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Assessing resilience potentials in management of occupational safety and health in hospitals: Development and validation of a tool

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ABSTRACT

A resilient Occupational Safety and Health (OSH) management system is crucial for effectively addressing potential future public emergencies, ensuring the continuous protection of workers' safety and health. Therefore, it is essential for organizations, particularly hospitals, to assess their resilient performance and employ tools that are appropriate and tailored to their specific context. This study aims to enhance the understanding of resilience potentials in OSH management within hospital settings. To this end, an assessment tool was developed based on the Resilience Assessment Grid (RAG). A Delphi study involving subject matter experts was conducted to refine the tailored RAG tool. Following this, a pilot test was administered to 404 healthcare professionals across three public hospitals, with subsequent psychometric analysis. Exploratory Factor Analysis (EFA) identified a four-dimensional structure. Goodness-of-fit indices demonstrated acceptable values, confirming the adequacy of the measurement model. Reliability testing indicated that the 29 item assessment tool is both valid and reliable. The tailored RAG tool was successfully validated, enabling the identification of strengths and weaknesses in OSH management.

1. Introduction

Workplaces are becoming increasingly complex, with healthcare often described as the quintessential example of non-linear and largely intractable system characterized by unpredictable pressures and demands [1,2]. The COVID-19 pandemic has underscored significant vulnerabilities within healthcare organizations, highlighting the urgent need to invest in resilient Occupational Safety and Health (OSH) systems [3]. OSH has become a critical concern, playing a central role in emergency response and public health crisis management. As emphasized by the International Labour Organization (ILO) [3], preparing for future global challenges requires a robust and resilient OSH system.

To address these challenges, several studies have highlighted the benefits of applying resilience engineering concepts for enhancing OSH management in complex sociotechnical systems (e.g., [4,5]). In contrast to the traditional Safety-I approach, which focuses on accident investigations and error analysis, resilience engineering, following a Safety-II approach, seeks to understand and promote the positive aspects of organizational functioning [6,7]. This proactive approach promotes resilience [8]. As it is not possible to measure resilience directly, Hollnagel [9] proposed the Resilience Assessment Grid (RAG), a well-established structure used to operationalize resilience engineering. RAG is based on four resilience potentials, widely known as cornerstones: potential to respond, potential to monitor, potential to learn, and potential to anticipate [9,10]. First, the potential to respond refers to an organization's ability to respond to what happens (changes, threats, and opportunities). The potential to monitor refers to the ability to detect changes that could positively or negatively affect performance in the near term. The potential to learn refers to the ability to learn from past experiences, including both successes and failures. Finally, the potential to anticipate refers to the system's ability to predict future opportunities and threats.

Originally, RAG consists of a set of general questions designed to assess the ability of an organization or a system to achieve resilient

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performance [9]. To apply it, these questions must be adapted to the specific organization being studied [10]. This set of questions is organized into four groups, corresponding to the four potentials. Its application allows for assessing the extent to which the four potentials are present or absent [9,11]. Once applied, the responses can be combined to generate an overall profile of the organization's potential for resilient performance [12].

Despite the innovative and recent nature of the RAG, several studies highlight its relevance and applicability in sociotechnical systems to assess and support resilient performance [13–15]. In healthcare, RAG has been applied in anesthesia departments [12,16], emergency care [11,17] and outpatient clinics [18,19]. Although the RAG has been applied in hospitals, its use in assessing the resilience potentials of OSH management within these environments remains unexplored. Nevertheless, the RAG holds promise in the field of OSH, and its application has been explored in different sectors. Peñaloza et al. [20] discussed for the first time the application of RAG in the construction sector. Pęciłło [21] used RAG to identify gaps in the safety management system of Polish enterprises. Adriaensen et al. [4] presented an instantiation of the RAG in cobot applications. Recently, Falegnami et al. [22] developed a specific RAG for the manufacturing sectors.

Therefore, this study aimed to develop, validate, and test a tailored RAG focused on hospital settings.

2. Methodology

The research process for developing a tailored RAG to assess the resilient performance of OSH management comprised two main phases, detailed in the following subsections. Initially, the tailored RAG was developed, and its content was validated by a panel of experts using the Delphi method [23], followed by a pretest. Subsequently, a pilot test was conducted in three public hospitals to analyze the psychometric properties of the construct. The overall research process is illustrated in Fig. 1.

2.1. Phase A: tool development

To develop the tool, a multidisciplinary team was assembled. Initially, three researchers worked closely with the hospital OSH manager to develop the first version. The primary reference was the book *Safety-II in Practice: Developing the Resilience Potentials* [9], which introduces the RAG and proposes a set of generic items for each of the four resilience potentials to be adapted to specific contexts. In addition, several studies were also consulted to support the design of the tool's items [11,12,16,19,21]. Specifically, tools designed for the French National Railway Company [14] and the Swedish Civil Aviation Administration [13] were consulted. Drawing on these sources and an analysis of the Portuguese health system, a set of items was developed and structured according to the four potentials for resilient performance. The resulting version was subsequently reviewed by two researchers with expertise in resilience engineering in collaboration with the rest of the team. This process led to the initial proposal of the tool.

The tailored RAG had two main parts. The first section contained demographic questions, including questions about gender, age, occupation, and seniority at the hospital. The second section comprised items to assess four specific dimensions: (1) potential to respond, (2) potential to monitor, (3) potential to learn, and (4) potential to anticipate. Each item in the tool corresponds to an indicator. A 5-point Likert scale was used to allow healthcare professionals to express a range of opinions with five response options (1 = Strongly disagree; 5 = Strongly agree). For each item, a unique code was used that includes the potential to which it corresponds, followed by the item number (n): Potential to Respond (PR_n); Potential to Monitor (PM_n); Potential to Learn (PL_n); and Potential to Anticipate (PA_n).

2.2. Phase B: tool validation

2.2.1. B1: content validation

Following the development of the tailored RAG by the research team, a content validation process was conducted to ensure the relevance and adequacy of the items included. To this end, a Delphi study consisting of three rounds was conducted. Therefore, the following inclusion criteria were established: (1) Safety practitioner; (2) Minimum of 5 years of experience in OSH; (3) Minimum of 3 years of experience in OSH in a hospital; (4) Member of a higher education institution; (5) Author or co-author of two or more scientific publications in the field of resilience engineering. The participants selected had to meet at least three of these criteria.

A total of 19 experts were included in the panel, of which 78.9 % met three of the established criteria, and the remaining participants (21.1 %) met four of the established criteria to be considered experts. The number of experts was considered appropriate according to the literature. Ideally, the panel should be composed of 8 to 23 experts [24]. Experts were recruited to identify and rate items. The criteria for selecting participants were defined based on guidelines suggested by Hallowell and Gambatese [25].

The Delphi study was conducted over three online rounds to maintain the anonymity of the answers and avoid interaction among the experts [26]. The anonymous and iterative features of the Delphi study allow experts to share and change their opinions [27].

