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*Review*

## **A conceptual review of human factors frameworks in nursing and patient safety**

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**Abstract:** *Purpose:* Within the multidisciplinary area of human factors, a variety of frameworks have been proposed and/or applied in patient safety research to analyze risks and guide improvements, each offering a different perspective on system performance. Within the healthcare environment, nursing is one of the most distinct areas that can drive and deliver results in the patient safety arena. This study provides a conceptual review of human factors and ergonomics (HFE) frameworks used in patient safety research. *Design/methodology/approach:* A structured literature mapping process identified empirical studies applying named HFE frameworks. This review identified 37 studies that applied HFE frameworks to nursing-related patient safety contexts including workflow analyses, adverse-event investigations, infection prevention, technology-related safety risks, and clinical decision-making. Each framework was examined according to predefined theoretical criteria (unit of analysis, assumptions about safety, representation of clinical work, and role of human performance). *Findings:* Among the various reviewed models used by nurses (either working within their discipline or part of multidisciplinary teams), the ones mostly used stem from engineering and aviation. The Systems Engineering Initiative for Patient Safety model was by far the most frequently applied framework, appearing in 26 of the 37 studies. Other frameworks were much less common: the Human Factors Classification Framework appeared in 5 studies. Frameworks such as the Yorkshire Contributory Factors Framework, Health Information Technology Classification System (HIT-CS), Perception–Action Cycle (PAC) model, and Comprehensive Unit-Based Safety Program (CUSP) each appeared in one study, whereas the RIPCHORD-TWA flow-disruption taxonomy appeared in two studies. *Originality/Value:* This review offers criteria to guide theoretically informed framework selection in nursing patient safety research and contributes to greater conceptual clarity within the field.

**Keywords:** human factors framework; patient safety; nursing research; clinical practice; multidisciplinary clinical teams

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## 1. Introduction

Patient safety has become a central focus for healthcare organizations, as it is closely associated with reduced complications and improved patient outcomes, promoting patient well-being and safer care outcomes [1]. Recent research considers patient safety to be a fundamental component of healthcare quality, thereby focusing on reducing avoidable harm by systematically identifying and managing risks inherent in care delivery [2]. Within this frame, the value of shared learning and multidisciplinary review of safety events have been highlighted as important mechanisms to improve care processes and strengthen organizational safety culture.

Encouraging reporting and learning, even from near-misses, helps build a stronger culture of safety and prevent future harm [3]. Recognizing that many safety issues arise from the interaction between people, tasks, technology, and environments, human factor principles offer a valuable framework to understand and address these complexities [4].

The report “To Err Is Human” reoriented the field towards a systemic view of patient safety, thereby showing that adverse events emerge from complex interactions among human performance and organizational structures [5]. Human factor is a multidisciplinary research area that amalgamates knowledge and practice from many other areas, such as engineering, psychology, and medicine, to systematically examine and improve human well-being and system performance. Human Factors and Ergonomics (HFE) is defined by the International Ergonomics Association (IEA) as the scientific discipline concerned with understanding interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and the overall system performance. In healthcare, HFE contributes to patient safety by examining how work systems, technologies, environments, organizational structures, and human performance interact within complex clinical settings. Healthcare initially adopted many human factors approaches from aviation and engineering and continues to adapt these principles within clinical environments [6–9].

Over the past fifteen years, healthcare human factors and patient safety research have steadily grown, and the field has increasingly established its own research direction within healthcare. Consequently, a variety of healthcare-specific human factors frameworks have been proposed and applied in patient safety research to analyze risks and guide improvements. Although healthcare has increasingly incorporated HFE approaches into patient safety research and practice, several authors argue that healthcare has often adopted selected HFE tools and methods rather than fully integrating the broader systems-oriented science of HFE. Consequently, applications may focus on isolated incident analysis or error reduction without fully addressing the work system design, adaptive performance, and sociotechnical complexity.

Each of these frameworks, stemming from healthcare researchers, offer a different perspective on system performance. Frameworks are often adopted to analyze each incident or guide interventions, but it remains unclear whether these models constitute a coherent body of healthcare-specific theory or a collection of partially transferred concepts from other safety-critical industries. These include linear accident causation such as the Swiss Cheese Model (Reason, 2000), systems engineering

approaches such as Systems Engineering Initiative for Patient Safety (SEIPS) [4], cognitive and decision-making models, and resilience-oriented frameworks [10,11]. In some, safety is conceptualized as the prevention of failure and error causation, while in others as the capacity of systems to maintain performance under varying conditions.

