Research Article

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Responsible use of exoskeletons and exosuits: Ensuring domestic security in a European context

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Abstract: This article aims to focus attention on the threat to domestic law and order posed by the misuse of wearable robotic exoskeletons and exosuits intended for beneficial uses such as rehabilitative care and industrial production. Threats to domestic law and order from the misuse of exoskeletons by rogue users range from creating havoc in public spaces, violent crime and endangerment of civilian(s) to enhanced burglary techniques. Drawing on existing legal-institutional frameworks and law enforcement apparatus, this article conceptualises a general framework for the responsible end use of exoskeletons and exosuits. It calls for proactive inward-looking state strategies to manage the *bads* of exoskeleton and exosuit acquisition, possession and trade while encouraging *good* uses. Importantly, this article does not suggest that the legal-institutional mechanisms discussed for managing misuse are the only ones relevant to the issue except as a guide for encouraging further discussion in the area.

Keywords: European security, misuse, RRI, domestic law and order, autonomous exoskeleton, autonomous exosuit, accessory to firearm, firearm directive

1 Introduction

Various types of wearable robotic exoskeletons ranging from powered, passive, pseudo-passive or active versions serve a range of uses from assisting in rehabilitative care [1,2] and industrial manufacturing [3,4] to leisure activities and military combat [5–7]. As these robotic exoskeletons can be taken off or put on the human body (or a body part) at will they are *wearable*, although some versions such as soft exoskeletons[1] (referred as "exosuits") made of soft materials are easier to wear than those made of rigid hard materials.[2] Exosuits and exoskeletons may be full-body or partial-body designed for upper or lower extremities, back, etc. From the end-use perspective, what weaves various types of exoskeletons and exosuits together are the substantial technological overlap between different uses whereby exoskeletons and exosuits designed for one purpose are easily used or adapted for various other purposes. A cogent example is the repurposing of the *ABLE 7-axes* upper limb exoskeleton. The *ABLE 7-axes* was initially developed by the French Atomic Energy Commission to rehabilitate stroke patients [8] but repurposed by PSA Peugeot Citroen (the automotive giant) to make it easier for its factory workers to hold screw guns [9].

It is thus conceivable that exoskeletons designed to reduce 50 to 70% arm weight when carrying screw [9] weld or paint guns [10] would also enhance firearm-wielding capabilities of a rogue user; making it easier to wreak greater havoc in crowded public spaces and or endanger lives. Likewise, it is also conceivable that commercially adapted versions of exoskeletons and exosuits initially designed for military use in battlefields pose a threat to public law and order in the hands of rogue users. Consider Sarcos Robotics' *Guardian XO*[3] – the commercially adapted "agile" version of the full-body "supersoldier" exoskeleton originally designed for use by the US military to lift weights up to 90 kg. Sarcos not only acknowledges the threat to civil law and order posed by the *Guardian XO* but proactively incorporates specific design features to make "legal [and illegal] misuse" harder (Sarcos' CEO Ben Wolff in *Wired* [11]). What is concern-

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1 Such as the *Soft Robotic Exosuit* under development at Harvard University's Wyss Institute:
https://wyss.harvard.edu/technology/soft-exosuits-for-lower-extremity-mobility/
or Panasonic's REALIVE:
https://news.panasonic.com/global/press/data/en060925-6/en060925-6.html.

2 https://rewalk.com/rewalk-personal-3/

3 https://www.sarcos.com/products/guardian-xo-powered-exoskeleton

ing here is that by Sarcos' own admission, the *Guardian XO*'s "safety-by-design" features would make misuse harder for rogue users but would not prevent it. Thus, if misuse is inevitable and expected even, as Ben Wolff suggests, the question then is how do we secure society from the misuse of exoskeletons and exosuits by rogue users?