In all rounds, the items were scored using a 5-point Likert scale (1 = Not important; 5 = Very important). After the completion of round 1, experts' scores were descriptively analyzed. This included calculating the median and interquartile range (IQR), which are commonly used and recommended as descriptive statistics in Delphi literature [28]. Consensus was considered achieved if the IQR was 1 or below (IQR $\leq$ 1)

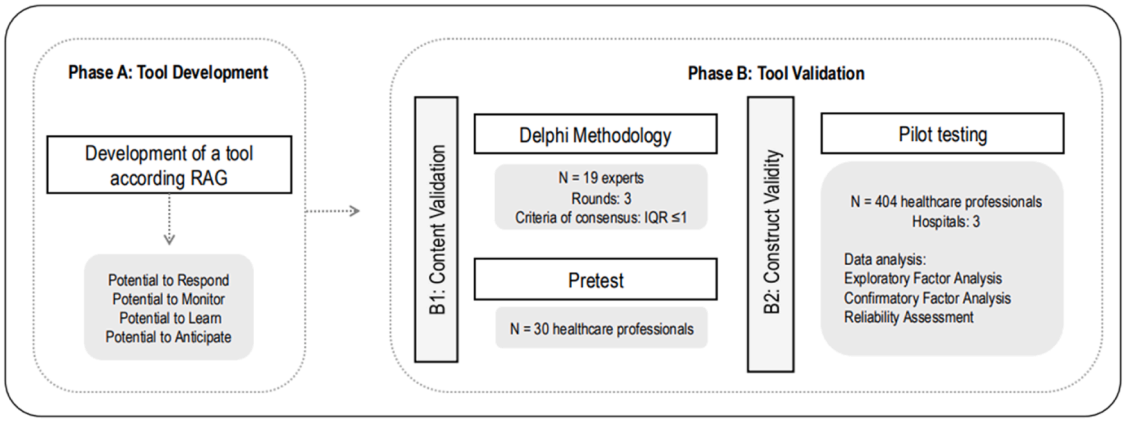

Fig. 1. Flowchart of the research process.

on a 5-point Likert scale. The IQR is the measure of dispersion for the median and consists of the middle 50 % of the observations; i.e., an IQR of <1 means that >50 % of all opinions fall within 1 point on the scale [29]. Items with an IQR larger than 1 indicated a lack of consensus and were retained or reformulated.

Controlled feedback provided insights into individual members about the trend and provided the opportunity to change members' responses in the second round if needed. Panel members were asked to clarify their position if they had an extreme choice of response, allowing experts to provide qualitative explanations for their quantitative responses in the second round. In the third round, only the reformulated items and those that did not reach consensus were sent to the experts.

After the Delphi study was completed, a pretest was performed on 30 healthcare professionals to obtain feedback to check if there were any errors, misunderstandings or difficulties that could affect the validity and reliability of the data [30]. The pretest was executed using Google Forms. Notably, the sample answering the pretest was not involved in the pilot test.

Data analysis procedures were performed using statistical software Statistical Package for Social Sciences (IBM SPSS® version 28, Inc., Chicago, Ill.).

2.2.2. B2: construct validity

Following content validation, a pilot test was conducted to assess the psychometric properties of the tailored RAG. The pilot test was conducted in three public hospitals located in the northern region of Portugal. Healthcare in Portugal is primarily provided by the National Health Service (NHS). This is a public service funded by the state budget, ensuring universal and largely free access to healthcare for all residents [31]. Complementing the NHS, private health services and specialized health subsystems exist for certain professional groups (e.g., civil servants, bank and insurance employees), which often serve to address gaps or limitations within the public system [32]. Although all the hospitals included in this study are public, each has distinct characteristics. Hospital A is focused on cancer patients. Therefore, human and technical resources are organized to provide personalized, homogeneous and comprehensive healthcare to such patients. Hospital B and Hospital C are local health units. Local health units were created to be single entities fully responsible for the health status of a given population, effectively coordinating the different levels of care (primary, hospital, and long-term care). Ethics committee approval was obtained from each of the hospitals before the study was undertaken.

Data collection in the three hospitals was conducted online using a Google Form. This approach offers several benefits, particularly in terms of reaching individuals across both space and time, thereby increasing the overall number of respondents [16]. To ensure the collection of complete and valid questionnaires, all responses were made mandatory.

After data collection was completed, an Exploratory Factor Analysis (EFA) using an orthogonal varimax rotation was performed to confirm the structure across the items. EFA has been suggested as the appropriate tool when new scales are being developed [33] and is used to examine construct validity. Bartlett's test of sphericity and Kaiser-Meyer-Olkin Measure (KMO) of sampling adequacy were used to confirm that the data were suitable for factor analysis. The KMO index ranges should be higher than 0.5, while the Bartlett's test of sphericity should result in a significant p-value ($p < 0.05$) [33,34]. Factor loadings should be higher than 0.4 [33]. Items with factor loading <0.4 or that were included in more than one factor were removed.

After the EFA, Confirmatory Factor Analysis (CFA) was used to confirm the factor structure using the same dataset. Model fit was determined using the following indices: Comparative Fit Index (CFI), Tucker-Lewis index (TLI), Root Mean Square Error of Approximation (RMSEA), Standardized Root Mean Square Residual (SRMR), and normed Chi-square (χ^2/df). Considered together, these indices provide a more conservative and reliable evaluation of the fit of the model [35].

For reliability testing, internal consistency was determined using Cronbach's alpha. The Cronbach's alpha should be >0.70 [36].

Data analysis procedures were performed using statistical software Statistical Package for Social Sciences (IBM SPSS® version 28, Inc., Chicago, Ill.).

3. Results

The initial version of the RAG was validated through a three-round Delphi study. The first round of the consensus survey elicited a response rate of 100 %, round 2 of 94.74 % (18/19) and round 3 of 89.47 % (17/19). After the first round, 42 items (84 %) reached consensus, i.e., all of them met the criteria of consensus (IQR ≤1). The questionnaire sent in the second round contained all the items and the statistical data (median and IQR). Based on experts' comments and consensus rate, 4 items were eliminated after the second round was completed. One of the items was divided into two items due to experts commenting that the same item covered two different aspects. In the third round, only items that did not reach a consensus in the previous rounds were sent by email. After the third round, the Delphi study was concluded, and a questionnaire consisting of a total of 47 items was obtained (Appendix A, Table A.1).

During the pretest phase, participants reported no difficulties in self-completing the questionnaire, demonstrating a clear understanding of the items. Consequently, the tool was retained without any modifications.