The emergence of a distinct human factors and patient safety field within healthcare has stimulated research specifically tailored to the clinical environment. Although the emergence of this healthcare-specific field is evident, it remains unclear whether these models represent coherent adaptations to the healthcare context or fragmented applications of concepts derived from other high-risk industries, as well as their suitability for the complex nature of nursing practice. Therefore, it is necessary to undertake a conceptual review to critically examine the origins, assumptions, and defining characteristics of these frameworks and to assess their alignment with the clinical reality of nursing. By synthesizing these frameworks, this review will contribute to a better understanding of patient safety within everyday nursing practice and will assist in establishing safety interventions in everyday nursing practice.

## **2. Materials and methods**

### *2.1. Aim*

Under the prism of newly created knowledge dedicated to healthcare's needs, it would be of great value to examine the characteristics of human factors frameworks/models that are used in healthcare. Within the healthcare environment, nursing is one of the most distinct areas that can drive and deliver results in the patient safety arena [2].

This conceptual review aims to examine how human factors frameworks are applied in nursing-related patient safety research, including the purposes and clinical contexts in which they are used. Given the size of the nursing workforce, its continuous presence at the patient bedside, and the increasing engagement of nursing research with patient safety, analyzing the human factors frameworks applied in nursing provides an opportunity to identify their conceptual similarities, differences, and gaps. For nurses to ensure safety, they must grasp the concept of patient safety and human factors, apply it to their daily practice, and have access to such necessary tools (human factors frameworks/models). This conceptual paper examines the origins and characteristics of these frameworks and evaluates their alignment with the characteristics of clinical work using explicit conceptual criteria, including primary unit of analysis (individual, task, or system level), underlying assumptions about safety, and the role attributed to human performance in nursing practice.

### *2.2. Method*

This study is a conceptual review supported by a structured literature mapping process designed to identify human factors frameworks applied in nursing patient safety research. A conceptual review aims to critically examine the theoretical assumptions, conceptual structures, and underlying perspectives of a body of literature rather than quantitatively synthesize outcomes. PubMed was searched between January 2000 and May 2025 using combinations of the terms “patient safety”, “human factors”, “ergonomics”, “framework”, “model”, and “nurs\*” in the title, abstract, and keyword fields. Searches were restricted to peer-reviewed English-language articles indexed within Nursing and Health Professions subject areas.

Although this study was designed as a conceptual review rather than a formal systematic review, PRISMA-informed principles were used to improve the transparency in the study's identification, screening, and selection procedures. The search strategy identified 122 records from PubMed (Figure 1). The titles, abstracts, and subsequently all full-text articles were independently reviewed by three reviewers. Studies were excluded if they did not apply a named human factors or ergonomics framework, lacked empirical data, were conducted outside healthcare settings, did not involve nurses either independently or as part of multidisciplinary teams, or represented commentaries, editorials, or theoretical papers without original research. Studies in which the framework was insufficiently described or not analytically applied were also excluded. Disagreements during study selection were resolved through discussion among the reviewers until consensus was achieved.

Data from all included studies were entered into a Microsoft Excel workbook structured with the following columns, each corresponding to fields in our a priori data-charting template:

- Study Title (from “Initial list of 122”);
- Inclusion Status (“YES” or “NO”);
- Rationale for Inclusion (free-text notes on why the paper was retained);
- Model/Framework Name (the specific human factors or ergonomics framework applied);
- Purpose/context of framework application (e.g., adverse event analysis, workflow evaluation, technology safety, teamwork assessment, prospective risk identification);
- Rationale for Exclusion (if excluded, why did it not meet criteria);
- Team Composition (categorical field: “Only nurses” or “Nurses part of multidisciplinary team”);
- Year of Publication;
- Reviewer Notes (any queries flagged for second-reader adjudication).

Three reviewers independently populated these fields for each study retained after full-text screening.

Following full-text assessment, 37 studies met the eligibility criteria and were included in the conceptual review. Each framework was examined according to predefined theoretical criteria (unit of analysis, assumptions about safety, representation of clinical work, and role of human performance).