Through a discussion of the existing legal-institutional frameworks and law enforcement apparatus for managing similar threats to public law and order within European borders, this article conceptualises a general framework for the responsible end use of exoskeletons and exosuits to begin a much-needed discussion in the area. The aim of this article is thus to go beyond the security risks of exoskeletons perceived mostly in national security contexts related to defence against external aggression, warfare and military strategy [6] or the ethical and philosophical concerns of military use [5,7]. The focus here is on the threats to domestic law and order from the misuse of exoskeletons and exosuits by rogue users such as for creating havoc in public spaces, wilfully endangering civilian live(s), committing violent crime akin to gun violence [12, p. 5], enhancing burglary techniques [11], etc. as acknowledged in literature (discussed later). As the article will show, the need is for proactive inward-looking state strategies to acknowledge and manage the misuse risks of exoskeleton possession while encouraging responsible use for the benefit of European society such as disability rehabilitation, industrial productivity, long-term health of workers, etc.

Importantly, the article does not suggest that the legal–institutional mechanisms discussed for managing misuse are the only ones relevant to the issue area except as a guide for encouraging further work in the area. Additionally, it is important to remember that exoskeleton-exosuit technologies are rapidly evolving and effective governance will depend on systematic and periodic regulatory reviews of technological advance to retain efficacy of enforcement and prevent regulatory obsolescence.

2 Exoskeletons, exosuits and their multiple uses

2.1 Rehabilitative use

Various types of available exoskeletons serve multiple uses. Exoskeletons in rehabilitative care are typically *powered* or *active*. This means that they require an electrical power source "to power a [computer board-controlled] system of motors, pneumatics, levers, or hydraulics" [13, p. 113]. When the power source is derived from a battery unit, hydraulic unit or pneumatic unit attached to the exoskeleton (and typically housed in a backpack carried by the user), the exoskeleton is considered *autonomous*[5] in the sense of being un-tethered. In turn, *tethered* versions use electrical wires to connect to an external power outlet. Commercially available powered rehabilitative exoskeletons such as *ReWalk*[4] and *The Phoenix*[5] are autonomous and assist in the ambulatory rehabilitation of non-ambulatory individuals such as sufferers of spinal cord injuries [14]. Partial-body powered autonomous *exosuits* are also under development for rehabilitative care, e.g. Harvard University's Wyss Institute's *Soft Robotic Exosuit*[2] for lower limb mobility.

2.2 Industrial use

In contrast to *powered* exoskeletons and exosuits, *passive* versions do not require an electric power source. Instead they rely on human energy (hence autonomous[6] or untethered) and are lighter but advantageously without statistically significant lower "walking/running economy" than tethered versions (t test: $p = 0.90$ in [15, p. 5]). Passive exoskeletons and exosuits are typically used for weight distribution or shock absorption purposes such as in industrial manufacturing to make tasks such as lifting, moving or working with heavy equipment easier for human workers [3,4,16]. By 2014, workers at South Korean shipyard builder Daewoo Shipbuilding and Marine Engineering were already lifting up to 62 pounds (30 kg) of industrial goods wearing special exoskeletons[7] designed by the company's R&D arm; with plans to increase lifting capacity up to 220 pounds (100 kg) [4]. Indeed, a recent survey by Forbes found that in the automotive industry alone, the use of exoskeletons had risen from a "few dozen to somewhere close to a thousand... [with].... 585 devices in use [among] BMW, Ford, Honda, Nissan, Toyota, and Volkswagen [by May 2019]... and at least a dozen other manufacturers using or testing exoskeletons" [17]. Exosuits in the sports and

4 https://rewalk.com/rewalk-personal-3/

5 https://futurism.com/phoenix-40000-robot-exoskeleton-lets-paralyzed-walk

6 "Autonomy" in the wider field of robotics is related to issues of human control over machine and commands substantial multidisciplinary scholarship (see e.g. Bekey [34] for a review of literature). In this article, "autonomous" exoskeletons refer to *un-tethered* versions.