Regarding the pilot test, 404 healthcare professionals participated, with 169 from Hospital A, 115 from Hospital B, and 120 from Hospital C. In terms of gender, the majority of participants identified as female, with 80.5 % in Hospital A, 73.9 % in Hospital B, and 79.2 % in Hospital C. Males comprised 18.4 % of Hospital A, 26.1 % of Hospital B, and 20.8 % of Hospital C. A small percentage identified as "Other," with 1.1 % in Hospital A and no representation in the other hospitals. Regarding seniority, 80.5 % of Hospital A had <15 years of experience, while only 35.6 % of Hospital B and 45 % of Hospital C fell into this category. Conversely, 19.5 % of Hospital A had >15 years of experience, compared to 64.4 % in Hospital B and 55 % in Hospital C. The demographic distribution by hospital is summarized in Table 1.

The overall sampling was considered appropriate for the EFA, as indicated by the KMO value of 0.957. The data matrix also had sufficient correlation to factor analysis, since Bartlett's test of sphericity was also significant ($\chi^2 = 6797.100$, $p < 0.001$). As expected, 4 factors (or dimensions) were obtained, explaining 58.484 % of the variance. The results from the EFA reflect a scale composition in accordance with the

Table 1
Demographic characteristics of 404 participants by hospital.

Variables	Hospital A	Hospital B	Hospital C
Gender			
% Female	80.5	73.9	79.2
% Male	18.4	26.1	20.8
Other	1.1	–	–
Seniority			
% <≤ 15 years	80.5	35.6	45.0
% > 15 years	19.5	64.4	55.0
Age			
% 18 – 30 years	8.3	5.2	12.6
% 31 – 40 years	24.9	17.4	21.6
% 41 – 50 years	40.2	33.1	30.0
% > 51 years	26.6	44.3	35.8
Occupation			
% Nurses	33.1	45.2	35.0
% Medical Doctors	15.4	20.0	13.3
% Operational assistants	13.6	3.5	15.8
% Technical assistants	14.8	9.6	20.8
% Diagnosis and therapeutics technicians	12.5	11.3	7.5
Other	10.6	10.4	7.6
Total sample (*N*)	**169**	**115**	**120**

starting assumption, confirming the following factors: potential to respond, potential to monitor, potential to learn and potential to anticipate. Items with communality values lower than 0.4 or with factor loadings lower than 0.4 or that were included in more than one factor were removed. Overall, 18 items were removed considering these criteria (Appendix A, Table A.1). After extracting these items, the final version of the questionnaire consists of 29 items. The factor loadings and communalities of the items are presented in Appendix A, specifically in Table A.2 and Table A.3, respectively.

After conducting the EFA, a CFA was performed, revealing an acceptable model fit with the following indices: CFI = 0.925, IFI = 0.925, TLI = 0.918, RMSEA = 0.058, SRMR = 0.0424, and $\chi^2/df = 2.34$ [37]. Finally, the Cronbach's alpha coefficient was determined for each factor/dimension (Appendix A, Table A.2). The Cronbach's alpha was higher than 0.8 ($\alpha > 0.8$) for all the factors, which is considered good [36].

The sample collected provided insights into the resilient profile of OSH management at each hospital. Table 2 presents the calculated mean scores, while Figs. 2, 3, and 4 further illustrate, through radar charts, the resilient profile of each hospital separately.

3.1. Resilient profile of hospital A

3.1.1. Potential to respond

The hospital's potential to respond was assessed using eight indicators. The radar chart (Fig. 2) illustrates that Hospital A scored high in PR_7 - Communication (3.9) and PR_1 - Organization support (3.5). On the other hand, lower mean scores were recorded in PR_3 - Resources (2.5) and PR_5 - Response capability (2.9). This suggests that although OSH issues are addressed in the development of work procedures, the resources available for healthcare professionals to perform their work safely are limited. Additionally, there are communication channels to report perceived risks in the workplace, but the response to identified risks is not good enough.

3.1.2. Potential to monitor

The hospital's potential to monitor was assessed using six indicators. Hospital A scored high in PM_6 - Post-accident monitoring (3.4), indicating that measures implemented as a result of occupational accidents or failures are monitored periodically. In contrast, PM_1 - Systemic examinations (2.5) and PM_2 - Periodic risk assessments (2.6) received the lowest score, suggesting that periodic inspections conducted in the workplace are insufficient and that risk assessments are not conducted or updated periodically.

3.1.3. Potential to learn

The hospital's potential to learn was assessed using five indicators. Higher scores were obtained in PL_1 - Event analysis (3.2) and PL_2 - Safety culture (3.2), i.e., healthcare professionals participate in event analysis and provide information about hazards. Lower scores were recorded for PL_3 - Learning culture (2.7), PL_4 - Knowledge dissemination (2.7) and PL_5 - Learning from what goes right (2.7). This suggests that, in regular meetings, there is a need for greater sharing of experiences, including both things that go wrong and things that go well. Furthermore, the hospital does not provide sufficient information to healthcare professionals regarding positive events.

3.1.4. Potential to anticipate

Hospital A's potential to anticipate was assessed using ten indicators. Hospital A scored high in PA_8 - Updating plans (3.6), i.e., the standards and procedures applied are updated in relation to internal and external changes. However, PA_2 - Strategy (2.7) received the lowest scores, indicating that the hospital needs to improve its ability to identify new and emerging risks to develop appropriate OSH measures.

Table 2
Mean scores for each hospital.

Item	Total respondents (*N*)	Hospital A *N* = 169	Hospital B *N* = 115	Hospital C *N* = 120
Potential to Respond				
PR_1	**Organization support:** Occupational Safety and Health issues are considered when preparing work procedures.	3.5	3.9	3.4
PR_2	**Flexibility:** In case of variability in the foreseen conditions, healthcare professionals can make the necessary and adequate adjustments to the execution of their activities.	3.3	3.4	3.2
PR_3	**Resources:** Healthcare professionals have access to the resources (financial, technical, and human) required to maintain the ability to perform work safely under conditions of pressure and high workload.	2.5	2.7	2.4
PR_4	**Event list:** Risks and critical events, both frequent and unexpected, are identified and evaluated.	3.2	3.5	2.9
PR_5	**Response capability:** When changes occur in the workplace, a risk assessment is conducted to implement measures addressing existing risks.	2.9	3.1	2.8
PR_6	**Risk communication:** Healthcare professionals receive information about the risks they are exposed to when carrying out their daily activities.	3.1	3.2	2.9
PR_7	**Communication:** Existing communication channels are adequate to allow a response to perceived risks in the workplace.	3.9	3.4	2.9
PR_8	**Speed:** The time elapsed from the moment a healthcare professional makes a risk notification to the response is appropriate.	3.2	3.0	2.6
	Total mean	**3.2**	**3.3**	**2.9**
Potential to Monitor				
PM_1	**Systemic examinations:** The number of periodic safety and health inspections in the workplace is adequate.	2.5	2.7	2.6
PM_2	**Periodic risk assessments:** Risk assessments for different workstations/tasks are conducted/updated periodically.	2.6	2.9	2.4
PM_3	**Communication:** The results of safety indicators measurements are communicated and disseminated effectively throughout the hospital.	2.9	3.2	2.4
PM_4	**Periodic medical examinations:** Medical examinations are carried out at appropriate intervals.	3.1	2.6	3.3
PM_5	**Periodic training:** Refresher training in Occupational Safety and Health is carried out at appropriate intervals.	3.1	2.9	2.7
PM_6	**Post-accident monitoring:** Measures implemented as a result of occupational accidents or failures are monitored periodically.	3.4	3.0	2.7
	Total mean	**2.9**	**2.9**	**2.7**
Potential to Learn				
PL_1	**Event analysis:** Healthcare professionals actively participate in the risk identification and assessment process.	3.2	3.3	2.7
PL_2	**Safety culture:** Healthcare professionals provide information about hazardous events without fear	3.2	3.6	2.9

