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An exploratory study of workplace occupational safety and health interventions and their impact on productivity and performance in an ageing workforce

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ABSTRACT

During the last decades, a significant change has taken place in the demographic characteristics of the workforce: a growing percentage of employees is ageing, and organizations are beginning to feel the impact of an Ageing Workforce (AW) on production system performance. Yet this aspect can play a significant role in effective OSH decision-making, it is often underestimated or overlooked. Hence, an exploratory questionnaire-based study—grounded in the existing literature—maps common OSH interventions in an AW context and assesses their impact on OSH performance and productivity. Additionally, the study investigates key drivers and barriers—both ageing-specific and more general—that shape, facilitate, or limit intervention outcomes. Findings reveal that targeted communication and training interventions, along with ergonomic and technical tools, most strongly enhance OSH performance and productivity for AWs. Key drivers include active worker involvement and management commitment, whereas barriers such as poor safety culture, limited risk awareness, and legislative complexity hinder success. Overall, while economic incentives and policy compliance matter, they are not sufficient to drive sustainable improvements in OSH performance. Instead, internal organizational dynamics—especially cultural and relational factors that emphasize stability, recognition, and meaningful participation—are the ones that most influence the successful deployment of effective, inclusive interventions in an AW context.

1. Introduction

In the 21st century, ageing represents one of the most significant concerns that humanity has to face. Actually, it is universally recognized that population ageing is a phenomenon of such magnitude that is altering the world's economic situation. Due mostly to the concurrent effect of declining birth rates and increasing lifespan, this phenomenon is currently resulting in a significant fraction of the elderly population throughout the world with considerable repercussions for economic growth, employment, consumption, savings, asset values, and fiscal balance (Piggott and Woodland, 2016). According to the report provided by the World Health Organization (WHO), the number and proportion of people aged 60 years and older in the population is increasing. If the number of people aged 60 years and older was 1 billion in 2019, the growth forecasts show a value of 1.4 billion by 2030 and 2.1 billion by 2050 (World Health Organization, 2020). The rate of increase is unparalleled and is expected to accelerate in the coming decades, particularly in developing countries. Therefore, this historical shift in global population distribution toward older ages requires essential adaptations in the organizational structure across all sectors of society (Varianou-Mikellidou et al., 2021). In this context, it is worth noting that the work environment is also undergoing the same transformation due to a general change in the workforce characteristics. The Organization for Economic Cooperation and Development (OECD) reports that in European Union countries, the labor force participation rate of workers aged 50 to 64 increased from 36 % in 2000 to 63 % in 2020 (OECD, 2023). Additionally, governments are adopting policies to raise the retirement age motivated by concerns for a viable pension system. In-

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deed, since more people work longer, the resulting increased labor force participation ought to boost the level of economic output (Hanson and Lindgren, 2021).

Working conditions and organizational factors have an important role in the ageing process, and in some cases, they can accelerate it considerably. Recent studies show that factors such as low job control, heavy physical tasks like lifting, and long working hours contribute strongly to faster biological ageing (Andrasfay et al., 2023; Schmitz, 2016). But it is not only the tasks themselves that matter: work organization also makes a difference. As Gaudart (2000) observed, repetitive work, constant time pressure, and limited chances for training or job rotation can make it harder for older workers to adapt, influencing their capacity to stay in employment. On the other hand, supportive workplace practices can help older workers remain healthy, skilled, and engaged (Cahill et al., 2015; Chang et al., 2021). This highlights the bidirectional relationship between ageing and work.

These issues raise the question of how ageing aspects may affect working conditions and whether they have direct implications for labor productivity. These concerns are especially relevant for workplaces where employees are expected to complete manual and mental tasks requiring their physical and cognitive abilities, such as in assembly or manufacturing processes (Battini et al., 2017; Calzavara et al., 2020). Thus, a better understanding of the complex relationship between age and productivity is required by focusing on how and to what extent the effects of ageing on workers' functional abilities (both physical and cognitive) influence their performance at work. The assessment of this relationship is not trivial: on the one hand, age naturally causes a decline of some functional capacities which negatively affects workers' performance – such as muscular strength, flexibility, motion capability, visual ability, learning, memory, concentration (Börsch-Supan and Weiss, 2016; EU-OSHA, 2016; Kenny et al., 2016) – while, on the other hand, it also confers benefits in terms of accumulated knowledge, experience, expertise, wisdom and strategic thinking that may improve productivity (Disney, 1996; WHO, 1993). However, challenges related to the ageing workforce (AW) not only impact operational performance but also affect occupational safety and health (OSH). Indeed, the increasing duration of working life has highlighted the issues related to both preserving workers' health and extending their employability and work capability until retirement. Workers may be exposed to occupational hazards over an extended time. This may have a severe impact, specifically for any cumulative health effects that such exposures might cause.

Addressing these challenges calls for innovative strategies to support older workers while maintaining productivity and well-being (Mothe and Nguyen-Thi, 2021; Simonetto et al., 2022). There is a growing demand for advanced technologies such as collaborative robots (cobots), exoskeletons, smart tools, and immersive virtual reality to create “age-friendly” production and logistics environments with the potential to preserve the productivity, quality, and well-being of the AW (Ranasinghe et al., 2024; Sgarbossa et al., 2020). Virtual reality (VR), augmented reality (AR), collaborative robots (cobots), and exoskeletons have shown that they can reduce fatigue stress and depression and can provide relaxation, which is highly beneficial for older people when using these new technologies (Babadi and Daneshmandi, 2021; Calzavara et al., 2020). They can be used for training, ergonomic design, and the simulation of safe working environments. In addition, wearable technologies, such as smartwatches and wristbands, can continuously monitor the physiological state of the user, such as heart rate and rhythm, and skin temperature, among others (Abuwarda et al., 2022), which are particularly relevant for older workers and those operating in extreme environments (De Felice et al., 2022). Furthermore, Artificial Intelligence (AI) tools such as AI-powered chatbots and virtual assistants will facilitate seamless communication between humans and machines, enabling humans to interact with machines in a more natural and intuitive way (Nazareno and Schiff, 2021).

Looking ahead, implementing these technologies will require addressing challenges related to training and acceptance among the AW (Calzavara et al., 2020; Chang et al., 2023; Nagarajan et al., 2019; Ranasinghe et al., 2024; Xie et al., 2023). Although these technologies are engineered to reduce physical strain, they also introduce new operational risks, requiring workers to adapt to more flexible interaction modalities and develop cognitive soft skills not traditionally needed in the manufacturing industry (Benos et al., 2020; Giallanza et al., 2024; Villani et al., 2018; Weiss et al., 2021). A recent analysis from the Italian National Institute for Insurance against Accidents at Work (INAIL) on human–machine interactions reported that traditionally, machine design focused primarily on functionality, often neglecting the cognitive impacts on operators (INAIL, 2024). However, with technological advances, the need to shift from a machine-centered approach to a human-centered one becomes increasingly essential, requiring the design of systems—according to cognitive psychology and neuroergonomics—that keep operators in a state of cognitive comfort, reducing the risk of errors and improving performance. Such an approach is particularly important for enabling older workers to perform their roles comfortably while continuing to feel “useful” and “active.”.

Promoting a strong safety culture becomes a crucial strategy in this context to improve the working conditions and the well-being of workers and, consequently, limit exposure to occupational risks (Tear et al., 2020). These aspects put the focus on the crucial role that OSH interventions and support technologies play in achieving the prevention of work-related and occupational diseases, the support for disabled workers, and the promotion of work ability as a consequence of the ageing phenomenon (Varianou-Mikellidou et al., 2019). Therefore, the improvement of the OSH interventions by adopting proper measures and procedures for a diverse workforce and incorporating them into the decision-making process may potentially be very beneficial for both workers and employers (Varianou-Mikellidou et al., 2021). In this regard, OSH performance provides a valuable means of assessment, as it can be understood as a qualitative or quantitative measure of the outcomes of all activities aimed at improving workers’ health, safety, and well-being in both the short and long term. In doing so, OSH performance serves as a practical expression of 'primary prevention,' as recommended by the OSH Framework Directive (Directive 89/391/EEC), which calls for proactively addressing risks at their source to achieve sustainable OSH improvements (European Union, 1989).

However, as stated by different authors (Fridrich et al., 2015; Robson et al., 2007; Vitrano et al., 2023; von Thiele Schwarz et al., 2016a), because interventions are context-dependent and subjected to multiple hard-to-track – mostly qualitative – factors, their effectiveness is rarely monitored. This certainly represents a major limitation in understanding which interventions work and which do not, and especially, whether their implementation has been done correctly (Vitrano et al., 2024). Moreover, industrial practice demonstrates that OSH interventions are rarely incorporated into company management systems as a factor influencing overall work process performance (Botti et al., 2022). Thus, there is only a partial understanding of the issue, overlooking the direct relationship between these interventions and outcomes related to system productivity, safety, and health. Hence, a proper design, implementation, and execution of OSH interventions are crucial for companies seeking to ensure workers' health, safety, and well-being, and, in turn, enhance productivity. In this context, the assessment of the OSH-related factors in terms of drivers (enablers) or barriers (inhibitors) may be valuable to shed light on why, in which context, and under what circumstances the intervention works or fails (Vitrano and Micheli, 2024). As said, this is especially valid considering the current ageing of the workforce since the emerging risks associated with it induce significant changes in the functional capacities of workers as well as in the working conditions and work organization. Accordingly, the trend of current scientific literature is heading in the same direction, highlighting the importance of considering the AW effects

when designing and managing OSH interventions. A deeper investigation is needed to identify various OSH-related factors and their potential interactions affecting safety and health performance at the organizational level (De Felice et al., 2022; Lari, 2024; Micheli et al., 2018).

This paper explores (i) how OSH interventions are approached in the AW context and (ii) the workplace factors that shape, facilitate, or limit their realization. Based on the conceptual research framework illustrated in Fig. 1, the goal is to evaluate the expected impact on OSH effectiveness – specifically in terms of safety, health performance, and labor productivity. An exploratory, questionnaire-based study was conducted with OSH professionals and experts experienced in AW from diverse backgrounds to obtain a clear and cohesive perspective on OSH interventions and their potential outcomes in terms of productivity, safety, and health. Adopting the proposed approach is expected to properly support practitioners within the organization, enabling them to better understand the dynamics at play and consequently to increase their ability to come up with effective solutions that improve safety, health, and well-being outcomes for older workers.

The remainder of this work is organized as follows: Section 2 provides a literature review on OSH interventions with a focus on those specifically implemented in the AW context and presents the different factors (barriers and drivers) that have an impact on OSH performance and productivity. The proposed research methodology is then explained in Section 3, while the discussion of the achieved results is depicted in Section 4. Finally, the main conclusions and implications, as well as the future research, are reported in Section 5.

2. State of the art on OSH interventions, barriers, and drivers

This section presents a summary of bibliographic evidence related to the various elements within the conceptual research framework shown in Fig. 1. The literature review is first conducted to synthesize and map general OSH interventions (Section 2.1), and to identify potential factors—both barriers and drivers (Section 2.2)—that impact their successful execution in terms of OSH performance and productivity, without focusing on any specific work environment. The focus then shifts to the specific context defined by the presence of an AW, emphasizing OSH interventions in an AW context (Section 2.3) and potential AW-oriented barriers and drivers (Section 2.4).