7 https://www.newscientist.com/article/mg22329803-900-robotic-suit-gives-shipyard-workers-super-strength/?ignored=irrelevant

leisure industries[8] are also on the rise and similarly easily repurposed for industrial or military use.[9]

2.3 Military use

Meanwhile, exoskeletons for military combat, often referred as "skin out enhancements" in the military, typically optimise powered designs to enable a variety of enhancements for the human soldier. These range from increasing their load-carrying and combat capacity for extended periods to increasing a human soldier's resistance against various forms of assault [18, p. S40]. However, full-body powered exoskeletons, popularly referred as "iron-man" suits based on the comic book character of the same name, are yet to become a reality despite substantial interest and support from governments worldwide. Raytheon's *XOS* and Lockheed Martin-Ekso Bionic's Human Universal Load Carrier (HULC) – both full-body powered prototypes supported by the US military and launched amidst much hype back in 2010 – were abandoned soon after launch [19]. A key factor was the technical issue that made multiple-jointed full-body versions too clunky, unwieldy and hard to control for military use in the battlefield. Meanwhile, development of partial-body variations for upper or lower extremities (both powered autonomous and passive versions) attracts substantial private and university interests alike (see e.g. Bobby Marinovs' Exoskeleton Report[10] for a detailed list).

2.4 Affordability, accessibility, agility: rethinking criteria for rogue use?

From the industry's commercialisability perspective, it is the practical "everyday" usefulness of technological advances that guide research and development. Russ Angold, president and co-founder of Ekso Bionics (and co-developer of the full-body HULC), perhaps best captured this view when he noted that:

> it's endurance first, then power. Powered is the future, but non-powered [i.e. passive versions] is the way to start. [16]

Behind Angold's prediction lies the irrefutable economics of commercial viability, market affordability and profitability. Not only are recent passive exoskeleton and exosuit designs for legs, shoulders and back lightweight enough to allow use over extended time periods with minimal fatigue but also substantively affordable. For instance, University of California, Berkeley's spin-off *SuitX's* passive *Modular Agile eXoskeleton* (MAX) combining detachable leg, back and shoulder exoskeletons (for workers) was expected to retail at less than US $5,000.[11] While the retail price of SuitX's powered *Phoenix* exoskeleton was eight times higher at US$40,000[18] and *ReWalk*'s powered exoskeleton *ReWalk* double that at around US$75,000–80,000.[19]

Apart from this substantive price difference, the key differentiator is that both *Phoenix* and *ReWalk* are intended for medical use in rehabilitative care and thus likely to be mostly accessible and reimbursable through institutional channels in healthcare such as hospitals and clinics via insurers and state payers. In contrast, *passive* lower or upper extremity exoskeletons and exosuits such as SuitX's *MAX* are not only more affordable but also intended to be accessible to workers across the spectrum of public and private sectors from "construction, material handling, shipbuilding, foundry, [to] airport baggage handling. [etc.]".[12] As SuitX's co-founder, Professor Hoomayun Kazerooni explained the logic of developing *MAX* (after *BLEEX*, *HULC* and *Phoenix*) as follows:

> [to create] something accessible. It's like making a Honda [referring to *MAX*] vs making a Lamborghini [referring to *BLEEX*, *HULC* and *Phoenix* powered prototypes]. Making a Lamborghini is not that difficult to me. You just keep adding things on. Creating a smaller car that millions of people can drive and is still useful – that's a huge deal. Unless you want to turn at a track at a 100 mph, the Honda is just fine. The performance is identical when you go 35 mph. That's what I was looking for. That's what MAX is all about [...] the promise of getting it accessible to people. For this [the *MAX*] to be a product, everything had to be simple, functional at lowest possible cost. If you make a building, to make it cost effective, you can't afford to buy a $20,000 exoskeleton. That's the business. A contractor who has 20 workers just wants his workers to come back the next day. They don't want to spend too much money [20].

