered as a motivation for discarding hazards, only because they might fade away with the passing of time. There are at least three reasons:

1) Novelty should be understood as an experiential rather than an ontological phenomenon (Smedegaard, 2019). Novelty is based on the person's experience with an object or event. Unlike familiarity, is 'the original feature of everything that we experience' (Smedegaard, 2019).. It is important to not deviate from the standard safety procedure/behaviour when operating or interacting with novel or experimental technologies. Individuals can always experience something as new, regardless of whether the technology is new in itself. Robots serving the public environments always encounter people who are not familiar with robots.

2) In a study on anthropomorphism is the authors point out that there are three stages to anthropomorphism towards a robot (Lemaignan et al., 2016). They are the initialization stage, the familiarization stage and the stabilization stage. Due to the novelty effect, humans often anthropomorphize the robot during their initial interactions. However, the level of anthropomorphism stabilizes after the initialization stage. A similar dynamic process applies to other perception-dependent aspects concerning H-RIs. These aspects include perceived safety, privacy, proxemics and transparency. Human's perceptions of robots are subjective. These perceptions change with increased interactions and engagements with the robot. Therefore, hazards may occur during the sequential phases of initialization and stabilization. For example, with increased exposure to robots, people do get used to robots moving very fast or very close to them. However, hazards might occur prior to this stabilization phase. Initially, people may be hurt or scared by the robots' walking speed or passing distance.

3) Unfortunately, not all acclamations towards the robots are beneficial. For instance, people may get used to the physical dangers or privacy intrusions robots might impose. Indeed, people do acclimate to unsafe robots behaviours with repeated exposures and increased familiarity with robots. Nevertheless, these hazards are still present and need to be mitigated.

EN ISO 13482:2014 has not given much attention to psychological safety. According to the standard, 'hazards can arise from both physical and mental aspects of using the personal care robot'. The hazards mentioned in the standard are stress and discomfort derived from robot use. These factors includes continuous use, unclear or incomprehensible user interface design, non-conformity to ergonomics standards, intolerable acoustic noise emitted by personal care robots and extreme temperature emanated from the robot or its components. As mentioned previously there is a need to update the range of psychological hazards included in EN ISO 13482:2014 (Fosch Villaronga, 2017). Hazards derived from the robot's appearances and movements will be discussed in the next subsection. Unfortunately, EN ISO 13482:2014 lacks comprehensive guidelines regarding these two safety aspects.

5.1 Psychological hazards deriving from robots' motions and appearances

EN ISO13482:2014 distinguishes intentional and unintentional robots' motions under proper usage and working conditions. The standard defines hazardous movements, as mechanical and motion instabilities. These instabilities can result from transporting loads or improper embarkation/disembarkation. Collisions due to physical contact, rollover and over speeding can cause robot instabilities including the detachment of body parts. According to the standard, external impact forces should be taken into consideration when designing robots' motion behaviours.

EN ISO 13482:2014 contains guidelines in reference to ISO 12100, ISO 13854 and ISO 15534 regarding the robot's shape/external appearance in order to minimize physical hazards to individuals. These hazards include crushing, cutting or severing injuries from sharp edges, holes in accessible parts, unprotected joints, and parts detachment. In order to increase individuals' awareness to robots' physical presence, EN ISO13482:2014 recommends robots to be implemented with highly noticeable appearances, such as warning lights or other optical devices. EN ISO13482:2014 also includes guidelines in robots' appearances as to promote user-friendly interfaces and to minimize psychological hazards. They include visible location of indicators and visual displays in robots.

These EN ISO13482:2014 psychological safety guidelines pertaining to the robots' appearances only relates to improving ergonomics and usability.[14]For instance, there is no reference to the relationship between the robot's shape/appearance with perceived safety or privacy. The next subsections discuss how robots' motions and appearances affect safety perception and privacy.

5.1.1 Safety Perception

A robot's movement affect individuals' safety perception on robots. For instance, the robot motion can be perceived as unstable or too fast with respect to the crowd. A Segway platform's continuous high-speed forward and backward movements could be negatively perceived as unstable (Salvini, Laschi and Dario, 2010). A study indicates the accepted approaching speed for robots is slower than normal walking speed for humans (Butler and Agah, 2001). Moreover, a study investigates individual's responses to a mobile robot's approaching motions (Pham et al., 2015). In the experiment, the robot travels with various speeds (slow/fast) and various proximities (close/far) relative to the individual. Based on psychophysiological analysis with electro dermal activities and semantic difference techniques, results showed a robot moving close to the individual increases his/her anxiety compared to a robot moving from a far distance. Interestingly, this anxiety is independent from the robot's speed.

[14] Only in ISO/TR23482-2:2019, the possibility that the robot is not noticed when operating in the dark is associate also with the possibility of frightening the user, namely with a psychological hazard.

