Delft University of Technology

Master Thesis Biomedical Engineering

Analysis of Workload and Job Satisfaction Among Intra-Operative Nurses: Impact of Procedure Type

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Abstract

Introduction: The Netherlands is experiencing a critical shortage of healthcare workers, particularly nurses. Operating rooms (ORs) face high turnover rates due to their unique and demanding environment. The introduction of Robot-Assisted Surgery (RAS) has added further complexity to the OR setting. While RAS offers benefits for patients and surgeons, its impact on the workload and job satisfaction of intra-operative nurses remains unclear. Given the link between workload and job satisfaction and nurse retention, it is essential to investigate how RAS affects the workload and job satisfaction of intra-operative nurses compared to laparoscopic and open procedures. This study aims to provide a nuanced understanding of these aspects and identify key influencing factors.

Method: A multi-method approach was employed among intra-operative nurses at Leids Universitair Medisch Centrum (LUMC), combining subjective data from questionnaires—including the Surgical Task Load Index (SURG-TLX)—with insights from semi-structured interviews. Additionally, objective data were analyzed from hospital records and video recordings. The study focused on the gynecology department, evaluating workload and job satisfaction across three main types of procedures: open, laparoscopic, and RAS. Variations in workload and job satisfaction during the pre-operative, intra-operative, and post-operative phases were also examined.

Results: The overall workload was deemed acceptable, with an average score of 34.58, below the detrimental threshold of 50. RAS procedures scored higher across multiple domains, resulting in a higher average workload score of 40.82, compared to 32.60 for open procedures and 30.32 for laparoscopic procedures. Open procedures were associated with greater job satisfaction than both laparoscopic and RAS procedures. Key factors affecting workload and job satisfaction included: team dynamics, procedural variation, preparation and equipment, working environment, appreciation and recognition, and physical demand. Interviews revealed that intra-operative nurses experienced more stress during RAS procedures, particularly in the pre-operative phase, largely due to a lack of technological knowledge. Additionally, they felt less involved, and the working environment was perceived as less pleasant. Objective data from hospital records supported these findings, showing that RAS procedures typically had longer durations and more frequent overruns, often involving patients with lower acuity scores. This combination of reduced procedural complexity and extended surgery times contributed to a higher perceived workload and lower job satisfaction. The extended periods of dim lighting and the more crowded operating room further exacerbated the working environment's discomfort, increasing the perceived workload and reducing job satisfaction. Video data analysis indicated less interaction with the operating table and reduced movement of personnel during RAS procedures, which potentially contributed to a diminished sense of activity and involvement, thereby increasing the perceived workload.

Conclusion: RAS procedures impose a greater workload on intra-operative nurses compared to open and laparoscopic procedures across multiple domains and result in less job satisfaction compared to open procedures. Data from questionnaires, interviews, hospital records, and video analysis consistently show a diminished sense of involvement and increased perceived workload during RAS procedures. This study underscores the need for improvements in preparation protocols, OR scheduling, intra-operative nurse involvement, and working conditions. These enhancements could help reduce perceived workload, increase job satisfaction, and ultimately address the growing nursing shortage in the Netherlands.

Contents

1 Introduction

1.1 Importance of Study

In the Netherlands, there is a critical shortage of healthcare workers, especially among nurses, with projected vacancies expected to increase from 61,000 in 2022 to 170,000 by 2032 according to ABF research [1]. The operating room (OR) department faces particularly high turnover rates due to its unique and demanding environment. The OR requires multidisciplinary teamwork, flexibility, and proficiency with advanced technology. Moreover, it is a highly stressful environment due to potential emergencies and patient safety concerns [2, 3].

Shortages of intra-operative nurses can lead to surgery cancellations, reduced OR capacity, and ultimately poorer outcomes for both patients and the healthcare system. Studies indicate that intra-operative nurses experience a higher workload and lower job satisfaction compared to their counterparts in other departments [2, 4, 5, 6]. Workload and job satisfaction are closely associated with burnout and intentions to leave [6, 7, 8]. Moreover, suboptimal workloads and reduced job dissatisfaction can impair performance, pose risks to patient safety, and exacerbate stress levels [9, 10, 11, 12, 13, 14].

The rapid advancement of technology, including the introduction of Robot-Assisted Surgery (RAS), has the potential to further complicate the already complex OR environment. While RAS offers potential benefits for patients and surgeons, its introduction may also potentially affect the workload and job satisfaction of other team members [15, 16, 17].

Despite the shortage of healthcare workers being particularly evident among nurses, most research on the effect of RAS on workload and job satisfaction has primarily focused on surgeons. Figure 1 highlights this focus by demonstrating the importance of the term 'surgeon' in literature searches related to RAS workload studies.

Currently, there is limited understanding of how intra-operative nurses experience and are impacted by RAS, despite the growing nurse shortage in the Netherlands. The factors significantly influencing their workload and job satisfaction are also not well understood [6, 9, 18, 19]. This study aims to thoroughly assess the current workload and job satisfaction of intra-operative nurses, and examine the differences across the three main types of procedures.

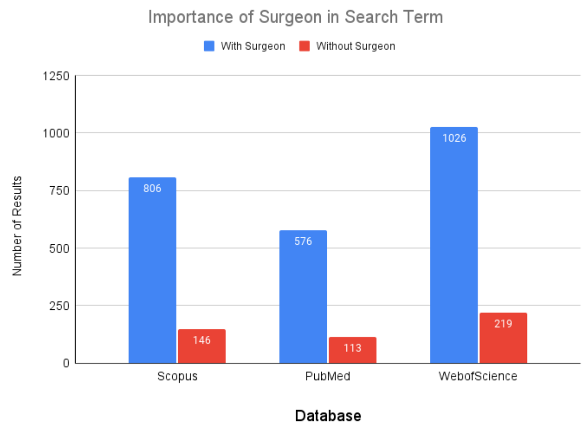

Figure 1: Comparison of search results across three databases for studies on the impact of RAS on workload, showing a larger number of results when the term 'surgeon' is included. This illustrates the predominant focus on surgeons in existing research.

1.2 Background

In the literature, a distinction is often made between three main types of surgery: open, laparoscopic, and RAS [20, 21]. Open surgery, the conventional method, is the oldest. In 1987, laparoscopic surgery emerged, offering better cosmetic results and less postoperative pain [21]. The most recent development is RAS which received Food and Drug Administration (FDA) approval in 2000 [22]. RAS is becoming increasingly prevalent, with a 15% annual increase in procedures [15, 23, 24]. RAS offers numerous benefits compared to the other types of surgery, including reduced blood loss, fewer transfusions, less pain, improved cosmetic results, shorter hospital stays, and faster recovery [15, 16, 17, 19]. Additionally, it mitigates some limitations of laparoscopic surgery by providing greater degrees of freedom for the surgeon and offering 3D vision [21]. Despite these benefits, RAS also comes with higher costs and poses challenges related to team dynamics and the roles of individual team members, potentially altering workload and affecting job satisfaction [4, 6, 9, 19].

In the Netherlands, a typical surgical team includes a surgeon, an assistant, an anesthesiologist, and two types of intra-operative nurses: scrub and circulating nurses [18, 25]. Scrub nurses work inside the sterile field, assisting the surgeon and ensuring all surgical items are accounted for. Circulating nurses work outside the sterile field, coordinating the team's needs and retrieving supplies. Both types of nurses are responsible for the correct set-up before the procedure [18, 26].

RAS reconfigures the OR layout by positioning the surgeon at a console (see Figure 2)[15, 27]. These consoles aim to improve ergonomics by reducing physical strain on the surgeon's shoulders, elbows, and wrists, thereby enhancing comfort [27]. However, this setup also has potential downsides, such as hindered nonverbal communication and situational awareness. Additionally, the absence of direct haptic feedback may increase the surgeon's cognitive workload[9, 15, 27].

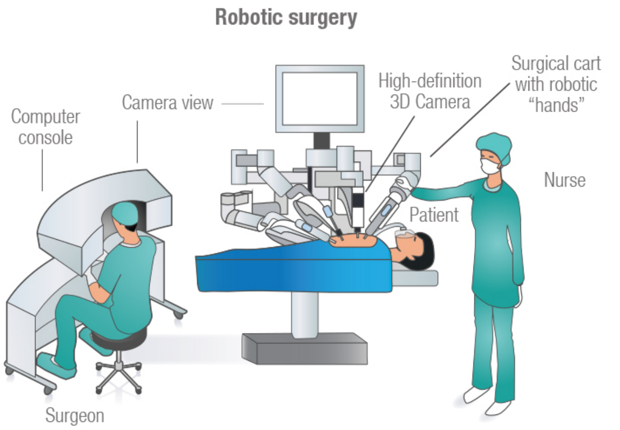

Figure 2: Graphic representation of an operating room during a RAS procedure. The image illustrates the surgeon positioned at the console, separated from the patient, highlighting the spatial arrangement typical of RAS procedures [28].

Other team members, including intra-operative nurses, assistants, and anesthesia providers are faced with new challenges due to the introduction of the robot. For example, the robot arms take up a lot of space and can complicate instrument changes [27, 29]. The addition of the robot can also lead to more distractions due to equipment noises [30]. Furthermore, RAS procedures typically take longer, involve larger team sizes, and utilize more complex equipment compared to open surgeries [31]. Team members may also face new demands beyond their original training [19, 32, 33, 34]. For instance, patient positioning during RAS procedures differs from traditional methods, presenting specific challenges such as preventing patients from sliding in steep Trendelenburg positions [16, 35] and the preparation of correct set-up may be more difficult due to the complex technology [26]. Previous research has also shown that teamwork and effective communication are more essential in RAS procedures compared to open and laparoscopic procedures, further contributing to a possibly elevated workload for the other team members [15, 36, 37].

1.2.1 Phases in Surgery

A typical surgical procedure comprises three distinct phases [38]:

1. **Pre-operative phase** (or anesthetic induction phase): This phase begins with surgery preparation and ends before the initial incision. It focuses on administering anesthesia, positioning the patient, and preparing the surgical team.

2. **Intra-operative phase** (or surgery phase): Starting with the first incision, this phase concludes upon the patient's closure. It includes the core surgical activities.

3. **Post-operative phase** (or anesthetic recovery phase): Involves the patient's recovery from anesthesia, along with operating room cleaning and instrument counting [39].

During different surgical phases, team members encounter varying tasks, which can affect their workload and job satisfaction. For example, intra-operative nurses are responsible for the correct setup before a procedure, and this varies by procedure type, with RAS involving more technology than open surgeries. This added complexity may increase stress during preparation, underscoring the need to evaluate workload and job satisfaction across all three phases [9, 18, 19, 26].

1.3 Goal and Structure

This study aims to bridge the gap in understanding how intra-operative nurses in the Netherlands experience different types of surgery—open, laparoscopic, and robot-assisted surgery—concerning their workload and job satisfaction. It also aims to identify key factors influencing these aspects. Workload and job satisfaction were evaluated across the various phases of surgery: pre-operative, intra-operative, and post-operative, to provide a nuanced understanding of how these factors vary throughout the surgical process.

First, the terms "workload" and "job satisfaction", as well as their interaction and effect on performance, are described to gain a better understanding of these concepts. A multi-method approach is then employed, integrating subjective data from questionnaires and interviews with objective data from hospital records and video analysis. This combination of data sources aims to validate and enhance the insights gained from subjective data.

By evaluating workload and job satisfaction, the study seeks to offer valuable insights into how different surgical methods, particularly RAS, impact intra-operative nurses. The primary goal is to provide a detailed overview of the current situation regarding workload and job satisfaction and to identify key influencing factors. Furthermore, initial recommendations are offered for potential improvements, which could serve as a foundation for future efforts to reduce nurse workload, enhance job satisfaction, and ultimately address the escalating nursing shortage in the Netherlands.

2 Theoretical Framework

2.1 Workload and Job Satisfaction

The concepts of workload and job satisfaction have gained increasing attention in recent research [11, 40]. Workload, a broad term, emerged prominently in the late 1930s with the implementation of the Fair Labor Standards Act, which aimed to optimize worker output by assessing individual workloads. The growing interest in this topic is evident from its rising frequency in academic literature, as illustrated in Figure 3 [11].

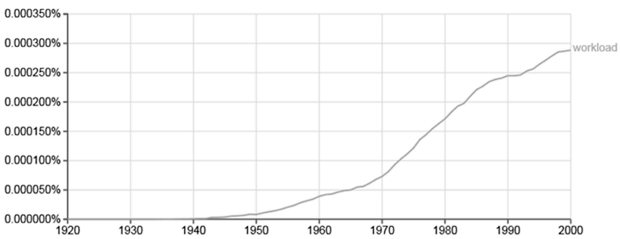

Figure 3: Trend in the Frequency of the Term 'Workload' in English-Language Publications. This graph depicts the growing occurrence of the term 'workload' in academic literature over time, highlighting its increasing prominence in research [11].

A similar trend is observed for job satisfaction. By 1955, over 2,000 articles had been published on this subject, with the number surpassing 4,000 by 1970 [40].

2.1.1 Definitions of Workload and Job Satisfaction

Defining workload presents challenges due to its varied interpretations across studies. Some research offers specific definitions tailored to healthcare settings [10, 11, 41, 42, 43, 44, 45, 46, 47], while other studies propose more general definitions [48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58].

Additionally, some research differentiates between mental (cognitive) and physical workload, while others provide a more generalized view. These components are interrelated; for instance, high mental workload can lead to increased physical strain and vice versa [41, 59, 60].

Longo et al. [48] reviewed numerous definitions of workload and described mental workload as a dynamic, person-specific construct associated with attention and effort. Their review identified 68 different definitions of mental workload, underscoring the complexity of this concept. A table summarizing these definitions is provided in Appendix A.

Based on a synthesis of the literature, the following comprehensive definition of workload is proposed:

> *Workload encompasses both physical and mental demands associated with a task, collectively representing the overall workload. This multidimensional construct is influenced by three key factors: task characteristics, individual attributes, and the environmental context. Mental workload specifically refers to the cognitive effort required for task completion and is closely associated with the stress and emotional experiences encountered during the task. Conversely, physical workload pertains to the bodily strain exerted during task performance. The interaction of these two components contributes to the overall experienced workload.*

In contrast, the definition of job satisfaction is more uniform across the literature. Locke et al. [40] define job satisfaction as:

> *A positive and pleasant emotional state resulting from the subjective perception of one's labor experiences.*

This definition reflects the quality of work life and employees' attitudes towards their jobs. Turgut et al. [34] describe job satisfaction as the emotional response to achieving work-related goals and expectations.

2.1.2 Interaction of Workload and Job Satisfaction

The literature presents mixed results on whether workload impacts job satisfaction or vice versa. Multiple studies [4, 7, 14, 34, 61, 62] indicate that workload has an inverse relationship with job satisfaction. Intense workload among intra-operative nurses likely increases stress, burnout, and anxiety, thereby decreasing job satisfaction.

Rostami et al. [62] specifically explore the association between individual domains of the NASA Task

Load Index (NASA-TLX), a measure used to investigate workload, and job satisfaction. Figure 4 presents a model illustrating the relationship between these variables. Importantly, the model clarifies that job satisfaction reflects the dynamics of individual NASA-TLX domains inversely, signifying that higher mental workload corresponds to lower job satisfaction.

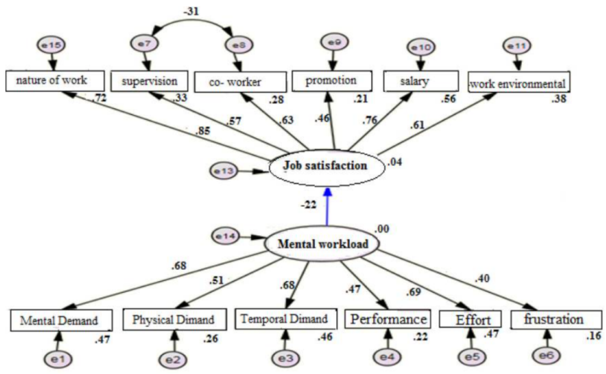

Figure 4: Relationship between individual NASA-TLX domains and job satisfaction. This Figure illustrates the inverse relationship between mental workload and job satisfaction, showing that higher mental workload is associated with lower job satisfaction [62].

2.1.3 Association of Workload and Job Satisfaction with Performance

The interplay between perceived workload, job satisfaction, and job performance is both complex and interdependent. Gotwald et al. [63] describe this relationship through a triangular model, illustrated in Figure 5. This model suggests that job satisfaction influences perceived workload, which, in turn, affects job performance. According to their study, job satisfaction is a crucial factor that shapes perceived workload, ultimately impacting job performance. Turgut et al. [34] emphasize that the quality of patient care is closely tied to the job satisfaction of intra-operative nurses, further underscoring the importance of this triangular relationship.

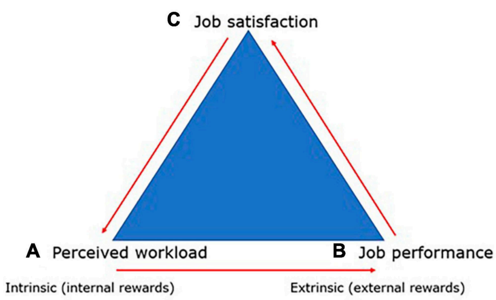

Figure 5: Triangular model depicting the relationship between perceived workload, job satisfaction, and job performance. Job satisfaction influences perceived workload, which subsequently affects job performance [63].

Maintaining an optimal workload balance is crucial for performance, as both underloading and overloading can impair performance, cause attentional lapses, and increase errors. Overloading occurs when task demands exceed cognitive resources, leading to cognitive overload, decreased focus, and potential musculoskeletal disorders, which can also reduce job satisfaction. Conversely, underloading, often due to technological advancements like automation, results in insufficient arousal and resource underutilization, leading to boredom and decreased responsibility [7, 54, 56, 64]. Figure 6 illustrates the interaction between activation level, workload, and performance, highlighting the need for a balanced workload to achieve optimal performance and job satisfaction.

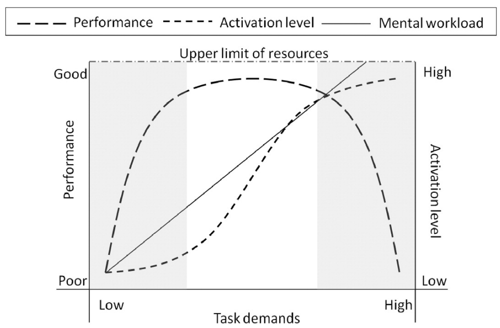

Figure 6: Relationship between activation level, workload, and performance. The Figure shows that performance is optimized when task demands and workload are balanced—not too low and not too high. The activation level exhibits an S-shaped curve, being higher with higher task demands and lower when demands are lower. This Figure also illustrates that both under-activation and over-activation can be detrimental to performance [56].

Together, these figures and concepts highlight the intricate balance required between workload, job satisfaction, and performance. Effective workload management is crucial to maintaining job satisfaction and optimizing performance.

2.2 Factors of Influence on Workload and Job Satisfaction

2.2.1 Individual Factors

Individual characteristics such as age, gender, experience, and education level have been shown to influence both workload and job satisfaction [2, 14, 26]. However, the literature presents mixed findings regarding their effects.

For instance, the impact of age on job satisfaction is inconsistent. Kurtovic et al. [65] found that younger nurses report higher job satisfaction, while other studies [2, 66] suggest that older nurses experience greater job satisfaction. Conversely, Soto et al. [67] discovered that older age is associated with increased mental workload.

The relationship between experience and job satisfaction is also inconclusive. Some studies suggest that greater experience correlates with higher job satisfaction [2, 65, 67], whereas others find no significant relationship between experience and satisfaction [68].

Regarding education, the literature also presents mixed results. Hayes et al. [66] report that higher education positively influences job satisfaction, while Han et al. [14] propose that increased education might decrease satisfaction due to heightened expectations and a broader range of job options.