Indeed, passive exosuit versions are purpose-built to be affordable (such as *MAX's* <US$5,000 price) by a

8 https://www.exosuit.co.uk/features/
9 https://wyss.harvard.edu/news/harder-better-faster-stronger-tethered-soft-exosuit-reduces-the-metabolic-cost-of-running/
10 https://exoskeletonreport.com/2016/07/military-exoskeletons/
11 https://canada.constructconnect.com/dcn/news/Technology/2015/7/US-Bionics-markets-robotic-exoskeletons-for-construction-1009234W
12 https://www.suitx.com/max-modular-agile-exoskeleton

broad and diverse swathe of individual consumers, small and medium enterprises (SMEs) and small institutional contractors, etc. In turn, greater affordability reflects the wider reach and (therein) greater accessibility of passive exosuits for diverse users with the accessibility set to expand substantially as industry forecasts predict:

> the market is finally growing [in the commercial passive exosuit space] as well after years relying on military and medical insurance companies with the construction, manufacturing, demolition and logistics industries to represent almost half the industry revenue within eight years. [16]

In sharp contrast, accessibility of powered rehabilitative versions is limited as they are available mostly via institutional channels in health and medicine.

For the purposes of this article – to better understand the threat to domestic law and order from emerging exoskeleton technologies – the affordability-accessibility advantage of available passive lower or upper extremity exoskeletons and exosuits suggests these to be the likeliest candidates for use by rogue users. This is further encouraged by the fact that these affordable and accessible versions also tend to be highly versatile and adaptable for various uses. Take *MAX*'s much hyped "versatility" as promoted by its developers at SuitX, which also inadvertently makes it highly amenable to misuse as it,

> can be adapted for a variety of different workplace tasks [and or misuses]. with reduced injury risk while remaining comfortable enough to wear all day… [requiring] reduce[*d*] muscle force… to complete tasks by as much as 60 percent… [and combining] intelligent design, effectiveness, affordability, outstanding ergonomic features and ease of use.[11]

That a rogue user might adapt the *MAX* to strengthen gun-wielding ability is not inconceivable. This is not to say that costlier versions such as Delta & Sarcos' battery-powered full-body *Guardian XO*[2] could not be misused, but that its higher cost would likely push users, including malafide ones, towards cheaper versions. Nevertheless, it is important to remember that while increasing affordability and accessibility thresholds would limit user access they would not deter resource-rich rogue users.

Rather, deterrence mechanisms based on technological (dis)advantages are likely to be more effective. For instance, tethered exoskeletons or exosuits are unlikely to be a rogue-user's weapon of choice as it limits, if not prohibits, a quick getaway; makes location detection easier; and are almost impossible to adapt into autonomous versions. In contrast, autonomous (i.e. movable or untethered), softshell, agile versions are likelier candidates for misuse, and law enforcement focused on their trade and ownership is likely to be more targeted and effective. At the same time, focusing law enforcement on autonomous versions would leave tethered versions (typically used in research laboratory environments) outside the legal purview, which might incentivise research attention on tethered versions, although whether such attention is desirable is less clear.

2.5 Uses and misuses

On the one hand, exoskeleton's or exosuit's inherent characteristic of enhancing human capacity has substantial beneficial uses in rehabilitative healthcare and industry [3]. On the other hand, this human-enhancement characteristic can have lethal or socio-ethically undesirable consequences if misused and or in the wrong hands [5,11,12,21–23]. One unintended consequence may be that if a critical mass of publics wear or use enhancements such as exoskeletons, it may pressure remaining others to wear them in order to remain competitive [22, p. 2]. This raises the socio-ethical question "if we want such an artificially 'enhanced' society?" [22, p. 2] among various other socio-ethical issues, which while germane are beyond the remit of this piece. The focus of this article is on threats to domestic law and order – i.e. threats to everyday human life and limb during peacetime from various misuses of exoskeletons by rogue users (discussed next).

So far, the scholarly discourse around the misuse risks of exoskeletons and exosuits has been tangentially discussed as one among the spectrum of risks arising from emerging technologies with similar use-misuse risk profiles such as neuroprostheses, brain-computer interfaces, "smart" drugs, synthetic biology, robotics and so on [5,12,21]. Within this discourse, issues related to responsible governance and management of research in these emerging technologies gain primacy [23,24]. Meanwhile, the security risks of exoskeletons or exosuits are mostly perceived in national security contexts relating to external aggression, warfare and military strategy or ethical concerns of military use [5,7]. The threat to domestic law and order from the misuse of exoskeletons by rogue users such as for creating havoc in public spaces, endangerment of civilian life, violent crime [12], enhancing burglary techniques [11] is acknowledged in literature but unaddressed in regulation or law enforcement.