A robot appearance can also influence perceived safety. A study investigated pedestrians' perceived safety with respect to autonomous vehicles with or without interfaces (Habibovic et al. 2018). The study found the robot's disagreeable visual appearance could be hazardous since it negatively affects the beholder's perceived safety on the robot. A robot's physical attributes including its dimension, shape, disagreeable appearance and dangerous protruding parts can elicit a sense of danger or fear to the beholder.

5.1.1.1 Perception of intrusion into one's privacy

The fear of being surveilled and the distress resulting from privacy violations are psychological hazards. Perpetrators can violate a person's privacy through implementing video cameras in a robot. Recoded videos will be transmitted through the Internet, breaching privacy. Apprehension could arise if a person is the victim or suspect of being a victim of such acts (Yip et al., 2019). This can cause stress, anxiety and even violent reactions towards the robot. Sensors including cameras or microphones can potentially violate a person's privacy. In order to protect individuals' privacy, a study proposed regulations to limit a robot's behaviour through altering its design (Rueben and Smart, 2016). The study suggests limiting what a robot can see/detect, where it can move and what it can touch. Implementation of transparent privacy policies is another method to protect users and bystanders' privacy. These policies include usage information and complementary measures to disclose privacy risks to people. This can be achieved via labelling system and graphical interfaces to visualize privacy settings (Rueben and Smart, 2016).

Table 6. Psychological hazards deriving from the robot's motions/movements

No.	Hazard item	Hazard analysis		
		Hazard	Potential consequences	Notes
	Hazard due to robot motion/movement	The robot motion does not elicit an acceptable level of perceived safety	Psychological	

Table 7. Hazards due to the robot's appearances

No.	Hazard item	Hazard analysis		
		Hazard	Potential consequences	Notes
1	Hazard due to the robot's appearances	The robot's appearances does not elicit an acceptable level of perceived safety	Psychological safety	
4		The robot's appearances does not elicit an acceptable level of perceived privacy	Psychological safety	

Conclusions

EN ISO 13482:2014 is the reference standard for personal care robots, namely service robots designed to improve people's quality of life. Service robots include information providers, guide robots, servant robots and carrier robots. Conformity to EN ISO 13482:2014 can facilitate the CE mark (Conformité Européenne) acquisition. This signifies the robot has met the European Union safety requirements and can be traded in the European market. This article highlights some limitations on EN ISO 13482:2014 regarding the safety of service robots operating in public environments. We conclude that the standard only includes guidelines to protect users' safety. It does not contain policies to protect pedestrians' and bystanders' safety when they encounter a robot in public spaces.

The standard fails to acknowledge the "bystander role" and the potential hazards emerging from their interactions. Moreover, the standard does not distinguish hazards related to the robot's and function from hazards emerging from the robot's operative environment. It implicitly assumes that private spaces, such as households, offices, and other private environments, present the same hazards as public spaces. The presence of crowds, social norms, proxemics rules and people's misbehaviours can affect robots' safety. EN ISO 13482:2014 safety requirements address mainly physical hazards. This does not withstand the concerns regarding psychological or cognitive hazards expressed by respected authorities including the European Parliament and the British Standards Association.

It is difficult, and not desirable, to translate all possible psychological hazards into standards. Nevertheless, we believe some psychological hazards cannot be ignored and must be taken into account in the robot's design. For instance, the robot's behaviours must be designed to mitigate fears for one's safety. This includes using acceptable speeds and accelerations. It is also important for a robot to communicate its presence to the pedestrian. Similarly, robots should not appear as if they were surveiling people. This undoubtedly generates the feeling of intrusion into one's privacy. It may be difficult to translate these concerns into safety guidelines in EN ISO 13482:2014. Nonetheless, we should adopt items listed in Table 6 and 7 as good practice measures. EN ISO 13482:2014 does not provide safety guidelines to protect both the robot and individuals operating in public spaces. Robots working in public spaces are working closer with people and are much more vulnerable to abuses and misbehaviours.

This paper aims to raise stakeholders' awareness on EN ISO 13482:2014's insufficiencies regarding servicing robots operating in public space. Indeed, EN ISO 13482:2014 conforms to the Machinery Directive 2006/42/EC and adherence to this directive ensures product circulation in the European market. Public spaces carry unique hazards compared to private spaces. Therefore, additional safety requirements are needed to guarantee personal care robots' safety. In our opinion, we need an amendment to EN ISO13482:2014 or a new standard devoted to personal care robots' operations in public spaces.
The standard's inadequacies can deem a product faulty in legal disputes, even if it complies with the standard. Therefore, improving ISO13482:2014 is the solution to improve users' and bystanders' safety. It also provides a safeguard for producers and manufacturers.

This article demonstrates the inadequacies in EN ISO13482:2014 regarding personal care robots' use in public spaces. This article also identified new hazards and suggested potential remedies. The future work is to further identify and analyse significant hazards, hazardous situations or events in public spaces. More importantly, risks reduction measures are urgently needed to rectify existing deficiencies in EN ISO 13482:2014.

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