2.1. OSH interventions

An OSH intervention is defined as an effort that aims to enhance workplace safety and health conditions through the implementation of safety-targeted activities, actions, and interventions (Micheli et al., 2018). In line with this perspective, the OSH Framework Directive (Directive 89/391/EEC) emphasizes the importance of primary OSH interventions, which focus on eliminating or minimizing risks before they result in harm (European Union, 1989). Such interventions may include educational and training activities, behavioral and attitudinal adjustments, modification to the work organization and working conditions, and engineering solutions aimed at reducing the likelihood of a worker being involved in at-risk behaviors (Masi et al., 2019). Hence, it is evident that the proper execution of OSH interventions is vital since they can have a positive impact on (i) the environment, by reducing the risk of accidents, (ii) the workers, by reducing the occurrence of occupational accidents and diseases, and by enhancing health, quality of life, motivation, and satisfaction, and (iii) the companies, by reducing the processes cost and by improving their outcomes and reputation among internal and external stakeholders (da Silva and Amaral, 2019). Four key elements of the OSH interventions are of significant concern since they may have both an immediate impact on employees' well-being and longer-term business outcomes. These elements are:

- Ergonomics
- Safety Leadership
- Disease Prevention and Health Promotion
- Training

In this regard, numerous studies are focusing on the importance of ergonomics (James et al., 1994; Lahiri et al., 2005; MacLeod, 1995; Sanders and McCormick, 1998; Shikdar and Sawaqed, 2003; Simpson, 1990; Thompson, 1995) while many of them are explaining why a good ergonomic workplace could be the link between OSH and productivity. In particular, "improving the fit between humans and tools inherently means a more effective match. Good ergonomic improvements often result in better ways of performing a task" (MacLeod, 1995). On the other hand, other studies have addressed specifically some health issues such as high blood pressure, breast cancer, prostate cancer, depression, etc. (Riedel et al., 2001) or work-related stress health effects (Hoboubi et al., 2017) and their link to a productivity consequence. By using a comprehensive corporate wellness effort, significant improvements have been documented not only in productivity, but to direct care costs of organizations, measured as absenteeism (Bunn et al., 2001). Of course, the potential value of an intervention depends on the goal: to reduce costs, to reduce performance loss, or to target a specific population based on age or gender. Leadership and positive control behaviors in safety interventions could lead to OSH productivity and performance (Clarke, 2013; Griffin and Hu, 2013; Inness et al., 2010; Tappura and Nenonen, 2019). Examples of positive control behaviors that are also directly related to safety compliance could be: monitoring feedback on errors and dealing with problems proactively (Clarke, 2013; Griffin and Hu, 2013). In addition to that, by focusing on the leader as the target level of intervention, safety becomes the objective and, among others, the responsibility of the leader, aiming for productivity, safety, and organizational performance (Andersen et al., 2019; von Thiele Schwarz et al., 2016b). Another important element is training, which, when combined with human factors, has a positive influence on reducing adverse impacts resulting from workplace production pressures (Karanikas et al., 2018). Indeed, when management training programs are implemented correctly, employees feel safer at work and are more satisfied with their working circumstances, which boosts productivity (Fiedler et al., 1984; von Thiele Schwarz et al., 2016b; Wilson et al., 2005). However, if these interventions have generally been shown to be beneficial, their actual implementation at the workplace is still challenging for practitioners, since they are frequently not as effective as expected with favorable or adverse conditions that can create respectively a positive or a negative bias (Micheli et al., 2018).

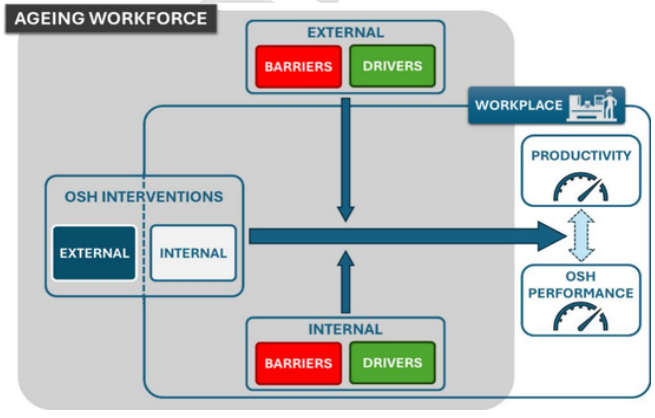

Fig. 1. Conceptual research context-design of the study.

2.2. Generic barriers and drivers

There are factors that influence the outcome of the interventions. These factors are also known as barriers and drivers. The barriers are defined as the set of internal and external factors that influence the process of intervention by inhibiting it; otherwise, the drivers are elements that facilitate the intervention process, helping to overcome difficulties (EASHW, 2011). Recently, there has been a growing body of research in which several models have focused on barriers and drivers and their impact on OSH interventions in terms of safety and health performance and, accordingly, productivity. Table 1 summarizes the main barriers and drivers that have been suggested to potentially affect a general OSH intervention.

2.2.1. Barriers

Masi and Cagno (2015) provided an effective description of the context, external or internal to the companies, focusing on Small and Medium-sized Enterprises (SMEs), where OSH interventions are implemented by identifying barriers, which can significantly affect the outcome of an intervention. After identifying 27 different barriers, the authors grouped them into seven-layer hierarchical categories named government, regulators and associations, intermediaries, management, staff, organizations, and technologies. Then, the barriers were arranged according to their frequency and intensity, considering separately the three phases of the intervention process, i.e., design, implementation, and evaluation. The results showed that the stringent legal requirements, bureaucracy, lack of time, and lack of economic resources are mainly perceived by practitioners as the most important factors that can hinder OSH interventions. Micheli et al. (2019) examined the barriers and drivers for the implementation of an OSH Management System in micro-and-small enterprises (MiSEs). The results showed that the lack of resources prevents the development of a safety culture and does not contribute to achieving the proper awareness of OSH relevance among workers and managers. Enhancing safety culture among the managers responsible for OSH increases the invested time and resources for OSH interventions, along with productivity as reported by Anger et al. (2009). The lack of efficient communication and information among workers and different business functions is also a barrier to the implementation of OSH interventions. Wong et al. (2015) ranked the main barriers that affect the OSH performance of small construction companies, reporting that the lack of awareness and concern is suggested to be the most critical, followed by cost issues and the lack of training and education, even though the time required to possess such knowledge is also considered an additional barrier. Similarly, Griffin and Neal (Griffin and Neal, 2000), Zohar (2003), and Pradeti et al. (2022) showed how these factors may influence safety and health and productivity outcomes. Whysall et al. (2004) determined the barriers perceived by ergonomics consultants in preventing work-related musculoskeletal disorders (MSDs). The results showed that they were mainly related to a lack of knowledge, resulting in risk underestimation or misplaced priorities, perception of cost, and clients' motivations to request help in facing safety and health concerns. The lack of awareness of OSH relevance generally can lead to prioritizing production over safety and, consequently, not fully completing the intervention as it was designed. In Whysall et al. (Whysall et al., 2006), the authors reported that the main factors affecting OSH interventions to tackle work-related MSDs were predominantly associated with employees' reluctance to modify their conduct, and the managers' general behavior, in terms of efforts taken and attitudes toward safety and health issues. The Fourth European Survey of Enterprises on New and Emerging Risks (ESENER, 2024) presented an overview of the results obtained from the large-scale survey. Concerning the hindering factors (barriers) for organizations to OSH management, seven major barriers have been found: (i) complexity of legal obligations, (ii) paperwork, (iii) lack of time or personnel, (iv) lack of money, (v) lack of awareness among workers, (vi) lack of expertise or specialist support, and (vii) lack of awareness among management.

Table 1
Generic barriers and drivers.

Generic Barriers and Drivers	
Barriers	*Drivers*
• Complexity of legislation • Lack of time • Lack of economic resources • Absent or ineffective communication and information • Prioritization of production over safety • Lack of awareness of OSH relevance • Employees' adaptation challenges	• Support of intermediaries: external consultants, other companies or associations, public authorities, other stakeholders (e.g., customers, contractors, and suppliers), etc. • Reduction of insurance costs • Monetary incentives (for the companies and/or for the individual employees) • Availability of knowledge of effective interventions • Education and training programs • Proper communication and information • ICT tools

2.2.2. Drivers

According to Cagno et al. (2016), companies often highlight the importance of intermediaries, considering external consultants, other companies/associations belonging to the same network, public authorities, and even other stakeholders (customers, contractors, suppliers, etc.). External consultants inside companies can counterbalance the lack of knowledge of OSH interventions by facilitating their quick implementation. Associations and companies' networks enhance the sharing of knowledge on OSH interventions among enterprises by helping them in designing and implementing effective actions. Indeed, there are (non-specific) OSH interventions that can be applied to several enterprises, and a simultaneous joint action among companies results in more efficiency than stand-alone interventions. On the other side, public intermediaries, such as the National Compensation Authority, can promote and motivate companies to invest in safety performance by reducing their insurance premiums. In light of the previous driver, it is noted that reducing insurance costs and/or providing monetary incentives (for the enterprises and/or for the individual employees) encourage companies to invest in implementing OSH interventions, which, in the end, will increase the overall safety and health performance of the enterprise. The availability of knowledge of effective interventions is considered a double factor. If it lacks, it is deemed as a barrier, and vice versa, if present, it is a driver that increases the efficacy of OSH interventions and consequently productivity (Stokols et al., 2001). A way to spread awareness and knowledge among workers is to introduce education and training programs, which instill correct, safe behavior in employees and let them understand the relevance of OSH interventions. Last, but not least, Micheli et al. (2019) noted an interesting driver, software or technological tools, safety-targeted, which can play an important role in properly implementing and managing OSH interventions. Indeed, Information Communication Technology (ICT) tools and other supportive technologies can enhance OSH interventions. This driver fosters communication and the sharing of information and knowledge among employees and, even, between different companies. Hale et al. (2010) emphasized the importance of proper communication about the health and safety issues between management and employees considered the key to successfully implementing OSH interventions. Andersen et al. (2019) reported that legislative and regulatory policies have proven beneficial for the proper implementation of OSH interventions, improving safety, health, and productivity.

2.3. OSH interventions in the AW scenario

Based on the pioneering works of Astrand (1958) and Bink (1962), numerous studies have explored the complex relationship between ageing and its potential impact on the ability to work at both physiological and psychosocial levels (Bal et al., 2011; Bentley et al., 2023; Dianat et al., 2015; Malhotra et al., 1966; Shephard, 1987). When implementing OSH interventions in workplaces characterized by AW, it is important to assess the different aspects that may influence the ability of the workers to perform their jobs and the corresponding work performance. Mainly, these are summarized in three categories: (i) the individual characteristics of the worker, (ii) the working environment, and (iii) the working organization. Concerning the first aspect, clear evidence of ageing is the progressive decline of overall performance affecting work capabilities such as a reduction in physical strength and power, joint mobility, and mental capacities (Abbasi et al., 2016; Ariëns et al., 2002; Buckle and Devereux, 2002; Choobineh et al., 2009; Čiutienė and Railaitė, 2014; Converso et al., 2018; Costa and Sartori, 2007; De Zwart et al., 1995; d'Errico et al., 2022; Fernandes et al., 2010; Freude et al., 2005; Gall and Parkhouse, 2004; Genaidy et al., 1993; Gilbert-Ouimet et al., 2011; Grandjean et al., 2006; Haukka et al., 2011; Ilmarinen, 2002; Johnston et al., 2010; Kenny et al., 2008; Lapointe et al., 2009; Lee et al., 2008; Leijten et al., 2014; Noone et al., 2014; Palmer and Smedley, 2007; Savinainen et al., 2004; Westgaard and Winkel, 2011). Concerning the second aspect, poor and demanding working conditions are generally tied to challenging ergonomic issues. Particularly, they can be categorized into (i) unhealthy workplaces due to vibration, temperature extremes, noise, glare, and inadequate lighting, and (ii) physically demanding exposures due to awkward postures, prolonged seating, repetition, material handling, force, standing, and mechanical compression (Choobineh et al., 2011; Driessen et al., 2011; Kemmlert and Lundholm, 2001, 1994; National Research Council and Institute of Medicine, 2001; Vandergrift et al., 2012). These mentioned factors might be considered as risk elements for all workers, but notably for older ones, and they might contribute to workplace injuries and diseases (musculoskeletal disorders are one of the most common work-related injuries) with a relevant effect of lower work ability, absenteeism, disability pension, and early retirement (Andrasfay et al., 2023). As a result, these adverse effects immediately lead to a reduction in the productivity and efficiency of older workers (Bell and Rutherford, 2013; Varianou-Mikellidou et al., 2019). Finally, the third aspect involves working organization conditions such as turnovers, responsibility, process management, role specification, excessive or lacking social interaction, boredom, and a sense of status (Botti et al., 2017; Farrow and Reynolds, 2012; Fredriksson et al., 2001; Gaudart, 2000; Ilmarinen, 2012; Lund et al., 2001; Oliv et al., 2017; Varianou-Mikellidou et al., 2020; Vilela et al., 2015; Warr, 1994; Westgaard and Winkel, 2011; Wilkie et al., 2011). It seems thus clear that the adoption of generic OSH interventions without considering the specific issues existing in an AW context might lead to adverse effects in terms of both mental and physical strain, resulting in a higher likelihood of occupational injuries and psychological discomfort and, consequently, a reduction in work intensity and productivity. Accordingly, a broader perspective is required to gain a better knowledge of the necessary conditions and actions aiming at ensuring the expected outcome of OSH interventions. To do this, the following section investigates the different factors from the literature review, in terms of barriers and drivers, that can potentially influence OSH performance in an AW context and their impact on productivity.

2.4. AW barriers and drivers

From the literature review discussed above, it is evident that the rising concern about AW is addressed through the analysis, design, and implementation of potential OSH interventions. However, further exploration is needed to assess the effectiveness of these interventions by also examining potential factors that may enhance productivity (Calzavara et al., 2020) or safety (Varianou-Mikellidou et al., 2020). To support this, a synthesis of various barriers and drivers in the AW context identified in the current literature is provided in Table 2.