Yet, addressing this emerging risk to domestic law and order is critical before exoskeleton technology becomes ubiquitous and harder to regulate [26]. Consider an exosuit in the hands of the now infamous Stephen Paddock – the "lone wolf" shooter responsible for shooting dead 58 and injuring 869 from the window of his room at the Mandalay Bay hotel, Las Vegas, on 1 October 2017. Paddock used a firearm accessory called *bump stock* to enhance the lethality of his semi-automatic rifle [25]. According to The Telegraph, bump stocks "replaces the gun's shoulder rest, with a 'support step' that covers the trigger opening. By holding the pistol grip with one hand and pushing forward on the barrel with the other, the shooter's finger comes in contact with the trigger. The recoil causes the gun to buck back and forth, 'bumping' the trigger" to enhance its lethality [25]. Now imagine the potentially exponential loss of life if Paddock was wearing an exosuit (such as the versatile MAX) that would not only be "comfortable enough to wear all day" but also "reduce muscle force by as much as 60 percent" to enhance the lethality of his shooting spree.[11] This threat to domestic law and order from misuse of emerging exosuits and exoskeletons is yet to be acknowledged or addressed as part of a state-initiated proactive "responsible use" strategy deterring, if not preventing, such eventualities.

2.6 Managing use and misuse

Meanwhile, the development of exoskeletons and exosuit technologies for civilian use in medicine and industry is advancing rapidly. The global exoskeleton market was a mere US$68 million[16] and US$98 million[12] in 2014 and 2016, respectively, with the bulk of the revenues coming from medical-use exoskeletons as most companies in the area focused on medical uses, but this is changing [16]. In 2014, Food and Drug Administration's (FDA's) approval of the *ReWalk* exoskeleton "for clinical and home use" coupled with at least some insurers willingness to reimburse them[13] encouraged further development in medical-use exoskeletons. This was further boosted by the FDA's quick successive approvals of *Parker Indegeo* and *Ekso GT* exoskeletons in 2016. In Europe, while all three – *ReWalk*, *Ekso GT* and *Indegeo* – received the CE mark, the total projected revenue for the European healthcare-exoskeleton market was expected to reach only US$32.31 million[14] in 2018. While this is a meagre revenue figure, it nevertheless contributed a sizeable chunk of the global market worth only US$96.7[15] in 2018 but expected to expand 43%[16] yearly (compounded) till 2027.

Arguably, global market predictions by various private sector market research outfits vary widely, ranging anywhere between US$1.8[17] and 8.3 billion[18] by 2025. The problem is that market projections claiming "*x*" number of exosuit units will have been sold in Europe (or globally) in "*x*" number of years are unreliable based on questionable assumptions. What is certain is that exoskeleton ownership will increase as prices invariably follow a downward trend with intensifying competition, e.g. SuitX almost halved its prices to US $40,000[19] for its *Phoenix* exoskeleton compared to *ReWalk's* introductory price of around US$75,000–80,000.[20] Thus, while the ever changing market dynamics might make it difficult to ascertain the extent to which exoskeletons will be ubiquitous by 2027, it is undeniable that they will be more widely used and available in a greater variety to serve myriad end uses.

