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Awareness, Perceptions, and Practices of Surgical Smoke Management: A Cross-Sectional Study Guided by Behavioral Reasoning Theory

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COVER PAGE

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Awareness, Perceptions, and Practices of Surgical Smoke Management: A Cross-Sectional Study Guided by Behavioral Reasoning Theory

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ABSTRACT

Background

Surgical smoke is an occupational health concern for operating theatre personnel because of repeated exposure to potentially hazardous substances. Despite available safety guidance, adherence to surgical smoke management practices remains inconsistent, and the behavioural factors influencing these practices are not well understood. This study aims to examine knowledge, awareness, perceptions, and practices from a behavioural perspective related to surgical smoke safety management among surgeons, anesthetists, and perioperative nurses in an acute hospital in Singapore.

Methods

A descriptive cross-sectional study was conducted among surgeons, anesthetists, and perioperative nurses who were recruited through convenience sampling. Participants voluntarily completed a validated online questionnaire guided by Westaby's Behavioral Reasoning Theory. The questionnaire assessed demographics, awareness, perceptions and practices, and surgical smoke-related feedback.

Results

Among 80 participants, the mean general knowledge score was 1.91 ± 0.76. Most participants demonstrated moderate awareness (80.00%) and moderate perception and practice scores (77.50%). Awareness differed significantly by professional role ($p < 0.001$), with a significant interaction between professional role and general knowledge ($p = 0.030$). Nurses had significantly higher perception and practice scores than anesthetists and surgeons ($p < 0.001$). No significant association was found between awareness and perception and practice scores ($p = 0.056$).

Conclusion

The findings indicate persistent gaps in SS knowledge and inconsistent implementation of protective measures. A multifactorial approach combining standardized interdisciplinary education, practical training, engineering controls, and organizational policies is warranted to strengthen SS safety and protect surgical teams and patients from potential exposure.

Keywords

Surgeons, nurses, occupational health, surgical smoke, plume, awareness, safety practices

INTRODUCTION

Surgical Smoke (SS) is the by-product aerosol produced during tissue dissection or cauterization by heat-generating devices like electrosurgical units (Liu et al., 2019). These aerosols contain water vapour and potentially hazardous constituents, including volatile organic compounds, particulate matter, and viable pathogens (Zhou et al, 2023). Surgical smoke has been considered an occupational health concern among surgical team members in the operating theatres (OT) who face the daily exposure to benzene, noxious odor, carbon monoxide, acrylonitrile and other volatile organic compounds in SS for an average of seven hours daily which was equivalent to 27-30 cigarettes (Dobrogowski et al., 2015; Hill et al., 2012; Okoshi et al., 2015). Despite established recommendations for SS control, inconsistent implementation persists, and the behavioural factors contributing to these practices remain insufficiently understood. This gap provides a rationale for examining SS management using a behavioural framework.

Background

The significant research gap becomes clearer when considering the range of acute and chronic health effects associated with SS exposure as well as documentation of low compliance with safety guidelines among surgical teams. Common acute clinical conditions linked to SS included dizziness, drowsiness, headaches, and acute otorhinolaryngological effects such as eye, nose, and respiratory tract irritation (Zhou et al., 2023; Kahramansoy, 2024). Fikri and Rahmawati reported acute health effects among approximately 60% of perioperative healthcare workers in Malaysia (Fikri and Rahmawati, 2019). Concerns have also been raised about exposure to carcinogenic compounds and potentially infectious biological material in surgical smoke like Human Papillomavirus and hepatitis B, has been linked to increased cancer risks and may cause cardiovascular and pulmonary diseases, damaging the nasal mucosa (Bree et

al., 2017; Kahramansoy, 2024; Merajikhah et al., 2022; Okoshi et al., 2015). Several studies have reported inadequate compliance with SS safety measures among surgical teams (Bree et al., 2017; Dobrogowski et al., 2015; Merajikhah et al., 2022; Zhou et al., 2023). Michaelis et al. (2020) found that German surgeons recognized SS-related health risks but did not consistently use protective measures, while operating theatre nurses reported concerns about inadequate SS awareness. Asdornwised et al. (2018) similarly reported that some perioperative nurses perceived SS safety recommendations as inconvenient or unnecessary. Together, these findings indicate that the availability of guidelines alone may be insufficient to achieve consistent behavioural adherence.

Several organizations have published guidance to reduce SS exposure, including the Association of periOperative Registered Nurses (AORN), the National Institute for Occupational Safety and Health (NIOSH), the International Federation of Perioperative Nurses (IFPN), and the International Council on Surgical Plumes (ICSP, 2022). NIOSH describes a hierarchy of controls comprising elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE). Although complete elimination of SS is generally impractical when electrosurgical devices are required, exposure can be reduced through engineering, administrative, and respiratory-protection measures.

Within this hierarchy, engineering controls include smoke evacuation systems and appropriate filtration. Current guidance recommends effective local smoke capture close to the operative field and appropriate filtration systems (AORN, 2021; IFPN, 2021; NIOSH, 2014). Room suction should not automatically be regarded as an equivalent substitute for a dedicated smoke evacuation system where the required filtration and capture characteristics are absent (NIOSH, 2014). These measures should be integrated into routine operating theatre workflows rather than applied solely at individual clinicians' discretion.

Administrative controls include education, policies, procedures, competency development, and monitoring of compliance. Respiratory protection including appropriately fitted high-filtration N95 facemasks with a 0.1 micron respirators where indicated, provides an additional layer of protection rather than replacing effective smoke evacuation well-fitted (ICSP, 2022). A part of administrative control includes SS education for surgical teams regarding SS, its sources, potential health risks, and the emphasized use and compliance of smoke evacuators and respiratory protection (ICSP, 2022). Policies should be accessible to staff, supported by practical workflows, and periodically reviewed to identify implementation barriers and opportunities for improvement. (AORN, 2021). AORN (2021) also recommends regular assessment of these policies to ensure compliance with the stated guidelines, identify barriers, and enhance existing practices. These policies should be practical, effectively implemented in daily operating theatre routines and continuously monitored to sustain improvements in safety culture.