(*continued on next page*)

Table 2 (*continued*)

Item	Total respondents (*N*)	Hospital A *N* = 169	Hospital B *N* = 115	Hospital C *N* = 120
	of reprisals when they are involved in their occurrence.			
PL_3	**Learning culture:** It is clearly established what types of potential hazards or unexpected and unpredictable events should be reported.	2.7	3.6	2.9
PL_4	**Knowledge dissemination:** In regular meetings, healthcare professionals share experiences of things that go wrong and things that go well.	2.7	3.3	2.9
PL_5	**Learning from what goes well:** The hospital provides healthcare professionals with information on positive events (e.g., good practices).	2.7	3.5	3.1
	Total mean	**2.9**	**3.5**	**2.9**
Potential to Anticipate				
PA_1	**Expertise:** In addition to quality and productivity, the hospital considers potential hazards that could affect Occupational Safety and Health.	3.4	3.3	2.8
PA_2	**Strategy:** The hospital seeks to identify new and emerging risks for the preparation of Occupational Safety and Health measures.	2.7	3.4	2.9
PA_3	**Vulnerability:** Potential changes in the workplace (e.g., a new protocol) that may pose a risk of undesirable results are properly controlled.	3.4	3.2	2.9
PA_4	**Prevention activities:** The hospital provides activities that promote Occupational Safety and Health.	2.9	2.7	2.4
PA_5	**Flexibility:** The hospital is flexible in adapting to future changes.	3.1	3.2	2.6
PA_6	**Unacceptable risks:** There is a clear understanding of what constitutes unacceptable risk.	3.2	3.2	2.7
PA_7	**Opportunistic mindset:** There is sufficient knowledge available in the hospital to collect and interpret data on future trends and threats.	2.9	3.1	2.8
PA_8	**Updating plans:** The standards and procedures applied are updated in relation to internal and external changes.	3.6	3.3	3.0
PA_9	**Future change analysis:** Potential future changes in the work environment are analyzed together with healthcare professionals.	3.2	2.7	2.4
PA_{10}	**Proactive management:** The hospital is prepared to manage demographic and healthcare professionals' health issues.	3.3	2.7	2.5
	Total mean	**3.2**	**3.1**	**2.7**

Note: The RAG scores range from 1 to 5 and are reported as mean. 5 indicates the highest score, and 1 represents the lowest score. The scale reflects responses ranging from 1 = Strongly disagree to 5 = Strongly agree.

3.2. Resilient profile of hospital B

3.2.1. Potential to respond

The radar chart (Fig. 3) illustrates that Hospital B emphasizes PR_1 - Organization support (3.9) and PR_4 - Event list (3.5). This suggests that OSH issues are considered when preparing work procedures, and risks and critical events are identified and evaluated. In Hospital B, as with Hospital A, the resources provided are insufficient (PR_3 - Resources, 2.7) and received the lowest score.

3.2.2. Potential to monitor

Hospital B performed better in PM_3 - Communication (3.2), meaning that the results of the safety indicator measurements were communicated and disseminated effectively. It also achieved a relatively high score for PM_6 - Post-accident monitoring (3.0), similar to Hospital A, indicating that measures are monitored periodically. Conversely, the lowest scores were recorded in PM_4 – Periodic medical examinations (2.6) and PM_1 - Systemic examinations (2.7). Medical examinations are not carried out at appropriate intervals, and as in Hospital A, periodic safety inspections conducted in the workplace receive the lowest score, suggesting that periodic inspections are insufficient.

3.2.3. Potential to learn

The radar chart for the learn indicators suggests that healthcare professionals have a high score in PL_2 - Safety Culture (3.6) and PL_3 - Learning culture (3.6). This demonstrates that in the hospital, it is established which types of potential risks or events should be communicated, and professionals should provide information about these events. However, the scores suggest potential for improvement in both PL_1 - Event analysis (3.3) and PL_4 - Knowledge dissemination (3.3). The participation of healthcare professionals in the process of identifying and assessing risks should be ensured, as well as the promotion of knowledge dissemination in regular meetings. PL_4 - Knowledge dissemination received the lowest score in both Hospital A and Hospital B.

3.2.4. Potential to anticipate

Among the 10 indicators used to assess this potential, the highest score was recorded for PA_2 - Strategy (3.4). In contrast, Hospital A received the lowest score in the same indicator. The lowest scores overall were observed for PA_4 - Prevention activities, PA_9 - Future change analysis and PA_{10} – Proactive management, each scoring 2.7. The score recorded demonstrates the need for more activities that promote OSH. Furthermore, the hospital needs to analyze potential future changes in the work environment in collaboration with healthcare professionals and adopt a proactive approach to managing demographic and health issues.

3.3. Resilient profile of hospital C

3.3.1. Potential to respond

The results in Hospital C for the response indicators (Fig. 4) suggest that the hospital performs well in PR_1 - Organization support (3.4), meaning that OSH is considered when work procedures are prepared. Hospital B, in turn, also recorded a higher score for this indicator. On the other hand, healthcare professionals do not agree that the resources are adequate to perform work safely (PR_3 - Resources, 2.4) and receive the lowest score. This indicator recorded the lowest score in all three hospitals. Furthermore, the response capability received the second-lowest score in Hospital C (PR_5 - Response capability, 2.8), indicating that the response to identified risks is not adequate, as reflected in the same indicator for Hospital A.

3.3.2. Potential to monitor

Hospital C scored high in PM_4 - Periodic medical examinations (3.3), in contrast to Hospital B, which received the lowest score for the same indicator. In Hospital C, medical examinations are carried out at appropriate intervals. Conversely, lower scores were recorded for PM_2 - Periodic risk assessments (2.4) and PM_3 - Communication (2.4). The results highlight the need to strengthen risk assessment practices and ensure that the results of safety indicator measurements are effectively communicated.