2.4.1. Barriers

The functional capacities and experience are considered distinguishing traits of older workers. However, their physical/cognitive capabilities can unfortunately diminish with ageing (Gonzalez and Morer, 2016). Many researchers observed that these skills actually lessen over time (Strasser, 2018). As already discussed above, manual dexterity, joint mobility, and the capacity to lift loads worsen with time and thus reduce the outcomes of the OSH interventions in terms of safety, health, and productivity. Older workers tend to develop muscle fatigue faster, with a higher potential risk of musculoskeletal symptoms and back problems. If these factors related to older workers are not considered when OSH interventions are put in place, the potential beneficial effects of these activities will be substantially reduced. The cognitive capabilities of ageing workers can even have a negative impact on OSH interventions and productivity. If new manual activities are required inside a production facility, these workers require significantly more time and training than younger ones to learn new tasks (Schwerha et al., 2007; Wiker et al., 2009). The implementation of new OSH interventions may sometimes face challenges in adoption among older workers, as long-established practices and routines can make adaptation slower (Cecchini et al., 2018). Job stress is a common psychological disease that negatively influences the performance of workers (Chan et al., 2018; Wong and Chan, 2018), their safety motivation and perception, and, thus, their behavior towards new OSH activities. The causes of job stress can be many, especially for older workers who may suffer from job insecurity (e.g., precarious/contingent work), working on shifts, nonstandard and, and even long working hours (Bohle et al., 2010; Liu et al., 2018).

2.4.2. Drivers

It is worth emphasizing that ageing workers are a valuable asset and not a burden for companies. Their awareness, consciousness, and knowledge can make a difference, especially in implementing effective OSH interventions and, consequently, in terms of productivity. The experience and knowledge of ageing workers can compensate for their physical and cognitive decline (Calzavara et al., 2020). In performing manual tasks, for instance, older workers can be slower, but more efficient, as they know how to better accomplish certain activities after having done them for a long time. As stated by Lombardi et al. (2009) and Arezes and Miguel (2013), ageing workers have more risk awareness and consciousness of individual protection systems' relevance; for this reason, they are more likely to observe safety procedures, even if these activities are new. According to Cagno et al. (2016), a driver perceived as of core importance, but still low developed, is the availability of knowledge of effective interventions. For the aforementioned reasons, this factor can be enhanced by leveraging workers' experience

Table 2
AW-oriented barriers and drivers.

Barriers and Drivers related to AW	
Barriers	*Drivers*
• Physical and cognitive capabilities • Experience (slower adaptation to change) • Job stress (job insecurity, working on shifts, nonstandard/long working hours)	• Experience and knowledge • Risk awareness • Consciousness • Supporting technologies: sharing information and knowledge among workers and enhancing physical and cognitive capabilities

and knowledge in the field. The last driver for older workers refers to the supporting technologies, which cannot only improve the sharing of information and knowledge among workers but can also properly assist ageing workers by increasing their productivity in their daily activities. Systems like wearable exoskeletons (e.g., for the back and the arms) (Borzelli et al., 2017) or augmented reality-based assistance (Saggiomo et al., 2016) can enhance the physical and cognitive capabilities of ageing workers, which have worsened over the years. In this context, Industry 4.0, digitalization, and information technologies are the perfect instruments to allow manufacturing systems to be ready for future challenges.

3. Methodology

The analysis of the current research has shown the importance of considering the effects of AW when designing and managing OSH interventions, as well as evaluating the expected outcomes in terms of OSH effectiveness and labor productivity. Although it appears evident that targeted actions and procedures should be adopted in any attempt to properly face the explicit OSH challenges arising from the AW, most companies usually approach the intervention process by neglecting the specificity of the context in which they should be implemented. As a result, the interventions implemented by practitioners might not always be effective (Masi et al., 2019). The main goal was to explore (i) common OSH interventions in an AW context and (ii) key factors, generic and AW-oriented – in terms of barriers and drivers – affecting safety, health, and productivity outcomes.

3.1. Data collection and administration

This study used a qualitative exploratory study based on an open-ended questionnaire to address the gaps, challenges, and distinctive needs identified in this specific case of interest. The insights gained from the literature provided a solid basis for developing the questionnaire.

Before sending, each questionnaire was prefaced with a confidentiality agreement outlining the objectives of the proposed study and assuring the respondents of the anonymity and confidentiality of their responses. To ensure the validity of the proposed study, it is necessary to recruit a heterogeneous group of participants with extensive expertise in AW issues across diverse, directly relevant domains. Thus, participants, 15 in total, who agreed to take part voluntarily, were professionals and experts in the OSH field with different backgrounds selected among these main groups: Owners of SMEs; OSH professionals; Shop floor managers; Academics – OSH senior researchers; Association representatives; OSH physicians.

All the participants received by email a Word document with details on the questionnaire and identical questions to enable and facilitate the proper comparison of their answers. The content of the questionnaire was structured in a live brainstorming meeting among the authors and refined following two pilot tests with selected respondents.

The questionnaire was designed to investigate the following two aspects: (i) to determine significant OSH interventions specifically suited for an AW context and (ii) to determine barriers and drivers directly affecting such interventions in terms of productivity and OSH performance. In the first part of the questionnaire, participants were asked to describe, based on their experience, some significant OSH interventions for the AW classified into four macro-categories – ergonomics, safety leadership, disease prevention, and training – as described in the literature (see section 2.1). Then, these interventions were classified in accordance with their impact on OSH performance with a qualitative scale (*none, limited, relevant*) and productivity with a qualitative scale (*negative impact, neutral, positive impact*). The second part of the questionnaire looked at common barriers and drivers that have an impact on OSH interventions in an AW context. Respondents were asked to list barriers and drivers affecting OSH interventions, and they were provided with an initial list of generic and AW-specific barriers and drivers derived from the analysis of the literature. Each factor was evaluated in terms of its impact on OSH interventions, using a qualitative scale (*secondary importance, significant importance, primary importance*). The detailed structure of the questionnaire is provided in Appendix A. Once the completed questionnaires were received, a few interviews were conducted with respondents to complement the data, particularly where answers were missing or unclear.

Ultimately, although interviews could have permitted flexible questioning, a self-administered open-ended questionnaire, complemented by a limited number of interviews, was selected for its methodological advantages. Since the questions required participants to reflect on their answers and rely on past experiences, this approach provided them with more time to reflect carefully on each question and provide detailed, considered responses, reducing the risk of superficial or improvised answers that can occur in real-time interviews. In this way, the method ensured greater consistency across participants while still allowing for in-depth qualitative insights.

3.2. Data analysis

The data analysis followed an abductive approach, coding the collected data according to the initial categories of OSH interventions, barriers, and drivers, and reorganizing the content into new categories when needed (Elo and Kyngäs, 2008). The preliminary analysis of the replies revealed that the respondents suggested interventions, barriers, and drivers that did not always fall exactly inside the macro-categories initially included in the questionnaire, but they could be classified into different or even more than one category. For instance, a respondent classified the answer "Participatory Ergonomics Programs: programs where workers are directly involved in understanding the ergonomics of their workplace, and in its evolution towards a healthier working environment" as falling under the *Ergonomics* macro-category; yet it may also fit in *Training* as originally established.

To ensure an accurate representation of the collected data and so, a deeper understanding of the OSH interventions, new categories were created by identifying more homogeneous and meaningful content areas, as detailed in the next section. To do this, the answers were analyzed and classified, representing similar thoughts via content analysis (Elo et al., 2014; Hsieh and Shannon, 2005). To ensure the validity of this step, two authors performed the analysis independently and then discussed their results aimed at obtaining a trustworthy consensus. The same procedure adopted to refine answers for OSH interventions was also applied to establish homogenous categories for barriers and drivers, as reported in the next section. To support and validate the achieved outcomes, they were then compared to the existing knowledge from earlier research.

4. New perspectives on OSH interventions in an AW context

4.1. OSH interventions in an AW context: Impact on OSH performance and productivity

The first result consisted of a total of 127 OSH interventions (the full list is included in Appendix B) identified by the respondents, most of them are included in the macro-category *Disease Prevention and Health Promotion* (32 %) and *Safety Leadership* (30 %), while *Ergonomics* and *Training* accounted for 24 % and 14 %, respectively. Building on the findings achieved, a rigorous analysis was carried out manually since, as discussed in the previous section, several responses did not fall exactly inside the macro-categories initially included in the questionnaire. Therefore, new pertinent categories along with their corresponding sub-categories were defined to develop an in-depth and coherent overview of the OSH interventions, as shown in Fig. 2.

Fig. 2. Categories and sub-categories of OSH interventions.

Firstly, it is noteworthy that the vast majority of interventions are considered to have a positive impact on companies' productivity. This idea contradicts a common, but erroneous, narrative about OSH interventions since it is a major misconception that OSH interventions and productivity are mutually exclusive, or even that they work in opposition to one another. Indeed, the potential economic outcomes as a result of proper OSH intervention implementation are often underestimated or neglected (Claxton et al., 2022; Lari, 2024; Micheli et al., 2024; Tremblay and Badri, 2018).

Additionally, users (managers) often overestimate the costs of OSH interventions and undervalue the costs caused by the negative effects of unhealthy and unsafe conditions. From this standpoint, it is important to note that several companies often consider workplace OSH-oriented investments as a further item of their expenditures, exclusively focusing on the alleged detrimental impact these have on the company's balance sheet. This has led to common beliefs that well-performing in safety might reduce operational performance related to economic (productivity), but also environmental, and social goals (Neri et al., 2022). However, as stated by Das et al. (2008), "Employees who do not feel safe in their jobs are not likely to do their jobs well". Consistent with this vision, there is the notion that "a safe and healthy worker is a productive worker" (Morris et al., 2021). These two core concepts imply that there is a complementary synergy between safety, health, and labor productivity since, in practice, companies characterized by poor workers' health, safety, and satisfaction would likely exhibit obstacles in their operations that negatively affect profitability and production outcomes (Calzavara et al., 2020; Lari, 2024).

Then, it is important to also highlight that the interviewees identified both general measures that concern all workers without making a clear distinction between younger and older workers, and other interventions more targeted to an AW context. These general measures were frequently mentioned due to their universal relevance and key role in ensuring workplace safety. Indeed, their inclusion reflects the general perspective that maintaining a safe and healthy work environment benefits all employees, including AW, and constitutes a prerequisite for effective OSH management. Nevertheless, while the analysis will adopt a comprehensive perspective seeking to determine the overall impact of the proposed interventions, particular attention will also be given to those measures that are explicitly designed to address the needs and challenges of older workers.

Fig. 3 presents the percentage distribution of OSH interventions related to their perceived impact on OSH performance across the newly defined categories.

The data indicate that the categories "*Interaction and Management*" and "*Awareness in the Workplace*" contain the highest proportion of interventions rated as substantially relevant. The interventions, identified

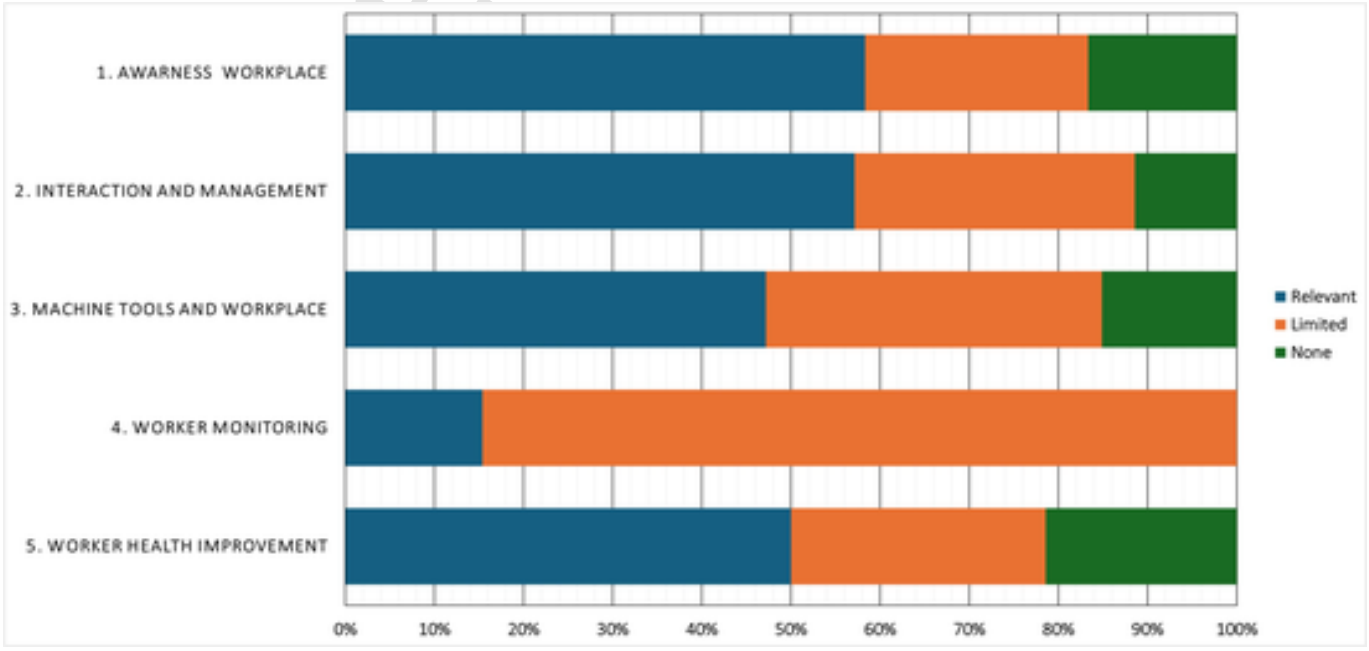

Fig. 3. OSH interventions by category: perceived impact on OSH performance.