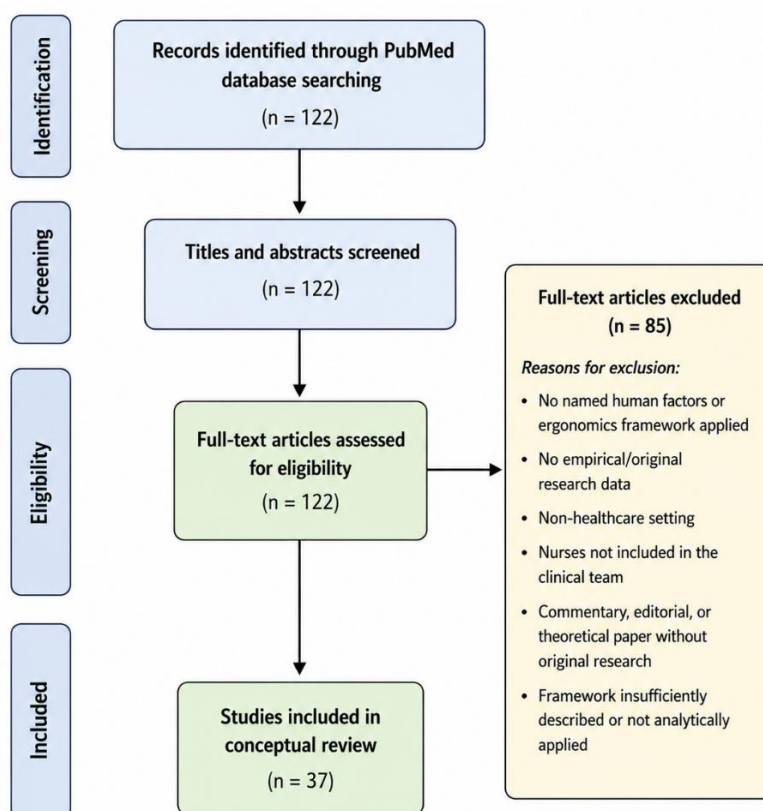


**Figure 1.** PRISMA-style flow diagram of study identification, screening eligibility assessment and inclusion.

### 3. Results

The SEIPS model was by far the most frequently applied framework, appearing in 26 of the 37 studies [12–36]. Other frameworks were much less common: the Human Factors Classification Framework (HFCF) appeared in 5 studies [37–41]. The Yorkshire contributory factors framework [42], Health Information Technology Classification System (HIT-CS) [43], Perception-action cycle (PAC) model [44], and Comprehensive Unit-Based Safety Program (CUSP) [45] were each identified in one study, whereas the RIPCHORD-TWA flow-disruption HF taxonomy [46,47] was identified in two studies. The characteristics of the included studies are summarized in Table 1.

Framework usage differed between studies that examined nurse-only teams and those that investigated multidisciplinary teams (Table 2). Among the seven studies focused exclusively on nurses, SEIPS was the most frequently applied framework appearing in five studies [14,27,30,34,36], whereas the HFCF [40] and the PAC [44] model were each applied in one study. In contrast, multidisciplinary team studies showed more diversity in framework use: HFCF [37,39,41], Yorkshire contributory factors framework [42], RIPCHORD-TWA flow-disruption HF taxonomy [46,47], CUSP [45], HIT-CS [43] appeared only in multidisciplinary contexts.