Yet this early stage of the technology development process – when global market penetration of exoskeleton technologies remains relatively low[13,16,17] – presents a unique opportunity for shaping governance structures necessary for responsible societal adoption. This is because shaping governance is relatively easy at the early stages of technology development than later when the technology itself and its use in society become more rigid, socially embedded and increasingly resistant to regulation [26]. The strength of the "anti-regulatory" alliance against CFC emissions regulation in USA in the 80s and 90s [27, pp. 140–153] provides an instructive example of industry resistance to reshaping governance at later stages. Likewise, where the development and adoption of exoskeleton technology are concerned,

13 https://www.spinalcord.com/blog/getting-an-exoskeleton-approved-for-home-use

14 https://www.businesswire.com/news/home/20181212005755/en/European-Healthcare-Exoskeletons-Market-Analysis-Outlook-2014-2023

15 https://www.prnewswire.com/news-releases/global-medical-exoskeleton-markets-2018-2019–2027—high-market-potential-in-developing-nations-300927577.html

16 https://www.marketwatch.com/press-release/global-wearable-robotic-exoskeleton-market-generated-1274-million-in-2017-and-is-estimated-to-grow-at-a-cagr-of-4348-during-2018-2028-2019-01-15

17 https://www.abiresearch.com/press/abi-research-predicts-robotic-exoskeleton-market-e/

18 https://www.statista.com/statistics/888936/global-exoskeleton-market/

19 https://www.technologyreview.com/s/546276/this-40000-robotic-exoskeleton-lets-the-paralyzed-walk/

20 https://xconomy.com/national/2017/12/04/rewalk-ekso-race-to-sell-exoskeletons-in-tough-rehab-market/

proactive state intervention in its acquisition, possession and trade is likely to be substantially easier at the current relatively early stages of development[13,16,17] than later when industry resistance (via lobbying, protesting) against regulation is likely to gain greater influence in policy realms.

Towards this aim, the existing governance apparatus of laws, acts, directives regulating trade, ownership and the use of firearms provides a useful framework to judiciously constrain the *bad* without frustrating the *good*. For the existing governance apparatus not only has evolved over decades in response to evolving social, ethical, legal needs and technological advances but also provides a ready structural framework for implementing responsible end use of autonomous exoskeletons and exosuits without reinventing the "regulatory" wheel. Recent precedence (for the use of existing governance apparatus to manage emerging threats) can be found in the use of existing law enforcement apparatus to govern the domestic law and order risks of emerging "unmanned aircraft systems" (UASs; or popularly "drones") [33]. For our purposes, a key takeaway from the UAS governance regime is how it's built around certain end-use outcomes considered liable for law-enforcement action. For instance, to govern threats of UAS misuse the United States' Federal Aviation Authority targets "reckless endangerment [of person(s) or property], voyeurism, privacy, criminal mischief, assault and battery, noise, trespassing, violation of state aviation/motor vehicle law, obstruction of justice and interfering with police officer" [33].[21]

Governing *bad* behavioural outcomes in the end use of a technology instead of the rapidly evolving technology itself is sensible; it helps to limit the need for regulatory revisions on the back of every technological advance and with it the prohibitive costs of too frequent regulatory amendments. Likewise, policy treatment of exoskeletons similar to that of UAS' but adapted for "dangerous instruments" – typically defined in criminal law as that which is "used, or attempted to be used, to cause death or serious physical injury" – such as firearms [28][22] would help to implement state controls over *bad* end-use behaviours while encouraging *good* uses such as disability rehabilitation, industrial productivity, long-term health of workers, etc.

However, as legal frameworks are jurisdiction-specific, the legal minutiae of incorporating emerging multiple use technologies such as exoskeletons within existing legal structures will not only differ across jurisdictions but also depend on individual political-economic imperatives faced by jurisdictions. Empirical explorations of these imperatives provide opportunities for future research. Next we draw on an analysis of existing European "firearms" directives and "dual-use" regulations to suggest a general framework for the responsible use of exoskeletons and exosuits within the European jurisdiction.