3.3.3. Potential to learn

Hospital C scored high in PL_5 - Learning from what goes well (3.1), in contrast to Hospital A, which received the lowest score for the same

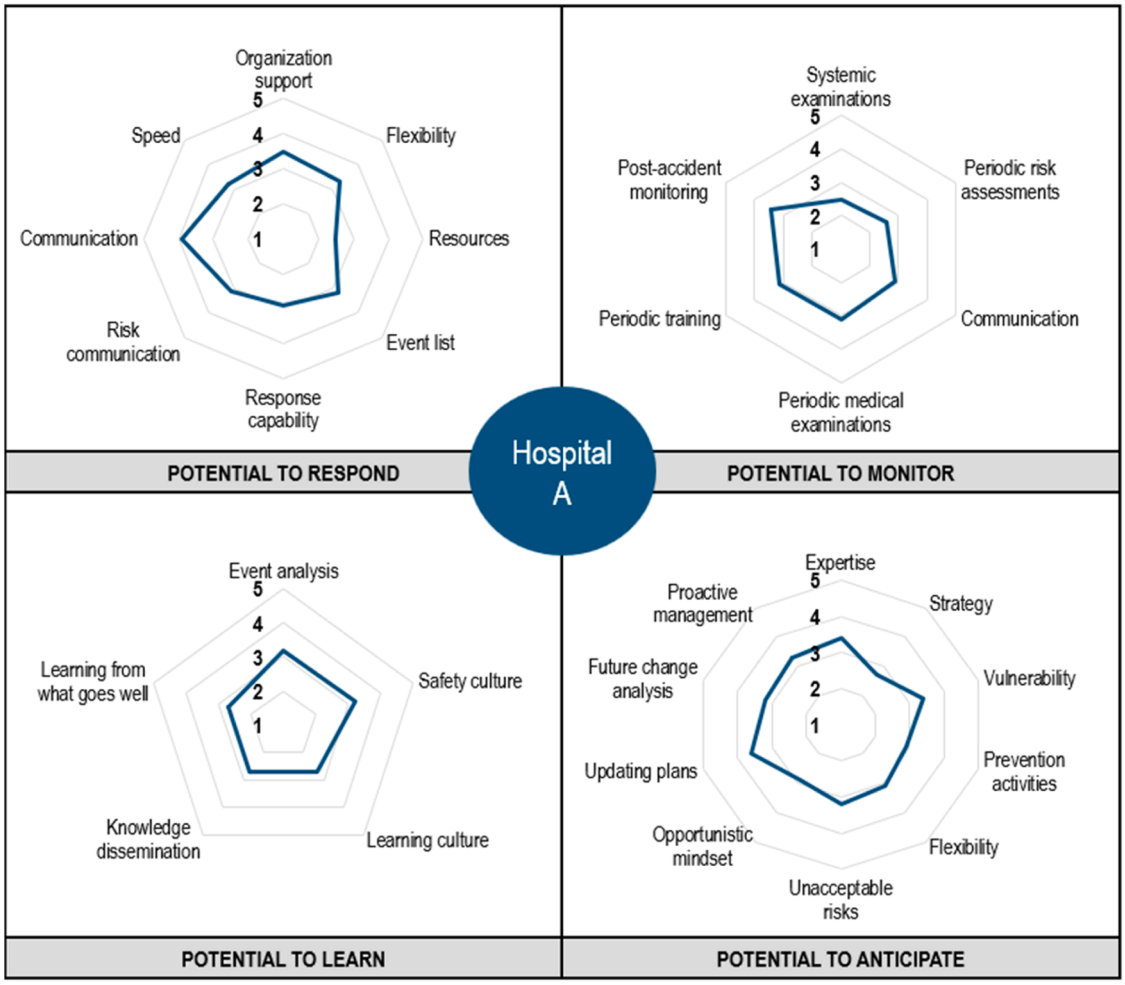

Fig. 2. Resilient profile of Hospital A. The results are presented on a 5-point Likert scale from 1 to 5, with 5 indicating the highest score and 1 representing the lowest score. The scale reflects responses ranging from 1 = Strongly disagree to 5 = Strongly agree.

indicator. Although all the indicators are close to a score of 3, the radar chart (Fig. 4) clearly shows that PL_1 - Event analysis received the lowest score compared to the others (2.7). This indicates that the participation of healthcare professionals in the process of identifying and assessing risks should be ensured. In Hospital B, this indicator was also reported as having the lowest score, although it was slightly higher than the score recorded in Hospital C.

3.3.4. Potential to anticipate

The radar chart illustrates that Hospital C emphasizes PA_8 - Updating plans (3.0), achieving the highest score for this indicator, similar to Hospital A. On the other hand, PA_4 - Prevention activities and PA_9 - Future change analysis received lower scores, 2.4. The need to adopt more activities that promote OSH was identified in Hospital C, along with the need to analyze potential future changes in the work environment in collaboration with healthcare professionals. This is similar to Hospital B, which recorded the lowest scores for these same indicators.

4. Discussion

The methods applied in the development and validation process of this adapted tool are not new. Similarly, Safi et al. [18] used a modified Delphi method to translate and validate the Danish RAG questionnaire. In our study, a strong consensus was achieved, which was crucial during the item selection process, as these items form the basis for establishing the resilient profile [12]. To achieve this adequate level of consensus, three rounds were used, as recommended in the literature [38]. Additionally, and as a complement to the Delphi method, our study included a pretest with healthcare professionals. This pretest was conducted to ensure the clarity of the items, allowing us to gather valuable feedback before finalizing the tool.

The psychometric properties of the construct were also tested through both EFA and CFA, resulting in a final RAG version with a total of 29 items and four demographic questions. A similar approach for assessing the construct validity of the RAG questionnaire was also used by Falegnami et al. [16]. The results reflect a structure in accordance with the starting assumption, confirming the four theoretical dimensions, i.e., the four resilience potentials proposed by Hollnagel [9]. Regarding the number of items or questions included in tailored RAG tools, it is important to note that the general version proposed by Hollnagel [9] serves as a flexible guide. This implies that the tools derived from the adaptation process may vary from the original version, contingent upon the specific context in which the study is conducted. For example, Faegnami et al. [16] developed a questionnaire with 57 items, while Chuang et al. [17] used 38 questions specifically tailored to emergency departments. In contrast, Safi et al. [18] finalized a RAG questionnaire with 29 items, including three demographic questions. Differences can also be seen in the way the data is collected. Previous studies that applied the RAG employed different data collection techniques, such as informal phone interviews [39] and open-ended questions in focus groups [14]. In our study, the RAG was adapted for administration as a questionnaire, similar to the study conducted by