Theoretical framework

SS safety practices are influenced not only by knowledge but also by behavioural beliefs, social norms, perceived control, and contextual barriers. Behavioral Reasoning Theory (BRT) provides a framework for examining how beliefs and values shape reasons for and against a behaviour, which in turn influence global motives, intentions, and behaviour. Hence, Behavioral Reasoning Theory (BRT) was therefore selected as the theoretical framework for this study because it provides a structured way to examine why surgical team members may or may not intend to comply with SS safety practices, beyond simply measuring whether they know the recommended measures (Westaby., 2005).

Research questions & operational definitions

The study aimed to examine the surgical team's general knowledge, awareness, perceptions, and practices regarding SS safety management in operating theatres. General knowledge was

defined as baseline knowledge about SS before the present study, whereas awareness referred to knowledge of specific SS hazards and recommended safety measures. Perceptions referred to attitudes and beliefs about SS risks and safety measures, while practices referred to reported behaviours undertaken to reduce exposure. The perception and practice score was treated as an indicator of self-reported compliance with recommended SS safety measures.

Therefore, the research question was: What are the levels of general knowledge, awareness, perceptions, and practices related to SS management among surgical team members? The prespecified hypothesis was that lower awareness of recommended SS safety measures would be associated with lower compliance with those measures.

METHODS

Aims

The study examined associations between participant characteristics, general knowledge, awareness, and self-reported SS safety practices; causal relationships were not inferred.

Study design

This descriptive cross-sectional study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations.

Study setting and sampling

The study was conducted in the operating theatres of an acute hospital in Singapore. The source population comprised 612 surgeons, 210 anesthetists, and 476 perioperative nurses. Participants were recruited using convenience sampling. The initial target sample size was 306, calculated using Yamane's formula based on a 5% allowable error (Uakarn et al., 2021). Owing to recruitment constraints, 80 participants were enrolled. The achieved sample was therefore substantially smaller than the target and may have reduced statistical power and precision;

findings should consequently be interpreted as exploratory and may not be generalizable beyond the study setting.

Inclusion and exclusion criteria

Participants were eligible if they were aged ≥21 years, had at least 2 years of operating theatre experience, and had participated in surgery involving electrosurgical devices within the preceding month. Individuals on extended leave, nursing or medical students, and surgical personnel not involved intraoperatively, including recovery nurses and operating theatre technicians, were excluded.

Measuring instrument

The instrument was guided by the BRT and consisted of four sections. The first section was a 9-item questionnaire related to the demographic characteristics of surgical team members and their general knowledge of SS. The second section consisted of 14 selected questions from the studies by Fencl (2017) and Williams (2022), using AORN guidelines, to assess surgical team members' awareness of surgical smoke. The second section score was based on the authors' answers, with participants' scores ranging from 0 to 14. To facilitate interpretation, scores were categorized into three levels: low (0–4.99), moderate (5–9.99), and high (10–14). These cut-offs were chosen to provide approximately equal intervals across the scale and to align with common practice in categorizing short awareness measures. The third section was a researcher-designed questionnaire to assess their perceptions and practices regarding SS, based on the SS safety guidelines and NIOSH's hierarchy of controls. It contained 14 questions using the 4-point Likert scale of (1) Never, (2) Rarely, (3) Often, (4) Every time. The questionnaire total score ranged from 14 to 56, and scores of 14-28, 29-43, and 44-56 were considered poor, moderate, and good levels of perception & practice regarding SS. The fourth section was a 6-

item questionnaire on surgical teams' feedback on SS safety measures. Five questions were based on the guidelines for SS safety for each NIOSH's hierarchy of controls and a final open-ended question for any other feedback. Despite the relevance to AORN and related guidelines, the current questionnaire was not validated. Hence, the study included content validation of the questionnaire by six surgical team members: two anesthetists, two surgeons, and two nurses. They were asked to complete a Content Validity Index (CVI) by selecting one of the four options of "not relevant," "somewhat relevant," "quite relevant," and "highly relevant" for each of the designed items. The received answers were calculated using the CVI formula. The overall CVI score for the present questionnaire was 0.96, which surpassed the passing benchmark of 0.83 set by Yusoff (2019). Internal consistency was assessed using Cronbach's alpha. The scale yielded an alpha of 0.913, indicating excellent reliability. The CVI and Cronbach's alpha score indicated excellent content validation and internal consistency by surgical team members, supporting the validity and reliability of the instrument.

Data collection

The study was conducted at an acute hospital in Singapore from April to September 2025. Participants were invited to participate voluntarily in this study through posters in clinical areas, word of mouth, and emails. Recruitment posters were placed in various operating theatre areas, including bulletin boards, pantries, and restrooms. The research team also shared the study details during department roll calls and staff and clinician leaders' meetings to disseminate study details. Study links and monthly reminders were sent as department-wide bulk emails by all clinical managers and secretaries of anesthetists and surgeons to increase participation rates. Voluntary participants who expressed interest in this study were required to complete the online questionnaire via the QR code on the recruitment poster or via the institution's online survey platform. Participants' involvement ended upon completion of the questionnaire.

Data analysis

Data analysis was performed using IBM SPSS statistical software version 31. Demographic characteristics, awareness, and compliance scores were described with frequencies and percentages for categorical variables, and means and standard deviations for continuous variables. The compliance score referred to the perception and practices section of the questionnaire. General knowledge on surgical smoke referred to individuals' SS knowledge before this study. Based on the literature review and reasoning, education, role, and SS general knowledge were identified as confounders that potentially influence their SS awareness and compliance. Independent t-tests, analysis of variance (ANOVA), and Pearson's correlation coefficient were used to analyze awareness and compliance scores across various demographic characteristics. The researchers also assessed the data normality and homogeneity of variances before conducting inferential analyses. A p-value of < 0.05 was considered statistically significant. The qualitative feedback on surgical smoke safety was analyzed using content analysis.

Ethical considerations

This research study was conducted in accordance with relevant ethical guidelines and regulations and approved by the SingHealth Centralised Institutional Review Board (ECOS: 2025-0107) before the commencement of the study. Written informed consent was not obtained; instead, implied consent was assumed upon completion of the questionnaire, which participants could access via their official email. Participants were provided with information about the study; completion and submission of the questionnaire indicated their consent to participate. Confidentiality was maintained, and no identifiable participant information was collected. All data were securely stored on an institution-approved, encrypted storage medium, accessible only to study team members.