by the respondents as highly impactful within the "*Interaction and Management*" category, are mainly focused on structured and proactive risk management to ensure organizational compliance and learning. Interventions such as *risk assessment, assisted risk identification by ageing workers, incident analysis, and near-miss reporting* are considered relevant to building a responsive work environment that involves both management and the workforce in the continuous process of hazard recognition and mitigation. Particularly, the involvement of ageing workers in risk identification ensures that their specific needs and experiences may be included in the assessment process, contributing to tailored risk prevention strategies. Conversely, more generic interventions such as *following legislation updates* and *using non-toxic substances* are also considered relevant, although those are not ageing-specific. However, they are also indirectly beneficial for older workers by minimizing exposure to cumulative or chronic hazards.

In the "*Awareness in the Workplace*" category, the interventions with the highest impact are mostly focused on communication, training, and promoting a culture of safety. Measures such as *dedicated and continuous OSH training*, *toolbox talks*, *coaching visits*, *safety performance-linked incentives*, *feedback loops,* and *gamified learning* are designed to enhance safety awareness and engagement among all workers in daily practices. Here, it is important to underline that these types of interventions should be implemented in an inclusive and participatory manner, so as to support older workers who may benefit from repetitive, visual, or interactive formats. Particularly, some proposed interventions are explicitly targeted at AW's needs and contributions. For instance, *encouraging older workers to transfer tacit knowledge and including them in participatory ergonomics programs* leverage their experience while adapting the work environment to their capabilities. This category also includes several non-ageing-specific interventions that foster a general culture of safety (e.g., the *Bradley Curve program, lean thinking, and annual safety campaigns*). Although they are advantageous to all employees, their impact on older workers is determined by how thoroughly and effectively the organization embraces and implements inclusive practices. Furthermore, all interventions included in the category "*Worker Monitoring*" were rated as having at least a positive impact, whether moderate (mostly) or relevant. These results highlight an increasing awareness that preserving long-term safety and well-being requires proactive and continuous monitoring of workers' health and work conditions. *Health surveillance programs, regular medical checks, and early diagnosis* were among the most relevant interventions, reflecting their role in preventing age-related health issues, as well as *ergonomic assessments and sedentary work management* are specifically beneficial to reduce physical strain and chronic conditions.

A more in-depth analysis of the findings obtained from the questionnaire was conducted to illustrate the OSH interventions classified within the identified macro-categories and assessed according to their perceived impact on both OSH performance and productivity. The interventions are reported in Table 3 using abbreviated codes due to space constraints; full descriptions are provided in Appendix B. Table 3 summarizes all OSH interventions reported by the experts, organized within the five main macro-categories defined in this study and further detailed by sub-category (see Fig. 2). The interventions are presented in a matrix, where they are classified according to their perceived impact on OSH performance (rows) and productivity (columns). For OSH performance, three levels are considered: "None" = interventions reported as having no impact, "Limited" = interventions evaluated as having some impact, and "Relevant" = interventions perceived as having a strong impact. For productivity, three levels are also distinguished: "Negative", "Neutral", and "Positive". Finally, empty cells indicate that no intervention was assigned to the corresponding category. This matrix-based representation enables a combined view of OSH and productivity outcomes, highlighting which interventions are perceived as mutually beneficial, which entail trade-offs, and which appear neutral. Overall, it provides a clear and structured visualization of the data, allowing readers to identify both the typology of interventions and their relative positioning in terms of perceived OSH and productivity impact. This makes it possible to see at a glance which categories of interventions are the most promising and where further research or application efforts could be prioritized. The row representing interventions with no perceived impact on OSH performance (for each macro-category) shows that even such interventions may influence productivity, particularly when they are designed to cope with AW needs. For instance, interventions such as *mentoring younger colleagues* or *promoting intergenerational knowledge transfer* emerged as particularly valuable since they help older workers feel more engaged and appreciated, while also strengthening collaboration across generations. This emphasizes the importance of cultural and managerial initiatives that should effectively integrate older workers into the organizational procedures (Andrasfay et al., 2023). It is worth noting that low-cost measures, such as *grip-friendly or long-handled tools, ergonomic office equipment, task adaptation*, and *flexible scheduling*, may help overcome age-related physical limitations by reducing fatigue and enhancing comfort, and their contribution was still considered positive in terms of productivity outcomes.

Conversely, more general interventions, such as *fire safety* or *first aid training*, showing a neutral impact on productivity, are also included in the categories *"Awareness" and "Interaction and Management"*. These are essential elements of any workplace safety program, but since they're not designed specifically for the needs of older workers, they may not be sufficiently inclusive or age-oriented to produce substantial improvements in safety or work efficiency.

The rows labelled as "Limited" present interventions that were perceived as having a tangible impact on OSH performance, yet differed significantly in terms of their impact on productivity. Several proposed interventions are aligned with the needs of older workers, including *flexible work arrangements for employees recovering from illness or injury*, *task adaptation based on health conditions*, and *the introduction of mentoring programs where older workers pass on their knowledge to younger colleagues*. Such interventions were considered to enhance both safety and productivity, likely because they may help retain valuable experience in the workforce while tailoring workloads to individual capabilities. Another cluster of impactful measures focused on training and awareness-raising for both managers and workers, including *leadership training*, *orientation programs for OSH managers*, and *job-shadowing schemes* that contribute to creating a more supportive and informed workplace culture. While these are not exclusively designed for an AW context, their success often depends on inclusivity and age-awareness. For instance, *training programs* that take into account different learning styles and experience levels were found to be accepted and consequently more effective. Specific interventions based on technological or ergonomic involvement, such as *the use of exoskeletons*, *electric lifters*, *noise-control measures*, or *height-adjustable platforms*, also positively affected the AW, since they may not only reduce physical strain but also prevent musculoskeletal disorders (as said, particularly beneficial for older workers). In this scenario, the enhancement of the working environment, in terms of air quality, ventilation, noise level, lighting, and overall employee comfort, has been shown to positively impact productivity (see section 2). Also, process-oriented interventions, such as *procedural improvements* or *reward systems*, were seen as beneficial, especially when they are implemented in a participatory way. Although many of these measures can be adopted by all employees, their positive impact increases significantly in age-diverse contexts where functional limitations are more prominent. However, not all interventions were positively assessed. For instance, risk assessment tools like *health surveillance* or specific structured programs like the *Dupont method* were considered to have neutral or even negative productivity impacts, respectively. This may reflect a perceived lack of adaptability or even impediments to daily operations, especially when they are not communicated or effectively integrated into existing workflows.

Table 3
OSH interventions identified by the respondents, grouped into the five macro-categories and classified by impact on OSH performance (rows: *None, Limited, Relevant*) and on productivity (columns: *Negative, Neutral, Positive*).

1. Awareness in the Workplace		**Impact on Productivity**		
		Negative	**Neutral**	**Positive**
Impact on OSH Performance	**None**	–	1.A Dangerous conditions prevention (*1.A3, 1.A4*)	–
	Limited	1.B Risk assessment (*1.B8*)	–	1.B Risk assessment (*1.B6, 1.B7*)
	Relevant	–	1.B Risk assessment (*1.A2*)	1.A Dangerous conditions prevention (*1.A1*); 1.B Risk assessment (*1.B1, 1.B2, 1.B3, 1.B4, 1.B5*)
2. Interaction and Management		**Impact on Productivity**		
		Negative	**Neutral**	**Positive**
Impact on OSH Performance	**None**	2.A Information, Training, and Engagement of workers and managers (*2.A14*)	2.C Sharing knowledge and feedback (*2.C13*); 2.D Network building (*2.D5*)	2.C Sharing knowledge and feedback (*2.C14*)
	Limited	–	2.C Sharing knowledge and feedback (*2.C10*); 2.D Network building (*2.D2, 2.D3*)	2.A Information, Training, and Engagement of workers and managers (*2.A11, 2.A12, A.A13*); 2.B Reward system (*2.B2*); 2.C Sharing knowledge and feedback (*2.C9, 2.C11, 2.C12*); 2.D Network building (*2.D4*)
	Relevant	–	2.A Information, Training, and Engagement of workers and managers (*2.A4*); 2.D Network building (*2.D1*)	2.A Information, Training, and Engagement of workers and managers (*2.A1, 2.A2, 2.A3, 2.A5, 2.A6, 2.A7, 2.A8, 2.A9, 2.A10*); 2.B Reward system (*2.B1*); 2.C Sharing knowledge and feedback (*2.C1, 2.C2, 2.C3, 2.C4, 2.C5, 2.C6, 2.C7, 2.C8*)
3. Machine Tools and Workplace		**Impact on Productivity**		
		Negative	**Neutral**	**Positive**
Impact on OSH Performance	**None**	–	3.A Equipment (Provision/Maintenance) (*3.A22*); 3.E Tasks (Training) (*3.E3*); 3.F Work procedures improvement (*3.F7*)	3.A Equipment (Provision/Maintenance) (*3.A21, 3.A23, 3.A24*); 3.C Task/Job rotation (*3.C4*)
	Limited	3.F Work procedures improvement (*3.F5*)	3.A Equipment (Provision/Maintenance) (*3.A14, 3.A15, 3.A17*); 3.D Task/working adaptation (*3.D11*)	3.A Equipment (Provision/Maintenance) (*3.A12, 3.A13, 3.A16, 3.A18, 3.A19, 3.A20*); 3.B Equipment (Training) (*3.B2*); 3.D Task/working adaptation (*3.D8, 3.D9, 3.D10, 3.D12, 3.D13*); 3.E Tasks (Training) (*3.E2*); 3.F Work procedures improvement (*3.F4, 3.F6*)
	Relevant	3.C Task/Job rotation (*3.C2*)	3.A Equipment (Provision/Maintenance) (*3.A11*); 3.D Task/working adaptation (*3.D4*); 3.F Work procedures improvement (*3.F3*)	3.A Equipment (Provision/Maintenance) (*3.A1, 3.A2, 3.A3, 3.A4, 3.A5, 3.A6, 3.A7, 3.A8, 3.A9, 3.A10*); 3.B Equipment (Training) (*3.B1*); 3.C Task/Job rotation (*3.C1, 3.C3*); 3.D Task/working adaptation (*3.D1, 3.D2, 3.D3, 3.D5, 3.D6, 3.D7*); 3.E Tasks (Training) (*3.E1*); 3.F Work procedures improvement (*3.F1, 3.F2*)
4. Worker Monitoring		**Impact on Productivity**		
		Negative	**Neutral**	**Positive**
Impact on OSH Performance	**None**	–	–	–
	Limited	4.A Monitoring, reminders, and rehearsals (*4.A8*)	4.A Monitoring, reminders, and rehearsals (*4.A9*); 4.B Workers' health monitoring (surveillance) (*4.B3*)	4.A Monitoring, reminders, and rehearsals (*4.A3, 4.A4, 4.A5, 4.A6, 4.A7*); 4.B Workers' health monitoring (surveillance) (*4.B1, 4.B2, 4.B4*)
	Relevant	4.A Monitoring, reminders, and rehearsals (*4.A2*)	–	4.A Monitoring, reminders, and rehearsals (*4.A1*)
5. Worker Health Improvement		**Impact on Productivity**		
		Negative	**Neutral**	**Positive**
Impact on OSH Performance	**None**	–	5.A Workers' health and well-being improvement (*5.A12, 5.A13*)	5.A Workers' health and well-being improvement (*5.A14*)
	Limited	–	5.A Workers' health and well-being improvement (*5.A10*)	5.A Workers' health and well-being improvement (*5.A8, 5.A9, 5.A11*)
	Relevant	–	5.A Workers' health and well-being improvement (*5.A7*)	5.A Workers' health and well-being improvement (*5.A1, 5.A2, 5.A3, 5.A4, 5.A5, 5.A6*)

Finally, the matrix (Table 3) also reports the OSH interventions perceived as the most impactful in terms of improving OSH performance (rows labeled "Relevant"). Particularly, to provide greater detail, Table 4 presents a selection of interventions that were assessed by respondents as having both a relevant impact on OSH performance and a positive impact on productivity. Unlike the coded representation, here the interventions are listed in full, allowing readers to immediately identify the specific ones that were considered most effective and beneficial. Thus, this table provides a clear overview of the subset of interventions (as said, the complete set of all 127 interventions is provided in Appendix B) representing the most promising "win–win" interventions, as they combine high effectiveness in improving safety and health with clear benefits for productivity.