2.2.2 Task and Circumstance Factors

Team dynamics, including teamwork and nurse-physician relationships, are crucial factors for workload and job satisfaction, with poor cooperation and workplace bullying increasing turnover intentions [6, 14, 26, 69, 70, 71]. Skilled colleagues and experienced surgeons also play a role [71, 72]. The type and duration of surgery can also impact workload, with longer, over-running, and complex procedures increasing workload [15, 72, 73, 74, 75, 76]. Technological issues or equipment failures add to stress and workload, as nurses are responsible for fixing these problems [6, 11, 26, 45, 77, 78, 79]. Environmental factors like noise affect workload and satisfaction, with higher noise levels linked to increased workload and lower satisfaction [6, 11, 69, 77, 80]. Physical demands are another critical factor, with higher physical demands correlating with a greater likelihood of nurses leaving their jobs [9, 14, 81]. Moreover organisational aspects such as long work hours, on-call duties, lack of breaks, exposure to day light, staffing adequacy, and higher salaries can influence job satisfaction [2, 14, 71, 82, 83]. Opportunities for career growth and recognition are also significant, with lack of recognition and support from peers and supervisors leading to higher stress and dissatisfaction [2, 5, 14].

2.3 Measurement of Workload and Job Satisfaction

According to the literature, there are three main categories of tools to measure the experienced workload or job satisfaction: subjective measures, objective physiological measures, and objective performance measures [84, 85].

2.3.1 Subjective Measures

There are multiple subjective measurement methods to evaluate workload and/or job satisfaction. A commonly used method is throught the use of questionnaires such as the NASA Task Load Index (NASA-TLX), the adaptated Surgical Task Load Index (SURG-TLX), The Dundee Stress State Questionnaire (DSSQ), the Rating Scale Mental Effort (RSME) or the Minnesota Job Satisfaction Questionnaire (MJSQ) [10, 54, 55, 84, 86, 87].

The most common method is the NASA-TLX which encompasses six dimensions: mental demand, physical demand, temporal demand, own performance, effort, and frustration [10, 54, 84, 86]. Specifically tailored for surgical procedures, another questionnaire, the SURG-TLX, mirrors NASA-TLX's first three dimensions and introduces three additional ones—task complexity, situational stress, and distraction—more relevant to surgical tasks [87]. Participants in both the NASA-TLX and SURG-TLX rank their perceived levels of workload per domain on a 20-point Likert Scale, where 1 indicates low demands and 20 signifies high demands. The scores can be aggregated and averaged to generate a total score out of 100. Although literature lacks clear benchmarks for what values are considered harmful [88], some studies suggest that surgeons' performance decreases with workloads approaching 50 or higher [89, 90]. Mazur et al. [89] report an increased amount of errors at subjective NASA-TLX scores around 50. Furthermore, physical demand scores over 50 could lead to musculoskeletal injury risks [91].

Moreover, employing interviews with participants has emerged as a pertinent source of information in workload evaluation [36, 45]. The semi-structured format provides space for interviewers to pose improvised follow-up questions and for participants to express themselves comprehensively [92, 93].

2.3.2 Physiological Measures

Workload is associated with changes in bodily processes, making physiological signals an objective method for measuring workload. Commonly used physiological measures in the literature include brain activity through electroencephalography (EEG), heart rate variability through electrocardiogram (ECG), muscle activity through electromyography (EMG), and movement through either inertial measurement units (IMU) or a pedometer [10, 42, 47, 55, 56, 81, 94, 95].

2.3.3 Objective Performance Measures

The final category of workload assessment is performance measures, which focus on an individual's behavior and task execution efficiency rather than directly measuring workload. Studies have shown a trade-off between performance criteria, such as task completion time, and experienced workload [10, 75, 94, 96, 97]. While performance measures provide valuable insights, they may not capture subtle workload variations. Therefore, researchers often combine performance measures with subjective or physiological assessments for a more comprehensive understanding of workload dynamics [84, 98, 99].

In healthcare, surgical outcomes can be used as indicators of workload and job satisfaction. Patient factors such as BMI, blood loss, length of stay, and patient acuity (as measured using the American Society of Anesthesiologists (ASA) classification system) have been linked to variations in workload and job satisfaction [18, 26, 69, 97]. Ugurlu et al. [100] explain that these factors can affect task complexity.

Procedure-specific factors, such as start time, planned duration, and operation time, also impact workload. Longer surgical cases are generally associated with higher levels of workload [26, 72, 73, 74].

Specifically in the context of RAS, factors such as camera movement, energy action, arm swaps, and surgical inactivity are significant workload indicators [97]. Additionally, the number of handoffs between the resident and attending surgeon can serve as a performance measure, indicating skill levels and workload [101].

3 Methods

3.1 Subjective Measures

A combination of questionnaires and semi-structured interviews was used to assess the workload and job satisfaction of intra-operative nurses across three types of procedures: open, laparoscopic, and robot-assisted surgery. The following sections provide a detailed explanation of the chosen measurement methods.

3.1.1 Setting and Particpants

The research was conducted at the Leiden University Medical Center (LUMC) in the Netherlands among intra-operative nurses from March 2024 until July 2024. At the LUMC, while the tasks of scrub and circulating nurses are distinct, the same individuals perform both roles throughout the day and week. The intra-operative nurses coordinate among themselves to decide who will take on which role and when [102]. This study focused on the gynecology department in collaboration with another current study [103].

3.1.2 Questionnaire

Participants completed a two-part questionnaire (see Appendix B) that assessed workload, job satisfaction, and the factors influencing both.

3.1.2.1 Questionnaire Part 1: General Experienced Workload and Job Satisfaction

The first part aimed to understand the overall workload and job satisfaction among participants, regardless of RAS experience. A total of 28 participants from various specializations filled out this section. Demographic information was collected, including gender, age, primary specialization department, general experience, experience with robotic procedures, weekly working hours, and weekly procedure counts for open, laparoscopic, and RAS surgeries.

Participants also responded to a question regarding whether they would recommend their job to their children, scored as 1 ("yes"), 0 ("neutral"), or -1 ("no"), serving as an indicator of job satisfaction [13]. In addition, two open-ended questions asked intra-operative nurses to identify at least three factors influencing their workload and three affecting their job satisfaction. These factors were inductively categorized into main factors and further explored in the interviews.

3.1.2.2 Questionnaire Part 2: SURG-TLX

In the second part, differences in workload and job satisfaction across procedural types and phases were assessed, specifically focusing on participants with RAS experience. Out of the 28 participants who completed Part 1, 19 also completed Part 2. This part utilized the SURG-TLX. The SURG-TLX was selected for its appropriateness, comprehensiveness, ease of use, and relevance.

The SURG-TLX assesses various stressors across six domains: mental demand, physical demand, temporal demand, task complexity, situational stress, and distractions. Recognizing the importance of job satisfaction in relation to workload and intention to leave [4, 34, 62], a seventh domain was added to assess job satisfaction, aiming to provide a comprehensive understanding of subjective workload experiences and job satisfaction.

Participants rated their perceived workload within each SURG-TLX domain using a 20-point Likert scale (1 = low demands, 20 = high demands) for each phase of the three different procedures. This approach was used to identify whether the type of procedure, the phase of the procedure, or an interaction between these factors affected the experienced workload per domain. To emphasize the difference in experienced workload by type of procedure, the procedures were scored per domain and listed beneath each other (see Figure 7 for an example of this scoring for the first domain of the SURG-TLX).

As suggested by literature [104], weighted SURG-TLX scores offer increased sensitivity and accuracy for analysis. Therefore, a pairwise comparison was conducted at the end of Part 2 of the questionnaire to determine if one domain, from the SURG-TLX, was deemed more important for workload than another.

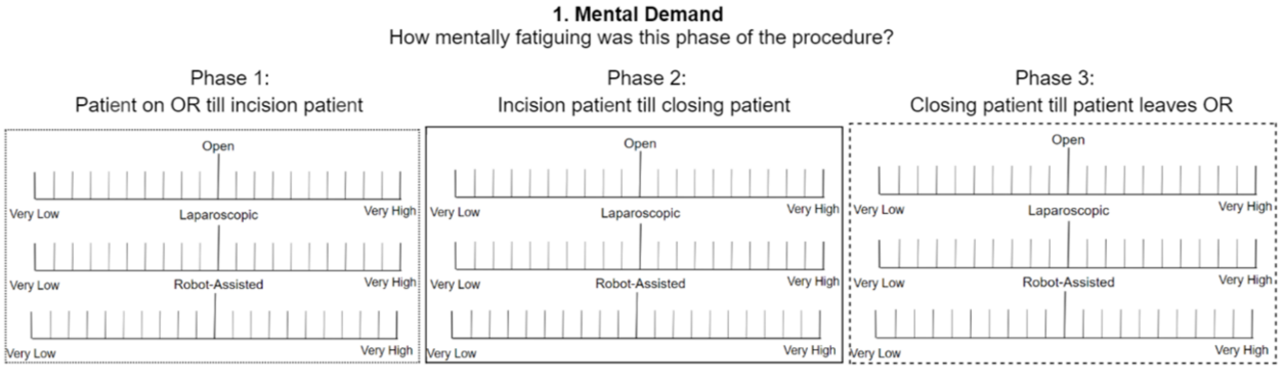

Figure 7: Example of SURG-TLX assessment for the first domain, showing how procedures were scored and listed sequentially to emphasize differences in experienced workload by procedure type.

Since this study introduced a new domain, job satisfaction, which is inversely correlated with workload, the total score was calculated using only the original first six domains. This approach was chosen to align with previous research and enable comparisons with existing literature. The final score was obtained by aggregating and averaging the scores from these six domains and expressed as a score out of 100.

3.1.3 Interviews

In addition to the SURG-TLX assessments, semi-structured interviews were conducted with five intra-operative nurses from the gynecology department who had experience with RAS. The primary objective of these interviews was to validate the questionnaire outcomes and delve deeper into the factors influencing workload and job satisfaction. Additionally, the intra-operative nurses were invited to provide suggestions for future improvements, focusing on both general work aspects and specific aspects of working with the robot, to reduce workload and enhance job satisfaction.

The interviews were held one-to-one and were transcribed with the help of WhisperAI (v20231117)[105], then manually checked by the researcher (C.V.). As it was a semi-structured interview, the questions were predetermined and open-ended (e.g., ”What is important for your experienced workload?”), with probes (e.g., ”How does this differ per type of procedure?”) allowing participants to discuss freely what they wished without losing focus on the research question (see Appendix C for interview questions).

Participants were subsequently asked to rank the SURG-TLX domains from most to least important for their perceived workload. They also ranked the identified categories from the questionnaires twice: once for their influence on workload and once for their impact on job satisfaction. Due to the limited number of participants, these results were analyzed visually.

3.2 Objective Measures

Two types of objective measures were used to complement and validate the findings of the subjective measures: hospital data and video data. These measures are explained in the following sections.

3.2.1 Hospital Data

For 686 gynecological procedures performed at LUMC in 2023, the collected data included the indication for the procedure, time registration stamps in the Healthcare Information eXchange (HiX) system (with corresponding phases outlined in Figure 8), the ASA score of the patient, the emergency classification and the planned duration for the net cutting time (phase 2) [106]. From this data, the following measures were extracted: length of procedure, time in the dark, planned duration, ASA score, and emergency classification.

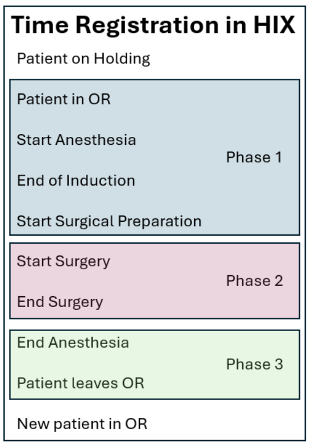

Figure 8: Registered Timestamps in HiX with the corresponding phases

Another datasheet included the staff composition for 622 gynecological procedures in the LUMC in 2023 with its indication. Microsoft Excel (Version 2460) was used to extract the number of people per procedure based on the staff composition.

Each procedure in both datasets was manually classified as open, laparoscopic, or RAS, or excluded if it did not fit into these categories, based on procedural indications and advice of a medical doctor [107]. Procedures were excluded from the analysis if they were too dissimilar to these categories, such as laser treatments or total ruptures, or if their procedural details were unclear, as in research under anesthesia. Vaginal procedures, such as hysteroscopies, were classified as laparoscopic procedures due to the study's focus on comparing three primary types of procedures. Although vaginal procedures differ from laparoscopic procedures in some aspects, they were considered the closest match for this comparison.

Detailed classification information, including the type of indication and the corresponding procedure type, is provided in Table 1.

It is important to note that not all data were available for every procedure. Consequently, analyses involving specific measures included only those procedures for which the relevant data were available. Procedures lacking the necessary data were excluded from those specific analyses. Flowcharts depicting the exclusion process for each measure are provided in Appendix D. The measures extracted from the hospital data are further explained in the following sections.

3.2.1.1 Length of Procedure

The duration of each procedural phase was calculated using timestamps (see Figure 8) in Microsoft Excel (Version 2460). Specifically, phase 1 was defined as the interval from the start of surgery to when the patient is in the OR; phase 2 as the interval from the start of surgery to the end of surgery; and phase 3 as the interval from the end of surgery to when the patient leaves the OR. Procedures were excluded from this analysis if they lacked complete data for the required time stamps needed to calculate the phases.

3.2.1.2 Time in the Dark

Another indirect measure evaluated was the duration that intra-operative nurses worked under dim lighting conditions. Following advice from a medical doctor, the concept of "time in the dark" was defined as the duration of Phase 2 in both laparoscopic and robotic-assisted surgeries. During this phase of those surgical types, dim lighting is used to enhance the surgeon's visibility [107].

3.2.1.3 Planned Duration

Additionally, the planned duration versus the actual duration of the procedures was considered, focusing on the difference between these times. The planned duration was estimated for phase 2 of the procedure [106]. Therefore, the difference was calculated using Microsoft Excel (Version 2460) by subtracting the actual duration of phase 2 from the planned duration.

3.2.1.4 ASA score

The ASA score of each patient was considered as an additional measure. This score indicates patient acuity and can potentially reflect the complexity of the surgical procedure. The ASA score is a subjective as-

Table 1: The Categorization into the three main Procedural Types based on its Indication

Open	Laparoscopic	Robot-Assisted	Excluded
Abdominal Surgery	(Diagnostic) Laparoscopy	Robot-Assisted Surgery	Radical Local Excision
(Exploratory) Laparotomy	Vaginal ...	Da Vinci Robot ..	Conization
(Emergency) Caesarean Section	Hysteroscopic ...		Research Under Anesthesia
Abdominal Hysterectomy + Bilateral Salpingo-Oophorectomy	(Vacuum) Curettage		IVF Puncture
(Interval) Debulking	Ectopic Pregnancy		Laser Treatment
Radical Hysterectomy + Bilateral Salpingo-Oophorectomy	Total Laparoscopic Hysterectomy		Local Excision
Uterus Extraction			Resection dVIN vulva
Radical Hysterectomy + Lymphadenectomy			Manual Placenta Removal
Radical Hysterectomy			Total Rupture
Radical Trachelectomy			Vulvar Mapping
			Spiral Insertion
			Removal of Retained Products
			Vulva/Vagina Resection
			Manual Exploration of the Placenta

sessment of a patient's overall health, categorized into five classes [108]:

1. **ASA 1:** Patient is a completely healthy and fit individual.
2. **ASA 2:** Patient has a mild systemic disease.
3. **ASA 3:** Patient has a severe systemic disease that is not incapacitating.
4. **ASA 4:** Patient has an incapacitating disease that is a constant threat to life.
5. **ASA 5:** A moribund patient who is not expected to live 24 hours, with or without surgery.

Procedures were excluded from this analysis if the ASA score was not available.

3.2.1.5 Emergency Classification

Another measure used for assessing patient acuity was emergency classification. At LUMC, this classification ranges from S1 to S4, with each level indicating the urgency of the surgical intervention required [106]:

- **S1 (Acute):** Requires immediate surgical intervention, ideally within one hour.
- **S2 (Emergency):** Requires surgery within a half-day (up to 8 hours).
- **S3 (Semi-Emergency):** Surgery is needed within a full day (up to 24 hours).
- **S4 (Semi-Elective):** Surgery should be scheduled within the next day or a few days, but not during non-working hours.

Procedures were excluded from this analysis if the emergency score was not available.

3.2.1.6 Number of People in the Room

A separate dataset provided the staff composition for 622 gynecological procedures performed at LUMC in 2023, detailing the indication of the procedures and roles of the personnel present. Microsoft Excel (Version 2460) was used to extract the number of individuals present for each procedure. Since the dataset did not include information on additional observers—those without assigned roles—only the registered personnel with specific functions were analyzed. The specific roles of these individuals were not considered in this analysis.

3.2.2 Video Data

A total of 35 gynecological procedures, including open, laparoscopic, and RAS, were recorded at LUMC. These recordings were analyzed using a specially developed algorithm [103]. The primary aim of this algorithm was to provide insights into the movement and interactions with the operating table of all personnel during different types of procedures. This effort marks an initial exploration towards utilizing video analysis for objective assessment of workload.

The algorithm tracked key anatomical points on each person in the OR, such as the eyes, knees, and hips, allowing for precise monitoring of their positions throughout the procedures. By analyzing these positional changes, the algorithm calculated two main metrics: Movement Score and Interaction with Operating Table Score. Pose detection was preferred over the bounding boxes method for its ability to track specific body parts, offering greater accuracy in understanding how personnel move and interact with the operating table. Unlike bounding boxes, which can be misleading due to camera angles, pose detection ensures more precise monitoring of true spatial relationships and movements, making it better suited for the complex and dynamic OR environment.

The data were averaged across all personnel involved in each procedure, with each individual contributing equally to the metrics. This approach provided information on all personnel present, including, but not limited to, intra-operative nurses.

Further details on the video analysis, including figures illustrating how key points were defined and the area closest to the operating table, are provided in the Appendix E.

3.2.2.1 Movement Score

The Movement Score represented the percentage of total procedure time during which individuals moved at speeds exceeding a specified threshold. This score was derived from changes in the positions of key anatomical points, with greater emphasis placed on movements of the legs, hips, and head, rather than wrist and arm movements. Consequently, activities involving smaller movements, such as instrument handovers, were not specifically captured by the algorithm. Instead, the Movement Score focused on broader movement patterns, providing an initial indication of personnel activity levels during the procedure.

3.2.2.2 Interaction with Operating Table Score

The Interaction with Operating Table Score measures the percentage of the procedure time that personnel were near the operating table. This metric provides insight into how frequently personnel were near the operating table, which could potentially suggest their level of involvement during the procedure

3.3 Ethics

Approval for this research was obtained from the Human Research Ethics Committee (HREC) on March 25, 2024, under application number 3822.

3.4 Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics (Version 29.0.0.0 (241)) to determine the statistical significance of the findings.

3.4.1 Subjective Measures

3.4.1.1 Questionnaire Analysis

Spearman's rank correlation coefficient was used to examine associations between participants' demographic characteristics and their likelihood of recommending their job to their children.

For the SURG-TLX outcomes, a Two-Way ANOVA was performed for each domain to test whether there were effects on the score due to the type of procedure, phase of the procedure, or an interaction between these two factors. If a statistically significant result was found ($p < 0.05$), a Bonferroni post-hoc test was conducted to identify the specific significant differences.

A non-parametric Friedman test was performed on the data to assess whether there were statistically significant differences in the importance of the SURG-TLX domains. If the Friedman test indicated a statistically significant difference ($p < 0.05$), post-hoc analysis using the Nemenyi test was conducted to identify which specific domains differed from each other. If the Friedman test did not show statistically significant differences ($p \geq 0.05$), all SURG-TLX domains were considered equally important and were assigned equal weights for calculating the total score.

3.4.2 Objective Measures

3.4.2.1 Hospital Data

To determine if the length of the procedure (numerical data) differed significantly based on the type of procedure, a One-Way ANOVA was conducted. This analysis was also used to assess differences in the three types of procedures between the planned and actual duration of procedures as well as the number of people present in the room during a procedure. When the One-Way ANOVA indicated significant results ($p < 0.05$), the Bonferroni post-hoc test was used to identify specific significant differences.

For ASA scores and emergency classifications (categorical data), the Chi-Squared test was first used to assess differences in classification frequencies across procedure types. Subsequently, the Mann-Whitney test was applied to examine whether ASA scores or emergency classifications differed significantly between types of procedures.

3.4.2.2 Video Data

Movement Scores and Interaction With the Operating Table scores were quantified as percentages. To assess whether these scores differed significantly based on the type of procedure, a One-Way ANOVA was conducted. This analysis compared the Movement Score and Interaction Score of the OR personnel across the different procedure types (open, laparoscopic, and RAS). When the One-Way ANOVA indicated significant differences ($p < 0.05$), a Bonferroni post-hoc test was applied to identify the specific procedure types between which statistically significant differences existed.