RESULTS

Characteristics of the sample

There were 80 participants: 45 nurses (56.25%) and 35 surgeons and anesthetists (43.75%), with the majority (91.30%) working in the Major Operating Theatre. Due to the small number of anesthestists (n = 9), we combined them with surgeons to form a surgeons and anesthetists group for comparison against nurses. The demographic characteristics were presented in Table 1 and stratified by professional groups in Table 2. General knowledge of SS prior to the present survey results was below the acceptable range (M = 1.91, SD = .766). Their general knowledge was mainly learnt through department training (41.30%), colleagues (25.00%), and self-directed learning (23.80%), as shown in Table 3.

Awareness Score

The mean awareness score was 6.83 ± 2.11 (range, 3–12). Most participants had moderate awareness (80.0%), followed by high awareness (12.50%) and low awareness (7.50%). The highest proportions of correct responses concerned placement of the smoke-capture device (96.25%), components of SS policies and procedures (88.75%), and respiratory protection with surgical masks (82.50%). The lowest proportions of correct responses concerned SS policies and procedures (2.50%), the type of filters used in vacuum systems (5.00%), and SS as a health risk and regulations protecting healthcare workers (10.00%) (Figure 1).

Awareness scores did not differ significantly by gender, age, years of working experience, or work unit (Table 4). A one-way ANOVA indicated an overall difference across education groups ($p = 0.045$); however, Tukey post-hoc comparisons did not identify a statistically significant pairwise difference. Awareness was significantly higher among anesthetists and surgeons than among nurses ($p < 0.001$). A two-way ANOVA demonstrated a significant interaction between professional role and general knowledge ($p = 0.030$), indicating that the association between general knowledge and awareness differed by professional role (Figure 2).

Perception & practice score

The mean perception and practice score was 35.05 ± 6.45. Most participants had moderate scores (77.50%), while 15.0% had low scores and 7.50% had high scores. The highest-frequency practices or perceptions included frequent use of diathermy pencils (75.0%), recognition of smoke evacuators as effective in reducing SS (61.25% reporting "Often"), and ready availability of PPE (55.00% reporting "Every time"). Lower-frequency practices included use of laparoscopic smoke-evacuation attachments (61.25% reporting "Never"), frequent use of N95 masks and protective eyewear (53.75% reporting "Rarely"), and use of telescoping diathermy pencils (42.50% reporting "Rarely") (.

Perception and practice scores differed significantly by professional role and education level (Table 5). Nurses had significantly higher scores than anesthetists and surgeons ($p < 0.001$). One-way ANOVA showed a significant overall difference across education groups ($p = 0.031$). Tukey post-hoc testing indicated that participants with post-secondary/diploma education had higher scores than those with master's/doctoral education; other pairwise comparisons were not statistically significant. The interaction between professional role and general knowledge was not statistically significant ($p = 0.345$). Pearson's correlation showed no statistically significant association between awareness and perception and practice scores ($p = 0.056$).

Feedbacks

Feedback on SS safety measures was analyzed using conventional content analysis (Table 6). Participants identified improvements across engineering, administrative, and PPE controls. Frequently reported priorities included reducing noise from smoke evacuators, providing clear clinical guidance, improving the practicality and size of equipment, promoting smoke evacuator use, strengthening policies and procedures, implementing regular audits, providing practical education on available products, and improving PPE comfort and usability.

DISCUSSION

This study examined general knowledge, awareness, perceptions, and self-reported practices related to SS safety among operating theatre personnel and interpreted the findings using BRT. Overall, participants demonstrated limited baseline knowledge, moderate awareness, and moderate perception and practice scores. Professional role was strongly associated with both awareness and perception and practice scores, while awareness was not significantly correlated with perception and practice scores. These findings suggest that knowledge alone may not be sufficient to produce consistent SS safety behaviour.

Key findings

The key findings integrated into Westaby's BRT were illustrated in Figure 3. According to BRT, surgical team members' limited general knowledge and its sources shaped their individual beliefs and values. The general knowledge of SS was limited prior to the survey with below the average general knowledge score. Operating theatre nurses were found to have low levels of knowledge, attributed to limited education on surgical smoke (Fereidouni et al., 2021). Rodrigues and Winnington (2024) reported that 1 of 6 participants had limited prior SS safety training among operating theatre personnel, while Arli (2020) reported 84% of surgical team members had low overall knowledge scores with no formal SS training. Conversely, higher proportions of formal SS education have been reported among Thai perioperative nurses (92.00%) and American nurses (79.00%) and surgical technologists had received education on SS and its potential health effects (Asdornwised et al., 2018; Wagner et al., 2024). Differences between studies may reflect variation in institutional training, professional roles, and exposure to formal SS education. The present findings therefore support the need for standardized, institution-led education rather than reliance on informal learning alone. Both the current study and Wagner et al. (2024) identified departmental training, colleagues, and self-directed learning as the primary sources of information. On the contrary, Asdornwised et al. (2018)

indicated that the most frequently cited sources were media, colleagues, and other informal sources. The findings highlight the potential educational gap for SS and underscore the need for standardized, institution-led training rather than relying on informal learning. Apart from limited general knowledge, professional role was associated with awareness and perception and practice scores. Surgeons may have greater familiarity with electrosurgical devices because of their direct involvement in selecting and using such equipment. For instance, a study by Barber et al. (2022) showed that surgeons and anesthetists reported lower exposure and perceived lower risk from surgical smoke than nurses. However, SS management should not depend on individual preference, procedure type, or duration; standardized controls are preferable where exposure is foreseeable. Nurses may have different responsibilities, including equipment preparation and maintenance of the operating environment, which can shape their exposure to and management of SS. Importantly, previous research has also reported greater SS hazard awareness among nurses than surgeons, demonstrating that professional-role effects are not necessarily consistent across settings. This inconsistency reinforces the value of multidisciplinary SS education rather than role-specific assumptions.