It is worth mentioning that the most effective interventions are those that combine strategic risk management and employee involvement, and they directly address the needs of an AW. These include tools such as *near-miss reporting*, *incident analysis*, and *assisted risk identification by older workers themselves*. Their relevance lies in the ability to prevent harm before it occurs, while also incorporating both the knowledge and awareness of older employees. A key aspect for organizations is the active involvement of AW since it may determine an improvement in the accuracy of their decision-making process, thanks to a

Table 4
Extract of OSH interventions assessed as having a relevant impact on OSH performance and a positive impact on productivity.

Workplace awareness	
1.A Dangerous conditions prevention	
1.A1	Use non-toxic substances and materials (e.g., water paint)
1.B Risk assessment	
1.B1	Assisted risk identification at the workplace by the ageing workers
1.B2	Risk assessment at the workplace
1.B3	Near Miss Reporting & Management
1.B4	Risk assessment
1.B5	Incident analysis with basic problem-solving (white belt)
Interaction and management	
2.A Information, Training, and Engagement of workers and managers	
2.A1	Dedicated continuous OSH Training Programs: OSH training programs for workers of all ages are implemented on a continuous basis. They can provide the basis for implementing all OSH intervention strategies described above.
2.A2	Participatory Ergonomics Programs: programs where workers are directly involved in understanding the ergonomics of their workplace, and in its evolution towards a healthier working environment
2.A3	Managers' Commitment to OSH
2.A5	Bradley Curve Program
2.A6	Coaching Visit
2.A7	Train the employees on how to do the work safely and what the consequences are if they do not work the right way. People cannot realize the chronic consequences of a risk (e.g., inhaling toxic material) during their everyday activities. (e.g., hairdressers, workers on asphalt paving, workers dealing with asbestos)
2.A8	Train managers or people with leadership positions on health and safety issues in order to understand and appreciate the use of protective and preventive measures
2.A9	Lean Thinking Program (to increase autonomy in operations)
2.A10	Annual Safety Campaign
2.B Reward system	
2.B1	Safety is part of everyone's performance contract and affects one's pay increase and bonus at the end of each year
2.C Sharing knowledge and feedback	
2.C1	Writing of safety procedures and communicating them
2.C2	Consultation between Employers and Employees on OSH issues
2.C3	Computerization of OSH records keeps the company updated on OSH initiatives, gains time, and promotes productivity
2.C4	Encouraging the ageing workforce to deliver their tacit knowledge and experience to younger workers
2.C5	Promoting good industrial relations promotes communication, OSH, and productivity
2.C6	Get feedback from employees about the way they do their jobs and how they can be more productive.
2.C7	Provision of regular training on OSH issues
2.C8	Key Learnings by Incident Analysis (global, zone, and market level)
Machine tools and workplace	
3.A Equipment (Provision/Maintenance)	
3.A1	Maintain machines at regular intervals and use noise barriers around noisy machines so other employees are not affected, or buy new machines with fewer dBs.
3.A2	Use of technical ventilation in the workplace.
3.A3	Use of mechanical means to move heavy material.
3.A4	Use seats for the employees (especially at the cashier's place in supermarkets)
3.A5	Reduction of physical workload during the tasks: by the automatization of processes or introducing auxiliary equipment, or collaborative robots.
3.A6	Buying equipment according to your needs. After that need analysis and risk assessment
3.A7	Equipment maintenance promotes productivity and OSH
3.A8	Mechanizing work, like delivering lifting equipment, promotes ageing workforce's health through ergonomics
3.A9	Introduction of new equipment that adjusts to individual's characteristics
3.A10	Equip employees with the appropriate equipment for work at height.
3.B Equipment (Training)	
3.B1	Training for equipment operation
3.C Task/Job rotation	
3.C1	Avoid repeated movements for a long period of time. Rotate the work, especially in the packaging activity.
3.C3	Task Rotation Programs: programs designed to allow workers to alternate between tasks to reduce MSD risk
3.D Task/working adaptation	
3.D1	Reduction of physical workload during the tasks: by reducing the exposure time.
3.D2	Allocation of workers to tasks according to their physical and cognitive abilities (including medical conditions).
3.D3	Adapt the work content to the workers' needs and abilities.
3.D5	Do not ask visually impaired employees to operate small-screen equipment.
3.D6	Avoid workload or underload, reduce multitasking, and increase time for decision making
3.D7	Consider a reduction in night shift, allow a choice of shift, and reduce the number of sequential shifts
3.E Tasks (Training)	
3.E1	Training for OSH. After needs analysis and risk assessment
3.F Work procedures improvement	
3.F1	Improve the physical work environment
3.F2	Ergonomic design of workplaces and tools.
Worker monitoring	
4.A Monitoring, reminders, and rehearsals	
4.A1	Health monitoring on a regular basis and early diagnosis
Worker health improvement	
5.A Workers' health and well-being improvement	
5.A1	Integrated systems that allow to identify and provide appropriate intervention strategies to improve mental health in occupational settings (consider the three levels of intervention for mental disorders).
5.A2	Specific Programs related to Mental Health, Ergonomics, Nutrition, and Eye screening and counseling
5.A3	Promotion of a healthy lifestyle and eating habits
5.A4	Tobacco-Free Campaigns
5.A5	Organize the work and put priorities so the employees do not work under stress and anxiety.
5.A6	Specific annual personal objects

wealth of experience in identifying risks. Another group of interventions consists of *training and information dissemination*, characterized by several programs designed to foster a proactive safety culture across all levels of the organization. *Continuous OSH training*, *participatory ergonomics*, and *leadership development* were consistently associated with both effective OSH outcomes and positive productivity impacts. Particularly, the role of ergonomics and technical adaptation emerged as highly significant. Indeed, measures such as *automating physically demanding tasks*, *introducing collaborative robots*, *adjusting workstations to individual needs*, and *mechanizing lifting or handling operations* were all perceived to reduce strain, helping to maintain performance without compromising well-being. Likewise, several task adaptation and scheduling measures were highlighted for their ability to adapt workloads according to workers' physical and cognitive capabilities, ensuring both safety and productivity. These include *reducing night shifts*, *adjusting shift sequences*, *avoiding repetitive tasks*, and *ensuring the right task fit for workers with specific medical needs*. Interventions such as the *Bradley Curve Program*, *lean thinking*, and *coaching visits,* though not specifically designed for older workers, when inclusively applied, may effectively promote safety in daily routines and decision-making processes, contributing significantly to safer and more efficient work environments, as already suggested by Gaudart (2000). Moreover, *mental health*, *stress reduction*, *healthy lifestyle promotion*, *ergonomic awareness,* and *well-being programs* emerged as key aspects among respondents. Indeed, they were not only considered crucial for OSH but also for fostering a more resilient and motivated workforce. This reflects a growing recognition of psychosocial risks, especially for ageing workers who may be more vulnerable to chronic stress and mental fatigue (consequently, this might have a detrimental impact on productivity). However, a few interventions, such as *general legislative updates* or *static procedures*, while necessary from a compliance perspective, were considered as having a limited or neutral impact on productivity. This indicates that without practical relevance to daily working activities or a focus on employees' needs, even well-meaning measures may lack real effectiveness.

Finally, it is worth mentioning the somewhat surprising results that emerged from Table 3. Indeed, it shows that for some experts, potential OSH interventions such as *safety training (2.A14)*, *job and task rotation (3.C2), courses on safety (4.A2)*, and *verifying and knowing ergonomics (4.A8)*, might have a negative impact on productivity. A possible explanation is that such interventions often require a significant investment of time and resources; for example, training sessions can take employees away from their primary tasks, temporarily reducing productivity, especially if these activities are frequent or lengthy. Job rotation may also require a learning curve as employees adjust to new tasks, potentially slowing down work processes in the short term. Furthermore, the effectiveness of these interventions may depend heavily on context. In cases where tasks are highly specialized or require specific expertise, job rotation or additional training may disrupt workflow and decrease productivity. However, in contexts with repetitive work, job rotation combined with on-the-job training has been shown to improve ergonomics and productivity by reducing strain and aligning tasks more closely with workers' skills.

4.2. Barriers and drivers in an AW context: Impact on OSH interventions

The second part of the questionnaire asked the participants to identify barriers and drivers and evaluate them based on their impact on OSH interventions using a qualitative scale (*secondary importance, significant importance, primary importance*). The preliminary analysis of the replies revealed that the respondents suggested additional barriers and drivers that were not previously identified in the prior literature. This result offered intriguing new insights about the potential impact of OSH intervention within the AW context. The same procedure previously adopted to refine answers for OSH interventions was also applied here to establish homogenous categories. Tables 5 and 6 present the drivers and barriers of OSH interventions for AW in a structured way. The first column reports on the categories in which drivers and barriers were grouped. These categories were defined to reflect the main thematic areas that emerged from the conducted analysis and provide a coherent framework for organizing the wide range of responses. The second column lists the specific drivers (Table 5) and barriers (Table 6) that were mentioned by the respondents within each category. These represent the specific factors identified during the survey as influencing the implementation of OSH interventions. The third column indicates the perceived impact of each driver or barrier on OSH interventions. This classification follows three levels: primary importance refers to those considered to have the strongest impact, significant importance corresponds to factors with a medium impact, and secondary importance identifies those with a lower impact. By combining categories, specific factors, and their perceived level of importance, the tables provide a clear overview of how drivers and barriers were assessed by the respondents, highlighting both the diversity of influencing factors and their relative importance in executing OSH interventions in the AW context.

In addition, Figs. 4 and 5 illustrate the main drivers and barriers of OSH interventions for AW using radial charts, respectively. In both figures, the innermost ring shows the categories of drivers (Fig. 4) and barriers (Fig. 5), while the outer ring displays the corresponding individual drivers and barriers that emerged from the conducted analysis. The width of each circular sector represents the frequency with which a given driver or barrier was mentioned: the larger the sector, the more often it was cited as a factor influencing OSH interventions. In addition, colors indicate the perceived level of importance. Green identifies drivers or barriers of primary importance (those considered to have the strongest impact), yellow corresponds to those of significant importance (medium impact), and orange represents those of secondary importance (lower impact). This structure allows readers to see at a glance not only which factors were most frequently reported, but also their relative importance in shaping the effectiveness of OSH interventions in the AW context.

Table 5
Drivers and their impact on OSH interventions for the AW, grouped into thematic categories.

Category	Drivers	Impact on OSH interventions
Supporting items	Education and training programs	Secondary Importance
	Availability of knowledge of effective interventions	Secondary Importance
	Support of intermediaries: external consultants, other companies or associations, public authorities, other stakeholders (e.g., customers, contractors, and suppliers), etc.	Secondary Importance
Workers dependent	Consciousness	Secondary Importance
	Experience and knowledge of the workers	Secondary Importance
	Risk awareness	Secondary Importance
	Loyalty of employees	Significant Importance
	Positive safety culture	Primary Importance
	Two-way communication between management and employees	Primary Importance
	Commitment by top management	Primary Importance
Incentives and pressures	Ethical incentives	Secondary Importance
	Reduction of insurance costs	Secondary Importance
	Internal and external pressure (surveillance, inspections)	Secondary Importance
	Legal requirements	Secondary Importance
	Monetary incentives (for the companies and/or for the individual employees)	Significant Importance
Ubiquitous information	Information availability	Secondary Importance
	ICT tools	Secondary Importance
	Supporting technologies: sharing information and knowledge among workers and enhancing physical and cognitive capabilities	Significant Importance

4.2.1. Drivers

Concerning the drivers, four distinct content areas have been defined (see Table 5): Supporting items; Workers dependent; Incentives and pressures; and Ubiquitous information. By analyzing Fig. 4, it emerges that the most impactful drivers are those that strengthen organizational culture, communication, and leadership commitment, particularly when they foster inclusivity and responsiveness to the needs of an AW. One of the most prominent drivers, both in terms of frequency and importance, is related to technological enablers and information-sharing tools, classified into the "*Ubiquitous Information*" category. Particularly, *supporting technologies*, such as *digital platforms and ICT tools*, have a key role in enhancing communication on OSH interventions and help in the design of effective interventions when cognitive or physical limitations are involved, reinforcing both safety and productivity. The "*Worker Dependent*" category contains three drivers indicated as of primary importance, namely *positive safety culture*, *commitment by top management*, and *two-way communication between management and employees*. Additionally, as observed by Vecchio-Sadus and Griffiths (2004), it is worth underlining that these drivers are fundamental in developing a workplace where safety is integrated into the organization's core values and decision-making processes. This kind of culture requires both management commitment and employee involvement, and it is especially important for ageing workers, as it fosters a sense of trust, inclusion, and acknowledgment of their specific needs and valuable experience. Employees often mirror management's attitudes, so if management's commitment to OSH is not evident, employee behavior may reflect this

Table 6
Barriers and their impact on OSH interventions for the AW, grouped into thematic categories.