4 Subjective Results

4.1 Evaluation of Current Workload and Job Satisfaction

4.1.1 Questionnaire

28 intra-operative nurses completed the first part of the questionnaire. Their demographic data is shown in Table 2. The average score for recommending the job to their children was 0.3571 (Standard Deviation, $SD = 0.67847$), reflecting a slight positive tendency with some variability. Moreover, Spearman's rank correlation revealed a negative association between the age of intra-operative nurses (-0.426, $p = 0.024$) and their overall experience (-0.494, $p = 0.007$) with their tendency to recommend the job to their children. No statistically significant correlations were found between their experience with RAS, weekly working hours, or the number of open, laparoscopic, or RAS procedures performed per week and their likelihood to recommend their job (all $p > 0.05$).

Table 2: Demographic data of the participants

Characteristic	Mean	SD	Min	Max
Number of Women	26 (93%)	-	-	-
Age (years)	36.4	5.2	25	50
General Experience (years)	14.18	9.92	1	40
Experience with RAS (years)	4.19	2.76	0	10
Work Hours per Week	30.71	4.30	24	36

Since many intra-operative nurses selected multiple specializations in the questionnaires rather than just their primary one, the impact of specializations on workload and job satisfaction was not analyzed in this study.

4.1.2 SURG-TLX

The Two-Way ANOVA analysis revealed that the type of procedure had a statistically significant effect on four SURG-TLX domains:

- **Mental Demand**: RAS procedures were scored higher on mental demand than laparoscopic procedures ($p = 0.023$).
- **Temporal Demand**: RAS procedures were scored higher than both open ($p < 0.001$) and laparoscopic procedures ($p < 0.001$).
- **Distractions**: RAS procedures received higher scores than open procedures ($p = 0.030$).
- **Job Satisfaction**: Open procedures showed higher job satisfaction scores than laparoscopic ($p = 0.023$) and RAS procedures ($p = 0.001$).

No statistically significant differences were found in the physical demand, task complexity, and situational stress domains between the three types of procedures (all $p > 0.05$).

In Figure 9 the boxplot for the total SURG-TLX score (score phase 1 + score phase 2 + score phase 3) for the three different types of procedures is depicted.

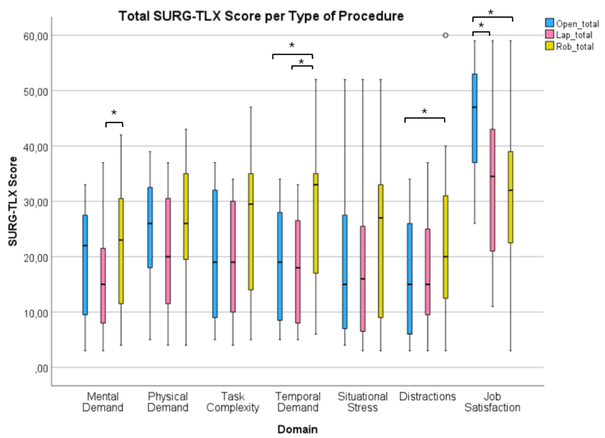

Figure 9: Boxplot showing the SURG-TLX scores for each surgical procedure type: open, laparoscopic, RAS. The scores are calculated by summing the scores for each procedure across all phases (phase 1, phase 2, phase 3). This Figure highlights the differences in perceived workload and job satisfaction across the three procedure types, with asterisks denoting statistically significant differences.

For the effect of phase on the SURG-TLX score, a statistically significant difference was found in the mental demand domain. Specifically, in phase 2 (intra-operative) higher scores were noted compared to phase 1 (preparation phase) ($p = 0.033$). In Figure 10 the total SURG-TLX scores (score open + score lap + score RAS) for the three different phases are depicted.

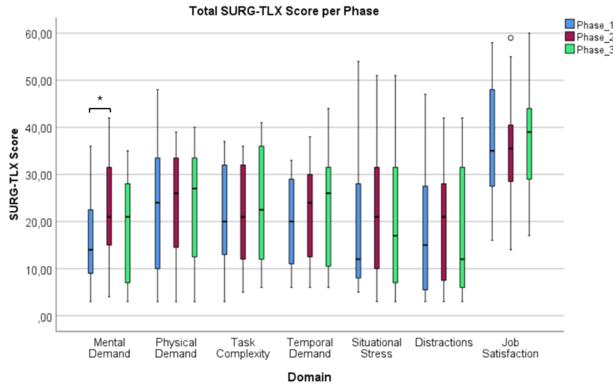

Figure 10: Boxplot showing the SURG-TLX scores for each surgical phase: phase 1, phase 2, and phase 3. The scores are calculated by summing the scores for each phase across all procedure types (open, laparoscopic, and RAS). This Figure highlights the differences in perceived workload and job satisfaction across the three phases of the surgery, with asterisks denoting statistically significant differences.

No statistically significant differences were found for the interaction effect in the domains.

In Appendix F, boxplots are presented for the SURG-TLX scores for each phase across the different procedures, as well as for each procedure type across the different phases.

4.1.3 Importance of Individual Domains

Figure 11 illustrates the aggregated scores for each SURG-TLX domain based on the pairwise comparisons. The Friedman test revealed no statistically significant differences in the importance of the SURG-TLX domains on workload ($p = 0.813$).

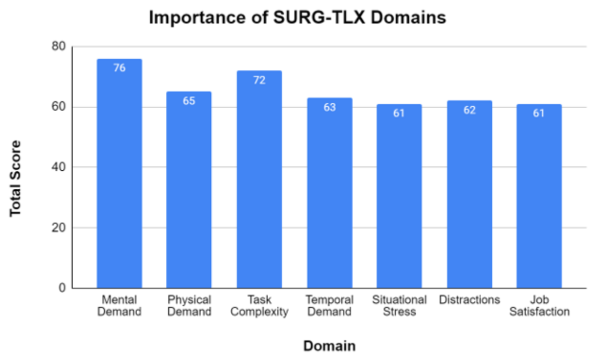

Figure 11: Importance of SURG-TLX Domains on Workload: Analysis Based on Pairwise Comparison. This figure illustrates minimal differences between the total scores per domain

Figure 12 represents the responses of the interview participants who were asked to rank the domains from most to least important. Visual inspection indicated that task complexity and situational stress seemed most influential on workload, whereas job satisfaction seemed to have the least impact.

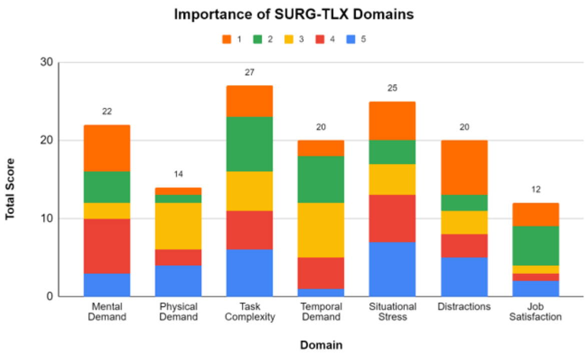

Figure 12: Importance of SURG-TLX Domains on Workload: Analysis Based on Interview Ranking. The numbers indicate the responses of individual participants

Given the lack of statistically significant differences among the domains, the total score was calculated without weighting. Table 3 presents the average score for each domain (out of 20) and the total score (out of 100). On average, intra-operative nurses had a total workload score of 34.58. RAS procedures had the highest total workload score (40.82), followed by open procedures (32.60), and laparoscopic procedures (30.32).

4.2 Factors of Influence

Using inductive categorization, the factors identified by the 28 participants were grouped into seven main categories. These factors are considered influential on both workload and/or job satisfaction. Figure 13 illustrates a sunburst diagram depicting the main categories, their respective subcategories, and their relative importance. Additionally, a bar chart showing the importance of each main factor for both workload and job satisfaction is included in Appendix F.

Table 3: Average Score Per Domain (Out of 20)

	Open Procedures	Laparoscopic Procedures	RAS Procedures	In Total
Mental Demand	6.32	5.33	7.53	6.39
Physical Demand	8.23	6.86	8.40	7.83
Task Complexity	6.75	6.56	8.46	7.26
Temporal Demand	6.14	5.98	9.19	7.11
Situational Stress	6.30	6.04	7.72	6.68
Distractions	5.39	5.61	7.68	6.23
Job Satisfaction	15.49	11.51	10.65	12.55
Total Score *	32.60	30.32	40.82	34.58

The Total Score, out of 100, is calculated by averaging the scores from the first six domains, excluding Job Satisfaction, to facilitate comparison with previous studies.

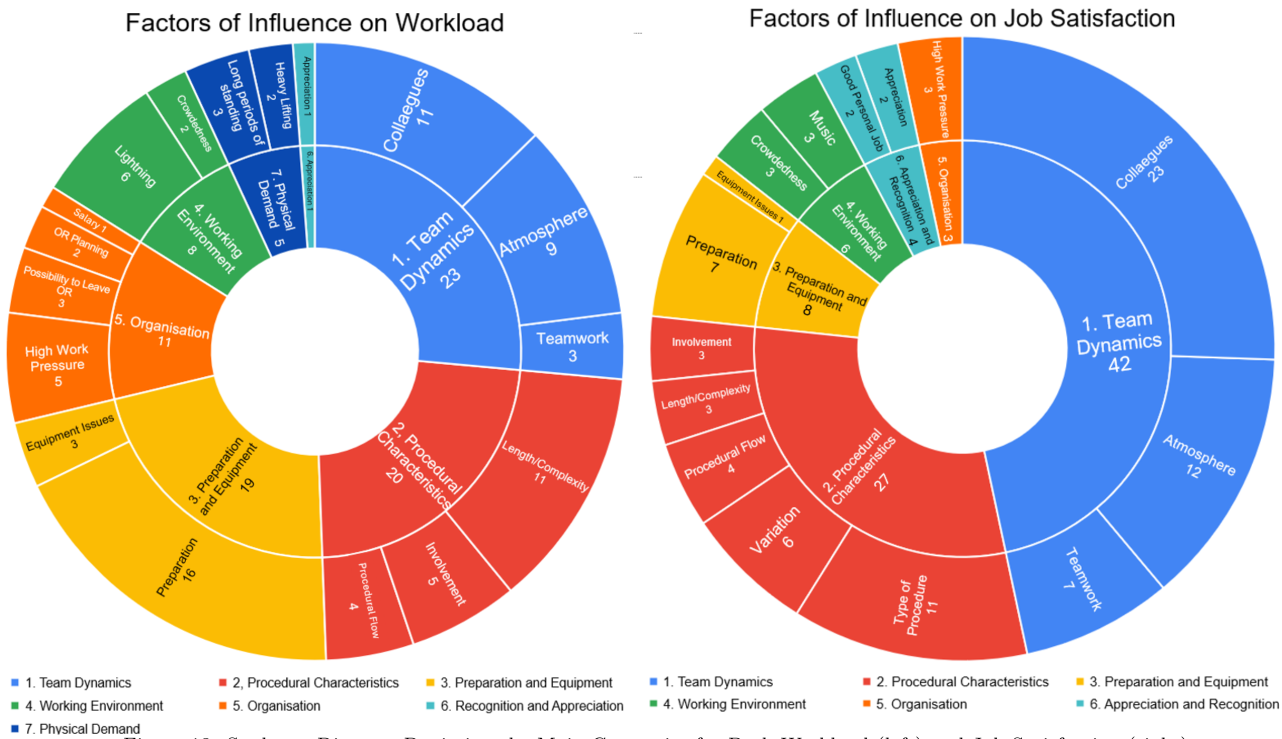

Figure 13: Sunburst Diagram Depicting the Main Categories for Both Workload (left) and Job Satisfaction (right)

4.2.1 Factor 1: Team Dynamics

The questionnaires revealed that team dynamics significantly impact the workload (N=23) and job satisfaction (N=42) of intra-operative nurses. This category includes several factors, which are discussed below.

4.2.1.1 Colleagues

Colleagues play a vital role in perceived workload (N=11) and job satisfaction (N=23), as noted by the intra-operative nurses in the questionnaires. Some respondents specified that colleagues should be skilled and competent for both job satisfaction and workload, while others emphasized the importance of colleagues being pleasant to work with.

During the interviews, multiple nurses highlighted the importance of having skilled direct colleagues and how this affected their workload. Intra-operative nurses stated that working with students or temporary staff increases their workload:

> *"Sometimes you have a colleague who often works in the same specialism, and then you only need a few words to understand each other. You can have pleasant conversations, it's all fun, and jokes are made. But sometimes you're with a colleague where you have to explain everything or ask five times and that is more exhausting."*

Some intra-operative nurses also distinguished between their direct coworkers, the other intra-operative nurses, and other team members, like surgeons. The personality of a surgeon was influential on workload and job satisfaction for multiple intra-operative nurses. Moreover, two of them underlined the importance of having a capable surgeon as this decreased their perceived workload. This was reiterated by another intra-operative nurse in the interviews, who emphasized the surgeon's capabilities as a key factor in team dynamics.

4.2.1.2 Atmosphere

The atmosphere was also considered an important aspect of team dynamics, as noted by intra-operative nurses in the questionnaires as influencing workload (N=9) and job satisfaction (N=12). During the interviews, one intra-operative nurse elaborated that a good atmosphere is usually evident when procedures run smoothly with minimal complications.

Moreover, multiple intra-operative nurses noted that the personality of the surgeon had the most influence on the atmosphere, which varies among different specializations, as certain specialists naturally gravitate towards certain cultures, as stated during the interviews:

> *"Well, certain specialists also choose a certain culture. And you generally choose that culture. One culture is a bit harsher, and the other is softer and more sociable. There is definitely a difference."*

Consequently, there are substantial differences in the atmosphere among various specializations. For instance, gynecology and ophthalmology were described as having a more friendly atmosphere, while thoracic surgery and general surgery, were described as having a less approachable environment.

4.2.1.3 Teamwork

Teamwork was highlighted as considerably influencing the experienced workload (N=3) and job satisfaction (N=7) in the questionnaires. During the interviews, some intra-operative nurses also emphasized the importance of smooth teamwork for lower levels of perceived workload and higher levels of job satisfaction.

4.2.2 Factor 2: Procedural Characteristics

The characteristics of a procedure were also noted to influence both experienced workload (N=27) and job satisfaction (N=20) in the questionnaires. Key aspects under this factor include the type of procedure, its complexity or duration, procedural flow, level of involvement, and variation.

4.2.2.1 Procedure Type

The type of procedure affects the experienced workload and job satisfaction (N=11) of intra-operative nurses as stated in the questionnaires and reiterated in the interviews.

In the interviews, participants reported the highest job satisfaction during open abdominal surgeries compared to laparoscopic or RAS surgeries. They noted that open surgeries offer more tasks and active participation, which contribute to greater job satisfaction:

> *"Open abdominal surgeries are much more enjoyable than robot and laparoscopic surgeries. They are more challenging for us because you can think along, stay busy, and keep moving. And it's just fun to be actively engaged, in my opinion."*

4.2.2.2 Complexity or Duration

Additionally, the complexity or length of a procedure could influence experienced workload (N=11) and job satisfaction (N=3). During the interviews, several intra-operative nurses explained that more complex procedures are often more enjoyable for them as these require more equipment and keep them busier, thus increasing their job satisfaction. However, job satisfaction could decrease, and workload could increase if a procedure was too complex due to their lack of knowledge or if a surgeon was stressed due to the complexity.

The duration of a procedure was noted to influence workload, especially in cases where there is little to do for the intra-operative nurses. This is particularly true during phase 2 of RAS, as emphasized by one intra-operative nurse during the interviews:

> *"Once the robot is set up and running, the surgeon is busy with the robot, and we have nothing more to do. There's not much needed then. You end up sitting still for hours."*

4.2.2.3 Procedure Flow

The procedural flow could also impact the experienced workload (N=4) and job satisfaction (N=4) of intra-operative nurses. Smooth procedures are associated with a lower workload and higher job satisfaction. Conversely, chaotic and stressful procedures tend to increase workload and decrease job satisfaction.

4.2.2.4 Involvement

Involvement during procedures can also influence experienced workload (N=5) and job satisfaction (N=3). Interviews revealed that, particularly during phase 2 of RAS procedures, intra-operative nurses often have fewer tasks, which can diminish their sense of involvement and increase their perceived workload. It was noted that, in the gynecology department, they are not permitted to change the robotic arms, unlike in other specialties, which further reduces their involvement. Additionally, difficulties in clearly viewing screens during laparoscopy and RAS procedures were reported, contributing to a diminished sense of engagement.

Additionally, two intra-operative nurses noted that feeling truly involved requires sufficient knowledge of procedures and equipment to contribute effectively and anticipate needs.

4.2.2.5 Variation

Six intra-operative nurses mentioned that the variation between procedures influenced their job satisfaction. This was confirmed during interviews, where they explained that having a mix of more demanding procedures, which require active involvement, and less intense procedures, which offer a moment of rest, is preferable. During the interviews, one intra-operative nurse mentioned that laparoscopic procedures can offer a moment of rest.

However, intra-operative nurses also highlighted the challenges of working across multiple specialties and managing rotating shifts, which can increase their workload. One intra-operative nurse explained that within their cluster, there are seven different specializations, and they need to be knowledgeable in all of these. The difficulty of maintaining proficiency across so many areas can heighten stress levels and, consequently, increase the overall workload.

4.2.3 Factor 3: Preparation and Equipment

Preparation and equipment were considered influential on the experienced workload (N=19) and job satisfaction (N=8) of intra-operative nurses.

4.2.3.1 Preparation

Many intra-operative nurses (N=16 for workload and N=7 for job satisfaction) indicated that inadequate preparation increased their experienced workload and decreased their job satisfaction. Some of them distinguished poor preparation as a specific indicator of workload, mentioning not having a clear plan beforehand or an incomplete setup, while others simply mentioned preparation as a factor in the questionnaires.

During the interviews, it was noted that insufficient preparation particularly affects circulating nurses, who often need to retrieve additional equipment when the initial setup is incomplete.

Moreover, when the plan is not clear beforehand, this could also elevate workload levels. During the interview, one intra-operative nurse stated:

> *"Or they say at the last minute, 'Yes, we thought about it last night, and we decided to do this and that for the patient.' Then you have to rebuild your whole cart to have everything you need and put away the other stuff. That causes a lot of unrest for us before we've even started."*

The amount of preparation also varied by procedure type. Some intra-operative nurses noted that RAS procedures require significantly more preparation compared to open or laparoscopic procedures. As one intra-operative nurse explained:

> *"The preparation for RAS procedures is more than for an open or laparoscopic procedure. I find starting with the robot really involves a lot—a lot of equipment, many people in the room, a lot of devices, complicated."*

4.2.3.2 Equipment Issues

Problems with technology and non-functioning equipment emerged as another factor in questionnaires, with several intra-operative nurses reporting increased workload (N=3) and decreased job satisfaction (N=1) due to these issues. Specifically, one intra-operative nurse highlighted frequent technical failures during RAS procedures, which escalate stress and elevate workload levels due to inadequate training to address these problems. She noted:

> *"It happens quite regularly with a robot that something breaks. In an open procedure, we can fix technical issues quickly. But with the robot, there is so much technology that we can't solve it. I'm not a technician."*

Additionally, other intra-operative nurses reported that malfunctioning equipment consistently increases their workload. Multiple interviewees confirmed this, citing specific devices that frequently fail, which heightens their stress, elevates workload and decreases job satisfaction.

4.2.4 Factor 4: Working Environment

The working environment is another factor influencing workload (N=8) and job satisfaction (N=6). The working environment entails the level lighting, amount of sounds, and the crowdedness of the room.

4.2.4.1 Lighting

The level of lighting in the operating room can also affect workload. Six intra-operative nurses noted in the questionnaires that the dim lighting during phase 2 of laparoscopic and RAS procedures increased their workload, as they preferred not to work in low-light conditions all day. This observation was also confirmed in the interviews.