The current study also identified significant differences in values among the surgical team members which were influenced by their professional roles & responsibilities. Surgeons had a higher level of awareness regarding electrosurgical devices, given their greater involvement in and decision-making about them as the primary users of such equipment (Wagner et al., 2024; Moore and Palokas, 2024). However, Wagner et al. (2024) stressed that the use of smoke evacuators should be standardized across all surgeries rather than dependent on an individual's preference, type of surgery, or duration. Conversely, nurses fulfilled their professional roles and responsibilities by ensuring that equipment and the operating theatre were prepared preoperatively, according to surgeons' preferences (Moore and Palokas, 2024; Wevling and Leonardsen, 2025; Wheelock et al., 2015). Despite surgeons' preferences, Michaelis et al.

(2020) found that nurses were significantly more aware of surgical smoke hazards than surgeons ($p < .001$), which accounted for their higher compliance score to SS safety measures.

Upon knowing their beliefs & values, there were reasons for and against SS safety measures to justify their SS awareness and motivation to comply. The reasons for their compliance with SS safety measures included the perceived effectiveness of SS management by using smoke evacuators and personal protection equipment. Smoke evacuators were effective at reducing SS, with significantly lower levels of acetaldehyde and acetone during their usage (Tokuda et al., 2020). 82.2% of participants in this study agreed that smoke evacuators were effective, with 55% reporting that the equipment was readily available in the operating rooms. Multiple studies also reported that surgical team members, particularly nurses, were concerned about the possible transmission of infectious disease, especially COVID-19, via surgical smoke (Chapman et al., 2017; Lotfi et al., 2022; Michaelis et al., 2020). There were variations across studies in PPE compliance (Asdornwised et al., 2018; Chapman et al., 2017; Ilce et al., 2017). 85% of respondents reported adequate PPE supplies in the OR, yet 66.25% do not frequently wear high-filtration (N95) masks and protective eyewear. Both Wagner et al. (2024) and Meretsky et al. (2024) agreed that high-filtration masks were superior to surgical masks for minimizing SS exposure. However, Lotfi et al. (2022) stated that donning of PPE should be the second line of defense for respiratory protection against surgical smoke. Similarly, AORN (2021) guidelines recommend that wearing high-filtration respiratory protection does not replace the effectiveness of surgical smoke evacuation but serves as secondary protection against residual surgical smoke.

Conversely, the reasons for their noncompliance with SS safety measures included unintentional omission, financial and functional considerations regarding smoke evacuators. Despite their concerns and perceived effectiveness, more than half of the participants (62.5%)

in this study reported that surgical teams used smoke evacuators poorly in the past month. Numerous studies reported that surgical team members did not consider SS management an important consideration and were unfamiliar with the use and availability of smoke evacuators in their OTs, leading to unintentional omissions (Chapman et al., 2017; Ilce et al., 2017; Michaelis et al., 2020). Surgical team members also stated that financial considerations and the functionality of smoke evacuators and personal protective equipment were important. Ilce et al. (2017) highlighted the reasons for not using an effective preventive measure as significant financial considerations (21%) and limited educational information (38.3%). Rodrigues and Winnington (2024) found that poor utilization of smoke evacuators was due to nurses prioritizing cost savings for patients. Similarly, Chapman et al. (2017) discussed the significant cost difference between respiratory protections as well as smoke evacuation, with lifetime maintenance costing more than $1500 per unit. York and Autry (2018) also analyzed that a smoke-evacuating electrosurgical pencil costs nearly thrice of a standard pencil, amounting to $22000 for the pencils per annum. Other additional costs include ULPA filters for smoke evacuators and one-time filters for laparoscopic smoke-evacuating devices, which cost the hospital $7400 annually. Despite the mounting cost of SS management, the cost factor was not an excuse for failing to protect surgical team members from surgical smoke. Steege et al. (2016) also highlighted that the decision to use electrosurgery units should not be made at the discretion of an individual practitioner when the entire surgical team and the patient are exposed to SS.

The global motives of surgical team members were then analyzed to understand their individual reasons behind their intentions and compliance with SS safety measures. Based on their beliefs, values and reasons, surgical team members had opposing attitudes and low perceived control towards SS safety measures, which were influenced by the subjective norms. Subjective norms had three categories, namely: environmental, interdisciplinary, and organizational factors.

The environmental factor that contributed to the moderate compliance score included time pressures in the operating theatre, which prioritized speed and productivity to ensure uninterrupted surgical schedules (Ball, 2010a; Bong et al., 2025; Harten et al., 2025). Moon et al. (2021) noted that nurses tend to be task-oriented in preparing surgical instruments and the operating theatre rather than prioritizing environmental cleanup of SS.

The interdisciplinary factors of workplace socialization were rooted in workplace cultures and norms. The observable differences in SS safety compliance behavior across education levels were mediated by workplace cultural barriers like complacency, available equipment, and resistance to change by surgeons that shaped their personal risk assessment and professional expectations (Ball, 2010b). Jayasuriya-Illesinghe et al. (2016) described this behavior as a reflection of workplace socialization, influenced by norms and role modelling rather than academic attainment. The existing workplace socialization resulted in the negative influence of SS compliance, as unconscious and involuntary exposure to SS was deemed as a workplace norm (Moon et al., 2021; Wagner et al., 2024). Thus, Tan and Russell (2017) emphasized that role modelling and supportive leadership were important interdisciplinary factors for achieving compliance and adopting best practices within the allocated time and funds for SS safety measures.

The organizational factors that influenced surgical team members' compliance were organizational support and administrative control of SS safety. 72.5% of participants in this study recommended administrative control of surgical smoke safety, including the enforcement of compulsory use of evacuators for all surgeries. Similarly, Barber et al. (2022) reported a higher support among nurses (95%) and anesthetists (92%) and lower support among surgeons (78%) for a smoke-free policy. Lotfi et al. (2022) also cited the lack of policies, managerial support, and staff knowledge on SS. AORN (2021) stated the need to develop policies and

procedures for SS safety, with periodic review and revision as needed, and to make these guidelines available for use in clinical practice. Quality assurance and improvement programs should also be included to assess surgical team members' compliance with SS safety (AORN, 2021). Wagner et al. (2024) highlighted that organizational leaders may consider the inclusion of all perioperative personnels especially surgeons, as the key stakeholders who generally make the decision to use smoke evacuation.