**Table 1.** Characteristics of the studies included in the conceptual review (n = 37).

| Author                  | Year | Country   | Study design           | Clinical setting            | Human factors framework | Main findings                                                                         |
|-------------------------|------|-----------|------------------------|-----------------------------|-------------------------|---------------------------------------------------------------------------------------|
| Boyce et al. [12]       | 2024 | USA       | Observational          | Hand hygiene                | SEIPS                   | Human factors engineering improved hand hygiene quality through work-system redesign. |
| Aaberg et al. [13]      | 2021 | Norway    | Intervention           | Surgical ward               | SEIPS                   | TeamSTEPPS intervention improved teamwork and patient safety culture.                 |
| Bethel et al. [14]      | 2022 | USA       | Qualitative            | Critical care nursing       | SEIPS                   | COVID-19 substantially altered nursing work systems and care delivery.                |
| Higham et al. [15]      | 2024 | UK        | Pilot observational    | Clinical research           | SEIPS                   | Human factors identified vulnerabilities in clinical research processes.              |
| Glatkauskas et al. [16] | 2025 | Norway    | Qualitative            | Hospital-to-home transition | SEIPS                   | Systems analysis identified barriers affecting care transitions.                      |
| Xie et al. [17]         | 2015 | USA       | Participatory redesign | Family-centred rounds       | SEIPS                   | Participatory ergonomics improved communication and workflow.                         |
| Barker et al. [18]      | 2017 | India     | Qualitative            | Infection prevention        | SEIPS                   | Organizational barriers to infection control were identified.                         |
| Safdar et al. [19]      | 2021 | USA       | Study protocol         | Intensive care              | SEIPS                   | Human factors guided ICU infection-prevention interventions.                          |
| Konwinski et al. [20]   | 2024 | USA       | Quality improvement    | PICU                        | SEIPS                   | Human factors improved medication double-check processes.                             |
| Werner et al. [21]      | 2020 | USA       | Qualitative            | Care transitions            | SEIPS 2.0               | SEIPS 2.0 effectively analysed care transitions across work systems.                  |
| Chua et al. [22]        | 2018 | Singapore | Systematic review      | Rapid response systems      | SEIPS                   | Organizational factors influenced rapid response activation.                          |
| Bugeja et al. [23]      | 2020 | UK        | Systematic review      | OPAT services               | SEIPS                   | Human factors approaches identified service-design weaknesses.                        |

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| Author                     | Year | Country   | Study design        | Clinical setting          | Human factors framework | Main findings                                                                     |
|----------------------------|------|-----------|---------------------|---------------------------|-------------------------|-----------------------------------------------------------------------------------|
| Keller et al. [24]         | 2017 | USA       | Mixed methods       | Home healthcare           | SEIPS                   | Five requirements for safe home medical-device use were identified.               |
| Guisse et al. [25]         | 2014 | UK        | Systematic review   | Telecare                  | SEIPS                   | Telecare safety depended on system integration and workflow.                      |
| Bernstein et al. [26]      | 2021 | USA       | Realist review      | Obstetric care            | SEIPS                   | Systems approach supported prevention of failure-to-rescue.                       |
| Santos et al. [27]         | 2016 | Haiti     | Observational       | Nurse anaesthesia         | SEIPS                   | Equipment usability affected safe nurse anaesthesia training.                     |
| Ballangrud et al. [28]     | 2017 | Norway    | Study protocol      | Hospital teamwork         | SEIPS                   | Human factors supported evaluation of teamwork interventions.                     |
| Yanke et al. [29]          | 2021 | USA       | Qualitative         | Environmental services    | SEIPS                   | Work-system barriers to infection prevention were identified.                     |
| Xiao et al. [30]           | 2022 | USA       | Qualitative         | Medication safety         | SEIPS                   | Human factors identified medication safety hazards after discharge.               |
| Yanke et al. [31]          | 2015 | USA       | Mixed methods       | Infection prevention      | SEIPS                   | Work-system redesign supported prevention of <i>C. difficile</i> infection.       |
| Vaughan-Malloy et al. [32] | 2023 | USA       | Cross-sectional     | Hand hygiene              | SEIPS                   | Framework identified barriers to high-reliability practices.                      |
| Kwan et al. [33]           | 2021 | Hong Kong | Descriptive         | COVID-19 management       | SEIPS                   | SEIPS described organizational adaptations during the pandemic.                   |
| Probst et al. [34]         | 2017 | USA       | Quality improvement | Nursing workflow          | SEIPS                   | Nursing work-system redesign increased bedside nursing time.                      |
| Yardley et al. [35]        | 2022 | UK        | Realist evaluation  | Community palliative care | SEIPS                   | Human factors identified barriers affecting out-of-hours care.                    |
| Benjamin et al. [36]       | 2024 | USA       | Grounded theory     | Emergency nursing         | SEIPS                   | Work-system analysis improved understanding of emergency department patient flow. |
| Munroe et al. [37]         | 2023 | Australia | Controlled pre–post | Emergency care            | HFCF                    | Human factors analysis supported evaluation of rapid response systems.            |