4.2.4.2 Sounds

The impact of sounds during a procedure encompasses both background noise and the presence of a radio or music. According to the questionnaires, three intra-operative nurses indicated that having a radio or music could enhance their job satisfaction, while others felt it increased their workload by introducing additional distractions. Interviews revealed that the decision to play music during procedures is typically made by the surgeon, often without consulting other team members. This lack of consultation can sometimes lead to frustration among intra-operative nurses. Moreover, background noises, such as equipment sounds, were noted to contribute to fatigue and elevated workload levels. One nurse described the effect of constant noise:

> *"Sounds are irritating, whether it's people talking a lot or the equipment humming and buzzing all day. It can make me very tired."*

4.2.4.3 Crowdedness

Crowdedness in the operating room is another factor affecting workload (N=2) and job satisfaction (N=3). Factors contributing to crowdedness include additional (technological) equipment, extra personnel, and observers without assigned roles,

During the interviews, it was emphasized that the number of people in the room significantly impacts its crowdedness and consequently influences workload. The maximum number of individuals allowed in the OR in the LUMC during a procedure is currently 12 or 13, which some intra-operative nurses consider to be quite high. One intra-operative nurse highlighted that RAS procedures often involve more people, including observers without assigned tasks, which alters the dynamics. The presence of additional observers necessitates heightened vigilance to maintain sterility, further increasing workload. Additionally, having more people in the room can lead to more conversations which can create more distractions and thereby increase the experienced workload.

Moreover, limited space for movement due to the volume of equipment and technology required for certain procedures can be frustrating. Several intra-operative nurses pointed out that RAS procedures, in particular, result in a more cramped environment because of the extensive equipment needed.

> *"During RAS procedures, the room is very full because there is just more equipment—more of everything. Yes, laparoscopic procedures are also quite crowded, but with the robot, it is a very cramped room."*

4.2.5 Factor 5: Organization

Some intra-operative nurses mentioned various organizational aspects that significantly influence their workload (N=11) or their job satisfaction (N=3). These organizational aspects encompass multiple subcategories.

4.2.5.1 OR Planning

In the questionnaires, OR planning was noted to influence workload for two intra-operative nurses. During interviews, intra-operative nurses elaborated that poor OR planning could involve inadequate break times, inconvenient timing of procedures, or inadequate spatial planning.

One intra-operative nurse further mentioned the challenge of short breaks due to the restroom being far away, resulting in effectively shorter breaks. Moreover, inconvenient timing of procedures can lead to increased workload:

> *"If we have to switch between different types of surgeries like laparoscopic, RAS, and then laparoscopic again, it becomes very inconvenient. Each change requires extra preparation, elevating workload."*

Furthermore, OR scheduling can be inconvenient when surgeries are performed in rooms not equipped for specific specialties. This can increase workload as each OR room is designed for particular types of procedures.

4.2.5.2 High Work Pressure

High work pressure was identified as a factor increasing workload by five intra-operative nurses and influencing job satisfaction by three intra-operative nurses in the questionnaires. It can result from staff shortages, which necessitate increased responsibilities such as managing protocols that don't align, or the need to perform procedures quickly.

4.2.5.3 Salary

One intra-operative nurse indicated that salary could influence her workload. Recently, many intra-operative nurses have left their positions for agency work where they perform the same duties but earn more. During the interviews, some intra-operative nurses mentioned that this trend is particularly noticeable among younger intra-operative nurs

4.2.5.4 Ability to Leave the Room

The ability to leave the room during a procedure was noted to influence workload for three intra-operative nurses in the questionnaires. One intra-operative nurse elaborated on this during the interviews, explaining that it allows for more breaks and the opportunity to use the restroom more frequently.

4.2.6 Factor 6: Appreciation and Recognition

Appreciation and recognition were highlighted as important factors affecting both workload (N=1) and job satisfaction (N=4) in the questionnaires.

4.2.6.1 Appreciation

The need for appreciation was highlighted in the questionnaires, affecting both workload (N=1) and job satisfaction (N=2). During interviews, intra-operative nurses emphasized the importance of being acknowledged for their contributions. One nurse shared:

> *"It makes a big difference if, at the end of the day, everyone is thanked for their hard work as a team. A simple 'Hey guys, we worked really hard together today, thank you so much' can have a large impact."*

Furthermore, some intra-operative nurses observed that the level of recognition varies greatly depending on the specialization. There were reports of some specialists not fully acknowledging the intra-operative nurses' efforts, with occasional instances of less supportive remarks. For example, one specialist once commented about their work:

> *"Even a monkey could learn to do that."*

4.2.6.2 Personal Satisfaction

Personal satisfaction with one's work was also noted to influence job satisfaction (N=2) in the questionnaires. Multiple intra-operative nurses stated that feeling actively involved in and contributing to procedures enhances their job satisfaction.

4.2.7 Factor 7: Physical Demand

In the questionnaires, five intra-operative nurses mentioned physical demand as a contributing factor to workload.

4.2.7.1 Prolonged Standing

Some intra-operative nurses elaborated on the physical demands, noting that prolonged periods of standing can significantly increase their workload (N=3), especially when coupled with periods of inactivity. One intra-operative nurse specifically described how the experienced physical demand differs across procedures:

> *"During RAS, you sit a lot. With laparoscopy that often doesn't take long, so you stand a bit shorter generally. Open surgery generally means standing longer, but you hardly notice it because the work is so engaging."*

Another intra-operative nurse explained that physical demands vary depending on their role during a procedure, whether as a scrub nurse (more sitting) or as a circulating nurse (more active, particularly during RAS procedures involving connecting cables).

Moreover, during interviews, two intra-operative nurses noted that age could influence physical demand, with older nurses feeling more physically tired by the end of the day.

4.2.7.2 Heavy Lifting

Heavy lifting was another significant aspect of physical demand affecting workload, as highlighted by two intra-operative nurses in the questionnaires. They noted that handling equipment during RAS procedures, particularly during the setup and cleanup phases, involves substantial physical effort:

> *"We often need to move heavy equipment into place and clean up afterwards. These machines are quite heavy, so it's physically demanding."*

4.3 Importance of Factors

Regarding the factors identified in the questionnaire, procedural characteristics were ranked as the most influential for workload, with team dynamics closely following, according to the intra-operative nurses interviewed. For job satisfaction, team dynamics emerged as the most influential factor. Physical demand was considered the least important factor for both workload and job satisfaction (see Figure 14)

5 Objective Results

5.1 Hospital Data

5.1.1 Length of Procedure

The first objective measure considered was the length of the procedure. In Table 4 the type of procedure and its length are depicted. After excluding the procedures that did not have the corresponding information, it was revealed that laparoscopic procedures are the most frequent (272), followed by open procedures (159), and RAS procedures (27).

From the One-Way ANOVA, it became clear that laparoscopic procedures have a shorter operating time than both open and RAS procedures in phase 1 with respective Mean Differences (MD) of 19.90 and 17.11 minutes (min), phase 2 ($MD = 102.54$ min, $MD = 116.92$ min), and in total time ($MD = 123.04$ min; $MD = 135.98$ min) (all $p < 0.001$). No significant differences were found in the length of time between open and RAS procedures.

5.1.2 Time in the Dark

In both laparoscopic and RAS procedures, Phase 2 involves dim lighting conditions, making the duration of "time in the dark" equivalent to the length of Phase 2 for these procedures. The One-Way ANOVA indicated that RAS procedures had a significantly longer Phase 2 compared to laparoscopic procedures ($p < 0.001$), resulting in a longer "time in the dark" during RAS procedures.

5.1.3 Planned Duration

Additionally, the planned duration versus the actual duration of the procedures was considered, focusing on the difference between these times. The One-Way ANOVA results indicated that open procedures are often shorter than planned ($N = 148$; $M = -13.32, SD = 59.09$) when compared to laparoscopic procedures ($N = 236$; $M = -1.66; SD = 29.26$) ($p = 0.037$). RAS procedures, on the other hand, are the only type that generally take longer than the planned duration ($N = 27$; $M = 6.26; SD = 66.75$). See Table 4.

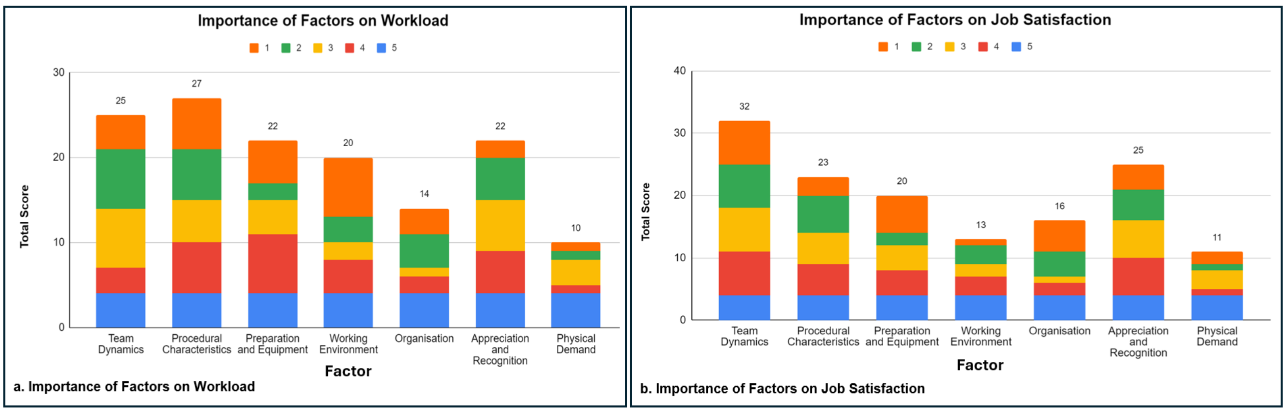

Figure 14: Importance of Identified Factors on a. Workload (left) and b. Job Satisfaction (right): Analysis Based on Interview Ranking. The numbers indicate the responses of individual participants

Table 4: Duration metrics by procedural type, showing average duration with Standard Deviation and Confidence Interval (in minutes)

	Open Procedures	Laparoscopic Procedures	RAS Procedures
Total Duration [min]	236.47 ± 113.96 (CI: 218.62 – 254.31)	113.42 ± 65.10 (CI: 105.65 – 121.19)	249.41 ± 74.61 (CI: 219.89 – 278.92)
Duration Phase 1 [min]	51.94 ± 23.50 (CI: 48.26 – 55.62)	32.04 ± 17.69 (CI: 29.93 – 34.15)	49.15 ± 13.52 (CI: 43.80 – 54.50)
Duration Phase 2 [min]	174.10 ± 94.85 (CI: 159.24 – 188.96)	71.56 ± 55.60 (CI: 64.92 – 78.20)	188.48 ± 70.65 (CI: 160.53 – 216.43)
Duration Phase 3 [min]	10.43 ± 8.25 (CI: 9.14 – 11.72)	9.83 ± 6.83 (CI: 9.01 – 10.64)	11.78 ± 6.78 (CI: 9.10 – 14.46)
Difference with Planned Duration [min]	-13.32 ± 59.09 (CI: -22.92 – -3.72)	-1.66 ± 29.26 (CI: -5.41 – 2.10)	6.26 ± 66.75 (CI: -20.15 – 32.66)

5.1.4 ASA Score

Data about the ASA score of the patient was available for 180 open procedures, 304 laparoscopic procedures, and 27 RAS procedures.

A Chi-Squared test revealed a statistically significant association between ASA score and type of procedure ($p < 0.001$). Specifically, patients with higher ASA scores, particularly ASA 3, underwent open surgery more frequently. In contrast, patients with lower ASA scores, especially ASA 1, were more commonly treated with RAS. Laparoscopic procedures displayed a relatively even distribution of ASA scores.

The Mann-Whitney test further confirmed these findings. Open procedures were significantly associated with higher ASA scores ($M = 2.01, SD = 0.68$) compared to both laparoscopic procedures ($M = 1.74$; $SD = 0.61$) ($p < 0.001$) and RAS procedures ($M = 1.40; SD = 0.50$) ($p < 0.001$). Additionally, laparoscopic procedures had significantly higher ASA scores than RAS procedures ($p = 0.007$).

The mean ASA classification scores per type of procedure are shown in Table 5.

5.1.5 Emergency Classification

Data about the emergency classification score of the patient was available for 21 open procedures and 74 laparoscopic procedures. No emergency classification data was available for any of the RAS procedures.

The Chi-Squared test indicated that S1 procedures, representing the highest emergency classification, were more frequently performed via open surgery compared to laparoscopic surgery ($p < 0.001$).

The Mann-Whitney test further confirmed these findings, showing a significant association between open procedures and higher emergency scores ($M = 1.19; SD = 0.40$) compared to laparoscopic procedures ($M = 1.86; SD$ 0.51) ($p < 0,001$). The emergency scores per type of procedure are shown in Table 5.

5.1.6 Number of People

The analysis concerning the number of people with function present involved data from 148 open procedures, 279 laparoscopic procedures, and 25 RAS procedures. The One-Way ANOVA revealed a statistically significant difference in the number of people present based on the type of procedure. Specifically, there were more people in the room during open procedures ($M = 11.08; SD = 2.39$) and RAS procedures ($M = 10.90; SD = 2.29$) compared to laparoscopic procedures ($M = 9.46; SD = 2.66$). The mean differences in the number of people were 1.62 ($p < 0.001$) and 1.34 ($p = 0.038$), respectively. No statistically significant difference was found between the number of people in the room during open and RAS procedures. In Table 5, the mean number of people in the room, along with the standard deviation and confidence interval, is depicted.

5.2 Video Data

In total 35 surgical procedures were recorded, comprising 4 open surgeries, 25 laparoscopic surgeries, and 6 RAS procedures.

5.2.1 Movement Score

The average movement scores varied across the different types of procedures: 1.90% for open surgeries, 2.50% for laparoscopic surgeries, and 0.87% for RAS (see Table 6). A One-Way ANOVA revealed a statistically significant difference in movement scores between laparoscopic and RAS procedures, with laparoscopic procedures exhibiting more movement ($MD = 1.63$, $p = 0.018$). Figure 15 presents a boxplot of these data, with asterisks indicating statistically significant differences.

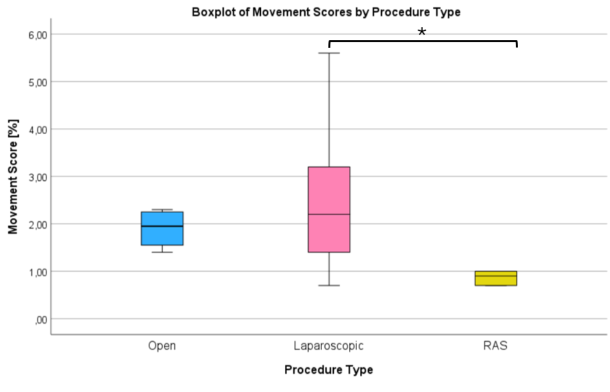

Figure 15: Boxplot showing the movement scores for each surgical procedure type: open, laparoscopic, RAS. This Figure highlights the differences in movement scores across the three procedure types, with asterisks denoting statistically significant differences.

Table 5: Additional metrics by procedural type, showing its average value with Standard Deviation and Confidence Interval

	Open Procedures	Laparoscopic Procedures	RAS Procedures
ASA Score	2.01 ± 0.68 (CI: 1,89 – 2.12)	1.74 ± 0.61 (CI: 1.66 – 1.82)	1.40 ± 0.50 (CI: 1.19 – 1.61)
Emergency Classification	1.19 ± 0.40 (CI: 1.01 – 1.37)	1.86 ± 0.51 (CI: 1.75 – 1.98)	-
Amount of People	11.08 ± 2.39 (CI: 10.69 – 11.47)	9.46 ± 2.66 (CI: 9.15 – 9.78)	10.80 ± 2.29 (CI: 9.85 – 11.75)

5.2.2 Interaction with Operating Table Score

The average percentage of time spent in the area closest to the operating table was 71.2% for open surgeries, 66.9% for laparoscopic surgeries, and 30.3% for RAS (see Table 6). The One-Way ANOVA indicated statistically significant differences, with RAS procedures showing lower interaction with the operating table compared to both open surgeries ($MD = 40.88$, $p < 0.001$) and laparoscopic surgeries ($MD = 36.63$, $p < 0.001$). Figure 16 displays a boxplot of these data, with asterisks marking statistically significant differences

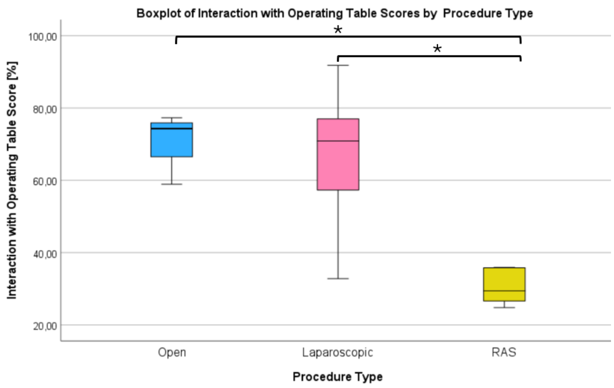

Figure 16: Boxplot showing the interaction with operating table scores for each surgical procedure type: open, laparoscopic, RAS. This Figure highlights the differences in interaction with the operating table across the three procedure types, with asterisks denoting statistically significant differences.

6 Discussion

This research utilized a multi-method approach combining questionnaires, interviews, and objective data analysis to assess the current workload and job satisfaction of intra-operative nurses in the Netherlands and to identify factors influencing these aspects.

Key findings reveal that RAS procedures generally impose a heavier workload on intra-operative nurses across multiple domains, while open procedures often result in higher job satisfaction. The main factors influencing workload and/or job satisfaction include: team dynamics, procedural characteristics, preparation and equipment, working environment, organization, appreciation and recognition, and physical demand. No single domain of the SURG-TLX or main factor was considered to be consistently more influential than others on workload or job satisfaction.

6.1 Analysis of Current Workload

Intra-operative nurses generally expressed moderate job satisfaction, as indicated by their average score of 0.3571 ($SD : 0.67847$) for recommending their profession to their children. This average score reflects a slight positive tendency, but the standard deviation reveals variability in individual responses. This variability underscores that while some intra-operative nurses experience their jobs positively, others may have neutral or negative perceptions.

The lower likelihood of older intra-operative nurses recommending their job to their children may be attributed to several aspects. One nurse noted that her age led to lower tolerance for decisions about the work environment, such as music choices, made solely by the surgeon without consulting the team. She felt that her increased irritability and frustration were linked to her age, as she was less willing to accept these unilateral decisions as she grew older. Additionally, the physical demands placed on older intra-operative nurses might be more burdensome. Furthermore, experience—correlated with age—could be a confounding factor, as older intra-operative nurses generally possess more experience.

Overall, the current workload was deemed acceptable for intra-operative nurses. On average, combining the three procedures, nurses scored 34.58 in total, which is below the detrimental threshold of 50 as established by Mazur et al. [89, 90]. RAS procedures (40.82) were rated higher in terms of workload compared to open procedures (32.60) and laparoscopic procedures (30.32).

These findings are consistent with values suggested in the literature, although intra-operative nurses in this study rated RAS procedures slightly higher. For RAS procedures, the literature reports that circulating nurses scored 32.20 according to Zamudio et al. [9], and 30 according to Weber et al. [109]. In Totonchilar's study [110], which combined scores for laparoscopic and open procedures, both types of nurses reported an average score of around 30.

The pairwise comparison revealed no statistically significant differences in the importance of factors affecting workload. Visual inspection also indicated minimal differences in the importance of factors influencing both workload and job satisfaction, with substantial variation between individuals.

Table 6: Results of Video Data per Procedural Type, showing average score with Standard Deviation and Confidence Interval

	Open Procedures	Laparoscopic Procedures	RAS Procedures
Movement Score [%]	1.90 ± 0.42 (CI: 1.22 – 2.58)	2.50 ± 1.40 (CI: 1.92 – 3.07)	0.87 ± 0.14 (CI: 0.72 – 1.01)
Interaction With Operating Table Score [%]	71.2 ± 8.32 (CI: 57.96 – 84.44)	66.9 ± 15.7 (CI: 60.46 – 73.43)	30.3 ± 4.74 (CI: 25.34 – 35.29)

Task complexity appeared to be a very influential factor for workload, consistent with the findings of Totonchilar et al. [110].

6.2 Summary of Factors of Influence

Seven categories influencing the workload and/or job satisfaction of intra-operative nurses were identified. These factors align with previous research, while also presenting unique aspects and important nuances specific to the context of intra-operative nurses in the OR, during the three different types of surgery.