The present study suggested the relatively low global motive levels regarding the SS safety measures, reflecting their opposing attitudes and low perceived control towards SS safety measures that were influenced by clinical settings, stressful environment, workload and underestimated potential health concerns of SS with no immediate threat to their health. Low global motives and varied beliefs contributed to a conflicted and neutral behavioral intentions toward the SS safety, suggesting the reports of the moderate awareness and compliance scores.

Recommendations for further research

Training and education were fundamental to strengthening SS management's general knowledge. Surprisingly, more than half of the participants (65%) in this study also suggested the need for practical and educational sessions on existing products and their usage. A comprehensive education program, as shown by Chavis et al. (2016), led to a 14.6% increase in smoke evacuator use, driven by staff members' awareness of surgical smoke. AORN (2021) recommended establishing prior and ongoing interdisciplinary education and competency related to surgical smoke safety, especially before introducing new smoke management systems and accessories. Apart from education on existing products, Tan and Russell (2017) discussed the need for regular in-service education sessions conducted by sales representatives and the display of informative posters in operating theatres, staff rooms, and along theatre corridors to attract staff attention.

Modifications to existing smoke-evacuation devices, based on feedback from surgical team members, would reinforce their reasons and motivations for complying with SS safety management. Participants in this study suggested improvements, including universal compatibility of electrosurgical pencils across manufacturers and reduced noise from smoke evacuators. Noise had deleterious effects on surgical team members by interfering with communications, surgical performance, increased stress among surgical team members (Wahr et al., 2024). Keller et al. (2018) found that second surgeons were more likely to be distracted when noise pollution was high during the main surgical phase, and anesthetists were more likely to be distracted during the closing phase. Dobbie et al. (2017) also noted that some surgeons complained about the distractions caused by different smoke evacuation system modes, which were barriers to SS management. There were also suggestions to modify existing PPE to increase its usability.

Strength and limitations

This study has several limitations. This study was limited by its small sample size of 80 participants in this study which may reduce the statistical power to detect significant differences and affect the ability to generalize the findings. Another limitation of this study was using an extensive questionnaire with two self-reporting sections to collect the data. Hence, the small sample size and answers might be affected by the extended duration to complete the questionnaire and social desirability bias to provide honest answers to all questions. Participants may provide responses based on their perceived socially acceptable outcomes, which may lead to an overestimation of their actual responses.

Implications for perioperative nursing

The findings of this study indicate moderate levels of awareness and compliance regarding surgical smoke, underscoring the need to address existing educational gaps. At the individual level, surgical team members are recommended to recognize the importance of self-care and

occupational well-being by prioritizing adherence to SS measures in the operating theatre. At the interdisciplinary level, perioperative teams may benefit from standardized surgical smoke education across perioperative units, provide regular updates and refresher training, encourage openness to trying and adopting smoke evacuation devices and good practices, and promote knowledge through educational materials, research sharing, and knowledge from surgical smoke champions. At the organizational level, institutions may consider to move beyond a focus on cost-effectiveness, demonstrate institutional commitment to staff safety, reinforce established guidelines, develop clear and comprehensive policies and procedures, and provide sustained administrative and managerial support to ensure consistent implementation of surgical smoke safety practices.

CONCLUSION

Surgical smoke posed potential health risks to surgical team members. Despite the availability of several guidelines for surgical smoke safety, surgical team members did not consistently adopt such protective measures. The study's findings demonstrated low general knowledge, moderate awareness, and moderate compliance. The factors that influenced surgical smoke safety awareness and compliance included perceived lower risk of health effects, professional roles & responsibilities, as well as environmental, interdisciplinary, and organizational factors. Hence, it is fundamental to adopt a multifactorial approach to achieve a smoke-free environment and protect surgical teams and patients from potential health effects, with organizational leadership support and educational interventions based on surgical smoke guidelines.

LIST OF ABBREVIATIONS

AORN	Association of periOperative Registered Nurses
ANOVA	Analysis of Variance
BRT	Behavioral Reasoning Theory
CVI	Content Validity Index
ICSP	International Council on Surgical Plumes
IFPN	International Federation of Perioperative Nurses
NIOSH	National Institute for Occupational Safety and Health
OT	Operating Theatres
PPE	Personal Protective Equipment
SS	Surgical Smoke
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology

DECLARATIONS

Ethics approval

Ethics approval and consent to participate. This research study was approved by the SingHealth Centralized Institutional Review Board (ECOS: 2025-0107).

Consent for publication

The article has not been published elsewhere and reports original research by the authors. None of the authors has conflicts of interest to disclose for this study.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available due to restrictions related to participant confidentiality and the ethical approval governing the study, but may be available from the corresponding author on reasonable request, subject to institutional and ethical approval.

Competing interests

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Authors' contributions

Lim Jia Hui Petrina and Ng Si Lei Annalyn conceived and designed the study, developed the methodology, collected and analysed the data, interpreted the findings, and drafted the manuscript. Lim Jia Hui Petrina contributed to the study design, data interpretation, and critical revision of the manuscript. Voo Pui San and Lim Siew Hoon contributed to the supervision of the study, interpretation of the findings, and critical revision of the manuscript. All authors

reviewed and approved the final manuscript and agree to be accountable for all aspects of the work.