2.7 The case of Europe

In the European legal-institutional context, a primary issue to consider is whether exoskeletons and exosuits could be recognised as "dual-use items"[23] to help control their trade, transfer and use within European borders. Under the European Union's (EU) export control policy, the term "dual-use" means "goods, software and technology that can be used for both civilian and military applications" while malafide use of these items is classified as "misuse" [29]. On the one hand, a *dual-use* designation in the European regulatory context has the advantage of recognising and acknowledging the dual "civilian and military applications" and the threats arising from the misuse of autonomous exoskeletons and exosuits. However, this "dual-use items" designation would bring exoskeletons under the regulatory purview of the Council Regulation (ECR) 428/2009 "for the control of **exports**, transfer, brokering and transit of dual-use items" (ECR, 2009) outward from Europe to non-EU nations. This would not have a direct impact on the trade, transfer and use of autonomous exoskeletons and exosuits within Europe (which is the focus of this article).

In any event, the items which will be included in the EU's "dual-use items" list is rarely the result of an unilateral decision by any single actor but rather informed by the work of several international bodies such as the influential Wassenaar Arrangement's annually updated dual-use lists as well as recommendations of the EU's own Dual-Use

21 https://www.faa.gov/uas/

22 Although taken from US-Delaware Criminal Code [in 27], this is consistent with criminal code elsewhere allowing for variations across jurisdictions e.g. see https://www.oregonlaws.org/ors/161.015; https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/518193/Guidance_on_Firearms_Licensing_Law_April_2016_v20.pdf; https://www.atf.gov/resource-center/docs/guide/state-laws-and-published-ordinances-2010-2011-new-york/download

23 As of writing, exoskeletons are not listed as dual-use items under the December 2018 version of the Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies (https://www.wassenaar.org/app/uploads/2019/consolidated/WA-DOC-18-PUB-001-Public-Docs-Vol-II-2018-List-of-DU-Goods-and-Technologies-and-Munitions-List-Dec-18.pdf) or the Consolidated 2017 version of ECR 428/2009 (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02009R0428-20171216&from=EN).

Coordination Group. Until there is an international consensus on extending the dual-use designation to exoskeletons, it is unlikely they will come within the purview of ECR 428/2009. On the other hand, being under the purview of ECR 428/2009 in Europe before other countries agree to control exportation of exoskeletons and exosuits would place additional transaction costs burdens (such as acquiring "general export authorisations") on European development and commercialisation of exoskeleton technologies. This would invariably adversely impact Europe's international competitiveness in an emerging promissory technology.

Instead, the Council's Firearms Directive 91/477/EEC [30][24] (hereafter CFD) defining "a set of common minimum rules for the control of the acquisition and possession of firearms in the EU, as well as the transfer of firearms to another EU country" reformed and strengthened in 2017 to "increase citizens' security" is useful. For it provides an advantageous alternative for managing misuses of autonomous exoskeletons and exosuit technologies within Europe [30]. Extending the CFD to include autonomous exoskeletons and exosuits as "accessories to firearms" presents several advantages not least of all a ready legal-institutional and law enforcement apparatus to tackle the threats, if and when they arise, without having to reinvent the "regulatory" wheel as below:

> The 2017 revision [to the CFD] brings substantial improvements to security by making it **harder to legally acquire** certain high capacity weapons. The firearms directive also strengthens **cooperation between EU countries** by improving the exchange of information between EU countries, and brings substantial improvements to **traceability** of firearms by improving the **tracking of legally** held firearms, to reduce the **risk of diversion into illegal markets**.[25] [31] [bold added for emphasis]

Basic minimum legal requirements for the acquisition and possession of firearms under the directive such as the minimum age limit of 18 years but allowing for "except[ions] for hunting or target shooting" (in the case of "firearms") provide key legal flexibilities. In the case of exoskeletons and exosuits, flexibility provisions could be extended to certain demographics such as individuals below 18 years eligible for disability rehabilitation (Art. 5a in [31]). This combined with law enforcement checks and balances that ensure firearm buyers "are not likely to be a danger to themselves, to public order or to public safety" (Art. 5b in [31]) if extended to include autonomous exoskeletons and exosuits would make it "harder [for rogue users] to legally acquire" them (Art. 5 in [31]).[26] Medical evidence requirements as a pre-requisite for authorisation to acquire firearms might also be used for exoskeletons, e.g. patient medical records as evidence of medically recognised disability. In turn, legal authorisation requirements for exoskeleton ownership coupled with inbuilt remote tracking mechanisms (as in *Guardian XO* [11]) would enhance traceability within the EU through "information exchange" arrangements between EU member states currently being used for firearms. This is likely to deter bad actors, including (il)legal sales to untraceable individuals and entities (Art. 11 in [31]).