Category	Barriers	Impact on OSH interventions
Worker dependent	Job stress (job insecurity, working on shifts, nonstandard/long working hours)	Secondary Importance
	Physical and cognitive capabilities of the workers	Significant Importance
	Employees' adaptation challenges – Experience of the workers	Significant Importance
External barriers	Complexity of legislation	Secondary Importance
	Inadequate national health system	Significant Importance
Internal cultural barriers	No involvement of employees in the decision-making process	Secondary Importance
	Lack of awareness of OSH relevance and commitment of the workers and managers	Significant Importance
	Prioritization of production over safety	Significant Importance
	Lack of safety culture	Primary Importance
Internal management barriers	Inadequate dedication to economic resources	Secondary Importance
	Inadequate dedication to time	Secondary Importance
	Overcontrolled management	Significant Importance
	Lack of monitoring	Significant Importance
	Absent or ineffective communication and information	Significant Importance

lack of commitment. Involving employees in decision-making and problem-solving processes fosters a sense of commitment to OSH, encouraging feelings of self-worth and belonging and contributing to elevating safety to a core organizational value (Cagno et al., 2016; Hale et al., 2010; Kogi, 2006).

A second cluster of impactful drivers also emerged in this category, consisting of *employee loyalty* and *accumulated experience*. Indeed, respondents emphasized that older workers' knowledge and commitment to the company are crucial to implementing effective safety measures. Indeed, according to Suardi et al. (2022), "Employee loyalty has also been evidenced to give impact to job satisfaction, aligning employees' behaviors to the organization, organizational objectives, productivity and quality, capability, and competency, and motivation to work" and consequently, it represents an essential element required for the effective implementation of OSH interventions. Consistent with the prior literature (see Section 2.4), other effective drivers are the *consciousness*, *experience*, and *knowledge of the workers*. These drivers should be recommended and promoted among companies dealing with AW. Respondents perceived the invaluable know-how and consciousness that older and experienced workers bring with them, which are essential for the implementation of effective OSH interventions. Moreover, in an AW, accumulated expertise and knowledge transfer, facilitated by cross-functional mentoring programs, can help prevent knowledge loss and contribute to organizational success. However, their engagement strongly depends on inclusion and trust, especially in participatory processes like risk assessment or training programs. *Monetary incentives*, such as performance-based rewards, were recognized as having significant importance, particularly when aimed at motivating companies or individual employees. Generally, setting clear goals, providing feedback to encourage the application of learned knowledge and skills, and offering incentives or rewards to support OSH performance are all valuable strategies for achieving positive outcomes. Beyond monetary value, incentives or rewards are often perceived as a recognition of the employee's importance to the company, so here is a way of recognizing older workers' capability and commitment to being actively part of a successful safety culture. Older employees, in particular, tend to value recognition, knowledge-sharing opportunities, and personal satisfaction. However, they were generally considered less critical than cultural and relational factors. This may suggest that, while financial motivation can support OSH implementation, the success of such interventions, especially in the AW context, is more strongly influenced by an ethical commitment to safety, open communication, and positive workplace relationships. In a workplace where stability, respect, and meaningful involvement are foundational elements, these human-centered factors are often considered more important than short-term economic motivations. Other financial or regulatory compliance-related drivers, such as *ethical incentives*, *reduced insurance costs*, *legal obligations*, and *external pressures*, were perceived as having secondary importance, reinforcing the perspective that permanent improvements in OSH depend more on internal culture than external enforcement or economic return. Moreover, it is important to underline that OSH is often seen merely as a cost rather than an investment; consequently, companies do not frequently include it within other economic areas like investments and related credit allocations (Cagno et al., 2016). Therefore, this tends to reduce this driver's relevance, but it is important to emphasize that investments in effective OSH interventions not only enhance safety and well-being but can also positively impact productivity.

Interestingly, drivers like *education and training programs*, or *support from external intermediaries*, were considered to have secondary importance despite the high frequency of mentions. Likely, this may suggest that, although these supports are helpful, they are not sufficient on their own unless they are integrated into a broader culture of internal accountability and ongoing commitment. Particularly, *education and training programs* also generated significant discussion in the AW context. On the one hand, training on equipment, environmental hazards, policies, and procedures is widely recognized as essential for raising employees' awareness and understanding of safe and unsafe behaviors and addressing the root causes of occupational accidents. In this setting, the accumulated knowledge and experience of older workers can serve as a solid basis for properly designing OSH interventions. On the other hand, research indicates that traditional training programs may not always be efficient for older workers (e.g., Zwick, 2015). Indeed, training for older employees should be tailored to their specific needs and interests, delivering immediate, practical knowledge, such as programs based on self-induced training and training on the job.

4.2.2. Barriers

Concerning the barriers, four distinct content areas have been defined (see Table 6): Worker dependent; External barriers; Internal cultural barriers; and Internal management barriers. As previously mentioned, Fig. 5 illustrates the key barriers that respondents identified as hindering the effective implementation of OSH interventions.

The most critical barrier, in terms of importance, is the *lack of a safety culture* since it may negatively affect the whole process of OSH implementation. Safety culture may be defined as learned habits reflecting safety management practices and organizational safety behaviors. It represents the observable efforts or actions performed on a daily basis by all members of the organization aimed at improving OSH performance (Harvey et al., 2001). As reported by Ghahramani (2017), safety culture encompasses several actions such as *management commitment to safety, employee involvement, safety communication, safety training, reward system, reporting system, employee empowerment, policies and procedures of the safety management system, pressure for production, local work practices and supervision, and the existence of a learning culture*. Hence, it follows that a lack of these actions might lead to a poor or absent safety culture, which will have a detrimental impact on OSH interventions. Indeed, if safety is not firmly integrated into the organization's principles, interventions may be superficial, inconsistently implemented, or even ignored. This may be especially critical in the context of an AW, where greater attention is required to individual health, flexi-

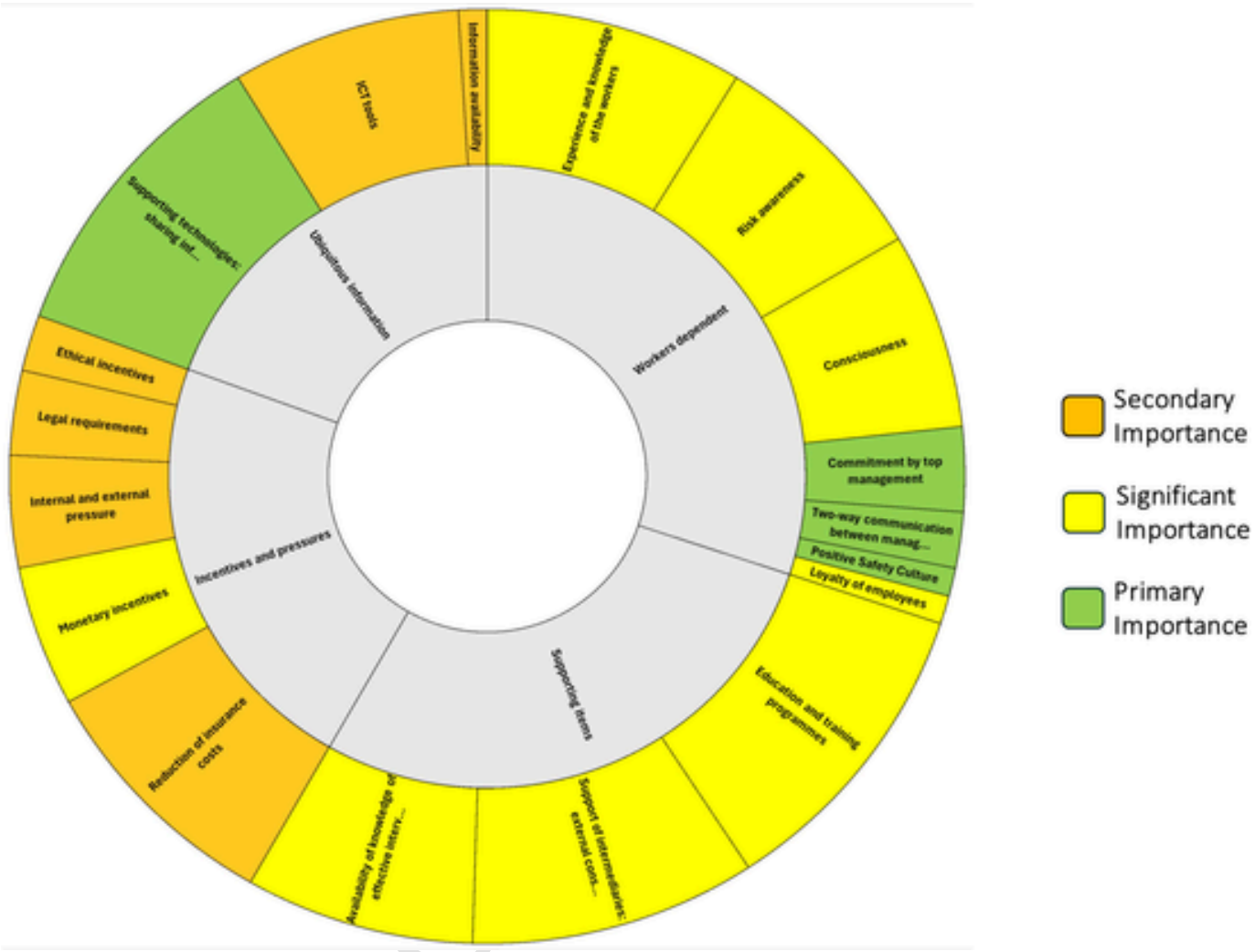

Fig. 4. Radial chart showing the distribution of drivers influencing OSH interventions for AW. The inner ring represents categories, while the outer ring shows the corresponding individual drivers identified by respondents. The width of each sector indicates how frequently each factor was cited, while colors denote perceived importance: green = primary importance (highest impact), yellow = significant importance (medium impact), orange = secondary importance (lower impact).

bility, and long-term strategies. These needs are often neglected as a result of a weak safety culture, leading to reduced trust and engagement among older employees.

It is worth mentioning that several internal cultural and management barriers, such as the *prioritization of production over safety*, *overcontrolled or rigid management*, *ineffective communication*, *lack of awareness of OSH relevance and commitment of the workers and managers* (the most mentioned by the interviewees), and *lack of employee involvement in decision-making*, are closely related. Indeed, these barriers reflect a misalignment between strategic goals and safety practices, where short-term productivity pressures or rigid hierarchical leadership structures limit the flexibility needed to adapt OSH interventions to the specific workers' needs. This is especially relevant for older employees, who may require more inclusive approaches such as participatory planning, ergonomic solutions, or flexible work arrangements. This kind of cooperation between employees and their representatives is crucial to the management of OSH interventions, as it enables the sharing of different or divergent ideas and viewpoints on issues about enhancing workplace safety and OSH performance. Furthermore, the successful implementation of OSH interventions requires effective communication in order to support employees in reducing unsafe events, boosting their motivation, and exhibiting their commitment to workplace safety. However, numerous barriers can inhibit effective communication and information, including language hurdles, lack of knowledge and training, cultural differences, and insufficient communication channels. These may determine misunderstandings, misinterpretations, and miscommunications between workers and their representatives, hindering the implementation of OSH interventions. Other commonly perceived Internal management barriers include a *lack of dedication to economic resources, a lack of dedication to time*, a *lack of monitoring*, and redundant and wasteful processes (*overcontrolled management*, bureaucracy). Without adequate dedication of economic resources and time to OSH, the possibility of implementing OSH interventions is very limited, with poor effects, which also determines a lack of monitoring, preventing the identification of hazards and the assessment of intervention effectiveness. Additionally, overcontrolled management can limit employee engagement and innovation.

