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Systematic Review

The Effectiveness of Educational Interventions in Improving Waste Management Knowledge, Attitudes, and Practices among Healthcare Workers: A Systematic Review and Meta-Analysis

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Abstract: The healthcare sector represents a major source of waste production, and healthcare workers (HCWs) are crucial in waste management. Educational interventions (EIs) can be delivered through a single component (mono-component) or by combining different components (multi-component); although they have a potential impact on the sustainability of healthcare, their effectiveness in waste management still needs to be identified. The aim of this systematic review and meta-analysis was to describe EIs to improve waste management knowledge, attitudes, and practices among HCWs and provide an estimate of their effectiveness. Six relevant databases were searched; 24 articles were included, and 19 were meta-analyzed. These were mainly from low-income countries and did not consider EIs for recycling, reducing, and reusing. Compared to the mono-component EIs, the multi-component Eis showed a higher statistically significant positive post-intervention effect on knowledge, with greater retention in the medium–long term, and on practices, particularly among non-hands-on HCWs. The effects of the EIs on attitudes were not significant. Our results suggest that multi-component EIs should be preferred to improve waste management standards in the healthcare sector. Given the heterogeneity found among EIs, the standardization of types, content, duration, and assessment methods should be considered. Finally, their harmonization at a global level could influence international and national policies on sustainability.

Keywords: medical waste; education; interventions; healthcare workers; systematic review; meta-analysis

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1. Introduction

Waste management, which involves reusing, recycling, and reducing, has been recognized as a major pillar of sustainability [1–3]. Among the main waste producers, the healthcare sector is responsible for approximately 4 to 5% of the total global greenhouse gas emissions [1], and according to the United States Environmental Protection Agency, waste produced in the healthcare sector from human activities is the third largest source of pollution worldwide [4]. The World Health Organization (WHO) has defined healthcare waste as all waste generated within healthcare facilities, research centers, blood banks, and laboratories related to medical procedures. However, this term also refers to waste produced from other healthcare sources in the community, such as home care or long-term care (e.g., nursing homes), which contribute to the increase in global healthcare waste and are mostly unregulated [5]. Healthcare waste can be "hazardous", posing various environmental and public health risks, and includes infectious, sharp, chemical, cytotoxic,

pharmaceutical, radioactive, or pathological waste. However, 80% of healthcare waste is classified as "non-hazardous" or "general waste", making it completely assimilated to domestic waste [6]. Despite the increased attention being paid to waste management efforts to address the recommendations released to achieve sustainability, the waste volume has increased in recent years in response to the COVID-19 pandemic, exacerbating its impact on the environment [7].

Among the effects of inappropriate waste management, there is the exposure of healthcare workers (HCWs), waste handlers, and the general population to infection, toxicants, and injuries (e.g., needlestick injury). In addition, non-compliance with proper waste management can also cause the spread of a number of drug-resistant microorganisms in the environment, which can then penetrate into water springs and increase the level of pollution [8]. In contrast, it has been shown that proper waste disposal and recycling mitigates these risks and reduces the volume of waste in landfills or incinerators, thereby decreasing greenhouse gas emissions and air pollution [9]. Therefore, the implementation of waste management policies in the healthcare sector is a priority today more than ever. WHO and the United Nations Environment Program have emphasized the need to properly manage and dispose of healthcare waste and developed recommendations and strategies to reduce the impact of waste on public health and promote sustainability development [9,10].

It has been widely recognized that HCWs play a key role in waste management. In fact, they are the first actors to have an impact on the sustainability of healthcare systems, starting with wise waste management [11,12]. However, to embrace sustainability as a paradigm for action, it is necessary for HCWs to be educated starting from the undergraduate curricula and to continue being educated throughout their careers through education interventions [13]. In addition, they should be supported in developing awareness of the value of waste management in general and the connection that exists between its specific phases, as they depend on each other [14,15]. When they are adequately aware of these concepts, HCWs become more responsible for the waste they produce, support best environmental practices, and ensure good standards that contribute to the improvement and sustainability of the waste management system [5].

Although the WHO recommends conducting educational interventions aimed at promoting environmental awareness among health workers, suggesting the application of multi-component rather than mono-component educational interventions, a detailed summary of the contents included in these interventions has never been produced [5,16]. Furthermore, the effectiveness of multi-component and mono-component educational interventions in improving waste management has never been examined, and an analysis of their effectiveness among different groups of HCWs or in terms of retention of the education received has not been conducted. The identification of the most effective educational interventions could have an impact on the sustainability of healthcare systems by targeting these interventions to the existing context and population, rationalizing available resources.

Previous literature reviews have focused mainly on healthcare waste management methods and practices [17–19], occasionally providing an overview of different global approaches, programs, or regulations for waste collection and disposal [14,20–22]. Other authors have analyzed the practices adopted in response to the COVID-19 pandemic and their impact on public health and the environment [8,23], identifying few feasible and sustainable strategies, a lack of strict regulation and legislation, and inadequate knowledge and awareness of this topic among stakeholders. In this regard, Caniato et al. provided a geographical analysis of the level of awareness possessed by HCWs in terms of knowledge about waste management and training [14]. Similarly, Yazie et al., in their systematic review, highlighted unfavorable attitudes of HCWs, poor managerial commitment, and lack of awareness and training as potential challenges to waste management [24]. Finally, Cutter and Gammon showed that safe waste handling and management are compromised due to poor compliance with standard precautions [25].

A widely recognized method for investigating health-related behaviors, changes in such behaviors over time, and the effectiveness of policy or educational interventions is

using a knowledge, attitudes, and practices (KAP) survey [26]. A KAP survey study is intended to be representative of a specific population and aims to evaluate what is known, believed, and done in a defined context about a topic of interest [27,28]. The information collected through KAP questionnaires can help identify gaps in the three domains of knowledge, attitudes, and practices, which can enhance our understanding of a specific problem, facilitating us to take actions to address it [28].

Despite the clear need to identify effective educational interventions to improve knowledge, attitudes, and practices regarding healthcare waste management, only Ashtari et al. performed a systematic review and meta-analysis of the characteristics and results of interventions in this field in 2020. They included educational interventions, which were principally based on the KAP method, and managerial interventions that focused more on changing waste management policies and processes and developing guidelines for HCWs. They found that these interventions were effective in reducing the amount of waste produced, reducing waste management costs, and improving overall performance in terms of waste management [29]. However, a deeper investigation on the content of the educational interventions, an evaluation of the efficacy of multi-component and mono-component interventions, as well as an evaluation of their effectiveness in different groups of HCWs and retention rates are still needed.

Thus, the aim of this systematic review and meta-analysis is to describe educational interventions to improve waste management knowledge, attitudes, and practices among healthcare workers and provide an estimate of their effectiveness.

2. Materials and Methods

2.1. Design

A systematic literature review (intended to be a comprehensive synthesis of the existing literature) with a meta-analysis (intended to be used as a statistical technique to combine the results of primary studies to obtain cumulative evidence) was conducted in accordance with the updated Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria [30]. These consist of a series of reporting recommendations reflecting the methods of identification, selection, evaluation, and evidence synthesis. The protocol for this review was registered in the PROSPERO register of systematic reviews (registration number CRD42023424627).