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Awareness, Perception & Practices of Surgical Smoke
TABLES

Table 1. Demographic characteristics (n = 80)

Variables	Frequency	Percentage
Gender		
Female	56	70.00%
Male	24	30.00%
Age		
21 to 30 years old	20	25.00%
>30 to 40 years old	27	33.75%
>40 to 50 years old	20	25.00%
>50 years old	13	16.25%
Highest Education Level		
Post-secondary & Diploma	12	15.00%
Degree	40	50.00%
Masters & Doctorate	28	35.00%
Years of Working Experience		
2 to 5 years	20	25.00%
>5 to 10 years	14	17.50%
>10 to 15 years	14	17.50%
>15 to 20 years	12	15.00%
>20 years	20	25.00%
Role		
Nurses	45	56.25%
Anesthetist & Surgeons	35	43.75%

Awareness, Perception & Practices of Surgical Smoke
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Workplace		
Major Operating Theatre	73	91.30%
Urology Operating Theatre	3	3.70%
Ambulatory Surgery Centre	1	1.30%
Combination of all areas	3	3.70%
Work Units		
Multi-disciplinary	42	52.50%
General Surgery, Obstetrics & Gynaecology, Urology	15	18.75%
Orthopedic, Hand Surgery	8	10.00%
Cardiothoracic, Neurosurgery	8	10.00%
Plastic & Reconstruction, Ear, Nose & Throat	7	8.75%

Table 2. Demographic characteristics by professional groups

Variables	Nurses (n = 45)		Anesthetist & Surgeons (n = 35)	
Gender				
Female	39	86.67%	18	51.43%
Male	6	13.33%	17	48.57%
Age				
21 to 30 years old	16	35.56%	4	11.43%
>30 to 40 years old	17	37.78%	10	28.57%
>40 to 50 years old	9	20.00%	11	31.43%
>50 years old	3	6.67%	10	28.57%
Highest Education Level				
Post-secondary & Diploma	10	22.22%	2	5.71%
Degree	31	68.89%	9	25.71%
Masters & Doctorate	4	8.89%	24	68.57%
Years of Working Experience				
2 to 5 years	15	33.33%	5	14.29%
>5 to 10 years	12	26.67%	2	5.71%
>10 to 15 years	7	15.56%	7	20.00%
>15 to 20 years	6	13.33%	6	17.14%
>20 years	5	11.11%	15	42.86%
Workplace				
Major Operating Theatre	42	93.33%	31	88.57%

Urology Operating Theatre	2	4.44%	1	2.86%
Ambulatory Surgery Centre	1	2.22%	0	0.00%
Combination of all areas	0	0.00%	3	8.57%
Work Units				
Multi-disciplinary	30	66.67%	12	34.29%
General Surgery, Obstetrics & Gynaecology, Urology	6	13.33%	9	25.71%
Orthopedic, Hand Surgery	2	4.44%	6	17.14%
Cardiothoracic, Neurosurgery	6	13.33%	2	5.71%
Plastic & Reconstruction, Ear, Nose & Throat	1	2.22%	6	17.14%

Table 3. Score and sources of SS general knowledge before present survey (n=80)

Variables	Frequency	Percentage
General Knowledge of SS Score		
Poor	27	33.75%
Acceptable	33	41.25%
Good	20	25.00%
General Knowledge of SS Sources		
Department training/ staff meeting	33	41.30%
Colleagues	20	25.00%
Self-directed Learning	19	23.80%
Unsure	3	3.80%
School Program	2	2.40%
Vendor	2	2.40%
Media	1	1.30%
Quantitative Variables	**Mean ± SD***	
General Knowledge	1.91 ± .766	

*Standard Deviation

Table 4. Awareness and compliance scores with different sociodemographic variables

Variables	Awareness scores Significance	Compliance scores Significance
Gender	.290	.307
Age	.856	.096
Education	.045	.031
Years of working experience	.212	.056
Role	<.001	<.001
Work Unit	.919	.551

Table 5. Compliance and its subcategorical scores

Item	Never N (%)	Rarely N (%)	Often N (%)	Every time N (%)	Mean ± SD*	Subcategorical score range	Subcategorical score Mean ± SD*
NIOSH category: Substitution							
Use of smoke evacuator	19 (23.75)	31 (38.75)	26 (32.5)	4 (5)	2.187 ± .858		
Readily available smoke evacuators	7 (8.75)	29 (36.25)	27 (33.75)	17 (21.25)	2.675 ± .911	3 - 12	7.038 ± 1.865
Use of wall suction instrument as an alternative	22 (27.5)	29 (36.25)	22 (27.5)	7 (8.75)	2.175 ± .938		
NIOSH category: Engineering Control							
Use of diathermy pencils	1 (1.25)	3 (3.75)	16 (20)	60 (75)	3.688 ± .608		
Seen the diathermy pencil with smoke evacuator attachment	8 (10)	30 (37.5)	23 (28.75)	19 (23.75)	2.662 ± .954		
Seen the telescoping diathermy pencil	11 (13.75)	34 (42.5)	19 (23.75)	16 (20)	2.5 ± .968	7 - 28	18.188 ± 3.424
Seen the smoke evacuation attachment (laparoscopic)	49 (61.25)	18 (22.5)	8 (10)	5 (6.25)	1.612 ± .907		
Effectiveness of smoke evacuators	6 (7.5)	8 (10)	49 (61.25)	17 (21.25)	2.963 ± .787		

Weight and size of the smoke evacuator affect equipment placement	19 (23.75)	26 (32.5)	23 (28.75)	12 (15)	2.35 ± 1.008		
Noise distraction from the smoke evacuator	16 (20)	28 (35)	23 (28.75)	13 (16.25)	2.413 ± .990		
NIOSH category: Administrative Control							
Adequate resources on surgical smoke safety measures	20 (25)	33 (41.25)	20 (25)	7 (8.75)	2.175 ± .911		
						2 - 8	4.125 ± 1.672
Availability of quality controls (like audits)	30 (37.5)	31 (38.75)	12 (15)	7 (8.75)	1.95 ± .940		
NIOSH category: PPE							
Daily use of Personal Protection Equipment (PPE) in OR	10 (12.5)	43 (53.75)	18 (22.5)	9 (11.25)	2.325 ± .839		
						2 - 8	5.700 ± 1.287
Readily available PPE	2 (2.5)	10 (12.5)	24 (30)	44 (55)	3.375 ± .802		
					Minimum total score		14
					Maximum total score		56

*Standard Deviation

Table 6. Feedback on surgical smoke

Questions	Frequency
Engineering Control: Diathermy pencils	
User-friendly	42
Integration with surgical instruments	32
Streamlined process in clinical settings	35
Compatibility with technology of other manufacturers	42
No improvement required	10
Others: Not applicable	3
Engineering Control: Smoke evacuators	
User-friendly	35
Promote the use of evacuators	40
Practicality in terms of weight and size	45
Reduction of noise disruption	54
Clinical guidelines on smoke evacuators	54
Financial concerns	26
No improvement required	5
Others: Doubts on its effectiveness	1
Others: Less bulky size as hinder surgical field visualisation	1
Administrative control: Policy and procedures, quality reassurance	
Compulsory use of evacuators for all surgeries	58
Available policies and procedures	56
Organizational culture	52