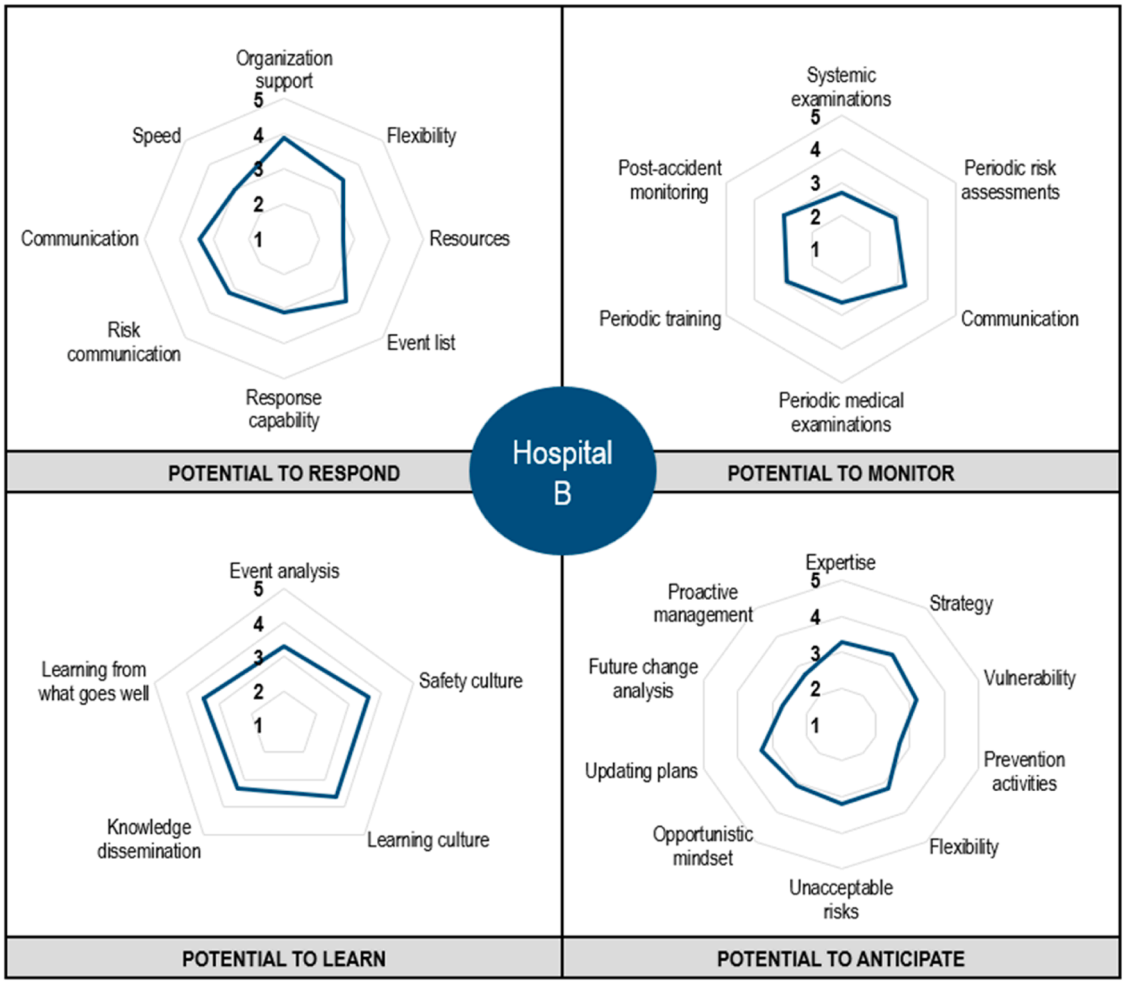

Fig. 3. Resilient profile of Hospital B. The results are presented on a 5-point Likert scale from 1 to 5, with 5 indicating the highest score and 1 representing the lowest score. The scale reflects responses ranging from 1 = Strongly disagree to 5 = Strongly agree.

Falegnami et al. [16]. Importantly, there is no specific data collection technique. However, the samples used in studies conducted in the healthcare domain are typically relatively small. Patriarca et al. [12] used a sample of 12 neuroanesthetists, while Safi et al. [18] applied the RAG to 19 participants. In contrast, the sample included in our study allowed for a statistical analysis of the data and provided a comprehensive representation of resilience potentials.

RAG profiles serve as a starting point to understand how organizations function [9]. The scores obtained by each hospital highlight the need for targeted improvement actions to strengthen the resilience potentials. Although the potential to respond received the highest scores in Hospitals A and C, it remains important for hospitals to invest, as ensuring an adequate response is essential for effective OSH management. In turn, the potential to monitor received the lowest average score across all three hospitals. This suggests that this potential requires improvement, as inadequate monitoring leads to situations where all events are unexpected and unforeseen, thereby hindering proactive risk management. Furthermore, inadequate monitoring negatively impacts response ability [10]. Regarding the potential to anticipate, it requires further attention from hospitals. While uncertainty is inherent in anticipation, situations that deviate from predictions can provide valuable learning experiences [10]. In the absense of learning, responses would always be prepared for the same events [10].

Note that none of the hospitals had a certified OSH management system. A study based on the RAG demonstrates that the implementation of an OSH management system does not necessarily impact safety and resilience levels [39]. Although ISO 45001:2018 places OSH at the centre of organizational strategy and advocates for proactive risk management, it does not refer to the non-linear relationships between system elements [40].

In contrast to our study, previous studies in healthcare using the RAG (e.g., [12,17,19]) have typically focused on a single unit or department. Our study expanded the validation process to include three hospitals. However, due to ethical considerations imposed by the hospitals, the questionnaires were administered anonymously, and the departments were not identified.

Unlike broader resilience assessment methods, such as the Functional Resonance Analysis Method (FRAM) [41], the tool developed in this study adopts a different approach. Although FRAM has been more widely studied than RAG, it is not, in itself, an assessment tool for resilience, as noted by Trancoso et al. [42]. FRAM is a modelling method that describes how daily work is carried out and how variabilities may interact and influence system performance [41]. In contrast, our tool provides a structured, questionnaire-based approach that captures key resilience potentials within hospitals. Moreover, it can be applied to a wide range of participants directly involved in frontline work, enabling a comprehensive exploration of resilience potentials grounded in practical experience.

Despite its contributions, this study has several limitations, which suggest avenues for future research. The knowledge level of healthcare professionals may have had a significant impact on the results. Self-administered questionnaires are inherently prone to biases, and