2.2. Search Strategy

A researcher and an expert librarian (AC, BM) conceived and carried out all searches of the literature. Exploratory searches in PubMed and CINAHL EBSCO were initially conducted in June 2022 to create a comprehensive search strategy and identify the most appropriate keywords for review. Subsequently, a comprehensive search of six databases (PubMed, CINAHL EBSCO, Scopus, EMBASE, Web of Science, and the Cochrane Library) was performed from their inception to September 2022. The search strings were tailored for each database and both a thesaurus and free terms were used (Supplementary Material—Table S1) without applying any temporal or language limit. These strings included terms related to the phenomenon of interest (i.e., the environmental field), such as "healthcare waste or waste disposal"; the educational interventions, such as "training, teaching, or course"; and the population of interest, with terms such as "health personnel, healthcare". Finally, the reference lists of the included articles were manually searched to identify additional relevant publications. Furthermore, the PROSPERO register of systematic reviews was scanned to identify ongoing or recently completed reviews.

2.3. Eligibility Criteria

Studies evaluating educational interventions to improve waste management knowledge, attitudes, and practices (i.e., randomized controlled clinical trials, clinical trials, Pre–post studies, case–control studies, retrospective studies, and clinical audits) were included. The inclusion criteria were that they had to be original, written in English or Italian, and published in peer-reviewed journals. To be included in the systematic review,

studies had to be conducted on healthcare workers (e.g., physicians, nurses, technicians, paramedics, or environmental workers) without any restriction in terms of setting (e.g., hospital, outpatient services, or home care). Interventions in the included articles could be conducted through a single educational component (mono-component, e.g., lessons, workshops, or practical training) or through a multi-component approach (combining lessons/workshops, practical training, and educational materials/practical changes to waste disposal methods) provided by HCWs or other specialists in the field of waste management. Conference proceedings, theses, letters to the editor, and all the grey literature were excluded.

2.4. Article Screening and Study Selection

After the removal of duplicates from the records retrieved through the searches of the literature, two researchers (AC and CP) independently screened the titles and abstracts against the eligibility criteria. Subsequently, full-text assessments of potentially relevant articles were performed, and a decision on their inclusion was made. Any disagreement regarding the eligibility of the articles was resolved by achieving an agreement with a third researcher (EV). Articles for which the full texts could not be found online or could not be accessed upon request to the journal in which they were published or to the corresponding author were excluded.

2.5. Quality Appraisal

Two researchers (AC and CP) independently assessed the methodological quality of the selected studies using the quality assessment tool for quantitative studies developed by the Effective Public Health Practice Project (EPHPP) [31,32]. This eight-item instrument was developed by the Evidence-Based Practice Centre at McMaster University for evaluating the methodological quality of different types of intervention studies, including case–control studies, pre–post studies, and randomized controlled clinical trials. This instrument covers eight domains: (1) selection bias; (2) study design; (3) confounders; (4) blinding; (5) data collection method; (6) withdrawals/dropouts; (7) intervention integrity; and (8) analysis. Each domain could be assessed as weak, moderate, or strong. Only the first six domains contribute to the global rating of the study's methodology, which can be categorized as weak, moderate, or strong. If none of the domains receives a weak rating, the overall rating of the study is strong; a moderate overall rating is assigned if one domain is assessed as weak; and if two or more domains are assessed as weak, the overall study rating is weak. The EPHPP tool has shown content and construct validity and has been deemed appropriate for its use in systematic reviews of effectiveness [31,33]. Moreover, the EPHPP tool showed better inter-rater reliability compared to that of the Cochrane Collaboration Risk of Bias [32].

2.6. Data Extraction

A data collection form, adapted on an Excel spreadsheet, was used to extract data about the study characteristics (author, country, and year), study design, type of setting (hospital or primary care), sample size, type of HCWs included (physicians, nurses, technicians, pharmacists, or environmental workers), description of the intervention (delivery mode, duration, and time of assessment), assessment tool or method used (e.g., direct observations), and quantitative results (i.e., frequencies of correct answers and means/medians with standard deviations/ranges) for the knowledge, attitudes, and practices domains. Data were extracted by two independent researchers (CP and EV) and verified by a third researcher (AC).

The data to be reported in each of the three KAP domains were extracted as classified by the authors if they adopted these categories, or as categorized by two independent researchers (AC and EV). Any disagreement in the categorization was discussed with a third researcher (CP).

2.7. Interventions and Assessment Methods

Educational interventions were classified as mono-components if they comprised a single component or as multi-component if two or more components were combined. The components of educational interventions were classified by two independent researchers (AC and EV) as follows: (i) lessons (theoretical transfer of information during classes or lectures, including informational workshops or newsletters); (ii) audits (inspection of the current waste management processes performed for quality improvement in a specific context); (iii) training (practical experiences through simulation or scenarios, implying hands-on demonstrations or games); (iv) system change (major reorganization of the context in terms of waste allocation and treatment); (v) reminders (educational support tools used to reinforce the adoption of practices); and (vi) technology (technological support and virtual reality simulation used in the delivery of education).

Assessment methods were classified by two independent researchers (AC and EV) as self-reported (if HCWs completed a questionnaire themselves), observed (if an evaluation was recorded by an external observer), or mixed (if self-reported and observed methods were combined). Furthermore, HCWs were classified as "hands-on" (nurses, physicians, and HCWs in general), "non-hands-on" (laboratory technicians, pharmacists, and environmental services) or "mixed" (when the effectiveness was not described per a single HCW category but in an aggregated form).

A third researcher (RIC) verified and confirmed the proper classification of educational components, assessment methods, and HCW categories.

2.8. Data Synthesis and Statistical Analysis

The primary outcome of this review is the assessment of the effectiveness of educational interventions in improving the waste management knowledge, attitudes, and practices of HCWs. Study results expressed as absolute and relative frequencies could be included in the meta-analyses. If a study reported results as continuous effectiveness measures (such as mean scores from an assessment tool), these were only included in the meta-analytical process if the assessment tool used was the same (or if the measures were comparable). Otherwise, such results were only included in the narrative synthesis.

The overall prevalence ratio (PR) for the comparison between post-intervention timing and pre-intervention timing was estimated using both the fixed-effects model and the random-effects model proposed by DerSimonian and Laird [34]. Both 95% confidence intervals (CIs) and 95% prediction intervals [35] were estimated. When significant heterogeneity was found, the results from the random-effects model were presented. The heterogeneity between study-specific estimates was measured with the I^2 statistic [36]. Statistical significance level was set at a p value < 0.05.

Subgroup analyses were performed to assess the effects of different educational intervention types (mono-component and multi-component), types of HCWs (hands-on and non-hands-on), and time of assessment (short term and medium–long term) on post-intervention waste management knowledge, attitude, and practice rates. Sensitivity analyses were performed using the leave-one-out technique to control between-study heterogeneity [37]. Both subgroup analyses and sensitivity analyses were carried out if there were at least three studies per category/domain explored. Therefore, a subgroup analysis based on quality rating was not performed. The presence of publication bias and small study effects were assessed through a visual inspection of the funnel plots and Egger's test [38].

Analyses were performed using the statistical program R with metafor and meta packages [37,39]. We performed a systematic narrative synthesis to present available data for all studies that could not be included in the meta-analyses.

3. Results

3.1. Articles Included

The search strategy produced 839 records. After the removal of 294 duplicates, 545 titles and abstracts were screened. Among these, 35 full-text articles were read, and 11 did not

meet the inclusion criteria and were excluded (Supplementary Material—Table S2). No further relevant studies were identified after examining the reference lists of the included articles. At the end of the screening process (Figure 1), 24 articles were included in the systematic review, and 19 of them were meta-analyzed.