Support from unit committees	17
Regular audits	27
Others: Informed surgeon for compulsory use of evacuators	1
Others: Development of SS clinical key performance indicator	1
Administrative control: Education	
Formal education programs	42
Mandatory online educational module	28
Educational poster	31
Educational reference book	18
Practical session on the available products and its usage	52
Personnel Protective Equipment (PPE)	
Compulsory use of N95 mask and eyewear	21
Modifications to existing PPE	61
Others: Discomfort and hard to communicate when using N95	2
Others: Not applicable	4
Others: Mask with activated carbon to filter smoke and odour	1
Others: Not aware of organisational requirement	1
Others: Compulsory use of PPE based on scientific explanation	1
Other feedback	
Not applicable	71
Inadequate smoke evacuation units	1
Compulsory or standby of smoke evacuator for all surgeries, surgeons may opt out based on preference	3

Sufficient equipment for usage	1
Universal use of smoke evacuation	1
Belief of interdepartmental sharing of smoke evacuators was not allowed	1
Questionnaire should provide " Not applicable" option as some never seen smoke evacuators. Thus, default answers were mostly "rarely"	1
Surgical smoke is an important topic	1
No training as anesthetist medical officer	1

Figure 1. Awareness on surgical smoke: questions and scores

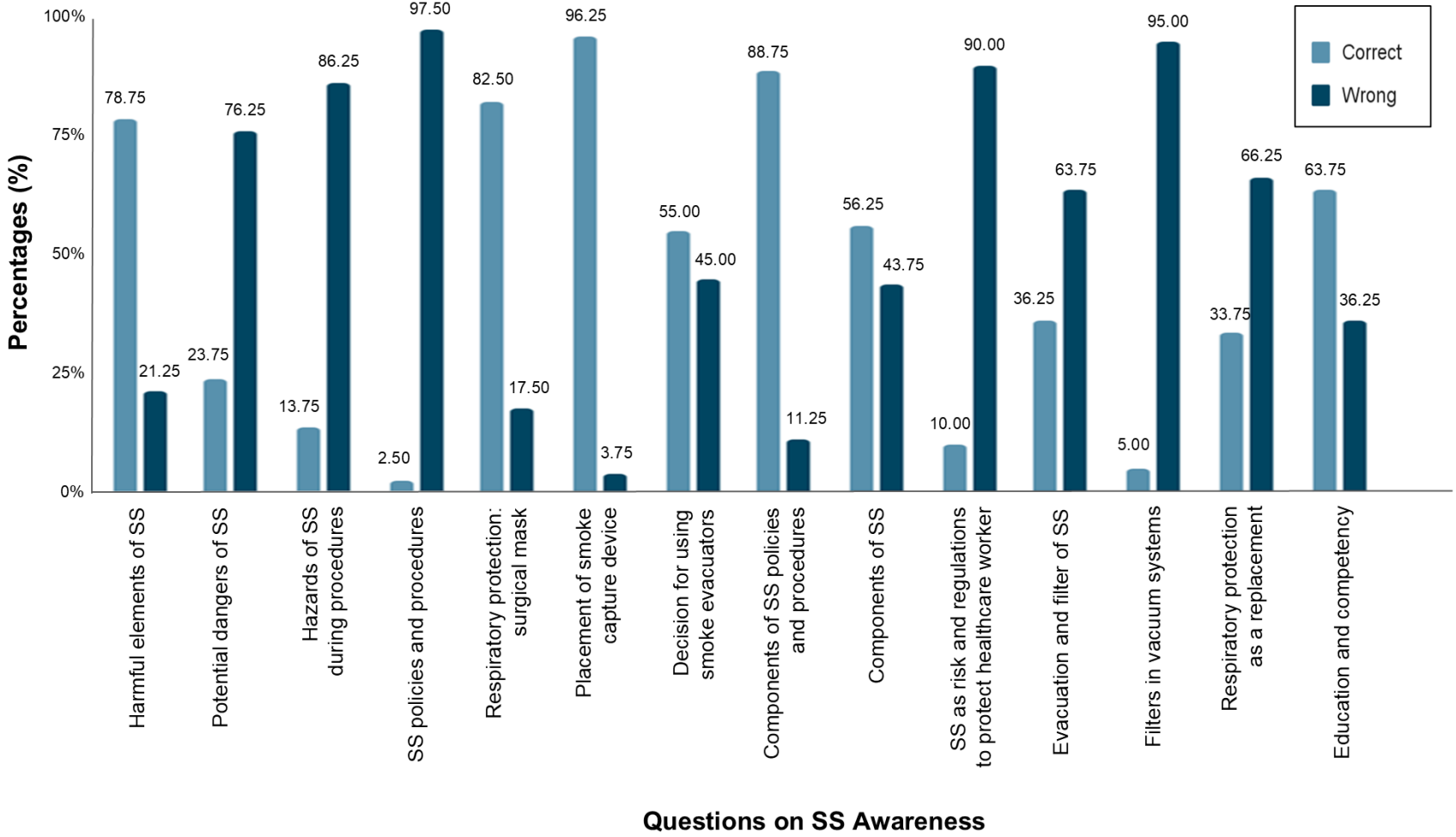


Figure 2. Two-way ANOVA of awareness scores, roles and SS general knowledge

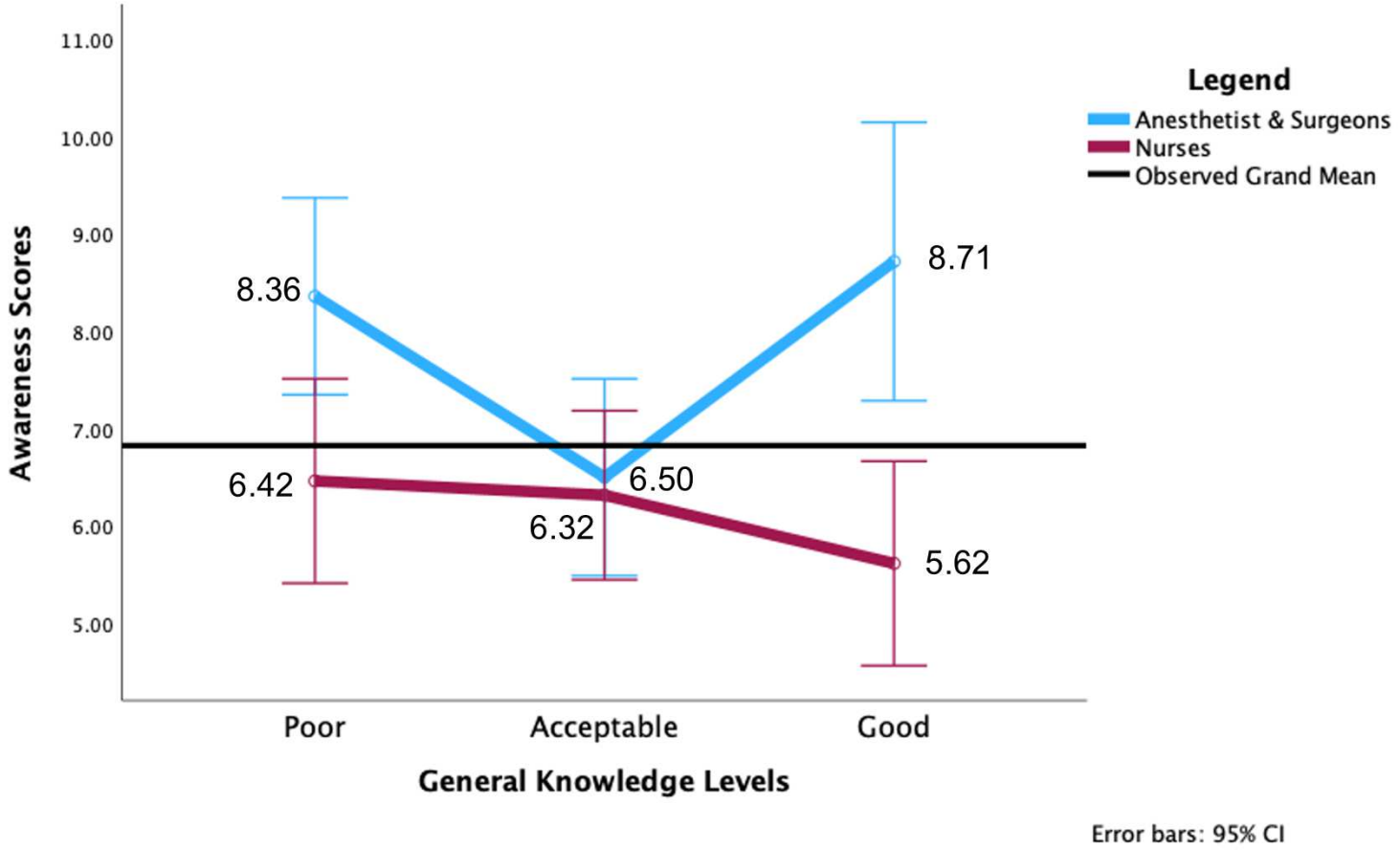
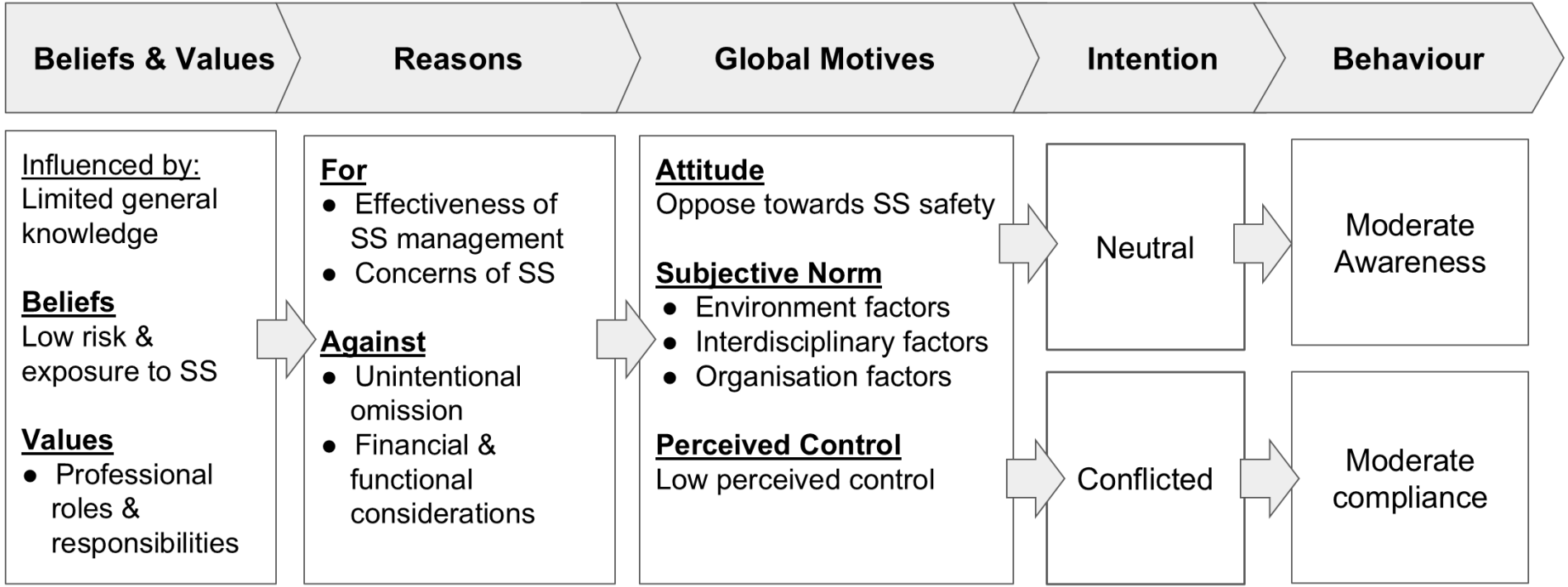


Figure 3. Study findings integrated into Westaby's BRT (2005)



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