Another cluster of significant barriers falls into the "*Worker Dependent*" category. Here, there are some of the most frequently mentioned barriers, such as the *adaptation challenges*, typically attributed to years of deep-seated habits or past experiences, and the *limitations in physical or cognitive capabilities*. These aspects underline the importance of properly designing OSH interventions, i.e., they should not only be technically suitable but also psychologically acceptable and adaptable to dif-

Fig. 5. Radial chart showing the distribution of barriers influencing OSH interventions for AW. The inner ring represents categories, while the outer ring shows the corresponding individual barriers identified by respondents. The width of each sector indicates how frequently each factor was cited, while colors denote perceived importance: green = primary importance (highest impact), yellow = significant importance (medium impact), orange = secondary importance (lower impact).

ferent capabilities, especially as workers age. Indeed, if not addressed thoughtfully, such barriers may negatively affect the OSH intervention performance. In this context, poor and inadequate work organizational measures can adversely impact older workers' physical health and psychological well-being, reducing their commitment and work engagement. They may also suffer from work-related stress when faced with excessive demands, expectations, or pressures.

Finally, external barriers, such as the *complexity of legislation* or an *inadequate national health system*, were considered less influential than internal ones. Meeting the legal requirements is a fundamental responsibility of any organization, and legislation provides a foundation for effective OSH interventions. It provides organizations with valuable knowledge of health and safety standards, policies, tools, methodologies, and their appropriate applications. Additionally, according to national/international policies, the national health system is responsible for setting, adopting, and enforcing OSH guidelines (Naegele and Walker, 2006). In an AW, legislation should address the adaptation of older workers to workplace technological advancements and the creation of age-friendly work environments. However, certain regulatory aspects create challenges for organizations in complying with current OSH legislation and managing the process effectively. Hale et al. (2015) further emphasized how some OSH regulations may inhibit industrial and creative innovation, fostering a culture of bureaucratic aversion. In this scenario, organizations are strongly advocating for the simplification and modernization of current legislation to reduce regulatory burdens that hinder the effectiveness of related OSH interventions. Thus, this supports the idea that, although regulatory environments provide a general framework, the success of OSH interventions largely depends on how they are implemented and managed within the organization.

5. Conclusions

This exploratory study seeks to contribute further to the discussion on OSH interventions and, particularly, on the need to provide information on the potential influence that the AW has on the effective implementation of OSH interventions. Particularly, two different objectives were achieved. Firstly, the review of the extant literature was performed to provide a theoretical overview of the different OSH interventions specifically adopted to address age-related concerns, along with the main barriers and drivers hindering and enabling the implementation of such interventions. Secondly, an exploratory, questionnaire-based study was conducted to explore and examine (i) common OSH interventions in an AW context and their impact on OSH performance and productivity, and (ii) the related barriers and drivers, based on the experts' perception from academics and industries.

The theoretical overview provided a solid background for defining the application domain in which OSH interventions can be specifically implemented for an AW context and also identifying the relevant factors that mainly affect them in terms of OSH performance and productivity. Practitioners may use these findings to properly manage the design of these interventions, focusing on all the factors that are often neglected, particularly in the case of AW. Indeed, on the one hand, the

achieved findings may aid in determining which factors limit or enhance the potential to fully exploit the beneficial characteristics of the older workforce, including experience, commitment, loyalty, and physical and cognitive abilities (despite some limitations). On the other hand, they may help companies to change and improve their work environment by implementing targeted measures and procedures aimed at reducing accidents and enhancing the health and well-being of all workers. A strategic, inclusive, and human-centered approach based on a strong safety culture and active worker participation is essential to promote health, safety, and productivity to deal with the demographic shifts in the workforce.

The conducted exploratory study showed which OSH interventions mainly affect safety, health, and productivity. A content analysis was performed to summarize and categorize them into content areas named Awareness workplace, Interaction and management, Machine tools and workplace, Worker monitoring, and Worker health improvement. Involvement in dedicated training and information programs (OSH, ergonomics…) for workers and managers, the adoption of technical tools and organizational measures to improve the work environment, and risk assessment emerged as the interventions with the strongest influence on OSH performance and productivity. Notably, the study also revealed that interventions not explicitly designed for ageing workers, such as lean management tools, safety campaigns, or coaching programs, may still produce significant positive impacts when implemented inclusively and with attention to age-related challenges. Thus, these findings reinforce the importance of designing OSH interventions that are not only effective but also adaptable and inclusive, recognizing the diversity of workers' physical and cognitive capacities.

The analysis of the responses concerning the barriers and drivers showed that participants indicated additional and significant factors (distinct from those that emerged from the literature review) that influence OSH interventions, either positively or negatively. This demonstrates that the proper management of OSH interventions is an area of great concern for academics and practitioners. Indeed, several barriers and drivers have been identified as having a significant influence. For instance, factors such as constant and active communication, as well as worker commitment in the decision-making process at different stages of managing OSH interventions (from design to implementation), determine a beneficial impact, especially if the experience and wisdom of older workers are considered valuable contributions. Additionally, the adoption of supportive technologies contributes to the improvement of the well-being of workers by fostering a safe and healthy work environment, especially in light of an AW. Conversely, the absence of these elements, reflected in barriers such as the lack of safety culture and awareness of OSH relevance, as well as the lack of worker involvement in the decision-making process and complexity of legislation, are the barriers mainly perceived as significant limitations to the success of OSH interventions in an AW context. Interestingly, financial and regulatory drivers, including monetary incentives, insurance reductions, and compliance with legal requirements, were considered of secondary importance. This finding suggests that while economic and policy-based motivations play a role, they are not sufficient to drive sustainable improvements in OSH performance. Instead, internal organizational dynamics, particularly cultural and relational factors, are the ones that most influence the successful deployment of interventions, especially in the AW context, which aims to prioritize stability, recognition, and meaningful involvement rather than short-term financial gains. Another interesting aspect is the emerging needs and perspectives regarding information-sharing technologies and health surveillance systems, which can support real-time monitoring and adaptation of work conditions, proving especially valuable in preventing age-related risks and promoting long-term employability.

This study also has some limitations. First, the sample size and the types of respondents involved limit the generalizability of the results. In particular, the perspective of other stakeholders, including members of control agencies or managers not only from small and medium-sized enterprises but also from large companies, should be the subject of future research. Second, given the focus on OSH interventions in the AW context, it would be important for future studies to also include the views of workers themselves, rather than relying exclusively on the perspectives of professionals and experts in the OSH field. Third, as future research, now that OSH interventions, barriers, and drivers have been identified, subsequent steps could explore which specific barriers and drivers influence particular interventions and the impact of an AW on these dynamics. Moreover, a narrower focus on a single intervention or a specific application would enable a more context-sensitive assessment, offering stronger evidence on the effectiveness of targeted interventions and the interaction between AW factors and OSH measures.

Despite these limitations, the achieved outcomes are relevant and valuable to addressing key concerns associated with the phenomenon of AW. These insights can provide both academics and practitioners with practical guidance for improving the implementation and management of OSH interventions, especially in contexts with AWs.

Uncited references

de Fernandes et al. (2010), INAIL - National Institute for Insurance against Accidents at Work (2024), OECD - Organisation for Economic Co-operation and Development (2023), WHO Study Group on Aging and Working Capacity & World Health Organization (1993).

CRediT authorship contribution statement

Gaia Vitrano: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Data curation, Conceptualization. **Simone Arena:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation. **Cleo Varianou-Mikellidou:** Validation, Methodology, Investigation, Conceptualization. **Guido J.L. Micheli:** Validation, Project administration, Methodology, Investigation, Conceptualization. **Fabio Sgarbossa:** Validation, Methodology, Investigation, Conceptualization. **Georgios Boustras:** Validation, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A.

Structure of the questionnaire

From the analysis of the extant literature, different OSH interventions emerged as significant factors having a direct (positive or negative) impact on productivity and OSH performance based on the context in which they are developed. Two main sets of OSH interventions may be associated with an AW scenario.

- Interventions are not specifically designed for ageing workers but are relevant due to their implementation in an AW context.
- Interventions are set up since the workers are, or will soon be, older. In these cases, the OSH interventions are frequently developed to help ageing employees work better, by reducing barriers related to their functional capabilities and enhancing drivers linked to their knowledge and expertise.

In the first part of the questionnaire, participants were asked to describe, based on their experience, some significant OSH interventions for the AW classified in four macro-categories, as described in the literature:

- Ergonomics: studies people in their working environment, understanding the interactions among humans and other elements (tools) of a system. Ergonomic interventions are designed to optimize human well-being and overall system performance.
- Safety Leadership: this is the process of setting safe behaviors among motivated individuals who actively promote safety activities and engage other people (employees) in meeting safety goals and keeping safe behaviors in their jobs. Particularly, safety leadership interventions can establish positive control behaviors (active feedback) or increase the safety commitment of managers.
- Disease Prevention and Health Promotion: aims at keeping people (workers) healthy. Disease prevention interventions try to reduce the burden of diseases and associated risk factors by avoiding the manifestation of a disease or its early detection. Health promotion interventions encourage individuals and communities to adopt healthy behaviors (e.g., avoiding tobacco use and physical inactivity) with the primary aim of reducing the risks of developing chronic diseases.
- Training: focuses on helping workers perform specific tasks or roles by avoiding improper actions and behaviors. As a result, training positively affects OSH performance and injury reduction.

Then, these interventions were classified in accordance with their impact on OSH performance with a qualitative scale (*none, limited, relevant*) and productivity with a qualitative scale (*negative impact, neutral, positive impact*). The OSH performance scale was chosen for a fine-grained evaluation to capture subtle differences in perceived effectiveness across a diverse set of interventions. The productivity scale allowed respondents to register both positive and negative impacts on productivity without excessive granularity, expressing whether an intervention not only enhanced productivity but also potentially hindered it, a crucial aspect in AW contexts where trade-offs are often observed.

The second part of the questionnaire looked at common barriers and drivers that have an impact on OSH interventions in an AW context. Respondents were asked to list barriers and drivers affecting OSH interventions, and they were provided with an initial list of generic and AW-specific barriers and drivers derived from the analysis of the literature. Participants could add further details on the mentioned barriers and drivers or even replace them with other factors that they considered more suitable, justifying their choice with brief comments. Respondents then evaluated each factor in terms of its impact on OSH interventions, using a qualitative scale with three labeled anchors defined as follows:

- Secondary importance (Barrier: if not properly managed, this barrier can lead to minor worsening) / (Driver: if properly managed, this driver can lead to minor improvements).
- Significant importance (Barrier: if not properly managed, this barrier can determine the failure of the intervention) / (Driver: if properly managed, this driver can determine the success of the intervention).
- Primary importance (Barrier: if not properly managed, this barrier determines the failure of the intervention) / (Driver: if properly managed, this driver determines the full success of the intervention).

This scale was selected to allow participants to express varying degrees of influence on OSH interventions, enabling a more nuanced understanding of which barriers and drivers are perceived as most critical in practice.

Appendix B.