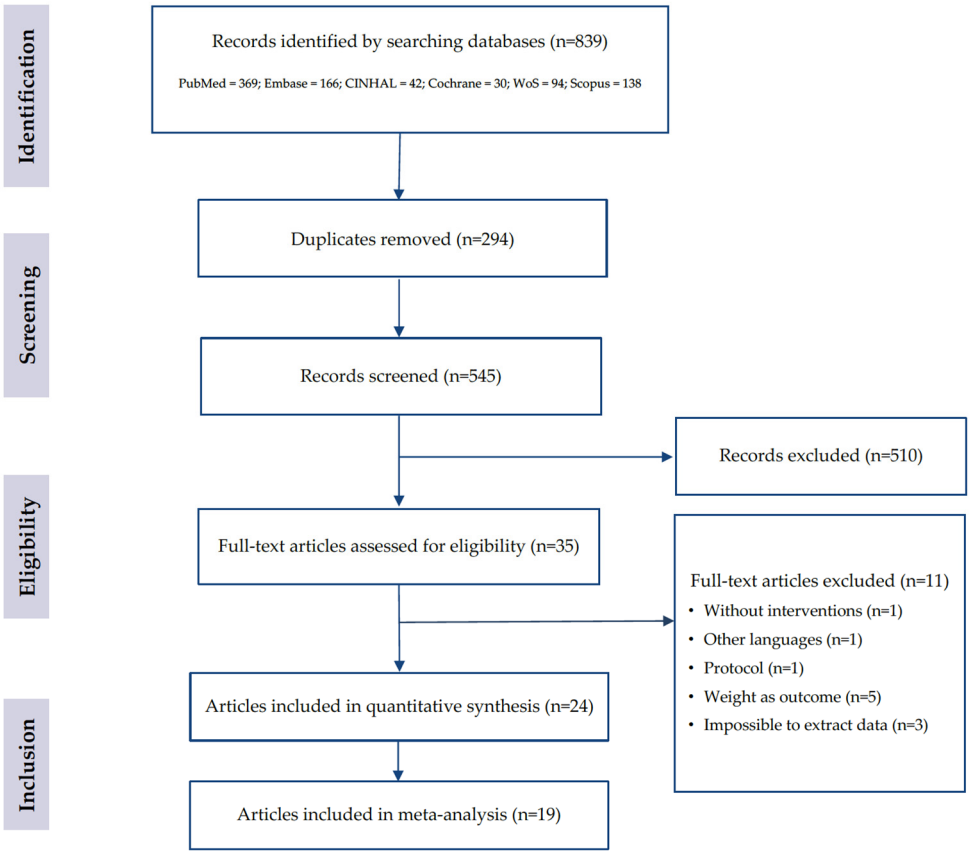

Figure 1. A flow chart depicting the search of the literature.

3.2. Characteristics of Studies Included

The included articles were published from 2009 to 2022. Fifteen studies were conducted in Asia, three in Africa, two in the Middle East, two in North America, and one each in Europe and Central America. Eighteen studies applied a pre–post design, four were case–control studies, one was a retrospective study, and one described the results obtained from a clinical audit cycle. Almost all studies (n = 20) were conducted in a hospital setting, with only one being conducted in a primary care setting, while three were carried out in a mixed setting (both in hospital and in primary care settings). A total of 4657 HCWs (range of 20–1083) were included, with studies including mixed HCW populations as the most represented (Table 1).

Table 1. A summary of the selected articles.

Author(s) (Country, Year) Quality	Study Design	Setting (s)	Participants (*n*)	Intervention (Duration/Time of Assessment)	Assessment Tool or Method (Self-Reported/Observed)	Main Results
Abdo et al. [40] (Kuwait, 2019) Moderate	Pre–post	Tertiary Hospital	Environmental workers (n = 102)	Multi-component (Lessons, training, and reminders) 3 days/3 months	Ad hoc KAP questionnaire Structured checklist (Self-reported and observed)	Improvement in all aspects of KAP regarding infectious and sharps wastes after intervention ($p < 0.01$)
Ahmed et al. [41] (India, 2018) Moderate	Pre–post	Tertiary Hospital	Healthcare workers (n = 100)	Mono-component (Lessons) 1 day/immediate	Ad hoc KAP questionnaire (Self-reported)	Significant improvement in waste management after intervention; BMW disposal improvement was particularly highly significant ($p < 0.001$)
Ara et al. [42] (Bangladesh, 2015) Weak	Pre–post	Community Hospital	Nurses (n = 96)	Multi-component (Lessons and training) Not reported	Ad hoc KAP questionnaire Structured checklist (Self-reported and observed)	Compliance to waste segregation improved significantly after intervention ($p < 0.001$)
Ara et al. [43] (Bangladesh, 2022) Weak	Pre–post	Tertiary Hospital (n = 4) Community Hospital (n = 3) Primary Hospital (n = 2)	Healthcare workers Environmental workers (not reported)	Multi-component (Lessons, training, and system change) 6 months/3 months	Structured checklist (Observed)	Significant improvement in waste segregation, use of PPE during waste transportation, compliance with standardized methods for collection, transportation, and disposal ($p < 0.001$)
El-Gilany et al. [44] (Egypt, 2017) Strong	Pre–post	Tertiary Hospital	Laboratory technicians (n = 20)	Mono-component (Lessons) 3 days/2 months	Ad hoc KAP questionnaire (Self-reported)	Significant improvements in knowledge ($p = 0.01$), attitudes ($p = 0.013$), and practices regarding waste management ($p = 0.01$)
Elnour et al. [45] (Sudan, 2015) Strong	Pre–post	Tertiary Hospital (n = 3)	Nurses Environmental workers (n = 100)	Mono-component (Lessons) (15 days/immediate and at 3 months)	Ad hoc KAP questionnaire (Self-reported)	Moderate improvement in knowledge of waste management in immediate post-test period and at three months Scarce improvement in waste management practices in immediate post-test period after intervention, and moderate improvement at three months