Team dynamics, encompassing colleagues, atmosphere, and teamwork, emerged as the most frequently cited factor affecting job satisfaction among intra-operative nurses in this study. Previous studies highlight the importance of teamwork and good personal relationships on workload and job satisfaction [6, 14, 26, 69, 70, 71]. Several studies [2, 14] emphasize that the relationships between nurses and physicians are particularly vital in the OR, where collaboration is more intensive, compared to other clinical departments. Moreover, Bjorn et al. [6] found that a lack of cooperation, exclusion, and workplace bullying increased intentions to leave the job. The importance of having skilled direct colleagues or an experienced surgeon was also found to be of influence [71, 72]. During interviews, intra-operative nurses emphasized that specialization influences the work atmosphere due to varying cultural norms among different specialties. They also highlighted the significant impact of direct colleagues on workload and job satisfaction, noting substantial differences in workload when working with skilled colleagues versus students or agency workers.

Moreover, procedural characteristics can significantly influence the workload, as indicated by intra-operative nurses. While multiple studies have shown that longer surgical cases are associated with higher levels of workload [15, 72, 73, 74, 75], this study adds an important nuance. Intra-operative nurses explained that the duration of the procedure is especially crucial for their workload and job satisfaction, particularly when they feel less involved. Additionally, procedures that over-run, meaning they take longer than planned, are also linked to higher workload scores [111, 112] due to increased temporal demands [14, 26, 69]. This study found that open surgeries generally experience the least overruns compared to laparoscopic procedures, with this difference being statistically significant. In contrast, RAS procedures were observed to have the most overruns, though this finding was not statistically significant. Moreover, while existing studies suggest that complex procedures contribute to increased workload [15, 113, 114], this study suggests that more complex procedures may actually lead to increased job satisfaction as intra-operative nurses may feel more involved then. This study also highlights the importance of procedural variation, suggesting that incorporating some degree of variation between procedures could enhance overall job satisfaction among intra-operative nurses. This variation is specifically among types of procedures and not between different specialization departments as too much variation in this can elevate the knowledge through a lack of knowledge.

Issues with equipment functionality and technological failures were consistently reported to increase workload and decrease job satisfaction as was also supported by literature [6, 11, 26, 45, 77, 78, 79]. Intra-operative nurses, who are responsible for ensuring smooth operations in the operating room, are particularly vulnerable to added stress when equipment malfunctions occur. This study specifically highlighted that during RAS procedures, intra-operative nurses experience heightened stress due to insufficient knowledge of the technology. They mentioned receiving basic information about operating the robot but lacked adequate training in preparing the robot and resolving technical malfunctions. These gaps in training are critical aspects of their responsibilities and contribute significantly to their stress and increased workload during RAS procedures.

The OR environment significantly influences the workload and job satisfaction of intra-operative nurses. While existing research primarily focused on noise levels as a critical factor affecting workload and job satisfaction [6, 11], this study also highlights the impact of room occupancy—particularly individuals without assigned tasks—and lighting levels during procedures. Noise, including equipment sounds and conversations, tends to be higher during RAS procedures, contributing to increased stress among intra-operative nurses. Additionally, this study's findings suggest that adequate room lighting throughout the day is crucial for intra-operative nurse workload and job satisfaction, complementing previous research on the positive effects of daylight exposure [82, 83, 115]. Interviews revealed that higher room occupancy adversely affects workload and job satisfaction, especially when there are individuals without tasks.

Organizational factors play a significant role in influencing workload and job satisfaction among intra-operative nurses. Studies have identified several critical organizational aspects, including work hours, staffing adequacy, salary, and opportunities for career growth [2, 14, 71]. Supportive organizational structures and adequate staffing have been consistently linked to higher levels of job satisfaction among intra-operative nurses [6]. In the context of this study, intra-operative nurses highlighted the importance of OR planning, both in terms of scheduling and spatial arrangements, as additional factors that impact their workload and job satisfaction.

Recognition is crucial for the job satisfaction of intra-operative nurses, as highlighted by several studies [5, 14]. Garcia et al. [5] found that a lack of recognition correlates with higher stress levels among intra-operative nurses. Similarly, Han et al. [14] emphasize that dissatisfied nurses often perceive a lack of support from peers and supervisors, which diminishes job satisfaction. Interestingly, while recognition was not frequently mentioned in the questionnaires, interviews revealed that intra-operative nurses consider it significant for job satisfaction. This discrepancy suggests that intra-operative nurses may not spontaneously express the importance of recognition unless prompted, indicating a potential gap in perceived versus actual needs regarding workplace recognition. Furthermore, it was observed that the level of recognition often depends on the specialist's personality. Some specialists may undervalue the contributions of intra-operative nurses and fail to view them as equal colleagues.

Lastly, physical demands have been identified as significant contributors to workload, as indicated by multiple studies [9, 14, 81]. These studies highlight that intra-operative nurses facing higher physical demands are more likely to experience increased workload and job dissatisfaction, which can potentially lead to turnover. The physical demand is especially perceived as higher in combination with not feeling involved during a procedure as mentioned by the intra-operative nurses.

6.3 Analysis per Procedure Type

Based on interviews and the SURG-TLX assessment, RAS procedures generally impose a higher workload on intra-operative nurses across multiple domains compared to open and laparoscopic procedures. Conversely, open procedures tend to yield higher job satisfaction scores. The following sections elaborate on these findings.

6.3.1 Open Procedures

Open procedures were consistently regarded as the most enjoyable by intra-operative nurses, which correlates with their elevated job satisfaction scores in the SURG-TLX assessment. Despite their longer duration, intra-operative nurses reported being constantly engaged and finding the workload manageable. One intra-operative nurse explained that the continuous activity during open surgeries contributes to their satisfaction.

In gynecological procedures at the LUMC, higher ASA score patients and higher emergency patients were frequently treated with open surgery. Intra-operative nurses prefer these procedures for their active involvement and the challenges they offer. Additionally, open surgeries tend to end sooner than planned, resulting in less overrun, which may reduce stress and perceived workload. The well-lit environment further enhances working conditions, while the use of simpler technical equipment minimizes the risk of equipment failures, thereby lowering stress and workload [26].

The video data supports these observations, showing higher Interaction with Operating Table Scores compared to RAS, which could indicate greater involvement in the procedure. Although Movement Scores for open procedures were not statistically significantly different from those for RAS procedures, the data still suggests that OR team members are likely more active during open surgeries.

6.3.2 Laparoscopic Procedures

Laparoscopic procedures generally entail a lower workload compared to open and RAS procedures and lower job satisfaction compared to open procedures. This can be attributed to several factors.

During laparoscopic surgery, intra-operative nurses often experience less workload than during RAS procedures. This difference can be attributed to the higher frequency of laparoscopic surgeries, which allows intra-operative nurses to gain more experience and familiarity with the procedures. Additionally, the shorter duration of laparoscopic surgeries contributes to reduced workload levels. The working environment during these surgeries is also perceived as more favorable, as it involves shorter periods in dim lighting and fewer people in the operating room.

The video data further supports this finding, showing higher Movement and Interaction with Operating Table Scores during laparoscopic procedures than during RAS. This suggests that team members are potentially more active and engaged during laparoscopic surgeries, which may contribute to a lower perceived workload compared to RAS procedures.

However, they also score lower on job satisfaction than open procedures. This lower satisfaction may be attributed to the lower ASA scores and lower emergency scores of patients undergoing laparoscopic procedures, which indicate less complexity and fewer opportunities for intra-operative nurses to feel fully engaged. Intra-operative nurses also noted in interviews that the limited visibility of the surgical site during laparoscopic procedures diminishes their sense of involvement compared to open surgeries. Additionally, the working environment, while more pleasant than in RAS procedures, still involves periods of working in low lighting, which can affect overall job satisfaction.

6.3.3 Robot-Assisted Procedures

RAS procedures exhibit higher workload across various domains compared to open and laparoscopic procedures, while also scoring lower in job satisfaction compared to open procedures. Several factors contribute to these findings.

The preparation phase for RAS procedures is notably demanding, as highlighted in interviews, placing significant stress on intra-operative nurses. This finding aligns with prior research indicating that intra-operative nurses bear the responsibility of preparing intricate surgical instruments and are frequently confronted with unexpected complications during this phase, thereby intensifying their workload [26]. Intra-operative nurses elaborated in interviews that they often lack sufficient technological knowledge to address these issues effectively, contributing to the heightened workload during RAS procedures. Working with the robotic system requires substantial technical expertise, further increasing workload levels for intra-operative nurses. Additionally, due to the infrequent occurrence of RAS procedures, especially when compared to laparoscopic procedures, intra-operative nurses have less exposure and experience with them, compounding the stress and workload associated with these surgeries.

The SURG-TLX assessment indicates that RAS procedures impose greater temporal demands compared to other types of surgeries. Discrepancies between planned and actual durations suggest that RAS procedures are often underestimated in terms of time, contributing to increased workload for intra-operative nurses.

Furthermore, the working environment during RAS procedures tends to be less pleasant, potentially explaining the increased distraction scores and lower job satisfaction as reflected in the SURG-TLX assessments. Intra-operative nurses in RAS procedures often work for extended periods in dimly lit conditions, which can contribute to discomfort and decreased satisfaction. Additionally, the presence of more equipment in the room leads to increased noise levels, further adding to the challenging environment. Moreover, data on staff composition indicates that more personnel are typically present during RAS procedures compared to laparoscopic surgeries, which likely contributes to distractions through more conversations and a more crowded environment. Notably, this count did not include additional observers. During interviews, intra-operative nurses explained that RAS procedures often attract more additional observers because they occur less frequently, further contributing to potential distractions, more crowded rooms, and heightened workload levels.

Lower job satisfaction among intra-operative nurses during RAS procedures can be attributed to reduced feelings of involvement in the surgical process. Intra-operative nurses stressed that active participation is crucial for job satisfaction, which is often hindered by limited visibility of the surgical site and fewer tasks during RAS, particularly in phase 2. As stated in the Theoretical Framework, maintaining a balanced workload is crucial for optimal performance and job satisfaction. Limited visibility and engagement with the surgical site during RAS surgeries hinder active participation, potentially leading to under-arousal and decreased job satisfaction (see Figure 6).

Moreover, patients undergoing RAS procedures generally have lower ASA scores, indicating less complexity and fewer challenges for intra-operative nurses. This reduced complexity, combined with the longer duration of surgeries, further contributes to decreased job satisfaction.

The video data further confirms these findings, revealing that RAS procedures are associated with lower Movement Scores than laparoscopic procedures and lower Interaction with Operating Table Scores compared to both open and laparoscopic procedures. This suggests potentially reduced activity levels and a diminished sense of involvement among team members during RAS procedures.

7 Strengths and Limitations

7.1 Limitations

This study was conducted at LUMC, a university hospital where medical trainees are involved in procedures. The presence of trainees, who may perform tasks typically handled by intra-operative nurses, could influence the nurses' roles and introduce potential bias. Additionally, the specialized nature of procedures at LUMC might limit the generalizability of the findings to other settings.

Another limitation is that the research does not distinguish between scrub nurses and circulating nurses, as the same individuals at LUMC perform both roles. This lack of distinction may affect the findings, given that Sonoda et al. [26] suggest that scrub nurses and circulating nurses perceive teamwork differently. Additionally, interviews highlighted that the physical demands and frustrations with inadequate preparation were role-dependent, with circulating nurses experiencing a greater physical burden and more frustration. This was particularly due to their responsibilities for retrieving additional equipment.

Moroever, the study focused exclusively on gynecological procedures for both the interviews and the objective data from hospital records and videos. Research suggests that workload and perceived atmosphere can vary significantly across different medical specializations [116]. In this study, intra-operative nurses reported that the gynecology department is generally perceived as a specialization with a particularly pleasant atmosphere. However, it was also noted that intra-operative nurses, in the gynecology department of the LUMC, are not permitted to change robotic arms, unlike in other departments such as urology. This restriction may contribute to a sense of reduced involvement during RAS procedures in the gynecology department. Additionally, in the questionnaire analysis, differentiating between the different specializations was not possible because intra-operative nurses at LUMC frequently work across multiple specializations each week. As a result, many intra-operative nurses selected multiple specialties on their questionnaires, despite being instructed to choose only one. This practice prevented effective analysis of differences between specializations.

Furthermore, the study did not include physiological workload measurements, such as EMG or EEG, due to their invasiveness and high cost. Thus, the findings are based solely on subjective assessments and objective data from hospital records and videos data, potentially limiting the comprehensiveness of the workload evaluation.

Workload and job satisfaction are highly personal and sensitive topics, leading to considerable variations in participants' perceptions of different procedures. Several factors influence these perceptions, including age, sensitivity to stimuli, and tolerance for hierarchy. The variability made it challenging to determine the relative importance of different domains. Additionally, while the open-ended questions in the questionnaires and interviews enriched the data, they also led to some interpretation challenges. For instance, some responses mentioned factors such as complexity or music without clarifying whether they increased or decreased workload. One participant might find the radio beneficial, while another might perceive it as an additional burden. Similarly, "complex procedures" were interpreted differently; some participants saw them as increasing workload, while others viewed them as a positive challenge. Moreover, some responses lacked clarity on whether factors like "colleagues" referred to enjoyable or skilled individuals. This nuance was not fully captured, contributing to the complexity of interpreting the data. During the ranking of the domains of the SURG-TLX and main factors, large individual variability was observed, underscoring the highly personal nature of the subjects discussed and likely contributing to differences in reported workload and job satisfaction.

Moreover, the study's relatively small sample size is a notable limitation. Of the 28 participants who completed part 1 of the questionnaire, only 19 completed part 2 (SURG-TLX). As shown in the boxplots, there was substantial variation in the SURG-TLX results across domains, reflecting differing experiences among intra-operative nurses regarding various procedures. Consequently, some observed differences, such as situational stress across procedures, may not have reached statistical significance despite visual indications of disparity see Figure 9. A larger sample size could yield more reliable results.

Additionally, only five participants were interviewed, which further limits the generalisability of the findings. The small sample size means that the results should be interpreted with caution, given the personal nature of the topics and the observed variability among participants' rankings. Nonetheless, the overall sentiment was consistent, with intra-operative nurses generally experiencing RAS procedures as less enjoyable compared to open procedures.

Furthermore, some participants did not fully understand the pairwise comparison method employed in the SURG-TLX assessment. This misunderstanding might have affected the sensitivity of the analysis and could explain the absence of statistically significant results. As there were no statistically significant differences between the domains, the SURG-TLX analysis was left unweighted, which may decrease the sensitivity of the analysis [104].

Procedures were manually classified by one researcher based on the indication of the procedure and advice from a medical doctor. The diverse range of procedures and inconsistent data reporting styles, including the use of abbreviations and full names, led to classification challenges. Additionally, in cases such as research conducted under anesthesia, it was sometimes unclear what the procedure entailed, leading to the exclusion of many procedures from the analysis. Moreover, vaginal procedures like hysteroscopies were classified under laparoscopies, although a separate analysis might be warranted. However, as the study aimed to provide a general understanding of the three main procedure types, such detailed separation was not performed.

Moreover, the lack of consistent data collection across procedures may introduce bias and affect the reliability of the analysis. For instance, emergency classification data were only available for 95 procedures, and none involved RAS procedures. Additionally, in the staff composition datasheet, only the primary personnel present at any point during the procedure was registered, without accounting for additional observers or ensuring that those listed were present throughout the entire procedure. This made it challenging to accurately determine how many people were actually in the room for the majority of the time. Interviews revealed that the presence of additional observers, in particular, heightened the perceived workload due to the need for increased vigilance. Unfortunately, the absence of data on these observers prevented an analysis of how their presence might vary by procedure type and its impact on workload

The study was limited to the ASA and emergency classification of patients, due to the unavailability of other potentially influential patient factors, such as BMI. As one intra-operative nurse highlighted, robot arms may struggle with obese patients due to reach limitations, indicating that such factors might also impact workload and job satisfaction.

Furthermore, the responses of intra-operative nurses during phase 2 of laparoscopic and RAS procedures may have been confounded by the "time in the dark." During this phase, the lighting is always dimmed to enhance the surgeon's visibility. Some intra-operative nurses reported in the questionnaires that these dim lighting conditions increased their workload, which may have influenced their responses and, consequently, served as a confounding factor.

The video data analysis algorithm employed in this research had several limitations, necessitating a cautious interpretation of its results. One major limitation is that the algorithm averaged the data for all personnel present during a procedure, treating each individual equally. This approach made it difficult to draw specific conclusions about the workload and involvement of intra-operative nurses.

Additionally, the algorithm faced challenges due to the complex OR environment. Personnel in the sterile area wore large sterile jackets, which complicated the identification of key anatomical points. Furthermore, obstructions in the camera view and the dim lighting conditions during phase 2 of both laparoscopic and RAS procedures further hindered the algorithm's ability to accurately track individuals.

Another limitation is that the algorithm did not differentiate between the various phases of a procedure, despite evidence suggesting that workload varies across these phases. Moreover, the distribution of recorded procedures—only 4 open and 6 RAS compared to 25 laparoscopic—could introduce bias and does not accurately reflect the actual distribution of procedures performed in the gynecology department at LUMC, according to hospital data.

Lastly, the metrics used by the algorithm do not serve as direct indicators of workload or job satisfaction. For instance, Movement Scores do not necessarily correspond to activity levels, and Interaction with Operating Table Scores do not directly reflect involvement. Activities such as instrument handovers, which were identified in interviews as significant for assessing both workload and involvement, were not captured by the algorithm. The Movement Scores primarily focused on the movement of legs and hips, rather than finer actions like those of the wrists. Literature underscores the significance of handovers as a performance measure, reflecting skill levels and workload, thus highlighting a critical gap in the algorithm's current capabilities [101].

A final limitation of this study is the violation of the normality assumption in the ANOVA test used to analyze the SURG-TLX data, which could introduce bias. However, since the SURG-TLX results align with the interview findings, this bias is likely minimal

7.2 Strengths

A key strength of this study is its comparative analysis of three procedural types: open, laparoscopic, and RAS procedures. Unlike prior research that often focuses on one or two procedural types [9, 15, 109, 110], this study thoroughly examines workload across all three major types. This broad comparison not only reveals nuanced differences between the procedural types but also highlights specific aspects of each procedure that influence workload and job satisfaction.

The open-ended questions in both the questionnaires and interviews allowed participants to discuss factors freely, contributing to a richer and more nuanced understanding of workload and job satisfaction. This approach helped identify new factors and offered deeper insights beyond pre-existing literature.

The use of the validated SURG-TLX tool to assess workload across multiple domains enhances the validity of the study. By incorporating a seventh domain to assess job satisfaction, the study offers a more comprehensive understanding of both subjective workload experiences and job satisfaction across different procedures. While current literature often examines these aspects separately [9, 13, 15, 81, 91], exploring both factors is crucial as they are both linked to higher turnover intentions and impaired performance.

The methodological approach of presenting SURG-TLX assessments sequentially enhanced participants' ability to discern and compare the differences between procedural types. This clarity helps in understanding the relative impacts of various procedures on workload and job satisfaction.

The integration of subjective findings from interviews and questionnaires with objective data from hospital records and video analysis strengthens the study's conclusions. By combining multiple data sources, the study offers a comprehensive understanding of the factors influencing workload and job satisfaction across different procedure types while also validating subjective perceptions. For example, the claim that there are more personnel are present during RAS procedures than during laparoscopic procedures, as reported in interviews, was confirmed by hospital records. Furthermore, although RAS procedures were perceived as longer, data showed similar durations for both RAS and open procedures, suggesting that perceived workload is influenced more by levels of activity and involvement than by procedure length alone. While the results of the video-based algorithm should be interpreted with caution, they still align with qualitative findings, such as the observed reduction in interaction with the operating table during RAS procedures, which may indicate reduced involvement. Ultimately, the convergence of these diverse data sources reinforces the overall conclusion: intra-operative nurses experience a higher workload during RAS procedures, likely due to feeling less active and involved.

8 Future Research

While this study provides a valuable initial assessment of the workload and job satisfaction of intra-operative nurses, further research is necessary to deepen understanding. For example, integrating objective physiological measurements—such as heart rate variability and brain activity—could offer additional insights into the actual workload experienced by these professionals. Future research should focus on developing and applying these measures in a non-intrusive and cost-effective manner, ensuring their practicality and relevance in real-world settings.

Additionally, to enhance the validity and generalizability of findings related to workload and job satisfaction in surgical environments, future research should include larger sample sizes. Increasing the number of participants would provide a more comprehensive view of the variability in experiences among intra-operative nurses and could potentially lead to more validated results.

Moreover, future research could incorporate other medical specializations, beyond the gynecology department. This approach will help to understand how specialization-specific factors affect workload and job satisfaction, allowing for the development of targeted interventions for different procedural fields. Furthermore, future research could include intra-operative nurses from other hospitals to explore how different institutional environments affect their experiences. This approach would help identify common challenges and best practices applicable across the different contexts, improving the overall understanding of these issues. By broadening the scope of future studies, researchers can obtain a more nuanced and generalizable perspective on the factors affecting the perceived workload and job satisfaction of intra-operative nurses in the OR.