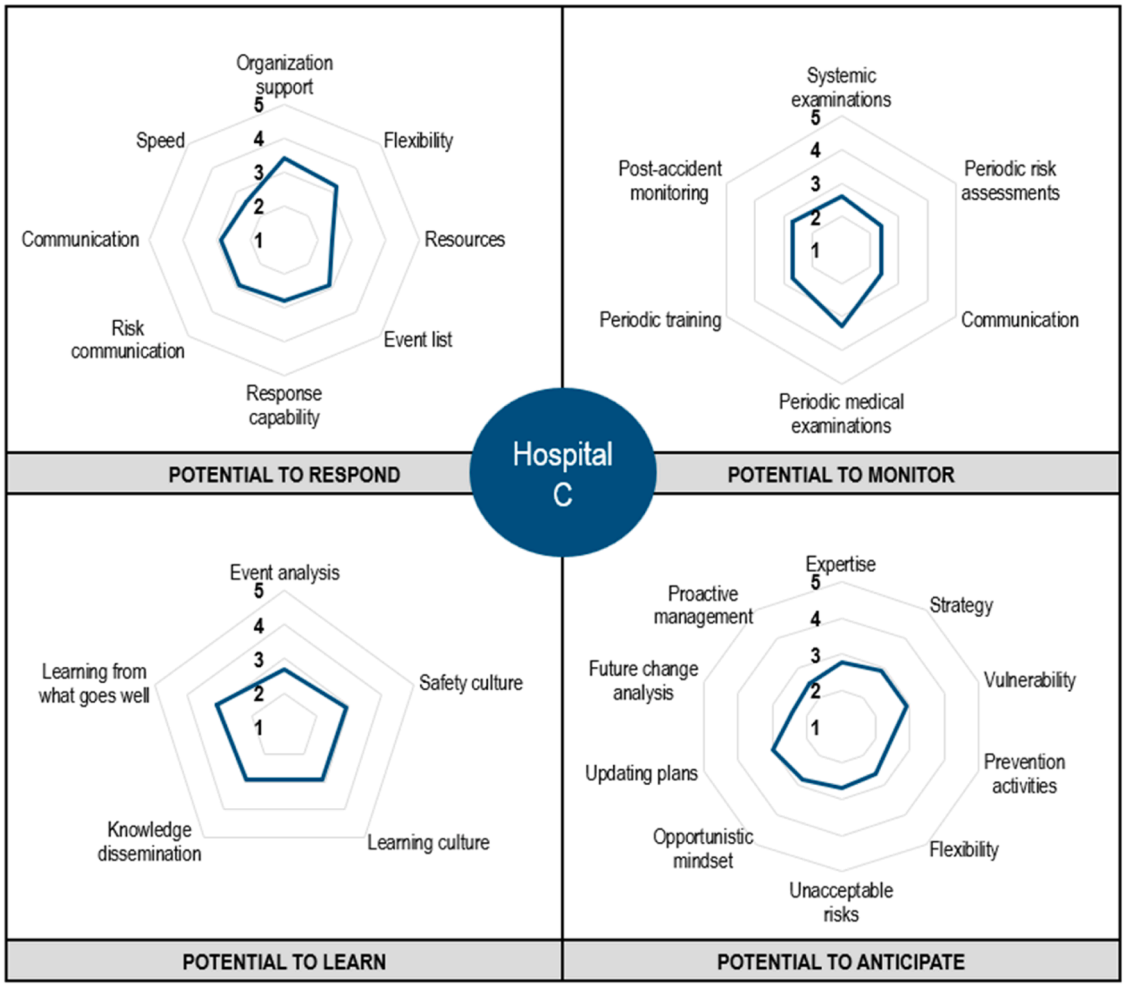

Fig. 4. Resilient profile of Hospital C. The results are presented on a 5-point Likert scale from 1 to 5, with 5 indicating the highest score and 1 representing the lowest score. The scale reflects responses ranging from 1 = Strongly disagree to 5 = Strongly agree.

potential misunderstandings of items may affect the reliability of the responses. Future applications of the RAG in hospital settings should follow a rigorous process for selecting participants to ensure the collection of accurate data, especially when hospitals plan to administer the RAG on a regular basis. While this study did not identify specific departments, such identification is crucial for improving OSH management in a more focused and detailed manner, enabling tailored interventions at the departmental level. Future research should also explore the differences between the responses of OSH managers, top administrators, and healthcare professionals to gain a deeper understanding of potential variations in perceptions and priorities. Ultimately, validating this tool across different health systems is essential for determining its applicability and adaptability in other countries.

5. Conclusion

This study presented the development, validation, and testing of a tool based on RAG to assess the resilience potentials of OSH management. The assessment of its construct validity and internal consistency in a large dataset, which is reported in this paper, yielded acceptable results. Introducing this tailored RAG represents a significant step forward in assessing and enhancing resilience within hospital settings. Hospitals can use the scores for each item to identify areas for improvement and gain insights into how OSH management performs across the four resilience potentials. By focusing on resilience potentials, hospitals can better prepare for, respond to, and recover from potential future public health crises. Continued refinement of this tool has the potential to strengthen and further develop a more resilient OSH system.

Ethics statement

This study was approved by the ethics committee under protocol number 175/2021, on 2 March 2022.

CRediT authorship contribution statement

J. Afonso-Fernandes: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **J. Barbosa:** Writing – original draft, Investigation. **P. Arezes:** Writing – review & editing, Supervision. **C. Pardo-Ferreira:** Writing – review & editing. **J.C. Rubio-Romero:** Writing – review & editing. **M.A. Rodrigues:** Writing – review & editing, Validation, Supervision, Formal analysis, 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.

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Appendix A

Table A.1, Table A.2, Table A.3.

Table A.1
Questionnaire applied in pilot test.

Potential to Respond		
PR_1	Occupational Safety and Health issues are considered when preparing work procedures.	✓
PR_2	In case of variability in the foreseen conditions, healthcare professionals can make the necessary and adequate adjustments to the execution of their activities.	✓
PR_3	Healthcare professionals have access to the resources (financial, technical, and human) required to maintain the ability to perform work safely under conditions of pressure and high workload.	✓
PR_4	Risks and critical events, both frequent and unexpected, are identified and evaluated.	✓
PR_5	When changes occur in the workplace, a review of the risk assessment is conducted to implement measures addressing existing risks.	✓
PR_6	Healthcare professionals receive information about the risks they are exposed to when carrying out their daily activities.	✓
PR_7	There are actions in place that contribute to improving the response to emergencies or unexpected events.	x
PR_8	Existing communication channels are adequate to allow a response to perceived risks in the workplace.	✓
PR_9	The time elapsed from the moment a healthcare professional makes a risk notification to the response is appropriate.	✓
PR_{10}	Changes in working conditions or equipment that increase healthcare professionals' exposure to risks, but do not interfere with their performance, are addressed in a timely manner.	x
PR_{11}	The existing risk control measures are adequate for the hazards to which healthcare professionals are exposed.	x
Potential to Monitor		
PM_1	Healthcare professionals are aware of the Occupational Safety and Health indicators used by the hospital.	x
PM_2	The Occupational Safety and Health indicators used are appropriate for the hospital context.	x
PM_3	The Occupational Safety and Health indicators defined and used are easy to understand.	x
PM_4	The Occupational Safety and Health indicators are used to improve working conditions.	x
PM_5	The approved Occupational Safety and Health policy is implemented in the hospital's practices.	x
PM_6	The number of periodic safety and health inspections in the workplace is adequate.	✓
PM_7	Risk assessments for different workstations/tasks are conducted/updated periodically.	✓
PM_8	The results of safety indicators measurements are communicated and disseminated effectively throughout the hospital.	✓
PM_9	Healthcare professionals are encouraged by the hospital to report hazards and dangerous events observed in the workplace.	x
PM_{10}	Medical examinations are carried out at appropriate intervals.	✓
PM_{11}	Refresher training in Occupational Safety and Health is carried out at appropriate intervals.	✓
PM_{12}	Measures implemented as a result of occupational accidents or failures are monitored periodically.	✓
Potential to Learn		
PL_1	Healthcare professionals actively participate in the risk identification and assessment process.	✓
PL_2	Healthcare professionals provide information about hazardous events without fear of reprisals when they are involved in their occurrence.	✓
PL_3	Improvements in Occupational Safety and Health are implemented based on proposals made by healthcare professionals.	x
PL_4	It is clearly established what types of potential hazards or unexpected and unpredictable events should be reported.	✓
PL_5	The existing communication channels effectively allow the dissemination of information and learning outcomes.	x
PL_6	The time interval between mandatory Occupational Safety and Health training sessions is adequate to keep knowledge up to date	x
PL_7	Occupational Safety and Health training courses are reviewed and improved to enhance their quality.	x
PL_8	Participation in Occupational Safety and Health training sessions results in safer performance by healthcare professionals in their daily activities.	x
PL_9	In regular meetings, healthcare professionals share experiences of things that go wrong and things that go well.	✓
PL_{10}	The hospital provides healthcare professionals with information on positive events (e.g., good practices).	✓
PL_{11}	Following an occupational accident or failure, the hospital seeks to draw conclusions for the future.	x
Potential to Anticipate		
PA_1	In addition to quality and productivity, the hospital considers potential hazards that could affect Occupational Safety and Health.	✓
PA_2	The hospital seeks to identify new and emerging risks for the preparation of Occupational Safety and Health measures.	✓
PA_3	The hospital considers new opportunities (e.g., good practices) when reviewing procedures.	x
PA_4	Drills and simulations are tested in an operational environment.	x
PA_5	The hospital ensures that any healthcare professionals, regardless of their employment status (e.g., subcontracted), can easily provide information about potential Occupational Safety and Health risks.	x
PA_6	Potential changes in the workplace (e.g., new protocol) that may pose a risk of undesirable results are properly controlled.	✓
PA_7	The hospital provides activities that promote Occupational Safety and Health.	✓
PA_8	The hospital is flexible in adapting to future changes.	✓
PA_9	There is a clear understanding of what constitutes unacceptable risk.	✓
PA_{10}	There is sufficient knowledge available in the hospital to collect and interpret data on future trends and threats.	✓
PA_{11}	The standards and procedures applied are updated in relation to internal and external changes.	✓
PA_{12}	Possible future changes in the work environment are analysed together with healthcare professionals.	✓
PA_{13}	The hospital is prepared to manage demographic and healthcare professionals 'health issues.	✓