Table 1. *Cont.*

Author(s) (Country, Year) Quality	Study Design	Setting (s)	Participants (*n*)	Intervention (Duration/Time of Assessment)	Assessment Tool or Method (Self-Reported/Observed)	Main Results
Fraifeld et al. [46]. (USA, 2021) Weak	Pre–post	Tertiary Hospital	Anesthesia staff (n = 172)	Multi-component (Lessons and system change) (15 min/6 weeks)	Previously used KAP questionnaire Weight of segregated waste (Self-reported and observed)	Significant increase in overall knowledge of waste management ($p < 0.001$), particularly in vial disposal, medication disposal, and sharps disposal ($p < 0.05$); significant decrease in overall weight of regulated healthcare waste ($p < 0.001$)
Hosny et al. [47] (Egypt, 2018) Moderate	Pre–post	Tertiary Hospital	Environmental workers (n = 365)	Mono-component (Lessons) (Not reported)	Ad hoc KAP questionnaire Structured checklist (Self-reported and observed)	Significant increase in knowledge was detected ($p < 0.001$), except for items related to necessity to segregate healthcare waste, color coding system, disposal of general waste, and disposal of infectious waste; significant increase in waste management practices ($p < 0.001$)
Jarvis et al. [48] (USA, 2009) Weak	Pre–post	Mixed (Hospitals and Primary Care)	Pharmacists (n = 158)	Mono-component (Lessons) (1 newsletter/3 months)	Ad hoc KAP questionnaire (Self-reported)	Significant improvement in perception of environmental problems connected to inappropriate medication disposal ($p = 0.03$) and methods of correct disposal ($p < 0.01$)
Johnson et al. [49] (El Salvador, 2013) Moderate	Pre–post	Tertiary Hospital	Healthcare workers Environmental workers (n = 86)	Mono-component (Lessons) (20 min/1 year)	Ad hoc KAP questionnaire Weight of infectious waste (Self-reported and observed)	Significant improvement in knowledge of waste management ($p = 0.012$) and significant reduction in infectious waste disposal ($p < 0.001$)
Joseph et al. [50] (India, 2015) Moderate	Pre–post	Tertiary Hospital	Healthcare workers (n = 90)	Mono-component (Audits) (2 months/3 years)	Structured questions (Self-reported and observed)	Improvement in segregation of cytotoxic drugs ($p < 0.05$), sharps, infectious plastic, and use of color bags for healthcare waste segregation
Krishnan et al. [51] (India, 2015) Moderate	Pre–post	Mixed (Hospitals and Primary Care)	Healthcare workers (n = 1083)	Multi-component (Lessons and training) (Not reported/immediate)	Ad hoc KAP questionnaire (Self-reported)	Significant improvement in knowledge of waste management for all participants ($p < 0.001$)

Table 1. *Cont.*

Author(s) (Country, Year) Quality	Study Design	Setting (s)	Participants (*n*)	Intervention (Duration/Time of Assessment)	Assessment Tool or Method (Self-Reported/Observed)	Main Results
Kumar et al. [52] (Pakistan, 2015) Strong	Case-control	Tertiary Hospital	Healthcare workers Environmental workers (n = 138)	Multi-component (Lessons, training, and reminders) (3 months/3 months)	Modified WHO tool (Self-reported)	Significant improvement in knowledge, attitudes, and practices ($p < 0.01$) in both healthcare and environmental workers
Kumar et al. [53] (Pakistan, 2016a) Weak	Case-control	Tertiary Hospital	Healthcare workers Environmental workers (n = 127)	Multi-component (Lessons, training, and reminders) 3 months/ 3 and 18 months)	Modified WHO tool (Self-reported)	Significant differences in knowledge, attitudes, and practices after 18 months compared to baseline ($p < 0.001$); these were retained over time by both healthcare and environmental workers
Kumar et al. [54] (Pakistan, 2016b) Moderate	Case-control	Tertiary Hospital	Physicians Nurses and paramedics (n = 222)	Multi-component (Lessons, training, and reminders) (3 months/ 3 and 18 months)	Modified WHO tool (Self-reported)	Nurses and paramedics showed better knowledge and practices compared to physicians; they retained higher level of knowledge than physicians, who achieved and retained positive attitudes towards waste management after intervention
Ozder et al. [55] (Turkey, 2013) Moderate	Pre–post	Mixed (Hospitals and Primary Care)	Healthcare managers (n = 240)	Multi-component (Lessons and training) (3 days/not reported)	Ad hoc KAP questionnaire (Self-reported)	Significant differences were found among managers who received healthcare waste management training and those who had not ($p < 0.01$); knowledge of managers who received healthcare waste management training improved significantly after intervention ($p < 0.001$)
Robat et al. [56] (Iran, 2022) Strong	Case-control	Tertiary Hospital	Healthcare workers Environmental workers (n = 128)	Multi-component (Lessons and training) (2 months/3 months)	Ad hoc KAP questionnaire (Self-reported)	Significant changes were shown in knowledge, attitudes, self-efficacy, beliefs, and motivation ($p < 0.001$); specifically, behavioral intentions toward waste management improved ($p = 0.001$)
Rohilla et al. [57] (India, 2021) Moderate	Retrospective	Tertiary Hospital	Healthcare workers (n = 450)	Multi-component (Lessons and training) (3 h/immediate)	Modified WHO tool Structured checklist (Self-reported and observed)	Significant increase in cognitive domain score from pre-test to post-test periods ($p < 0.05$) Overall change in psychomotor domains for all healthcare workers involved in intervention ($p < 0.05$)

Table 1. *Cont.*

Author(s) (Country, Year) Quality	Study Design	Setting (s)	Participants (*n*)	Intervention (Duration/Time of Assessment)	Assessment Tool or Method (Self-Reported/Observed)	Main Results
Sapkota et al. [58] (Nepal, 2014) Strong	Pre–post	Tertiary Hospital	Healthcare workers Environmental workers (n = 40)	Multi-component (Lessons, training, system change, and reminders) (Not reported/8 months)	Individualized Rapid assessment tool (Self-reported and observed)	Significant improvement from 26% pre-test to 86% post-test regarding waste management practices evaluation score
Shaheen et al. [59] (Pakistan, 2020) Moderate	Pre–post	Tertiary Hospital	Nurses (n = 64)	Multi-component (Lessons and training) (3 days/1 month)	Ad hoc KAP questionnaire Structured checklist (Self-reported and observed)	Significant improvement in knowledge (p = 0.001) after intervention; one month after training sessions, practices showed significant improvement (p < 0.001)
Singh et al. [60] (India, 2020) Weak	Pre–post	Tertiary Hospital	Nurses Laboratory technicians (n = 250)	Multi-component (Lessons and training) (1 day/immediate)	Ad hoc KAP questionnaire (Self-reported)	Significant improvement in knowledge about healthcare waste management and handling (p < 0.001) after intervention
Tabash et al. [61] (Palestine, 2016) Moderate	Pre–post	Tertiary Hospital (n = 5)	Healthcare workers Environmental workers (n = 530)	Multi-component (Lessons and training) (3 h/immediate and at 6 months)	Ad hoc KAP questionnaire (Self-reported)	Significant improvement in knowledge, attitudes, and practices of staff regarding pharmaceutical waste management (p < 0.001)
Tabrizi et al. [62] (Iran, 2019) Strong	Clinical audit cycle	Primary Care Community Health Centers (n = 87)	Healthcare workers Environmental workers (not reported)	Multi-component (Audits, system change, and reminders) (1 year/4 months)	Adherence of existing status with standards (Observed)	Adherence to healthcare waste management standards experienced 30% improvement after interventions; greatest improvements were for waste management, education, and separation and collection of healthcare waste, increasing from 28 to 30%
Wu et al. [63] (Taiwan, 2021) Moderate	Pre–post	Tertiary Hospital	Physicians Laboratory technicians (n = 96)	Mono-component (Technology) (1 day/immediate)	Accuracy rate and time to complete the scenario (Self-reported and observed)	Significant improvement in accuracy as well as shorter time to complete scenario among junior physicians and male trainees compared to junior laboratory technicians

3.3. Types of Educational Interventions to Improve Waste Management among HCWs

3.3.1. Mono-Component Educational Interventions

The use of mono-component educational interventions to improve waste management among HCWs has been addressed in eight articles [41,44,45,47–50,63]. These interventions lasted from 20 min to 2 months (Table 1) and were provided by the department of community medicine [41], infection nurses, or the quality management team [50]. The assessment of the interventions was performed immediately in three cases [41,45,63], whereas three studies applied a two- or three-month period to assess the efficacy of the educational interventions [44,45,48]. In two cases, the evaluation occurred after one year and three years post-intervention [49,50].