At the same time, the CFD's design "as a measure to balance [the EU's] internal market objectives and security imperatives regarding 'civil' firearms" enshrines key flexibilities needed to provision the beneficial uses of exoskeletons and exosuits for society as below:

> The revised directive imposes restrictions on the circulation of civil firearms and provides rights and obligations for private persons, dealers, brokers, collectors and museums. There are more flexible rules for hunting and target shooting in order to avoid unnecessary impediments. [31]

For exoskeletons and exosuits, similar "rights and obligations" could be extended to (a) authorised hospitals making it easier for eligible patients to receive rehabilitative exoskeletons and exosuits as well as (b) large industry actors with systems and procedures in place to ensure their safe and secure use and storage. Additionally, evolving enforcement measures for firearms being considered by the Council and Parliament to further strengthen the CFD such as "stricter conditions for the **online acquisition** of firearms to better control the acquisition of firearms via the internet, pieces thereof or ammunition through the internet"[24] would be beneficial in controlling import of exoskeletons and exosuits from nations with less stricter security standards than Europe.

Thus, in the context of a general framework for regulating the acquisition, possession and trade of exoskeletons and exosuits to secure domestic law and order in Europe, the CFD provides key focus areas to guide further discussion in the areas as listed below:

- tightening legal acquisition through authorisation requirements and licensing,
- tightening conditions for online acquisition,

24 Revised first in 2008 by Directive 2008/51/EC and then in 2017 by Directive 2017/853/EC wef 2018.

25 https://ec.europa.eu/growth/sectors/firearms_en

26 This does not contradict the European Commission's Responsible Research and Innovation (RRI) policy, which notes that "Ethics should not be perceived as a constraint to research and innovation, but rather as a way of ensuring high quality results" [32, p. 2].

– introducing traceability and tracking of legal ownership using existing networks of "information exchange" and cooperation between EU countries,
– preventing diversion into illegal markets,
– incorporating flexibilities (rights and obligations) for hospitals and industries.

3 Conclusion

This article aimed to focus attention on the threat to domestic law and order posed by the unregulated acquisition, possession and trade in exoskeletons and exosuits and called for proactive state strategies to secure society from the *bads* of exoskeleton ownership while encouraging its *good* uses such as in medicine and industrial production. Recognition of this threat in emerging exoskeleton design by prominent manufacturers such as Sarcos Robotics and in scholarly literature urge regulatory considerations as discussed here. The article argued that extending the existing legal-structural frameworks for implementing responsible end use of exoskeletons, instead of reinventing the wheel in the sense of enacting new laws or setting up new institutions for tackling the issue, was considered the best way forward.

Through the lens of two European mechanisms for governing objects of danger to humans, the article presented the key advantages and disadvantages of using the "firearms directive" (CFR 91/477/EEC) and or existing "dual-use items" regulation (ECR 428/2009) to shape the responsible use of exoskeletons in Europe. Importantly, as the global market penetration of exoskeleton technologies remains in its early stages at the time of writing this article, adopting these regulations is likely to be substantially easier now than later when both the technology and its use in society become more embedded and thus harder to (re)shape [26]. This suggests that jurisdictions that recognise these threats and implement necessary regulatory actions would set a precedence for other jurisdictions to follow. Furthermore, jurisdictions that take the lead at this early stage are likely to take a world-leading position in shaping the global discourse and standards on the responsible development and use of emerging exoskeleton-exosuit technologies. Ultimately, the aim for the state and policy is to secure society against the misuse of an emerging promissory technology without constraining its beneficial uses, and extending the existing responsible research and innovation (RRI) frameworks [32,35] beyond technology development to responsible use in and for society [32] would be the first step in that direction.

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