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| Author                   | Year | Country      | Study design              | Clinical setting           | Human factors framework                  | Main findings                                                                              |
|--------------------------|------|--------------|---------------------------|----------------------------|------------------------------------------|--------------------------------------------------------------------------------------------|
| Nassief et al. [38]      | 2021 | Australia    | Observational             | Emergency department       | HFCF                                     | Identified causal factors of inpatient deterioration.                                      |
| Isaacs et al. [39]       | 2023 | Australia    | Content analysis          | Medication safety          | HFCF                                     | Nurses' reflections identified human and organizational contributors to medication errors. |
| Lee et al. [40]          | 2025 | Taiwan       | Observational             | Medical centre             | HFCF                                     | HFACS strengthened root-cause analysis and patient safety culture.                         |
| Ravindran et al. [41]    | 2024 | UK           | Incident analysis         | Endoscopy                  | HFCF                                     | Human factors identified non-procedural safety risks.                                      |
| Goekcimen et al. [42]    | 2023 | Switzerland  | Systematic review         | Incident reporting         | Yorkshire Contributory Factors Framework | Framework supported systematic identification of contributory factors.                     |
| Rahman Jabin et al. [43] | 2023 | Sweden       | Incident analysis         | Digital incident reporting | HIT-CS                                   | Classified health information technology–related patient safety incidents.                 |
| Taft et al. [44]         | 2023 | USA          | Qualitative               | Medication administration  | PAC model                                | Identified persistent cognitive and workflow hazards affecting nurses.                     |
| Khan et al. [45]         | 2017 | Saudi Arabia | Quality improvement       | Intensive care             | CUSP                                     | Improved teamwork and safety culture in mechanically ventilated patients.                  |
| Khan et al. [46]         | 2025 | USA          | Observational             | Orthopaedic surgery        | RIPCHORD-TWA                             | Workflow disruptions increased safety threats during surgery.                              |
| Khan et al. [47]         | 2025 | USA          | Comparative observational | Multispecialty surgery     | RIPCHORD-TWA                             | Flow disruptions differed across surgical specialties.                                     |
| Boquet et al. [48]       | 2021 | USA          | Observational             | Surgery                    | Surgical Flow-Disruption Taxonomy        | Taxonomy categorized operating-room workflow disruptions associated with patient safety.   |

**Table 2.** Distribution of human factors frameworks according to team composition.

| Framework                                                    | Nurse-only teams<br>(n = 7) | Multidisciplinary<br>teams (n = 30) |
|--------------------------------------------------------------|-----------------------------|-------------------------------------|
| Systems engineering initiative for patient safety (SEIPS)    | 5                           | 21                                  |
| Human factors classification framework (HFCF)                | 1                           | 4                                   |
| Yorkshire contributory factors framework                     | 0                           | 1                                   |
| Health information technology classification system (HIT-CS) | 0                           | 1                                   |
| Perception–action cycle (PAC) model                          | 1                           | 0                                   |
| RIPCHORD-TWA flow-disruption taxonomy                        | 0                           | 2                                   |
| Surgical flow-disruption taxonomy                            | 0                           | 1                                   |

Frameworks were applied across several patient safety contexts and purposes. SEIPS was most commonly used to examine workflow processes, care transitions, infection prevention practices, and system-level redesign of clinical work environments. HFCF and Yorkshire Contributory Factors Framework (YCFF) were primarily used for retrospective analyses of adverse events and contributory factors. RIPCHORD-TWA and Surgical Flow-Disruption Taxonomy focused on workflow interruptions and operating-room disruptions affecting team performance and safety. HIT-CS was applied to analyze safety risks associated with health information technologies, while the PAC model examined cognitive processes and decision-making during medication administration and clinical work. Nurse-only studies primarily applied frameworks to examine nursing workflows, bedside care delivery, medication administration, and nursing work systems, whereas multidisciplinary studies more frequently focused on adverse-event analyses, organizational safety processes, workflow disruptions, and team communication.

SEIPS model provides a comprehensive systems-based framework that examines how interactions among people, tasks, tools, environments, and organizational factors affect patient safety and outcomes of care. University of Wisconsin-Madison developed the SEIPS model as an integration of human factors engineering and healthcare quality frameworks to address the lack of comprehensive, empirical models in the patient safety literature and is notable for its focus on systems design, its alignment with Donabedian's structure-process-outcome model, and its application to both patient safety and workforce well-being. It was originally proposed by Carayon and Smith by incorporating five key elements—person, tasks, tools and technologies, physical environment, and organizational conditions—whose interactions influence healthcare processes and outcomes [4]. Across the included studies, SEIPS was mainly applied to examine the workflow redesign, infection prevention practices, care transitions, and nursing work systems.