Lessons

Six studies used lessons to improve waste management among HCWs [41,44,45,47–49]. These educational interventions were provided mainly through lectures using PowerPoint presentations, videos, and discussions [44,47,49]. A study used a flipchart in addition to PowerPoint presentations to conduct lectures with small groups of HCWs [49], while the one that introduced a newsletter used a reminder that was sent after ten days to promote participation [48]. The content of the lessons primarily consisted of waste type classification, safety hazards, environmental/occupational risks, correct waste disposal, and roles and responsibilities in waste management [41,44,45,47–49]. The educational programs were pre-developed [45] or based on local regulations and the WHO guidelines [49].

Audits

A study conducted a series of audits over a two-month period on HCWs' awareness about waste management practices and related risks in an Indian tertiary hospital. The practices of healthcare waste segregation were assessed in 145 areas, and the obtained results were subsequently presented and used to increase the awareness of HCWs. The same areas were re-audited after three years using the same tools [50].

Technology

A study conducted in Taiwan used a virtual reality simulated environment. The participants were asked to correctly dispose of 10 randomly appearing healthcare waste items, which were hazardous, contaminated, or infectious. The accuracy and completion time were collected to provide real-time feedback to each HCW [63].

3.3.2. Multi-Component Educational Interventions

Sixteen articles assessed the effectiveness of multi-component educational interventions [40,42,43,46,51–62], which had durations ranging from 15 min to 1 year (Table 1). Experienced instructors, physicians, or nurses; the department of microbiology and infection control; and the company responsible for waste management delivered the interventions [43,46,55,57]. The effectiveness of multi-component educational interventions was evaluated immediately in four studies [51,57,60,61], in a period of less than two months in two studies [46,59], and after three months in four studies [40,43,52,56], while a long-term assessment (from four to 18 months) was reported in five articles [53,54,58,61,62].

Lessons and Training

The effectiveness of these educational interventions was reported in eight articles [42,51,55–57,59–61]. Lessons were conducted by combining different methodologies, such as lectures, open discussions, and focus groups delivered in person [42,51,56,57,59–61] and, in one case, remotely [55]. In two cases, up to 40–50 participants were included in the single activity [55,60], while the duration of the lessons was reported by three articles and ranged from 90 min to 3 hours [56,57,61]. Practical training was generally delivered after the theoretical lessons in the form of hands-on demonstrations or games [42,51,56,57,59,61]. In one case, the interven-

tion was tailored to the educational needs of the participants identified with the pre-intervention test [61]. The delivered contents covered waste classification, segregation, collection, storage, transportation, treatment, disposal, and awareness of potential risks derived from healthcare waste [42,59,61]. Local regulations and the WHO recommendations were used to design the interventions [55,59].

Lessons/Audits and System Change

Two studies described this combination of educational interventions [46,62]. Lessons were conducted as professional workshops or lectures, which were facilitated through the use of PowerPoint presentations, booklets, and posters. In one case, the theoretical session lasted 15 min and focused on waste segregation [46]. System change interventions consisted of the replacement of sharp containers with smaller containers, the introduction of pharmaceutical waste containers [46], and the provision of specific bins for infectious and non-infectious waste [62].

Lessons, Training, and Reminders

In four cases, reminders were added to reinforce educational interventions [40,52–54]. Theoretical sessions were provided for 6 [40] and 18 h [52–54] across three sessions in both cases. PowerPoint presentations were followed by role-playing demonstrations in one study. The lesson topics were based on the WHO guidelines that cover information on the classification, segregation, storage, transport, and disposal of infectious and sharps wastes. In both cases, practical training was conducted with hands-on sessions in the study areas and the use of personal protective equipment to simulate waste management practices. Reminders comprised posters placed in patient rooms or common areas and weekly follow-up meetings provided after the intervention.

Lessons, Training, System Change, and Reminders

Two articles presented a combination of these educational components [43,58]. The lessons were provided using theoretical and video content developed on WHO recommendations, and they focused on the segregation, collection, and handling of different categories of waste [58]. In addition, occupational safety and the use and disposal of protective personal equipment were included in the educational intervention [43]. Practical training was provided to hands-on HCWs after the theoretical lessons, whereas system changes such as replacements of existing bins with color-specific ones were implemented [43,58]. Reminders were provided through posters placed in the common areas and specifically designed leaflets for HCWs and patients [43,58]. In one study, continuous monitoring and feedback were provided by the infection control committee [43].

3.4. Assessment of Educational Interventions to Improve Waste Management among HCWs

The effectiveness of educational interventions has been mainly evaluated (n = 12 articles) through self-reported measures [41,44,45,48,51–56,60,61] and by using both self-reported measures (n = 10 articles) and structured observations of participants [40,42,46,47,49,50,57–59,63]. In two studies, the researchers only used structured observations to assess the adherence of participants to the waste management recommendations [43,62].

Most of the included studies (n = 9) used ad hoc questionnaires that were designed according to the KAP model to assess the effectiveness of the educational interventions [41,44,45,48,51,55,56,60,61]. In four cases, such questionnaires were used in combination with structured checklists to objectively assess the practices of the participants [40,42,47,59], while in two studies, questionnaires were combined with a weight measurement of segregated waste [46,49]. In three articles, researchers modified a pre-designed WHO tool [52–54]; in one case, it was corroborated by a structured checklist [57]. In two articles, the practices of the participants were exclusively evaluated through the application of a structured checklist [43] or by measuring their adherence to the expected standards [62]. In one case, the researchers used a set of structured

questions on waste segregation awareness [50]; in another study, a rapid assessment tool was developed [58]; and in the study adopting virtual reality, the accuracy rate and the time taken for completion were assessed [63].

The mainly assessed domains were knowledge and practices (19 articles evaluated each domain), while attitudes were only explored by eight studies. Finally, 13 studies assessing practices, 10 assessing knowledge, and 4 assessing attitudes were included in the meta-analysis.

3.5. Study Quality

The quality appraisal scores obtained for each included study were uniformly distributed (Supplementary Material—Table S3): six articles achieved a strong level of quality (three included in the meta-analysis), twelve studies were assessed to be of moderate quality (eight included in the meta-analysis), and six articles were of low quality (four included in the meta-analysis). The most critical scores were those assigned to the item related to the data collection method.

3.6. Efficacy of Educational Interventions to Improve Waste Management among HCWs

3.6.1. Efficacy of Educational Interventions in Improving Knowledge among HCWs

Figure 2 shows the effects of mono- and multi-component educational interventions on HCWs' knowledge. Multi-component interventions are associated with a higher statistically significant positive post-intervention effect (PR = 2.14; 95% CI 1.54–2.98) on the knowledge of HCWs regarding waste management compared to mono-component ones (PR = 1.32; 95% CI 1.19–1.47). The group of HCWs showing a higher statistically significant effect (Supplementary Material—Figure S1) was the "hands-on" one (PR = 1.71; 95% CI 1.39–2.12), followed by the "non-hands-on" group (PR = 1.45; 95% CI 1.31–1.61) and mixed HCWs group (PR = 1.21; 95% CI 1.01–1.46).