Additionally, patient outcomes such as length of stay and blood loss were not considered in this study, even though these factors are important in determining the choice of surgical procedures. As discussed in the Theoretical Framework, workload and job satisfaction are linked to performance. Including patient outcomes in future research could provide a more comprehensive understanding of how different procedures impact both staff workload and overall procedural effectiveness.

As the algorithm was considered an initial exploration in quantifying intra-operative nurse workload, several enhancements could improve its ability to accurately reflect their workload and job satisfaction. First, the algorithm should differentiate between intra-operative nurses and the rest of the surgical team, focusing specifically on tracking their movements and interactions with the operating table. Further refinement could include distinguishing between scrub and circulating nurses, given their distinct roles and tasks. Additionally, the algorithm should analyze different phases of the procedure separately, as workload and job satisfaction levels can vary significantly throughout the process. Enhancing the algorithm to detect and track more specific tasks, such as handing over instruments, would be valuable. Currently, the algorithm primarily tracks spatial movement within the room and does not capture finer movements, nor can it detect or track instruments. Adding this capability could provide a more nuanced understanding of workload. Moreover, some intra-operative nurses mentioned that prolonged standing or maintaining challenging positions, such as kneeling for extended periods, increased their workload and decreased job satisfaction; capturing these postures could offer additional insights. Furthermore, the importance of adequate preparation was emphasized, particularly regarding the workload of circulating nurses. Capturing the activity of circulating nurses retrieving additional equipment could help identify procedural differences that impact workload. Finally, increasing the number of video recordings analyzed, especially for open procedures, would improve the reliability of the results, as the current dataset is limited.

Assessing the effectiveness of training programs for robotic systems and other OR technologies is another important area for future research. Research should evaluate how different training approaches impact intra-operative nurses' proficiency, stress levels, and thereby workload and job satisfaction to optimize training methods.

Lastly, longitudinal studies that track changes in job satisfaction and workload over time could provide a deeper understanding of long-term trends and the impact of various interventions.

8.1 Recommendations for Improvement

Based on the study's findings, several recommendations for improvement have been identified, and categorized into general and robot-specific aspects as detailed below.

8.1.1 General Aspects

8.1.1.1 Short Term Implementation

1. **Improve Preparation Protocols:** Establish detailed protocols for staff filling in the HiX system prior to surgery to minimize last-minute changes and unnecessary equipment preparations. Currently, some staff members select all options, leading to unnecessary setups and inefficiencies. Refining these protocols will reduce workload, lower costs, and enhance sustainability.

2. **Enhance Scheduling and Allocation:** Optimize surgery schedules to minimize setup changes and ensure well-timed breaks. Standardize technology across OR rooms and designate specific rooms for certain types of procedures to improve efficiency. Additionally, longer breaks could help decrease workload and enhance job satisfaction.

3. **Increase Nurse Involvement:** Engage intra-operative nurses in decisions regarding devices and procedures. Provide advanced patient information before the procedure to help intra-operative nurses better anticipate needs during surgery. Moreover, enhance device explanations and provide more training opportunities to reduce stress and workload. Special attention should be given to the preparation and cleaning of devices, as intra-operative nurses currently find these tasks particularly burdensome due to insufficient knowledge. Additionally, involve intra-operative nurses in device evaluations to address issues with non-functional equipment.

4. **Reduce OR Occupancy:** Lower the maximum number of people allowed in the OR to improve the environment and reduce workload. Currently, the maximum is set at 12 or 13 at LUMC, but this limit may still be excessive, especially when many individuals are present without assigned tasks. This leads to increased vigilance and workload for intra-operative nurses. By reducing the maximum occupancy, the working conditions could become more manageable and pleasant.

5. **Enhance Recognition:** Increase appreciation and recognition for intra-operative nurses to improve job satisfaction and reduce turnover. Simple gestures, such as a small token of gratitude from the team leader, like a thank-you note or a treat, can make a large difference.

6. **Consider the Number of Students or Agency Workers per Procedure**: Implement policies to better distribute students and agency workers across procedures. This could help reduce workload and enhance job satisfaction.

7. **Senior Staff Policy:** Consider the age of intra-operative nurses when scheduling shifts. Older intra-operative nurses may face greater challenges during physically intense procedures, so they should be assigned to less demanding tasks whenever possible.

8. **Organize Data:** Improve data organization and reporting consistency for enhanced analysis and decision-making.

8.1.1.2 Future Directions

1. **OR Design:** Design larger OR spaces to facilitate better movement and reduce congestion. Implement universal mechanisms for equipment to simplify usage and minimize the need for frequent relocation. This will help decrease workload by reducing the amount of equipment movement required.

2. **Specialization Structure:** Reduce the number of specializations per cluster to improve knowledge retention and reduce complexity. A certain level of variation is, however, appreciated

3. **Cultural Improvement:** Address the lack of appreciation for intra-operative nurses, particularly among surgeons. Foster a more respectful and inclusive culture to enhance job satisfaction and teamwork.

8.1.2 Robot-Specific Suggestions

8.1.2.1 Short Term Implementation

1. **Increase Screens:** Invest in additional screens in the OR to improve intra-operative nurses' visibility and involvement in RAS surgeries. Cur-

rently, the lack of clear visibility of the available screens often diminishes their sense of involvement and job satisfaction.

2. **Improve Training:** Enhance training on robotic systems to reduce intra-operative nurse stress and workload. Special attention should be given to the preparation and cleaning of robotic systems, as these tasks are noted to particularly elevate workload levels.

3. **Reallocate Tasks:** Shift some tasks from residents to intra-operative nurses to improve their involvement and thereby their workload and job satisfaction.

8.1.2.2 Future Directions

1. **Integrate Robotic Systems:** Integrate robotic systems into the OR to reduce setup and cleaning-up issues, thereby reducing stress and physical demands associated with these tasks, and ultimately decreasing overall workload.

2. **Design Smaller Robots:** Develop smaller robotic systems to provide more space for movement within the OR.

3. **Reduce Noise Levels:** Design quieter robotic systems to create a more pleasant and less stressful working environment.

4. **Innovate Screen Technology:** Develop advanced screens that optimize visibility without needing to dim the lights, maintaining a more pleasant environment for the surgical team.

9 Conclusion

This study utilized a multi-method approach to assess the workload and job satisfaction of intra-operative nurses in the LUMC. In general, intra-operative nurses found their workload acceptable and were satisfied with their jobs. Open procedures lead to the highest job satisfaction due to continuous engagement and a manageable workload. In contrast, laparoscopic procedures, though less demanding, result in lower job satisfaction due to reduced involvement, simpler cases, being more frequent, and shorter durations. RAS procedures are linked to both increased workload and decreased job satisfaction, mainly because of preparation requirements, technological challenges, diminished sense of involvement, and a less pleasant work environment.

Key factors influencing workload and job satisfaction include team dynamics, procedural characteristics, preparation and equipment, working environment, organizational factors, recognition and appreciation, and physical demands. Notably, no single factor consistently dominated in affecting workload or job satisfaction, highlighting the complexity of these issues.

To address the identified challenges and enhance workload management and job satisfaction, several key improvements were recommended. Streamlining preparation protocols and optimizing OR scheduling could reduce stress and improve efficiency. Increasing nurse involvement in decision-making and providing better training and information can further support their engagement and satisfaction. Additionally, reducing OR occupancy and enhancing recognition for nurses can create a more supportive work environment. For RAS, integrating more screens into the OR can improve visibility and the feelings of involvement during a procedure. Designing smaller, quieter robots would make the work environment more comfortable, while the integration of the robotic systems into the OR layout can simplify setup and cleanup processes.

Despite its limitations, this research consistently indicates that the workload during RAS procedures is perceived as higher. Data from questionnaires, interviews, hospital records, and video analysis all indicate a diminished sense of involvement and increased workload for intra-operative nurses during RAS procedures. Addressing these issues is critical, especially in light of the escalating nursing shortage in the Netherlands. This study fills a crucial gap in understanding how RAS affects the workload and job satisfaction of intra-operative nurses and offers initial recommendations for potential improvements. While challenges remain, this research could serve as a foundation for future efforts to reduce nurse workload, enhance job satisfaction, and ultimately address the escalating nursing shortage in the Netherlands.

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Appendix A: Additional Information on Workload

10.1 Theories explaining Workload

Several theories aim to explain cognitive workload, with two of the most common being the Cognitive Load Theory developed by Sweller [118] and the Multiple Resource Theory developed by Wickens [119].

In Sweller's Cognitive Load Theory [118, 120], workload is categorized into three types: intrinsic load, germane load, and extraneous load. Intrinsic load describes the inherent complexity of a task, stating that as task complexity increases, so does the cognitive capacity needed to solve it. Intrinsic load can only be altered by changing the nature of what is learned or the act of learning itself. For example, task difficulty is an intrinsic cognitive load factor. Germane load involves the effort to process patterns within a task, contributing to task engagement. This load is influenced by task-relevant information, with factors such as the alertness of a person playing a role. Extraneous load is influenced by the task representation perceived by human perception, representing task-irrelevant information processed by the brain. Factors like time pressure can influence extraneous cognitive load. Ideally, efforts are made to minimize extraneous load. According to the additivity hypothesis [96], these three sources of load are additive elements of the total cognitive load [55].

Wickens' Multiple Resource Theory suggests that human operators possess multiple information processing channels. This theory asserts that people have a limited set of resources available for mental processes, distributed across various operations from sensory-level processing to meaning-level processing. In other words, during information processing the allocation of cognitive resources varies. The Multiple Resource Theory explains how dual-task performance is more likely to be hindered by performing similar tasks than dissimilar tasks. According to this theory, different tasks can use different pools of resources, and in cases of resource sharing, overload situations can occur, impairing an operator's performance. When the pools of resources are not shared, such as when a visual detection task needs to be performed while presenting auditory instructions, more information can be processed without impeding performance [50, 119, 121].

10.2 Articles on Workload Definitions

Table 7: Articles and Mental Workload Definitions

Article	Definition Mental Workload
Longo et al. [48]	Mental workload (MWL) represents the degree of activation of a finite pool of resources, limited in capacity, while cognitively processing a primary task over time. This process is mediated by external stochastic environmental and situational factors, as well as affected by definite internal characteristics of a human operator, for coping with static task demands, by devoted effort and attention.
Stramler et al. [49]	Any measure of the amount of mental effort required to perform a task
Young et al. [50]	The level of attentional resources required to meet both objective and subjective performance criteria, which may be mediated by task demands, external support, and past experience
Moray et al. [51]	Cognitive workload is an inferred construct that mediates between task difficulty, operator skill, and observed performance
Andre et al. [52]	Cognitive workload is a hypothetical construct that represents the cost incurred by a human operator to achieve a particular level of performance
Van Acker et al. [53]	Mental workload is a subjectively experienced physiological processing state, revealing the interplay between one's limited and multidimensional cognitive resources and the cognitive work demands being exposed to.
NASA-TLX researchers [54]	Cognitive workload is the user's perceived level of mental effort that is influenced by many factors, particularly task load and task design
Kosch et al. [55]	Mental workload encompasses the mental effort required to accomplish a task ('work'), coupled with various constraints ('load'), including elements like time pressure
Young et al. [56]	Mental workload is a multidimensional construct determined by task characteristics (e.g. demands, performance), operator attributes (e.g. skill, attention), and, to some extent, the environmental context in which the performance occurs.
Basahelet al. [57]	Mental workload is the amount of cognitive or attentional resources being expended at a given point in time

Table 8: Articles and Physical Workload Definitions

Article	Definition Physical Workload
Young et al. [56]	Physical workload can be described as the corporeal strain placed on the person during the task.
Bagheriferad et al. [58]	Physical workload is a measurable portion of physical resources expended when performing a given task such as manual lifting which is affected by various factors such as training and environmental factor.

Table 9: Articles and Workload Definitions in Healthcare

Article	Workload Definition in Healthcare
Ivziku et al. [41]	Mental workload arises from the cognitive efforts involved in processing information and making decisions. Physical workload is a result of the bodily strain in response to task demands, while emotional workload stems from emotionally challenging interactions with patients or within work situations.
Neto et al. [42]	Physical workload is the amount of physical effort that is expended by a worker to carry out several activities while working is estimated
Alghamdi et al. [43]	Nursing workload is the amount of time and care that a nurse can devote (directly and indirectly) towards patients, workplace, and professional development.
Haas et al. [44]	Workload is the amount of work to be done
Fishbein et al. [10]	Workload is the task demand of accomplishing mission requirements for the human operator.
Swiger et al. [11]	Nursing workload is the amount of time and physical and/or cognitive effort required to accomplish direct patient care, indirect patient care, and nonpatient care activities
Catchpole et al. [45]	Workload is the cost incurred by a human operator to achieve a particular level of performance, interaction between task demands, circumstances and personal skills, behavior and perceptions.
Ahmadi et al.[46]	Physical workload includes placing the body in a specific posture or condition
Chang et al. [47]	Physical workload of nurses includes activities that can be classified as standing, walking, running, lifting objects, moving objects or devices and items, moving patients, changing patient positions, supporting patient ambulation, dragging wheelchairs, providing hygienic care to patients, and changing bed sheets.

Appendix B: Questionnaire

Deel 1: Algemene Vragen (1/2)

Geef antwoord op de volgende vragen. U kunt uw antwoord noteren in het hokje onder de vraag.

1. Wat is uw leeftijd?

2. Wat is uw gender?

   O Vrouw O Man O Non-Binair O Anders O Wil ik liever niet zeggen

3. Bij welk specialisme bent u voornamelijk werkzaam?

   Kruis degene aan bij welke u het meest werkzaam bent. Als u betrokken bent bij meerdere specialismen, selecteer dan het specialisme waarin u de meeste robot-geassisteerde procedures uitvoert. **De vragen van deel 2 (SURG-TLX) moeten worden ingevuld voor dat specifiek gekozen specialisme.**

Cluster 1	Cluster 2	Cluster 3
O Orthopedie	O KNO	O Thorax (indien ja, kruis ook een van onderstaande aan)
O Traumachirurgie	O Neurochirurgie	O Long
O Urologie	O Kaakchirurgie	O Hart
O Vaatchirurgie	O Gynaecologie	O Pediatrie
O Transplantatie	O Plastische chirurgie	
O Heelkunde	O Oogchirurgie	
O Oncologie		

4. Hoeveel jaar ervaring heeft u als OK-assistent?

5. Hoeveel jaar ervaring heeft u als OK-assistent met robot-geassisteerde procedures?

6. Hoeveel uur werkt u gemiddeld per week?

Appendix B: Questionnaire

Deel 1: Algemene Vragen (2/2)

7. Hoeveel robot-geassisteerde procedures voert u gemiddeld uit per week?

8. Hoeveel open procedures voert u gemiddeld uit per week?

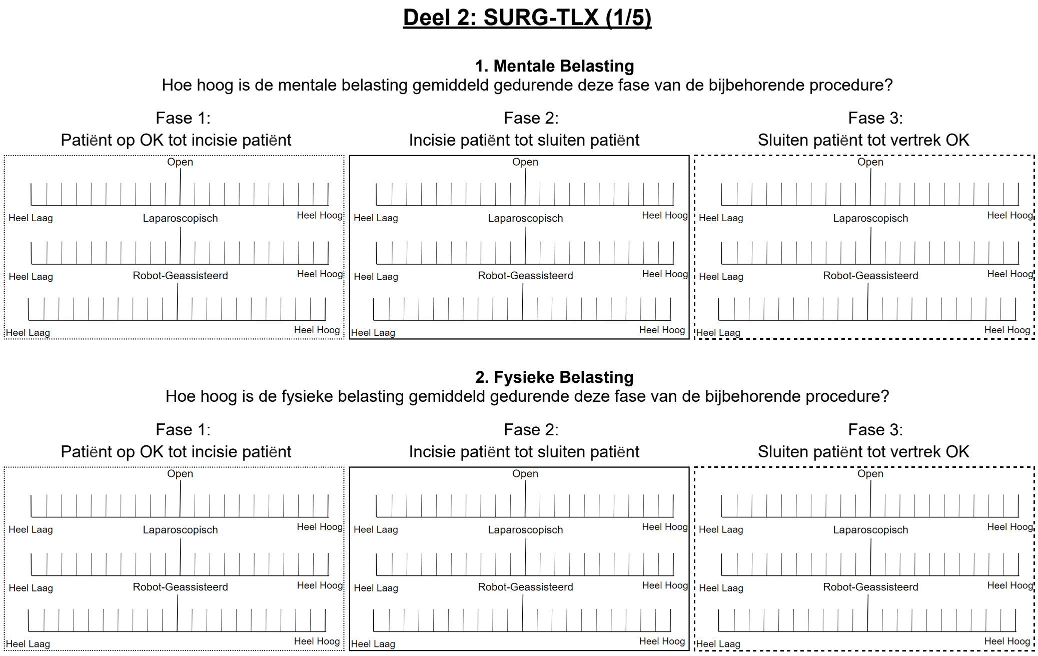
9. Hoeveel laparascopische procedures voert u gemiddeld uit per week?

10. Wat is voor u van belang voor het **werkplezier** dat u ervaart tijdens een procedure, noem minimaal 3 aspecten

11. Wat is voor u van belang voor de **werklast** die u ervaart tijdens een procedure, noem minimaal 3 aspecten.

12. Zou u uw baan aanraden aan uw kinderen?
    O Ja O Nee O Neutraal

Appendix B: Questionnaire



Deel 2: SURG-TLX (1/5)

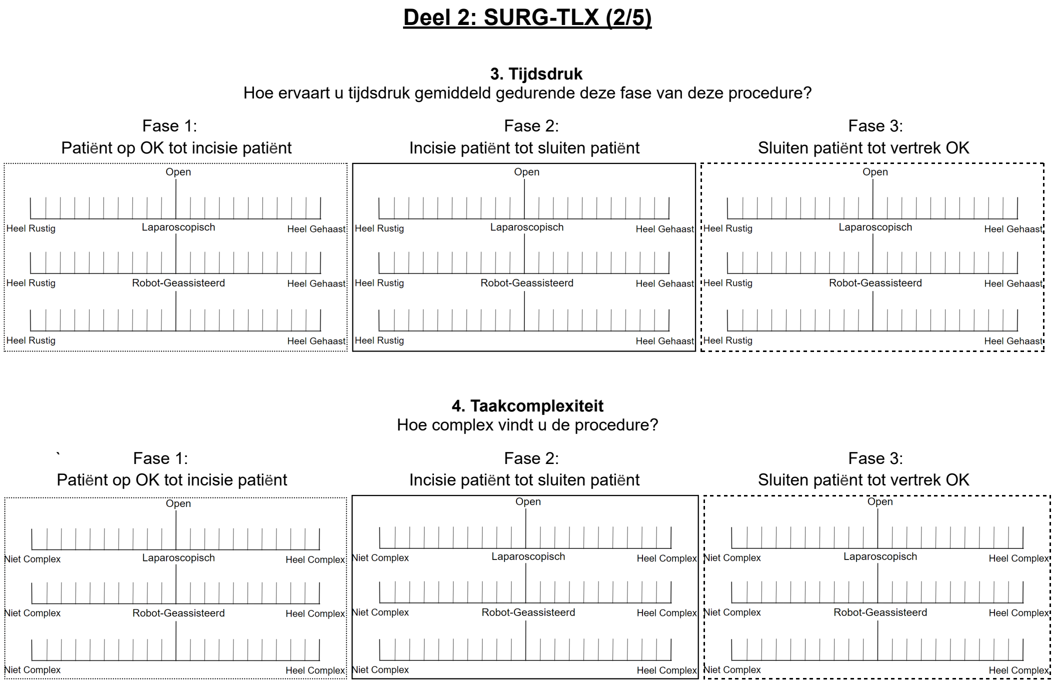
1. Mentale Belasting
Hoe hoog is de mentale belasting gemiddeld gedurende deze fase van de bijbehorende procedure?