The HFCF, which has been adapted from the Human Factors Analysis and Classification System (HFCAS), categorizes human error by tracing contributing factors across multiple organizational levels, from unsafe acts to latent systemic conditions [49]. In the included studies, HFCF was primarily used for retrospective analysis of adverse events and contributing factors.

HFACS was originally developed by Shappell and Wiegmann to analyze human error in military aviation and it was built upon Reason's model of accident causation. The core idea was to systematically identify the contributing factors to accidents, thereby breaking them down into different levels of organizational and individual influences [50]. The YCFF was built to address the lack of comprehensive, empirical models in the patient safety literature and is notable for its focus on systems

design, its alignment with Donabedian's structure-process-outcome model, and its application to both patient safety and workforce well-being. Included studies mainly applied YCFF to structured investigations of patient safety incidents and contributory organizational factors. YCFF identified and categorized 20 domains of system-level and individual-level factors that contribute to errors, including situational, organizational, task, and communication-related elements. It was designed to enable healthcare professionals, safety analysts, and researchers to understand the broader context in which patient safety incidents occur and to support more effective prevention strategies [51].

The HIT-CS specifically focuses on classifying patient safety events associated with health information technology, thereby addressing usability, workflow integration, and technical failures [52]. In the included study, HIT-CS was applied to classify and analyze technology-related patient safety incidents associated with health information technologies (HIT). It arose from the need to systematically categorize patient safety incidents related to HIT, which were not adequately captured by traditional medical device classifications. HIT-CS was specifically designed to address the increasing complexity and diversity of digital health tools—such as electronic health records, clinical decision support systems, and other software-intensive systems—by providing a framework that distinguishes between software and hardware-related incidents and identifies contributing factors, such as human or system errors. The classification system has since been used in several studies to analyze incident reports in real-world healthcare settings, helping to improve understanding of the risks associated with HIT and inform the development and implementation of safer technology [53].

The CUSP is an intervention framework designed to improve safety culture at the unit level by enhancing teamwork and identifying and mitigating hazards within clinical teams [54]. The CUSP was specifically designed to strengthen local safety culture across hospital units by combining a structured framework to learn from defects with efforts to improve teamwork, communication, and executive engagement. Within the included literature, CUSP was applied to strengthen teamwork and safety culture in intensive care settings. It was originally developed with funding from the Agency for Healthcare Research and Quality.

The PAC model describes the continuous cognitive process by which individuals perceive environmental cues and act upon them, thereby providing insights into decision-making under complex, dynamic conditions [55]. The PAC model originated from the work of neuroscientist Joaquín M. Fuster, who first conceptualized it as a core mechanism in the functioning of the prefrontal cortex and goal-directed behavior. Fuster described the PAC as a continuous, cyclical flow of information where perception of the environment informs actions, and the outcomes of actions update future perceptions, thus enabling adaptive behavior. This model moved beyond traditional linear stimulus-response theories by emphasizing the dynamic interplay between cognition, memory, and executive control [56]. The PAC model was used to examine cognitive workload, medication administration processes, and a nurse's decision-making during clinical work.

Lastly, taxonomies such as Realizing Improved Patient Care through Human-Centered Operating Room Design for Threat Window Analysis (RIPCHORD-TWA) classify and analyze flow disruptions in operating rooms, thereby focusing on interruptions that affect surgical team performance and patient safety [57], while the Surgical Flow-Disruption Taxonomy systematically categorizes disruptions during surgical procedures, including communication failures and equipment problems, to understand their relationship with surgical errors [49]. Its acronym stands for Resources, Interruptions, Personnel, Communication, Equipment, Layout, Documentation, Training, Availability, and Working Conditions, showing all categories of disruptions observed during surgeries, which can lead to increased stress,

cognitive workload, and impaired technical performance among surgical team members. Furthermore, they can create “threat windows”, which are periods during surgery when the likelihood of errors is elevated, thus posing significant risks to patient safety [48]. In the included studies, RIPCHORD-TWA was applied to identify workflow disruptions and interruption patterns affecting surgical team performance and patient safety.