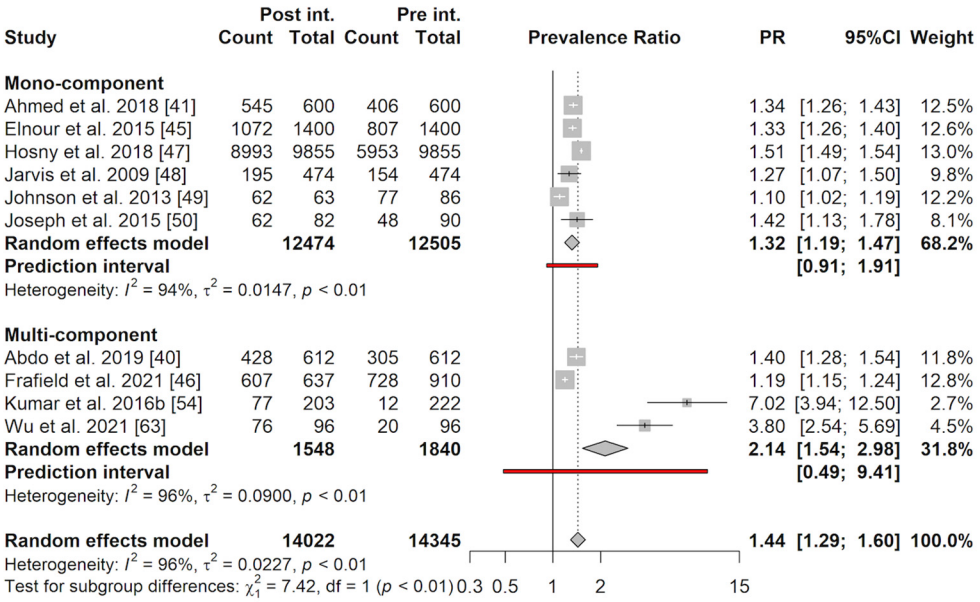

Figure 2. The forest plot of the subgroup meta-analysis for the effectiveness of mono-component and multi-component educational interventions in the knowledge domain. PR = prevalence ratio; CI = confidence interval. Squares represent each study PR estimate while diamonds represent the pooled PR estimate (for each subgroup and overall). Sidebars represent estimates' confidence intervals [40,41,45–50,54,63].

Considering the assessment time after the educational interventions (Figure 3), the retention of knowledge among HCWs was greater in the medium–long term (PR = 2.02;

95% CI 1.09–3.72) compared to short term (PR = 1.49; 95% CI 1.31–1.68), and both were statistically significant.

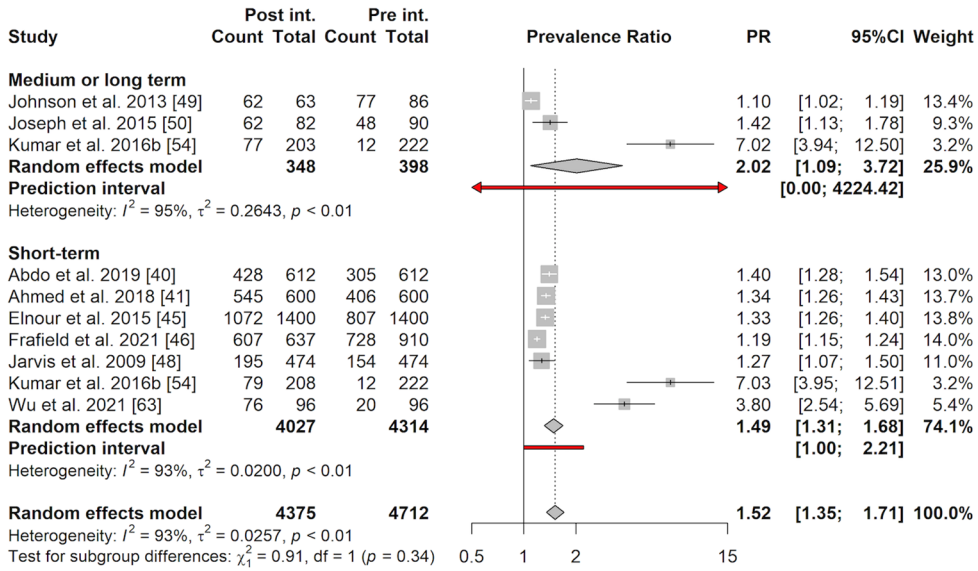

Figure 3. The forest plot of the subgroup meta-analysis for the effectiveness of medium- or long-term and short-term educational interventions in the knowledge domain. PR = prevalence ratio. Squares represent each study PR estimate while diamonds represent the pooled PR estimate (for each subgroup and overall). Sidebars represent estimates' confidence intervals [40,41,45,46,48–50,54,63].

The nine articles that were not included in the meta-analysis showed increased mean values of knowledge, which were assessed after the intervention. With the exception of one, all articles delivered multi-component interventions. The largest mean difference obtained in the post-intervention period (41; SD ± 21 vs. 77; SD ± 11) was achieved with medium–long-term interventions.

3.6.2. Efficacy of Educational Interventions in Improving Practices among HCWs

Figure 4 presents the effects of mono- and multi-component educational interventions on the practices of HCWs. Implementing multi-component interventions produced a higher statistically significant post-intervention effect (PR = 3.84; 95% CI 1.63–9.04) compared to when mono-component ones were implemented (PR = 1.72; 95% CI 0.91–3.27). The non-hands-on HCWs showed the highest effect (PR = 2.55; 95% CI 1.19–5.48), followed by the hands-on HCWs (PR = 2.06; 95% CI 1.29–3.28). The efficacy of the interventions in the mixed HCW populations was not significant (PR = 4.47; 95% CI 0.70–28.43) (Supplementary Material—Figure S2).

The retention of waste management practices among HCWs changed significantly after the introduction of educational interventions (Figure 5) and was greater in the short term (PR = 2.55; 95% CI 1.16–5.60) compared to the medium–long term (PR = 1.66; 95% CI 0.82–3.36), but this result was not significant.

The six articles that were not included in the meta-analysis showed increases in the mean values of the post-intervention practices among HCWs. Of these, five articles delivered multi-component educational interventions. The largest mean difference was obtained in the post-intervention practices of the mixed HCW group (34.3; SD ± 26 vs. 78.3; SD ± 30) and was achieved in the medium–long term.