Note: Items marked with (x) were removed after the EFA, while items marked with (✓) are those that constitute the final questionnaire.

Table A.2
Construct validity.

Items		1	2	3	4	Cronbach's alfa
Potential to Respond						
PR_1	Occupational Safety and Health issues are considered when preparing work procedures.		0.796			0.874

(continued on next page)

Table A.2 (*continued*)

Items		1	2	3	4	Cronbach's alfa
PR_2	In case of variability in the foreseen conditions, healthcare professionals can make the necessary and adequate adjustments to the execution of their activities.		0.704			
PR_3	Healthcare professionals have access to the resources (financial, technical, and human) required to maintain the ability to perform work safely under conditions of pressure and high workload.		0.563			
PR_4	Risks and critical events, both frequent and unexpected, are identified and evaluated.		0.634			
PR_5	When changes occur in the workplace, a review of the risk assessment is conducted to implement measures addressing existing risks.		0.627			
PR_6	Healthcare professionals receive information about the risks they are exposed to when carrying out their daily activities.		0.585			
PR_8	Existing communication channels are adequate to allow a response to perceived risks in the workplace.		0.458			
PR_9	The time elapsed from the moment a healthcare professional makes a risk notification to the response is appropriate.		0.406			
Potential to Monitor						
PM_6	Periodic safety inspections conducted in the workplace are effective.			0.691		0.874
PM_7	Risk assessments for different workstations/tasks are conducted/updated periodically.			0.649		
PM_8	The results of safety indicators measurements are communicated and disseminated effectively throughout the hospital.			0.425		
PM_{10}	Medical examinations are carried out at appropriate intervals.			0.670		
PM_{11}	Refresher training in Occupational Safety and Health is carried out at appropriate intervals.			0.510		
PM_{12}	Measures implemented as a result of occupational accident or failures are monitored periodically.			0.625		
Potential to Learn						
PL_1	Healthcare professionals actively participate in the risk identification and assessment process.				0.627	0.841
PL_2	Healthcare professionals provide information about hazardous events without fear of reprisals when they are involved in their occurrence.				0.535	
PL_4	It is clearly established what types of potential hazards or unexpected and unpredictable events should be reported.				0.519	
PL_9	In regular meetings, healthcare professionals share experiences of things that go wrong and things that go well.				0.711	
PL_{10}	The hospital provides healthcare professionals with information on positive events (e.g., good practices).				0.595	
Potential to Anticipate						
PA_1	In addition to quality and productivity, the hospital considers potential hazards that could affect Occupational Safety and Health.	0.572				0.877
PA_2	The hospital seeks to identify new and emerging risks for the preparation of Occupational Safety and Health measures.	0.572				
PA_6	Potential changes in the workplace (e.g., new protocol) that may pose a risk of undesirable results are properly controlled.	0.527				
PA_7	The hospital provides activities that promote Occupational Safety and Health.	0.667				
PA_8	The hospital is flexible in adapting to future changes.	0.741				
PA_9	There is a clear understanding of what constitutes unacceptable risk.	0.743				
PA_{10}	There is sufficient knowledge available in the hospital to collect and interpret data on future trends and threats.	0.658				
PA_{11}	The standards and procedures applied are updated in relation to internal and external changes.	0.580				
PA_{12}	Potential future changes in the work environment are analysed together with healthcare professionals.	0.557				
PA_{13}	The hospital is prepared to manage demographic and healthcare professionals' health issues.	0.569				

Table A.3
communalities.

Item	Initial	Extraction
PR_1	1.000	0.685
PR_2	1.000	0.587
PR_3	1.000	0.647
PR_4	1.000	0.645
PR_5	1.000	0.610
PR_6	1.000	0.579
PR_8	1.000	0.567
PR_9	1.000	0.439
PM_6	1.000	0.620
PM_7	1.000	0.633
PM_8	1.000	0.502
PM_{10}	1.000	0.473
PM_{11}	1.000	0.451
PM_{12}	1.000	0.636
PL_1	1.000	0.556
PL_2	1.000	0.510
PL_4	1.000	0.553
PL_9	1.000	0.592
PL_{10}	1.000	0.506
PA_1	1.000	0.669
PA_2	1.000	0.645
PA_6	1.000	0.609
PA_7	1.000	0.546
PA_8	1.000	0.673
PA_9	1.000	0.653
PA_{10}	1.000	0.626

(*continued on next page*)

Table A.3 (*continued*)

Item	Initial	Extraction
PA_{11}	1.000	0.604
PA_{12}	1.000	0.598
PA_{13}	1.000	0.547

Note: Extraction Method: Principal Component Analysis.

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