The RIPCHORD-TWA framework is rooted in principles from Human Factors Engineering and Resilience Engineering, which focus on understanding how complex systems—like operating rooms—function under varying conditions, especially when faced with interruptions and disruptions. More specifically, RIPCHORD-TWA draws on the PAC model and CSE frameworks, which emphasize the dynamic interaction between humans and their environments. These models highlight how individuals perceive changes (disruptions) in their environment, adapt their actions accordingly, and how these interactions influence the overall system safety and performance [58–60]. RIPCHORD-TWA incorporates concepts from the PAC, Resilience Engineering, and CSE. These perspectives explain how surgical teams continuously monitor and respond to disruptions, how interruptions create “threat windows” that increase safety vulnerability, and how cognitive workload and communication influence team performance and patient safety.

A summary of all frameworks that were identified in this study, with the frequency they were met, along with the research /practice area of their origin and the inception date is provided in Table 3.

**Table 3.** Frequency of identified human factors frameworks and their origins.

| Framework                                                    | Frequency (n = 37) | Origin and date                                                  |
|--------------------------------------------------------------|--------------------|------------------------------------------------------------------|
| Systems engineering initiative for patient safety (SEIPS)    | 26                 | Engineering and healthcare (2006)                                |
| Human factors classification framework (HFCF)                | 5                  | Engineering (aviation) (2000)                                    |
| Yorkshire contributory factors framework                     | 1                  | Healthcare (2012)                                                |
| Health information technology classification system (HIT-CS) | 1                  | Healthcare (informatics) (2012)                                  |
| Comprehensive unit-based safety program (CUSP)               | 1                  | Healthcare quality improvement (2008)                            |
| Perception–action cycle (PAC) model                          | 1                  | Cognitive neuroscience (2004)                                    |
| RIPCHORD-TWA flow-disruption taxonomy                        | 2                  | Human factors engineering / cognitive systems engineering (2006) |

#### 4. Discussion

Healthcare has increasingly adopted human factors and systems engineering models originally developed in high-risk industries such as aviation and manufacturing. Frameworks such as the SEIPS and the HFCF provide structured approaches to analyze complex work systems and safety incidents, thus helping healthcare improve patient safety [4,49]. These models emphasize systems thinking, human-machine interactions, and workflow analyses, which are critical to manage the complexity inherent in healthcare environments.

One reason healthcare relies on these engineering-origin models is their strong empirical foundation and long history of use in safety-critical domains [61]. Despite being designed outside healthcare, these models offer robust methodologies for identifying latent system vulnerabilities and human error mechanisms, which are transferable across contexts.

However, we have to recognize that healthcare has unique socio-cultural dynamics and a patient-centered nature that may not be fully captured by engineering-centric frameworks [62]. Healthcare-dedicated models such as the YCFF or the PAC model incorporate more clinical and organizational realities, including professional roles, communication patterns, and the unpredictable nature of patient care [50]. While engineering models provide an essential foundation, adaptation is required to better reflect healthcare-specific perspectives, particularly those relevant to nursing practice, thereby improving the applicability of human factor interventions. The PAC model contributes a distinct cognitive perspective by emphasizing how clinicians continuously interpret environmental cues and adapt their actions during dynamic clinical situations. Unlike incident-classification models, PAC focuses on situated cognition and real-time decision-making processes, making it particularly relevant to understand medication administration, workload, and adaptive nursing performance.

Several influential patient safety and sociotechnical frameworks, including the London Protocol, were not identified within the final included sample, likely reflecting the specific eligibility criteria applied in the present review, particularly the focus on empirical nursing-related studies which explicitly applied named HFE frameworks.

A comparative analysis of major human factor frameworks in patient safety reveals important differences in their unit of analysis, assumptions about safety, representation of clinical work, and conceptualization of human performance. The HFACS introduces a hierarchical classification system that organizes unsafe acts, preconditions, supervisory influences, and organizational factors [46,47]. Adapted from aviation, HFACS enables structured post-incident analyses and supports multi-level attribution of human error within organizational contexts. Nevertheless, the HFACS remains predominantly retrospective and classification-oriented, thereby focusing on error categorization rather than modeling dynamic clinical systems.