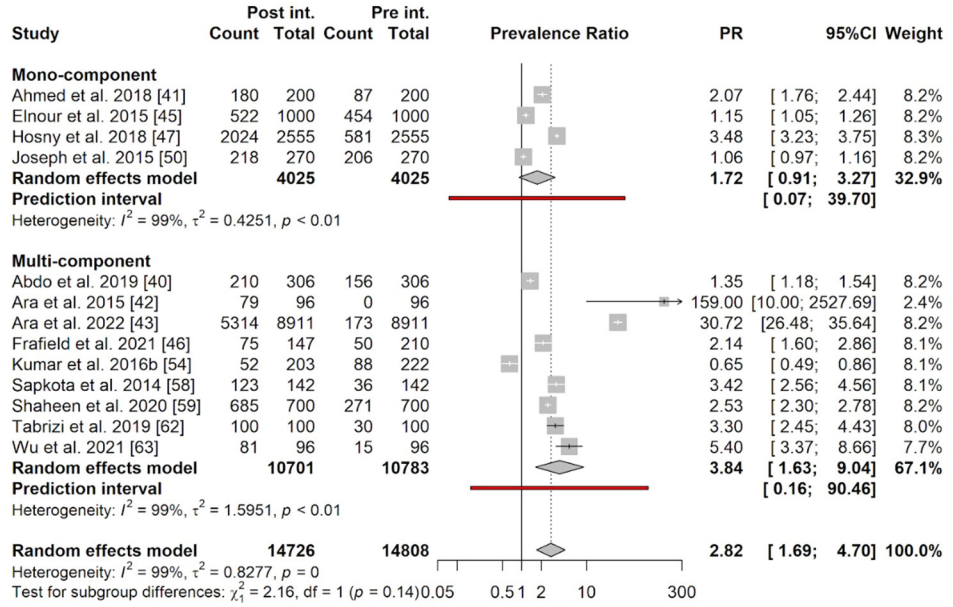

Figure 4. The forest plot of the subgroup meta-analysis for the effectiveness of mono-component and multi-component educational interventions in the practices domain. PR = prevalence ratio. Squares represent each study PR estimate while diamonds represent the pooled PR estimate (for each subgroup and overall). Sidebars represent estimates' confidence intervals [40–43,45–47,50,54,58,59,62,63].

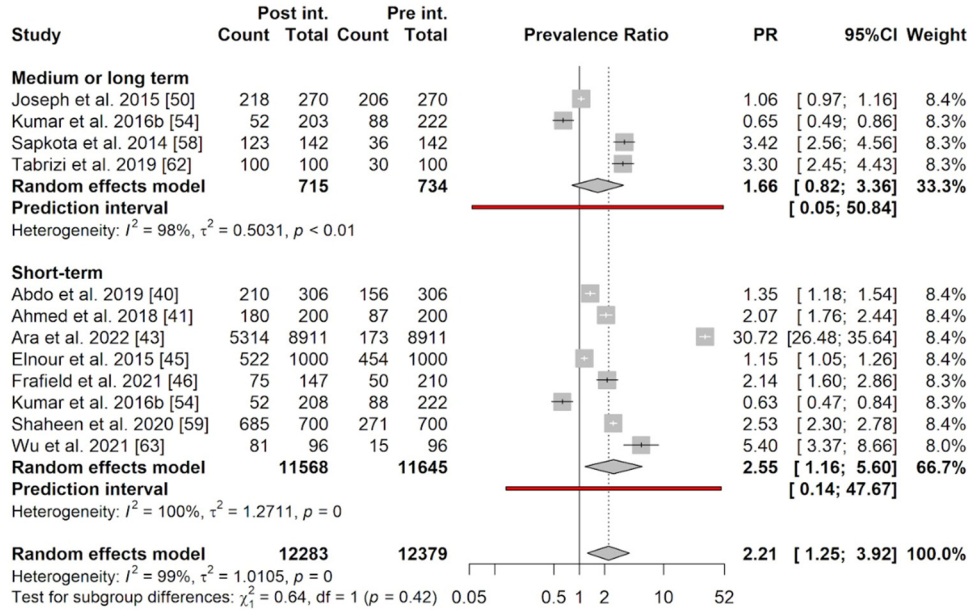

Figure 5. The forest plot of the subgroup meta-analysis for the effectiveness of medium- or long-term and short-term educational interventions in the practices domain. PR = prevalence ratio. Squares represent each study PR estimate while diamonds represent the pooled PR estimate (for each subgroup and overall). Sidebars represent estimates' confidence intervals [40,41,43,45,46,50,54,58,59,62,63].

3.6.3. Efficacy of Educational Interventions in Improving Attitudes among HCWs

Overall, the effects of mono- and multi-component educational interventions on the attitudes of the HCWs were not significant (Supplementary Material—Figure S3). Only one study assessed the efficacy of mono-component interventions in improving the attitudes of the HCWs, while the multi-component interventions showed a PR of 0.99 (95% CI 0.77–1.27). These interventions seemed to have a statistically significant higher effect on non-hands-on HCWs (PR = 1.25; 95% CI 1.08–1.45) compared to hands-on ones (PR = 0.85;

95% CI 0.55–1.29) (Supplementary Material—Figure S4). Considering the assessment time (Supplementary Material—Figure S5), the retention of attitudes among HCWs was not effective in the short term (PR = 1.02; 95% CI 0.83–1.25) and worsened significantly in the medium–long term (PR = 0.68; 95% CI 0.55–0.84).

The four articles not included in the meta-analysis showed that the educational interventions had a minor effect on increasing the mean values of the attitudes assessed post-intervention. Three articles implemented multi-component interventions, with the largest mean difference being observed in the post-intervention period in a mixed population of HCWs (27.4; SD ± 7.6 vs. 34.1; SD ± 4.2).

3.7. Publication Bias and Sensitivity Analyses

The results of Egger's test (Supplementary Material—Table S4) highlight the absence of publication bias for knowledge ($p = 0.711$), attitudes ($p = 0.944$), and practices ($p = 0.639$). This was also confirmed through a visual inspection of the funnel plots (Supplementary Material—Figure S6).

The leave-one-out sensitivity analysis did not modify the main findings presented, neither for knowledge nor practice ($p < 0.01$). If the attitude domain is considered, the results of the leave-one analysis did not change the obtained findings (PR values from 0.92; 95% CI 0.70–1.21 to 1.14; 95% CI 0.96–1.36), even if they were not statistically significant (Supplementary Material—Figure S7).

4. Discussion

The findings of this systematic review and meta-analysis highlighted that educational interventions are effective in improving the waste management knowledge and practices of HCWs, while they have a negligible impact on attitudes. Among these, multi-component interventions showed greater effectiveness than mono-component ones, had a greater impact on the knowledge of hands-on HCWs, and resulted in a higher increase in the practices of non-hands-on HCWs. The educational interventions presented in the included articles showed heterogeneity in their types, contents, and durations. Similarly, the tools and timing of the evaluation varied considerably, and a greater retention of knowledge in the medium–long term and of practices in the short term could be observed.

Although all interventions were shown to be effective in improving waste management knowledge and practices, multi-component interventions were found to have greater efficacy than mono-component ones in the subgroup meta-analyses. The fact that mono-component educational interventions are less effective among HCWs has already been observed for other behaviors in this population, such as vaccination adherence [64] or application of standard safety precautions [65]. Another aspect to consider is that there are individual, psychological, and attitudinal factors that influence the adherence to waste management recommendations among the general population [66–68], which could be extended to HCWs. The adoption of multiple educational strategies and instructional media has been recommended, and interventions should focus on at least two components to create behavioral change among HCWs, even in resource-limited settings [64,65]. Therefore, multi-component interventions should be preferred as they could better address the underlying individual characteristics by encouraging HCWs to adhere to proper waste management practices effectively. Moreover, promoting behaviors toward sustainability among HCWs, such as encouraging correct waste segregation in the workplace, can also create a rebound effect on the intention to recycle waste at home [68].