Fase 1: Patiënt op OK tot incisie patiënt	Fase 2: Incisie patiënt tot sluiten patiënt	Fase 3: Sluiten patiënt tot vertrek OK
Open: Heel Laag – Heel Hoog	Open: Heel Laag – Heel Hoog	Open: Heel Laag – Heel Hoog
Laparoscopisch: Heel Laag – Heel Hoog	Laparoscopisch: Heel Laag – Heel Hoog	Laparoscopisch: Heel Laag – Heel Hoog
Robot-Geassisteerd: Heel Laag – Heel Hoog	Robot-Geassisteerd: Heel Laag – Heel Hoog	Robot-Geassisteerd: Heel Laag – Heel Hoog

2. Fysieke Belasting
Hoe hoog is de fysieke belasting gemiddeld gedurende deze fase van de bijbehorende procedure?

Fase 1: Patiënt op OK tot incisie patiënt	Fase 2: Incisie patiënt tot sluiten patiënt	Fase 3: Sluiten patiënt tot vertrek OK
Open: Heel Laag – Heel Hoog	Open: Heel Laag – Heel Hoog	Open: Heel Laag – Heel Hoog
Laparoscopisch: Heel Laag – Heel Hoog	Laparoscopisch: Heel Laag – Heel Hoog	Laparoscopisch: Heel Laag – Heel Hoog
Robot-Geassisteerd: Heel Laag – Heel Hoog	Robot-Geassisteerd: Heel Laag – Heel Hoog	Robot-Geassisteerd: Heel Laag – Heel Hoog

Appendix B: Questionnaire



Deel 2: SURG-TLX (2/5)

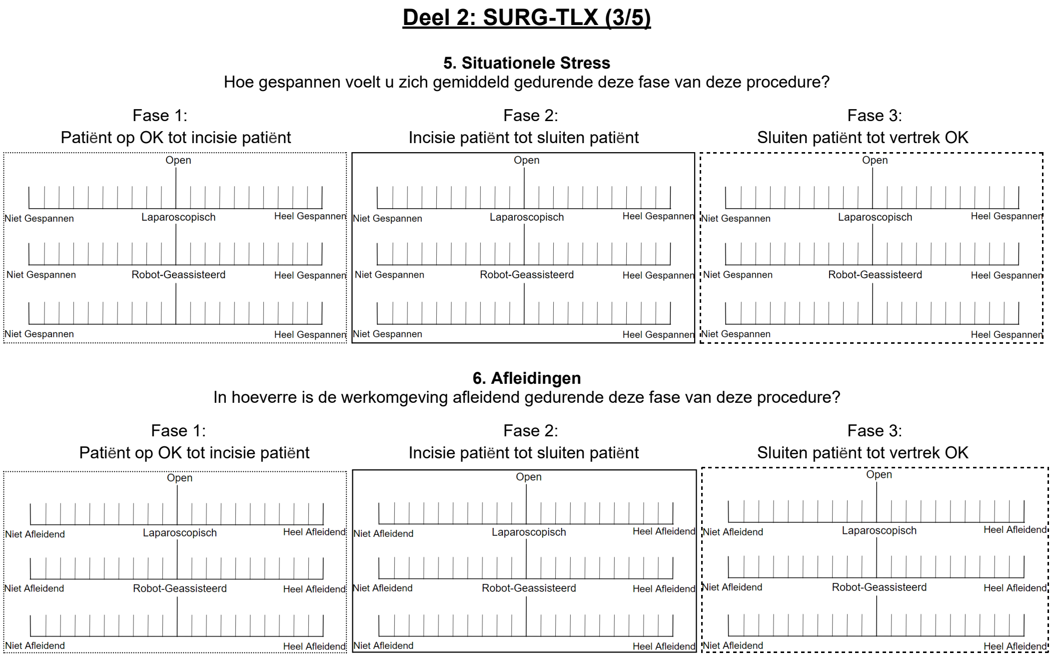
3. Tijdsdruk
Hoe ervaart u tijdsdruk gemiddeld gedurende deze fase van deze procedure?

Fase 1: Patiënt op OK tot incisie patiënt	Fase 2: Incisie patiënt tot sluiten patiënt	Fase 3: Sluiten patiënt tot vertrek OK
Open: Heel Rustig – Heel Gehaast	Open: Heel Rustig – Heel Gehaast	Open: Heel Rustig – Heel Gehaast
Laparoscopisch: Heel Rustig – Heel Gehaast	Laparoscopisch: Heel Rustig – Heel Gehaast	Laparoscopisch: Heel Rustig – Heel Gehaast
Robot-Geassisteerd: Heel Rustig – Heel Gehaast	Robot-Geassisteerd: Heel Rustig – Heel Gehaast	Robot-Geassisteerd: Heel Rustig – Heel Gehaast

4. Taakcomplexiteit
Hoe complex vindt u de procedure?

Fase 1: Patiënt op OK tot incisie patiënt	Fase 2: Incisie patiënt tot sluiten patiënt	Fase 3: Sluiten patiënt tot vertrek OK
Open: Niet Complex – Heel Complex	Open: Niet Complex – Heel Complex	Open: Niet Complex – Heel Complex
Laparoscopisch: Niet Complex – Heel Complex	Laparoscopisch: Niet Complex – Heel Complex	Laparoscopisch: Niet Complex – Heel Complex
Robot-Geassisteerd: Niet Complex – Heel Complex	Robot-Geassisteerd: Niet Complex – Heel Complex	Robot-Geassisteerd: Niet Complex – Heel Complex

Appendix B: Questionnaire



Deel 2: SURG-TLX (3/5)

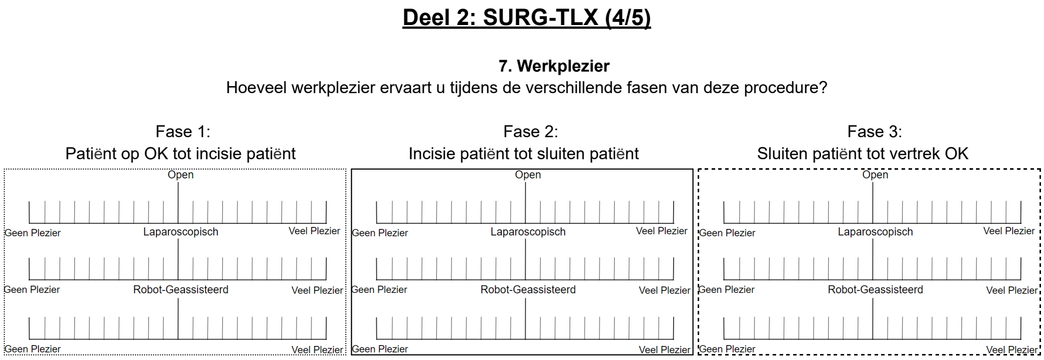
5. Situationele Stress
Hoe gespannen voelt u zich gemiddeld gedurende deze fase van deze procedure?

Fase 1: Patiënt op OK tot incisie patiënt	Fase 2: Incisie patiënt tot sluiten patiënt	Fase 3: Sluiten patiënt tot vertrek OK
Open: Niet Gespannen – Heel Gespannen	Open: Niet Gespannen – Heel Gespannen	Open: Niet Gespannen – Heel Gespannen
Laparoscopisch: Niet Gespannen – Heel Gespannen	Laparoscopisch: Niet Gespannen – Heel Gespannen	Laparoscopisch: Niet Gespannen – Heel Gespannen
Robot-Geassisteerd: Niet Gespannen – Heel Gespannen	Robot-Geassisteerd: Niet Gespannen – Heel Gespannen	Robot-Geassisteerd: Niet Gespannen – Heel Gespannen

6. Afleidingen
In hoeverre is de werkomgeving afleidend gedurende deze fase van deze procedure?

Fase 1: Patiënt op OK tot incisie patiënt	Fase 2: Incisie patiënt tot sluiten patiënt	Fase 3: Sluiten patiënt tot vertrek OK
Open: Niet Afleidend – Heel Afleidend	Open: Niet Afleidend – Heel Afleidend	Open: Niet Afleidend – Heel Afleidend
Laparoscopisch: Niet Afleidend – Heel Afleidend	Laparoscopisch: Niet Afleidend – Heel Afleidend	Laparoscopisch: Niet Afleidend – Heel Afleidend
Robot-Geassisteerd: Niet Afleidend – Heel Afleidend	Robot-Geassisteerd: Niet Afleidend – Heel Afleidend	Robot-Geassisteerd: Niet Afleidend – Heel Afleidend

Appendix B: Questionnaire



Deel 2: SURG-TLX (4/5)

7. Werkplezier

Hoeveel werkplezier ervaart u tijdens de verschillende fasen van deze procedure?

Appendix B: Questionnaire

<u>Deel 2: SURG-TLX (5/5)</u>

Paarvergelijking

Omcirkel in elk vakje het aspect dat u het belangrijkst vindt voor de **werklast** die u ervaart.
Er is geen goed of fout. Uw eerlijke mening is van belang

Taakcomplexiteit Of Mentale Belasting	Werkplezier Of Afleidingen	Taakcomplexiteit Of Afleidingen	Fysieke Belasting Of Tijdsdruk	Werkplezier Of Mentale Belasting	Tijdsdruk Of Situationele Stress	Situationele Stress Of Taakcomplexiteit
Taakcomplexiteit Of Tijdsdruk	Mentale Belasting Of Situationele Stress	Werkplezier Of Situationele Stress	Afleidingen Of Situationele Stress	Taakcomplexiteit Of Werkplezier	Fysieke Belasting Of Taakcomplexiteit	Tijdsdruk Of Mentale Belasting
Werkplezier Of Tijdsdruk	Situationele Stress Of Fysieke Belasting	Afleidingen Of Tijdsdruk	Fysieke Belasting Of Werkplezier	Mentale Belasting Of Fysieke Belasting	Fysieke Belasting Of Afleidingen	Afleidingen Of Mentale Belasting

Dit was het eind van de vragenlijst. Nogmaals enorm bedankt voor het invullen!

Appendix C: Interview Questions

Interview:

1. **Introducerende vragen - Doel: Ervaring in kaart brengen**
   a. Hoe oud bent u?
   b. Hoelang werkt u al met de robot ?

2. Open input factoren van invloed - Doel: Compleet beeld geven

   a. Welke dingen zijn er voor u van belang voor de werklast die u ervaart tijdens een procedure?
      i. Zijn er verschillen tussen de 3 soorten procedures (open/lap/robot?)
   b. Wat heeft u nodig voor werkplezier tijdens een procedure/wat betekent een fijne werkdag voor u?
      i. Zijn er verschillen tussen de 3 soorten procedures (open/lap/robot?)

3. Factoren verduidelijken enquetes - Doel; Enquetes valideren en verduidelijken + compleet beeld geven

   a. Factor 1: Teamdynamiek (Teams/samenwerking/collega's/sfeer)
      i. Wat is van belang voor open en goede werksfeer in het team?
      ii. Wat is van belang voor goede omgang met team?
      iii. Merkt u een verschil in de teamdynamiek tussen de type ingrepen (open/lap/robot)t?
      iv. In hoeverre is het belangrijk om goede/capabele collega's te hebben of zijn juist gezellig/fijne collega's meer van belang
         1. En gaat dit dan meer om directe collega's zoals OK-assistenten of juist chirurgen
   b. Factor 2: Ingrepen en variatie
      i. Wat maakt een ingreep interessant of leuk en wat maakt het juist saai of zwaar, waar ligt dat aan?
         1. Is er een verschil tussen de typen procedures (open/lap/robot)?
         2. Hoe beinvloedt dit je ervaren werklast en werkplezier?
            a. Zorgen saaie procedures bijv voor hogere werklast of lagere?
      ii. Wat maakt een ingreep groot en hoe beinvloedt de grootte van een ingreep uw werkplezier en werklast? (juist leuk of zwaar, is grootte meerdere specialismen/duur)
      iii. Wat maakt een ingreep complex en hoe beinvloedt de complexiteit van een ingreep uw werkplezier en werklast? (juist leuk of zwaar, is complexiteit afh van spoed procedures? meerdere specialismen? pt met hoge BMI? pt met hoge ASA score? als er risico is dat de pt komt te overlijden?)
      iv. Wanneer voel je je betrokken bij een ingreep, wat is daarvoor nodig?
         1. (Gaat dat om betrokkenheid bij patient zelf/hoeveelheid handelingen die je kan doen tijdens een ingreep/hoeveelheid invloed je hebt op de keuzes die gemaakt worden tijdens de ingreep?)
      v. Hoe beinvloedt de variatie in ingrepen jouw werkplezier en werklast
         1. Wanneer is het leuk de afwisseling en wanneer is het te afwisslend waardoor het juist zwaar wordt, hoe zie je dit ideaal voor je?
         2. Gaat variatie meer om de typen procedure of specialismen waar je bent ingedeeld?

Appendix C: Interview Questions

c. Factor 3: Voorbereiding en techniek/apparatuur
    i. Hoe beinvloedt een slechte voorbereiding of een onduidelijk plan jouw werkplezier en werklast?
        1. Waaraan merk je een slechte voorbereiding of een onduidelijk plan? (vaker spullen halen? langer bezig? afwezige spullen)
        2. verschilt dat nog per type procedure, is er vaker een slechte voorbereiding/onduidelijk plan bij een soort procedure (open/lap/robot)
    ii. Merk je verschillen in mankementen/technische errors bij de verschillende soorten procedures? Dus gaan bij ene soort vaker dingen kapot oid?
d. Factor 4: Fysieke belasting
    i. Waar hangt de hoeveelheid fysieke belasting van af tijdens een procedure? (hoeveelheid stilstaan/mogelijkheid tot zitten)
        1. Merk je verschil tussen de verschillende soorten procedures in de hoeveelheid fysieke belasting?
        2. Is er nog verschil in lang stil staan in algemeenheid of dat je in een bepaalde houding, moet stil staan
        3. Wat maakt dat je niet in en uit kan lopen? (of is dit werkomgeving?)
            a. Is dat dan als je steriel staat of ook als je omloop bent
e. Factor 5: Werkomgeivng
    i. Hoe beïnvloedt de werkomgeving (ruimte, apparatuur, geluiden) jouw werkplezier en werklast?
        1. Zijn er verschillen tussen de werkomgevingen bij de verschillende procedures (open/lap/robot)
    ii. Hoe belangrijk is de bewegingsruimte die je hebt tijdens een procedure voor de werklast en werkplezier die je ervaart?
        1. Wat is van invloed op de bewegingsruimte die je hebt? (Aantal mensen in de ruimte, Hoeveel spullen in de ruimte, Groote van OK)
    iii. Hoe belangrijk is de aanwezigheid van een radio of box tijdens een procedure voor de werklast en werkplezier die je ervaart?
        1. Zit er een verschil in tussen de verschillende soorten procedures, dus bijv dat die bij ene type procedure vaker aan mag dan bij ander? (chirurg zei dat die het bij robot irritant vond)
        2. Wat hangt er van af of die aan mag?
f. Factor 6: Erkenning en efficientie (waardering/prestatie/efficientie)
    i. Wanneer vindt je een procedure efficient?
    ii. Wanneer vindt je dat een goede persoonlijke prestatie hebt geleverd of voel je je van toegevoegde waarde?
        1. Zitten hier verschillen tussen de verschillende soorten procedures? Dus voel je je vaker gewaardeerd tijdens open procedure bijv, of juist tijdens lap?
        2. Wat zijn nog tekenen van waardering?
g. Factor 7: Organisatie
    i. Wat zijn volgens jou de belangrijkste oorzaken van een hoge werkdruk?
        1. Heb je vaak teveel taken, wat maakt dat?

Appendix C: Interview Questions

4. Vragen over toekomst - Doel: Suggesties voor toekomst verstrekken

a. Hoe kan uw huidige werklast verlaagd worden en uw werkplezier verhoogd?
b. Heeft u een wensenlijstje of ideeën voor de toekomst voor mogelijkheden tot verbetering van uw eigen werkervaring op de OK met de robot?
c. Hoe ziet u het gebruik van de robot voor u in de toekomst?
d. Op welke manier kan de organisatie jouw werklast verminderen?

6. Belang van deze domeinen - Doel: gewichten valideren SURG-TLX (kaartjes uitprinten)

a. Als u deze zeven aspecten (mentale last, fysieke last, tijdsdruk, taakcomplexiteit, situationele stress. afleidingen en werkplezier) zou moeten rangschikken op basis van welke de meest van invloed is op uw ervaren werklast, hoe zou u dat doen?

7**. Belang van deze factoren uit enquete- Doel: belang in kaart brengen (kaartjes uitprinten)**

a. Als u deze zeven aspecten (team dynamiek, procedurele karakteristieken, voorbereiding en apparatuur, werkomgeving, organisatie, erkenning en waardering, fysieke belasting) zou moeten rangschikken op basis van welke de meest van invloed is op uw ervaren **werklast**, hoe zou u dat doen?
b. Als u deze zeven aspecten (team dynamiek, procedurele karakteristieken, voorbereiding en apparatuur, werkomgeving, organisatie, erkenning en waardering, fysieke belasting) zou moeten rangschikken op basis van welke de meest van invloed is op uw ervaren **werkplezier**, hoe zou u dat doen?

Appendix D: Classification Flowcharts

The two datasheets with the hospital data were manually classified. Since not all data types were available for every procedure, only the procedures for which the relevant data were available were included. Procedures lacking the necessary data were excluded from those specific analyses. The following flowcharts illustrate the exclusion process for each measure.

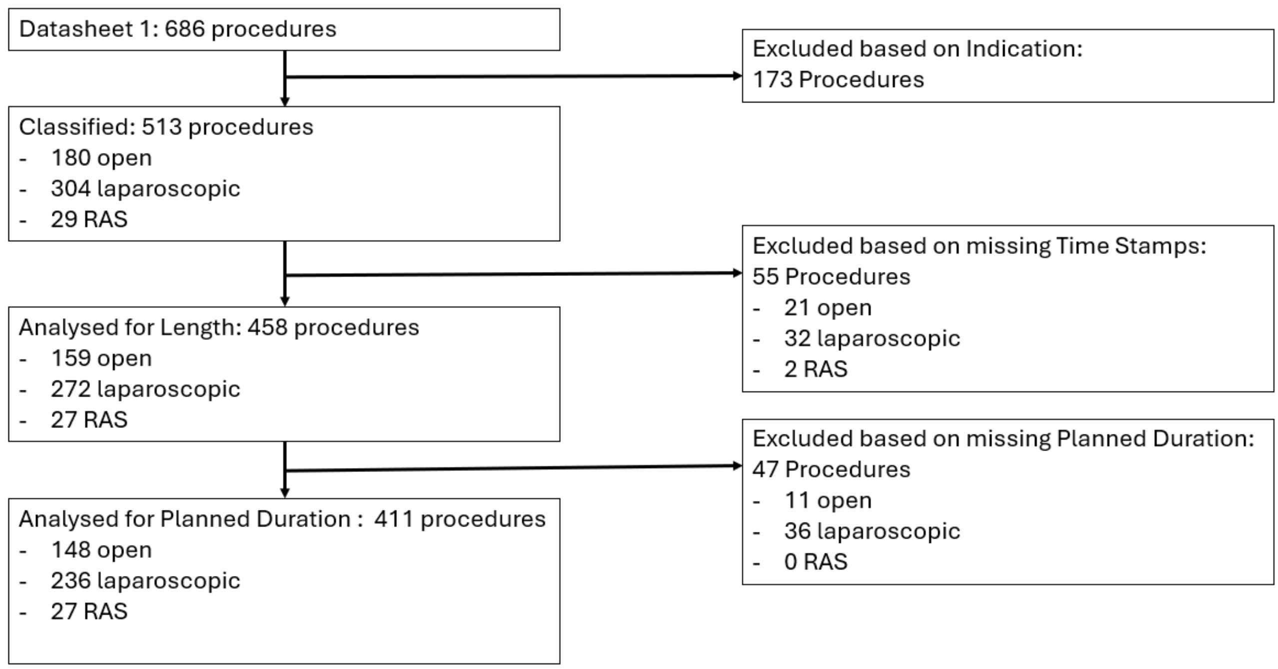


Figure 17: Flowchart depicting the exclusion process for the measures: Length of Procedure and Planned Duration