The YCFF maps individual, situational, organizational, and external influences contributing to patient safety incidents and has been operationalized for structured investigations [48]. Its primary strength lies in standardizing incident analyses and strengthening the rigor of root cause investigation. However, it remains incident-centered and primarily supports retrospective learning rather than prospective system redesign or modeling distributed care processes over time. The HFCF further extends causal analyses by introducing a hierarchical and temporally sensitive structure capable of identifying multiple interacting causation factors within adverse events. By reconstructing event sequences, the HFCF enhances analytic depth; nonetheless, it remains retrospective, emphasizing how incidents unfolded rather than how systems should be redesigned.

The SEIPS model integrates structure, process, and outcomes. It is a prospective, design-oriented framework that supports redesign rather than a merely retrospective explanation of failure. The RIPCHORD-TWA framework was applied at the micro-level of workflow within specific clinical environments. It contributes an important cognitive dimension by linking interruptions and situation awareness to safety threats [44,45]. This approach highlights how cumulative disruptions may degrade performance even in the absence of discrete adverse events.

The main conceptual finding of this review is that the identified frameworks differ in their unit of analysis, assumptions about safety, and interpretation of human performance.

At a theoretical level, the reviewed frameworks can be understood as reflecting three broad orientations. The HFACS [46,47], HFCF [38,39] and YCFF [48] conceptualize safety primarily as the prevention of failure. Their analytic focus lies in identifying unsafe acts, contributory factors, and latent organizational conditions that precede adverse events [46,48] and are suited to retrospective investigation of incident analysis. In contrast, the primary unit of analysis for the SEIPS shifts from isolated events to the work system, thereby encompassing people, tasks, technologies, environments, and organizational conditions [4,9]. RIPCHORD-TWA [44,45] conceptualizes safety vulnerability as accumulating through interruptions, cognitive load, and degraded situation awareness. Human performance is central, not as individual blame, but as situated cognition embedded within complex environments [56].

These distinctions have important implications for patient safety research. An incident-centered framework will prioritize the identification of contributory factors, whereas a systems model will emphasize structural redesign, and a cognitive model will focus on workflow stability and resilience.

Nursing work is characterized by continuous monitoring, prioritization, and coordination. There is no framework that is inherently superior; however, its selection underscores the nature of the clinical activity under investigation. Therefore, framework selection in nursing patient safety research should be linked to the research question and the purpose of the study in order to strengthen comparability within the field.

#### *4.1. Limitations*

This conceptual review has several limitations. First, the literature search was limited to English-language peer-reviewed publications, which may have excluded relevant studies published in other languages. Second, only studies explicitly applying named HFE frameworks within nursing-related patient safety contexts were included, meaning that influential patient safety models not explicitly identified as HFE frameworks or not involving nurses may have been omitted.

#### *4.2. Implications for nursing practice*

The findings of this review have important implications for nursing practice, education, and research. Nurses constitute the largest professional group in healthcare and are continuously involved in patient monitoring, clinical decision-making, care coordination, and risk management. Therefore, selecting an appropriate human factor framework can improve the identification of safety risks, support workflow redesign, enhance communication within multidisciplinary teams, and strengthen organizational learning following adverse events.

From an educational perspective, nursing curricula should incorporate systems thinking and human factor principles to prepare future nurses to recognize interactions between people, technology, organizational structures, and clinical environments.

At the organizational level, nurse leaders may use systems-oriented frameworks such as the SEIPS to guide quality improvement initiatives, whereas incident-analysis frameworks such as the HFCF or the YCFF may better support root-cause investigations. Matching the framework to the clinical problem can facilitate more targeted patient safety interventions and contribute to a stronger culture of safety.

## 5. Conclusion

This conceptual review has demonstrated that differences of human factor frameworks primarily lie in the unit of analysis and conceptual understanding of human performance. Recognizing these distinctions is essential for selecting appropriate frameworks and for developing cumulative knowledge in patient safety. By clarifying the framework of safety models, nursing science can be aligned with the complex reality of clinical work and contribute to a more comprehensive understanding of safety in healthcare systems.

### Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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### Authors’ contributions

IK: Literature search, data collection, data analysis, and writing—original draft. CEV: Literature screening, data analysis, and writing—original draft. PS: Interpretation of findings, and writing—review and editing. MM: Conceptualization, supervision, methodology, validation, and writing—review and editing. All authors read and approved the final version of the manuscript.

### Conflict of interest

Maria Malliarou is the guest editors for special issue of AIMS Public Health and was not involved in the editorial review or the decision to publish this article. All authors declare that there are no competing interests.

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