Regarding the findings obtained from the subgroup meta-analyses performed based on the type of HCWs and the time of assessment, there are some considerations that should be addressed. Educational interventions were more effective in increasing knowledge among hands-on HCWs and in the medium–long term. This could be attributable to a higher educational level possessed by hands-on HCWs in included articles, which may have resulted in higher scores attained in the knowledge domain and a longer retention of information received. On the other hand, effectiveness in the practices domain was

greater among non-hands-on HCWs and in the short term. In this sense, the practices are intended to be activities in the KAP model [26] and are therefore likely to be more modifiable in technical professions or when implemented by environmental workers. Thus, the implementation of practices could probably be affected by time and may require constant monitoring and educational reinforcement since it became consolidated. These considerations should guide the design of future interventions for waste management while considering the need for an educational follow-up, which has been highlighted by the WHO [5], and regular reinforcement has already been shown to have a positive impact in other studies [69]. In this sense, for the achievement of beneficial public health and economic standards, healthcare institutions and universities should work in synergy for the provision of training and continuing education in a sustainability-oriented workforce.

The educational interventions reported in the included articles did not show effectiveness in the attitudes domain. Attitudes are individual processes characterized by the interaction between multiple factors, including emotions, personal values, and developmental aspects, but also contextual factors such as time, space, and culture [70]. Therefore, it seems overambitious to assume that an educational intervention alone could consistently change the attitudes of HCWs, as it would be unlikely to be able to influence all of the factors mentioned above. The negative attitudes of HCWs have already been reported as one of the main challenges in waste management [24] that should be addressed to improve adherence to recommendations. Therefore, actions should be taken to influence the attitudes of HCWs regarding waste management by going beyond the previously adopted approaches. These should focus on effective communication of the values of sustainability provided during educational interventions in order to influence motivation and change individual beliefs [70,71], thus leading to a behavioral change in HCWs.

With respect to the heterogeneity of interventions delivered in the included studies, their content focused mainly on occupational risks, waste classification, segregation, disposal, and the roles and responsibilities of HCWs. Curiously, despite the fact that the articles included in this systematic review were published in the past 15 years, they did not report that the waste recycling and reuse practices were included in the content of the educational interventions. These concepts are becoming increasingly established as parts of environmental sustainability, and even in the biomedical field, which may allow for more efficient waste management [72,73]. Almost all of the waste produced in the healthcare sector could be recycled and would represent a resource for the environment; therefore, awareness should be raised by training HCWs on how to recycle these materials [5,73].

Many multi-component interventions were developed according to the WHO recommendations and based on local regulations. The WHO guidelines on the safe management of healthcare waste were published in 2014 and provided advice on the planning and implementation of educational programs for HCWs and examples of training packages that should be tailored to specific contexts [5,74]. If the standardization of interventions following the WHO recommendations should represent the benchmark for waste management awareness campaigns directed at HCWs, and for a better reproducibility and comparability of their outcomes, real generalization is not possible at this moment due to differences in local policies and regulations. Nevertheless, the conduction of rigorous studies examining the effectiveness of standardized educational interventions and using comparable assessment methods could contribute to international development and, consequently, to a national harmonization of waste management policies. The standardization of interventions should also cover their durations and follow-ups, which varied widely in the included articles, by considering the presence of specific contextual factors and the fact that approximately two months are needed to change a behavior [75].

As confirmed in this study, the literature on interventions to improve waste management among HCWs is fairly recent, and the studies were predominantly conducted in low-income countries [76]. This tendency could be attributed to the need for a transition of waste management from mostly unsustainable methods to accepted levels of sustainability emerging in recent decades, especially in low-income settings [77]. However, the global

issue of environmental contamination stems from the mismanagement of solid waste [78], which could be extended to healthcare waste and should also be considered as a priority in high-income countries [5]. In fact, in many low-income countries, healthcare waste management policies are absent or poorly implemented [79,80]. For example, Pakistan has entire districts in which healthcare waste is dumped in open areas or landfills [79], while India has had a regulation since 2016 mandating the incineration of healthcare waste but does not enough facilities to treat and dispose of them [80]. A timely lesson, even for countries where the concept of sustainability has already been incorporated into everyday practices, including waste management in the private and healthcare sectors, has been the COVID-19 pandemic [7,81]. In fact, during this emergency, an exponential increase in healthcare waste that represented a potential hazard to the environment was experienced [82,83]. Given this scenario and the systemic knowledge gap of HCWs on this topic [14,24,76], the results outlined in our systematic review emphasize the urgent need to raise global awareness and increase educational initiatives to improve waste management [82,84,85].

Strengths and Limitations

The limitations of this systematic review and meta-analysis are mainly related to the literature search and data analysis processes. The inclusion of six databases published in English and Italian could have led to the exclusion of other relevant studies. Additionally, as most of the included studies were conducted in low-income countries, the generalizability of our findings to high-income countries could be limited. Finally, although home care contexts could potentially be included in this review, no articles involving home care contexts were identified in the selected databases. However, the application of a systematic approach, combined with the inclusion of at least two independent reviewers and an expert librarian in each phase of the search, selection, and data extraction processes, contributed to the limitation bias.

The efficacy of the interventions refers to the knowledge, attitudes, and practices domains described in articles that applied the KAP method or in which the results could be extracted accordingly. Therefore, it is possible that other approaches used to assess the efficacy of interventions, such as the weight of waste produced by HCWs, could show discordant results with those found in this systematic review. Furthermore, the heterogeneity of the duration of educational interventions introduced in the included studies did not allow for a specific stratification through the conduction of sub-group meta-analyses.

Finally, the obtained results could also be affected by the quality of the included articles. In this regard, it is possible that the low scores obtained using the EPHPP tool item evaluating the data collection method applied were related to the KAP assessment tools, which do not require a preliminary psychometric validation for their administration. Nevertheless, these limitations were addressed by the performance of the sub-group analyses and leave-one-out analyses, which allowed the potential effect of heterogeneity to be reduced by evaluating the differences in the efficacy of the educational interventions depending on their characteristics and the influence of a single study on the dimensions of knowledge, attitudes, and practices.

5. Conclusions

The results of this systematic review and meta-analysis support the efficacy of educational interventions in improving the waste management knowledge and practices of HCWs. Among these, multi-component interventions were more effective than mono-component interventions and should be preferred to improve the waste management standards in the healthcare sector. Some differences were found between professional roles and assessment time, both for knowledge and practices, prompting a context-specific application and tailoring of educational interventions.

The design of future interventions should focus on influencing the attitudes of HCWs toward waste management by developing communication strategies that can impact the

motivation of individuals. Given their observed heterogeneity in type, content, and duration, it is necessary to standardize and assess the effectiveness of interventions directed at HCWs at the global level and in specific contexts, such as long-term care and home care, as they could influence international and national policies on sustainability.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su16093513/s1, Figure S1: The forest plot of the subgroup meta-analysis for the effectiveness of educational interventions on HCWs in the knowledge domain; Figure S2: The forest plot of the subgroup meta-analysis for the effectiveness of educational interventions on HCWs in the practices domain. Figure S3: The forest plot of the subgroup meta-analysis for the effectiveness of mono-component and multi-component educational interventions in the attitudes domain; Figure S4: The forest plot of the subgroup meta-analysis for the effectiveness of educational interventions on HCWs in the attitudes domain; Figure S5: The forest plot of the subgroup meta-analysis for the effectiveness of medium- or long-term and short-term educational interventions in the attitudes domain; Figure S6: Funnel plots for the knowledge (left), attitudes (middle), and practices (right) domains; Figure S7: Leave-one-out analyses for knowledge (top), attitudes (medium), and practices (down) domains; Table S1: Search strategies; Table S2: Papers excluded at the full-text level with reasons; Table S3: Quality appraisal; Table S4: Level of significance of Egger's test.

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