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OSH interventions collected from the questionnaire

		Impact on OSH performance	Impact on Productivity
Workplace awareness			
1.A Dangerous conditions prevention			
1.A1	Use non-toxic substances and materials (e.g., water paint)	Relevant	Positive
1.A2	Following legislation update	Relevant	Neutral
1.A3	Training for fire extinguishing	None	Neutral
1.A4	Training for First Aid	None	Neutral
1.B Risk assessment			

		Impact on OSH performance	Impact on Productivity
Workplace awareness			
1.B1	Assisted risk identification at the workplace by the ageing workers	Relevant	Positive
1.B2	Risk assessment at the workplace	Relevant	Positive
1.B3	Near Miss Reporting & Management	Relevant	Positive
1.B4	Risk assessment	Relevant	Positive
1.B5	Incident analysis with basic problem-solving (white belt)	Relevant	Positive
1.B6	Keeping records of sick leaves and performing an analysis to identify the main reasons for absenteeism	Limited	Positive
1.B7	Reassessing the Risk assessment concerning the ageing personnel.	Limited	Positive
1.B8	Dupont Method: supervisor	Limited	Negative
Interaction and management			
2.A Information, Training, and Engagement of workers and managers			
2.A1	Dedicated continuous OSH Training Programs: OSH training programs for workers of all ages are implemented on a continuous basis. They can provide the basis for implementing all OSH intervention strategies described above.	Relevant	Positive
2.A2	Participatory Ergonomics Programs: programs where workers are directly involved in understanding the ergonomics of their workplace, and in its evolution towards a healthier working environment	Relevant	Positive
2.A3	Managers' Commitment to OSH	Relevant	Positive
2.A4	Safety Culture intervention	Relevant	Neutral
2.A5	Bradley Curve Program	Relevant	Positive
2.A6	Coaching Visit	Relevant	Positive
2.A7	Train the employees on how to do the work safely and what the consequences are if they do not work the right way. People cannot realize the chronic consequences of a risk (e.g., inhaling toxic material) during their everyday activities. (e.g., hairdressers, workers on asphalt paving, workers dealing with asbestos)	Relevant	Positive
2.A8	Train managers or people with leadership positions on health and safety issues to understand and appreciate the use of protective and preventive measures	Relevant	Positive
2.A9	Lean Thinking Program (to increase autonomy in operations)	Relevant	Positive
2.A10	Annual Safety Campaign	Relevant	Positive
2.A11	Orientation Programs for OSH Managers: programs designed to introduce OSH managers to their working environment and its OSH characteristics	Limited	Positive
2.A12	Inform employees about the measures taken to deal with disease prevention (e.g., install new exhaust, new filters, new machinery with a vacuum that collects pollutants, or new machinery with fewer pollutants)	Limited	Positive
2.A13	Training for leaders, providing them with the necessary competencies to support workers in taking the necessary actions, and improving teamwork	Limited	Positive
2.A14	Safety training	None	Negative
2.B Reward system			
2.B1	Safety is part of everyone's performance contract and affects one's pay increase and bonus at the end of each year	Relevant	Positive
2.B2	Reward systems for teams that achieve the OSH goals.	Limited	Positive
2.C Sharing knowledge and feedback			
2.C1	Writing of safety procedures and communicating them	Relevant	Positive
2.C2	Consultation between Employers and Employees on OSH issues	Relevant	Positive
2.C3	Computerization of OSH records keeps the company updated on OSH initiatives, gains time, and promotes productivity	Relevant	Positive
2.C4	Encouraging the ageing workforce to deliver their tacit knowledge and experience to younger workers	Relevant	Positive
2.C5	Promoting good industrial relations promotes communication, OSH, and productivity	Relevant	Positive
2.C6	Get feedback from employees about the way they do their jobs and how they can be more productive.	Relevant	Positive
2.C7	Provision of regular training on OSH issues	Relevant	Positive
2.C8	Key Learnings by Incident Analysis (global, zone, and market level)	Relevant	Positive
2.C9	Introduction of Mentoring at the Workplace (older workers pass knowledge to younger workers)	Limited	Positive
2.C10	Safety Leadership: creating a safety operational manager who involves all operators is important to improve attention on the subject	Limited	Neutral
2.C11	Weekly Meetings with Leaders of sites/functions	Limited	Positive
2.C12	All company meetings start with a 'safety moment' during which one of the attendees shares a safety-related experience for the benefit of the group	Limited	Positive
2.C13	Provide guidelines for lifting, sitting, standing, bending, and stretching	None	Neutral
2.C14	Viewing older workers as an asset and developing their roles, for example, through training and mentoring of younger workers	None	Positive
2.D Network building			
2.D1	OSH training, including gamification, toolbox talks, prestart meetings, etc.	Relevant	Neutral
2.D2	Establishment of safety committees and promoting ownership	Limited	Neutral
2.D3	Further involvement of Stakeholders and especially trade unions in the effort made to promote a positive safety culture at workplaces	Limited	Neutral
2.D4	Team building programs		
2.D5	Safety day	None	Neutral
Machine tools and workplace			
3.A Equipment (Provision/Maintenance)			
3.A1	Maintain machines at regular intervals and use noise barriers around noisy machines so other employees are not affected, or buy new machines with fewer dBs.	Relevant	Positive
3.A2	Use of technical ventilation in the workplace.	Relevant	Positive
3.A3	Use of mechanical means to move heavy material.	Relevant	Positive
3.A4	Use seats for the employees (especially at the cashier's place in supermarkets)	Relevant	Positive
3.A5	Reduction of physical workload during the tasks: by the automatization of processes or introducing auxiliary equipment, or collaborative robots.	Relevant	Positive
3.A6	Buying equipment according to your needs. After that need analysis and risk assessment	Relevant	Positive
3.A7	Equipment maintenance promotes productivity and OSH	Relevant	Positive
3.A8	Mechanizing work, like delivering lifting equipment, promotes an ageing workforce's health through ergonomics	Relevant	Positive
3.A9	Introduction of new equipment that adjusts to individual's characteristics	Relevant	Positive
3.A10	Equip employees with the appropriate equipment for work at height.	Relevant	Positive

		Impact on OSH performance	Impact on Productivity
Workplace awareness			
3.A11	Improve contrast between objects, increase local lighting, reduce sunlight glare, and make signs clear	Relevant	Neutral
3.A12	Use of specialized equipment (e.g., exoskeletons)	Limited	Positive
3.A13	Personal Protective Equipment (PPE) programs: programs designed and minimize the risk of workers' exposure to specific hazards	Limited	Positive
3.A14	Substitution Knife for manual trimming (better handling)	Limited	Neutral
3.A15	Weightlifting problem: regardless of the age of the people, we have introduced several electric lifters into production to solve all the different situations.	Limited	Neutral
3.A16	Wrist vibration problem, wrist twisting, and safety connected to the electric wire of the drill: we have replaced the electric wire drills with small battery drills and modified some construction details to obviate the difference in power of the drills.	Limited	Positive
3.A17	Provide noise PPE, hearing aids	Limited	Neutral
3.A18	Control noise	Limited	Positive
3.A19	Reduce exposure to extreme temperatures	Limited	Positive
3.A20	Problem assembling refrigerators not in an upright position: we have introduced height-adjustable air platforms into production.	Limited	Positive
3.A21	Provide tools: grip-friendly tools, long-handled tools		
3.A22	Reduce exposure to chemicals	None	Neutral
3.A23	Ergonomic office equipment (chair, keyboard, mouse, etc.)	None	Positive
3.A24	Machine noise problems, noise connected to ventilation to heat rooms, etc.: over the years, we have worked to minimize noise in the various departments by replacing machines and building new warehouses with static heating.	None	Positive
3.B Equipment (Training)			
3.B1	Training for equipment operation	Relevant	Positive
3.B2	Train workers to use new machines with computerized controls. People get frustrated when they do not know or are not sure how to operate a machine.	Limited	Positive
3.C Task/Job rotation			
3.C1	Avoid repeated movements for a long period of time. Rotate the work, especially in the packaging activity.	Relevant	Positive
3.C2	Job and task rotation	Relevant	Negative
3.C3	Task Rotation Programs: programs designed to allow workers to alternate between tasks to reduce MSD risk	Relevant	Positive
3.C4	Job rotation and short breaks	None	Positive
3.D Task/working adaptation			
3.D1	Reduction of physical workload during the tasks: by reducing the exposure time.	Relevant	Positive
3.D2	Allocation of workers to tasks according to their physical and cognitive abilities (including medical conditions).	Relevant	Positive
3.D3	Adapt the work content to the workers' needs and abilities.	Relevant	Positive
3.D4	Task adaption	Relevant	Neutral
3.D5	Do not ask visually impaired employees to operate small-screen equipment.	Relevant	Positive
3.D6	Avoid workload or underload, reduce multitasking, and increase time for decision making	Relevant	Positive
3.D7	Consider a reduction in night shift, allow a choice of shift, and reduce the number of sequential shifts	Relevant	Positive
3.D8	Change of duties for older people who cannot adequately and productively perform their existing duties	Limited	Positive
3.D9	Change of duties for people recovering from an occupational accident or disease	Limited	Positive
3.D10	Flexible working hours for people recovering from an occupational accident or disease	Limited	Positive
3.D11	Work teams should be designed in order to consider diversity (age, gender, etc.).	Limited	Neutral
3.D12	Introduction of specific health interventions to improve workers' ability to perform tasks under a specific health disorder (e.g., an unbalance in Parkinson's patients can be reduced through specific exercises; wearables can be used to monitor health parameters in some workers with particular health disorders).	Limited	Positive
3.D13	Flexible working hours	Limited	Positive
3.E Tasks (Training)			
3.E1	Training for OSH. After needs analysis and risk assessment	Relevant	Positive
3.E2	Certain job groups identified as requiring a minimum (safety) training requirement or requiring specialist skills would have been recruited in a job shadowing program before being deemed ready to take on the specific role	Limited	Positive
3.E3	Provide training: for lifting, sitting, standing, bending, and stretching, for the job	None	Neutral
3.F Work procedures improvement			
3.F1	Improve the physical work environment	Relevant	Positive
3.F2	Ergonomic design of workplaces and tools.	Relevant	Positive
3.F3	Work procedures	Relevant	Neutral
3.F4	Change process (manual trimming to automatic trimming) with an optical sorter	Limited	Positive
3.F5	Reduction weight coil film	Limited	Negative
3.F6	Improve the procedures for companies' human resources management.	Limited	Positive
3.F7	OSH visuals at the workplace	None	Neutral
Worker monitoring			
4.A Monitoring, reminders, and rehearsals			
4.A1	Health monitoring on a regular basis and early diagnosis	Relevant	Positive
4.A2	The problem of accidents at work and safety in general: raising awareness among workers with continuous updates and courses on safety has drastically reduced accidents at work, bringing accidents to zero / year and all minor ones.	Relevant	Negative
4.A3	Interventions for employees who work for long periods of time on a computer (software tools are implemented to track the time and remind the employee to take breaks at regular intervals)	Limited	Positive
4.A4	Sedentary jobs (a new hire is taken through the motions of learning to adjust their workstation and chair, as well as the equipment in use – screen, keyboard, mouse, etc.) by the company nurse. Thereafter, all employees are required to take a refresher online course at least once a year. Failure to take the refresher automatically invalidates the person's access card to the building.	Limited	Positive
4.A5	Promoting health monitoring through the organization	Limited	Positive
4.A6	Training and procedures are applied and constantly explained, and updated according to the needs of people. No to static procedures	Limited	Positive
4.A7	Maintaining up-to-date skills and knowledge	Limited	Positive
4.A8	Verifying and knowing ergonomics in your workplace is very important for making strategic choices	Limited	Negative
4.A9	SHE Steering Committee at Market Level	Limited	Neutral
4.B Workers' health monitoring (surveillance)			

		Impact on OSH performance	Impact on Productivity
Workplace awareness			
4.B1	Medical Management Programs: Programs that run continuously, assessing the health state of workers and the corresponding health risk factors.	Limited	Positive
4.B2	Workers' health surveillance	Limited	Positive
4.B3	Provide health surveillance, health checks, hearing tests, eye light tests, and monitor the health of workers	Limited	Neutral
4.B4	Health Surveillance Program for Workers (upon recruitment and at regular intervals during their employment)	Limited	Positive
Worker health improvement			
5.A Workers' health and well-being improvement			
5.A1	Integrated systems that allow to identify and provide appropriate intervention strategies to improve mental health in occupational settings (consider the three levels of intervention for mental disorders).	Relevant	Positive
5.A2	Specific Programs related to Mental Health, Ergonomics, Nutrition, Eye screening, and counseling	Relevant	Positive
5.A3	Promotion of a healthy lifestyle and eating habits	Relevant	Positive
5.A4	Tobacco-Free Campaigns	Relevant	Positive
5.A5	Organize the work and put priorities so the employees do not work under stress and anxiety.	Relevant	Positive
5.A6	Specific annual personal objects	Relevant	Positive
5.A7	Specific Programs related to Ergonomics	Relevant	Neutral
5.A8	Workplace health promotion interventions should be age-appropriate, gender appropriate, and inclusive of all age groups.	Limited	Positive
5.A9	Programs to improve workers' physical activity. This can include two types of intervention, specific training, and programs implemented in the companies, such as labor gymnastics.	Limited	Positive
5.A10	Problem health promotion, and prevention of occupational diseases, especially for older workers: once a year the company doctor visits the workers and together with them tries to take a path to improve their lifestyle.	Limited	Neutral
5.A11	Programs to improve workers' diet. This can include two types of intervention, specific training and programs implemented in the companies, such as changing menus in the cafeteria.	Limited	Positive
5.A12	Cigarette smoking problem: we have imposed 1 break every 2 h of 10 min where people can smoke outside, and, in this way, the number of cigarettes consumed has been limited (also due to legal obligations)	None	Neutral
5.A13	Corporate welfare problem: we tried to put the person first, trying to create a more and more serene and stimulating work environment.	None	Neutral
5.A14	The Company has instigated a wellness program that allows employees to either take part in an exercise class (e.g., yoga or pilates) run by the company or have their gym subscription subsidized by the company	None	Positive

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