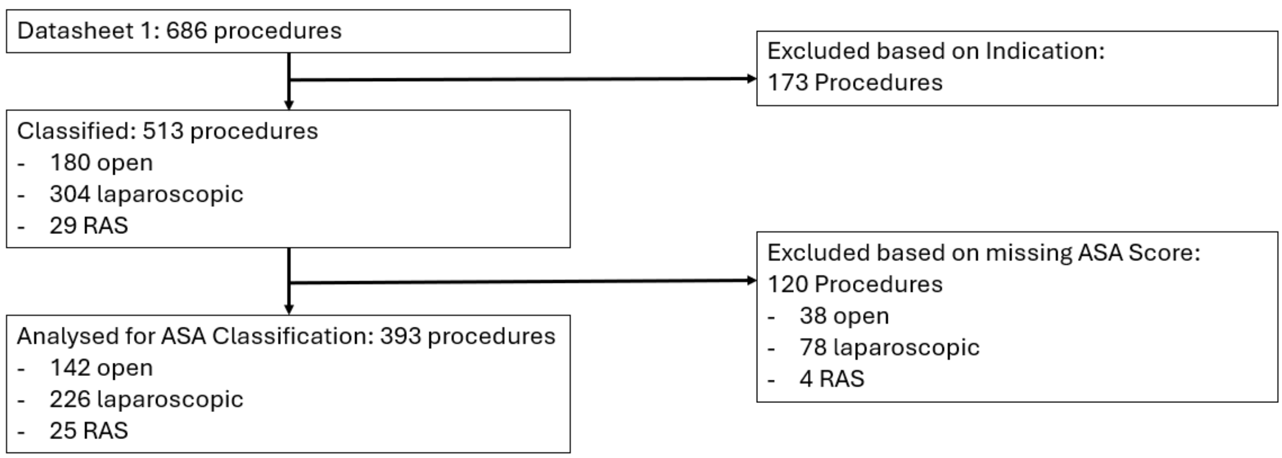


Figure 18: Flowchart depicting the exclusion process for the measure: ASA Classification

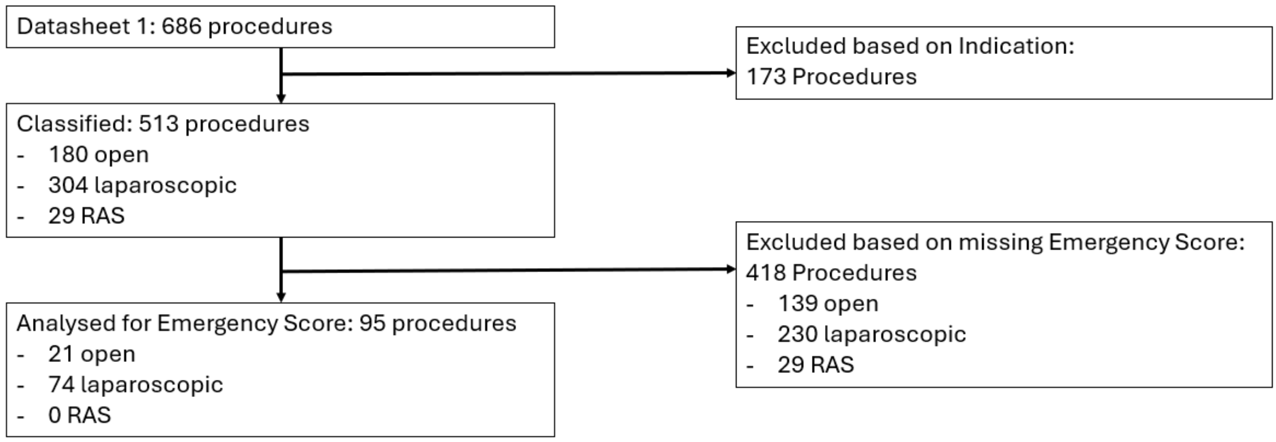


Figure 19: Flowchart depicting the exclusion process for the measure: Emergency Classification

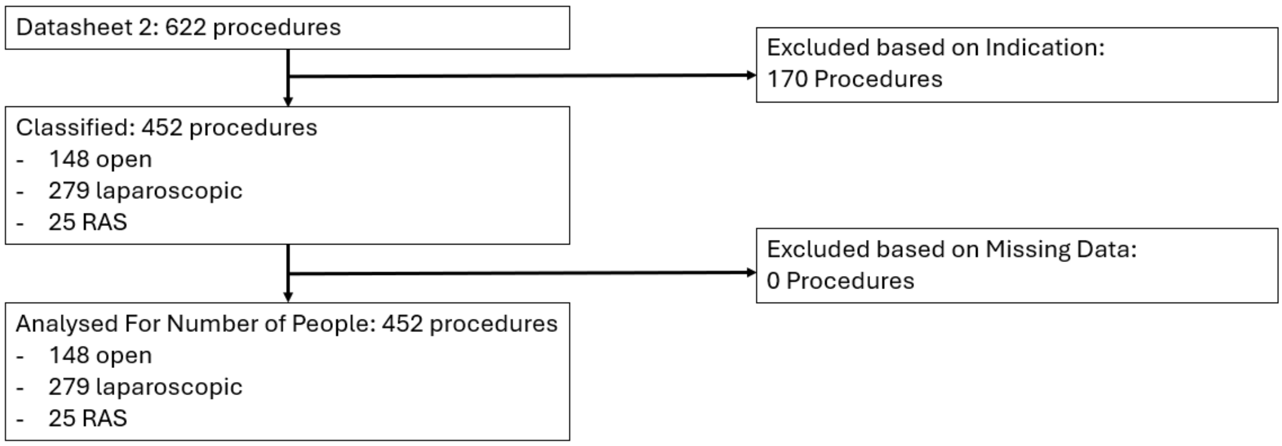


Figure 20: Flowchart depicting the exclusion process for the measure: Number of People in the Room

Appendix E: Video Based Algorithm

The video-based algorithm developed by Schouten et al.[103] identifies personnel in the OR and assigns key anatomical points to track their positions and movements. Figure 21 illustrates how these key points are assigned to different team members, allowing for measurement of their interaction with the operating table and overall movement.

Figure 21: Screenshot from a video recording showing OR personnel with the key points assigned to their bodies. To ensure privacy, the faces of the team members are blurred, and a black box covers the patient on the operating table. This Figure demonstrates how the key points are assigned to the different team members' bodies

The Interaction with the Operating Table Score is derived from the area closest to the operating table. The blue, purple, and orange lines define different interaction zones around the operating table. An individual is considered to be interacting with the operating table if the following conditions are met:

1. Their wrists fall within the blue line,
2. Their shoulders are within the purple line, and
3. Their head is inside the orange line

The three areas were all utilized to calculate the Interaction with the Operating Table Score, compensating for the camera perspective. The operating table with the blue, purple and orange lines are depicted in Figure 22.

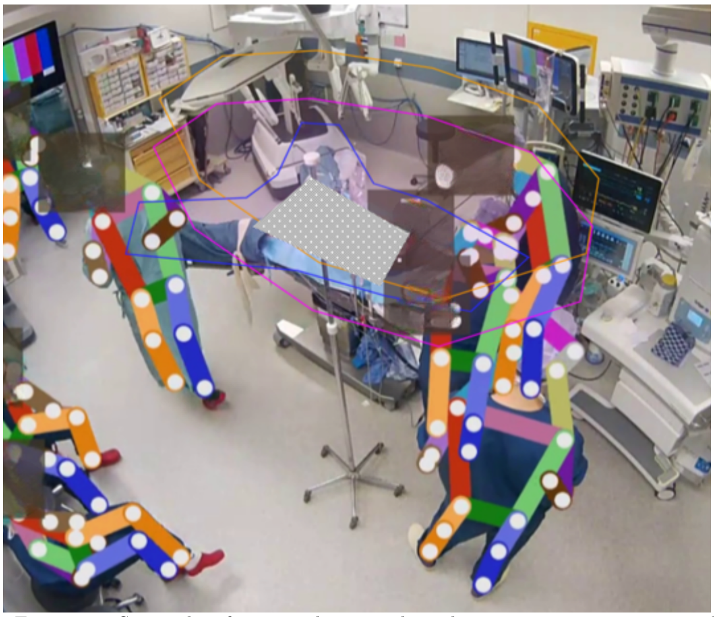


Figure 22: Screenshot from a video recording showing various zones around the operating table. The blue, purple, and orange lines, are all considered in deriving the Interaction with Operating Table Score.

Appendix F: Additional Figures

10.3 SURG-TLX Analysis

10.3.1 SURG-TLX Analysis per Procedure Type

In Figures 23, 24, and 25, the boxplots for the SURG-TLX scores (for phases 1, 2, and 3 respectively) for the three different types of procedures are depicted.

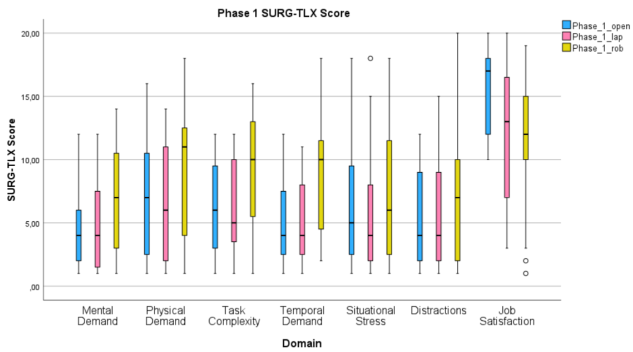


Figure 23: Boxplot showing the SURG-TLX scores for phase 1 for each surgical procedure type: open, laparoscopic, RAS. This figure highlights the differences in perceived workload and job satisfaction across the three procedure types during phase 1.

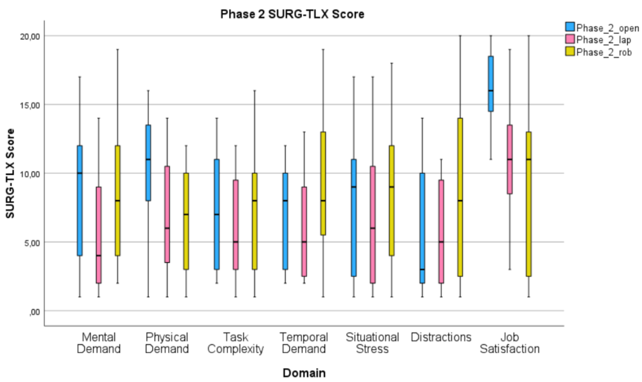


Figure 24: Boxplot showing the SURG-TLX scores for phase 2 for each surgical procedure type: open, laparoscopic, RAS. This figure highlights the differences in perceived workload and job satisfaction across the three procedure types during phase 2.

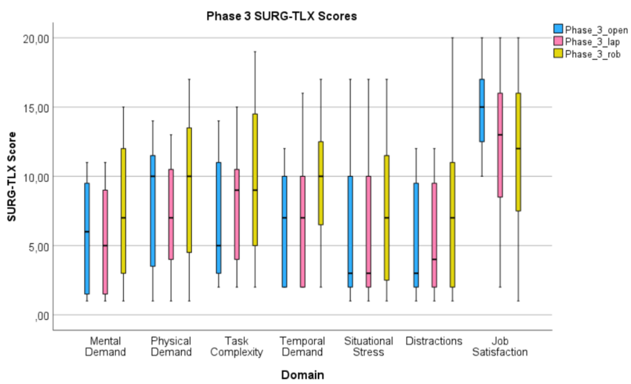


Figure 25: Boxplot showing the SURG-TLX scores for phase 3 for each surgical procedure type: open, laparoscopic, RAS. This figure highlights the differences in perceived workload and job satisfaction across the three procedure types during phase 3.

10.3.2 SURG-TLX Analysis per Phase

In Figures 26, 27, and 28, the SURG-TLX scores (for open, laparoscopic, and RAS procedures respectively) for the three different phases are shown.

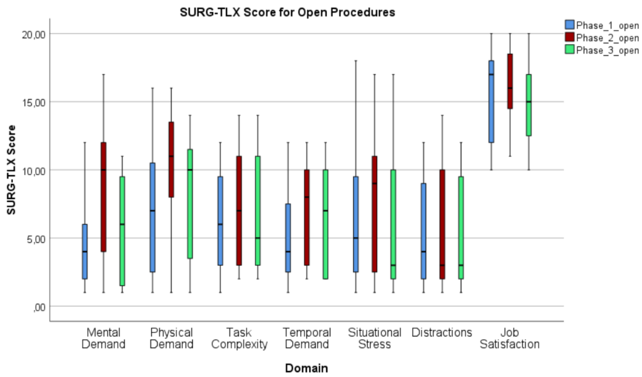


Figure 26: Boxplot showing the SURG-TLX scores for the three phases of the open procedures. This figure highlights the differences in perceived workload and job satisfaction across the three phases of open procedures.

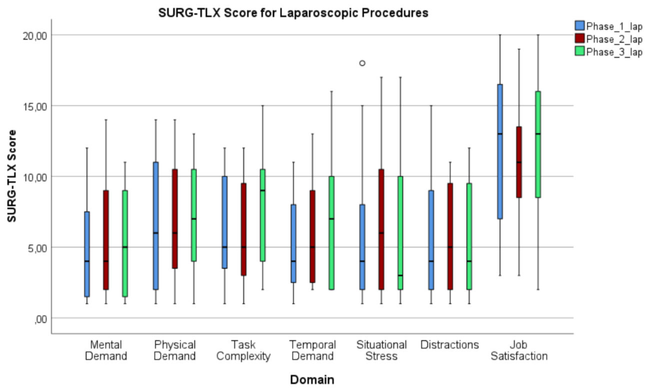


Figure 27: Boxplot showing the SURG-TLX scores for the three phases of the laparoscopic procedures. This figure highlights the differences in perceived workload and job satisfaction across the three phases of laparoscopic procedures.

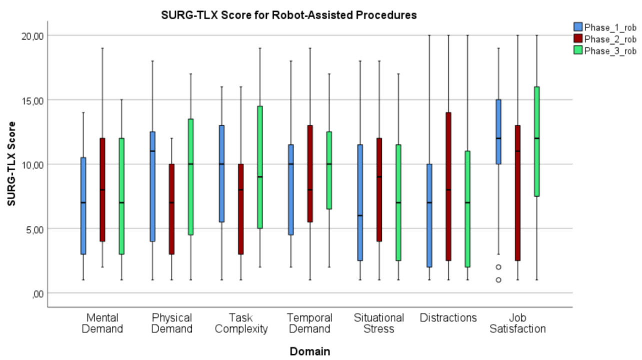


Figure 28: Boxplot showing the SURG-TLX scores for the three phases of the RAS procedures. This figure highlights the differences in perceived workload and job satisfaction across the three phases of RAS procedures.

For the effect of phase on the SURG-TLX score, a statistically significant difference was found in the mental demand domain. Specifically, in phase 2 (intra-operative) higher scores were noted compared to phase 1 (preparation phase) ($p = 0.033$). This result may seem contradictory to interview findings, which emphasized that the preparation phase for RAS procedures is particularly challenging. However, a closer examination of the data shows that mental demand is notably higher in Phase 2 of open procedures compared to Phase 1. Conversely, the differences in mental demand between phases for laparoscopic and RAS procedures are less pronounced.

Additionally, Figure 23 displays the SURG-TLX scores for the different procedures during Phase 1. Visual inspection of this Figure suggests that RAS procedures score higher across multiple domains compared to open and laparoscopic procedures. This observation aligns with the interview findings, which highlighted that Phase 1 of RAS procedures is particularly demanding

10.4 Factors of Influence

The bar chart showing the importance of each main factor for both workload and job satisfaction is depicted in Figure 29.

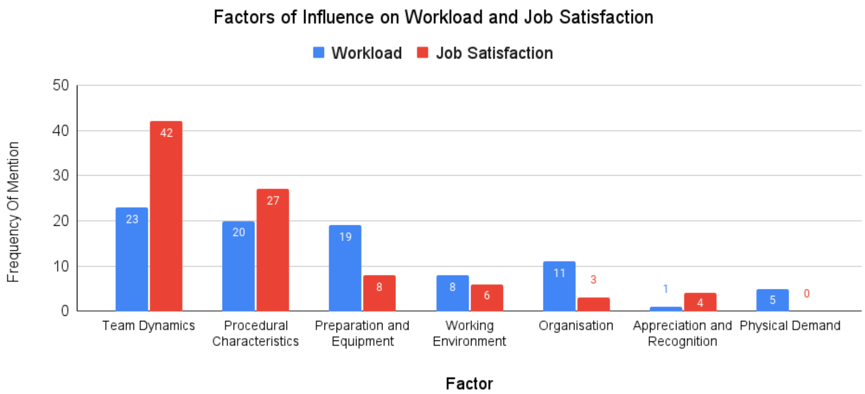


Figure 29: Bar graph depicting the frequency of mentions for both workload and job satisfaction respectively per main factor. This figure highlights the differences per factor of influence for either workload and/or job satisfaction.

Appendix G: Literature Review

Exploring the Cognitive and Physical Impact of Robot-Assisted Surgery on Surgical Team Members: A Systematic Review

Carlijn Vrins, 4667832[1]

Abstract

Introduction: Robot-Assisted Surgery (RAS) is gaining popularity due to benefits such as enhanced patient outcomes. However, the influence of RAS on the workload experienced by various surgical team members remains unclear. This systematic review aims to gain more insights into the influence of RAS on the workload experienced by various team members.
Methods: A systematic literature search was conducted using the PRISMA Guidelines on the following databases: PubMed, Scopus and WebOfScience. The articles were assessed on their quality using CASP checklists.
Results: From the initial 2411 publications, 39 were included after applying the eligibility criteria. Surgeons, nurses, assistants and anesthesia providers were the surgical team members involved in this study. The workload in the literature was examined using multiple tools such as NASA-TLX and EMG or by conducting interviews. RAS appears to decrease the physical workload for surgeons, while it may increase the physical burden on assistants. Additionally, RAS appears to elevate the cognitive workload for nurses, leading to heightened stress levels. There is no consensus about the influence of RAS on the workload of anesthesia providers. Factors such as communication and experience with the robot were commonly cited as influences on workload, with tailored team training frequently recommended to optimize the overall workload in the context of RAS.
Discussion: The largest limitation of this study involves the heterogeneity among studies and the bias introduced through assessment of the workload through post-operation self-reported subjective measures such as the NASA-TLX.
Conclusion: There is no clear consensus on the influence of RAS on the workload of surgical team members, rather than a reduction there seems to be a redistribution of workload. Future studies should focus on more objective ways of assessing the workload and explore other industries to find new optimization methods.

Keywords: Robot-Assisted Surgery, Workload, Surgical Team

1. Introduction

1.1. Background

The prevalence of robot-assisted surgery (RAS) is on the rise, with a 15% annual increase in procedures (1; 2; 3). RAS offers numerous benefits, including enhanced patient outcomes such as reduced blood loss, fewer blood transfusions, less pain, better cosmetic results, shorter hospital stays and faster recovery. Despite these advantages, the integration of this technology presents several challenges (1; 4; 5).

A significant challenge is the impact on team dynamics and the roles of individual team members, thereby altering the workload for the surgical team. While existing research (6; 7) has explored the effects of RAS on surgeons' physical workloads, recent studies emphasize the need to assess the efficacy of RAS across all surgical team members, considering both physical and cognitive workload (1; 4; 8; 9; 10). Assessing workload is crucial, as increases in workload may have severe consequences for both the patient and the surgical team members themselves. Patients risk a decreased performance and the surgical team members risk burnouts, career-ending injuries or musculoskeletal disorders (11). Furthermore, job satisfaction is closely linked to workload (12; 13). In the Netherlands, a shortage of healthcare workers, especially of nurses, is evident. This shortage is projected to escalate, surging from 61,000 vacancies in 2022 to an alarming 170,000 vacancies by 2032, as indicated by ABF research (14). Therefore, it is crucial to assess the workload and, consequently, the job satisfaction of all staff members to prevent any further escalation of this shortage.

One challenge associated with the integration of RAS is the engagement of multiple team members, implying potential changes in tasks and workload due to this technology. RAS has configured the Operating Room (OR) differently, with the surgeon, stationed at a console (see Figure 1). The consoles are specifically designed to improve surgeons' ergonomics and reduce their shoulder, elbow and wrist movements, leading to enhanced comfort. However, this setup may impede nonverbal team communication and situational awareness. Moreover, due to the absence of direct haptic feedback, the cognitive workload of the surgeon might increase. Other team members, including nurses, assistants and anesthesia providers, face potential new tasks and hazards. Robot arms can cause discomfort during instrument changes and effective verbal communication becomes crucial. Team members may find themselves required to perform new tasks for which they were not originally trained

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(8; 15). Moreover, the positioning of patients during RAS procedures differs from conventional procedures, possibly introducing additional challenges, such as preventing patients from sliding while being positioned in steep Trendelenburg (4; 9).

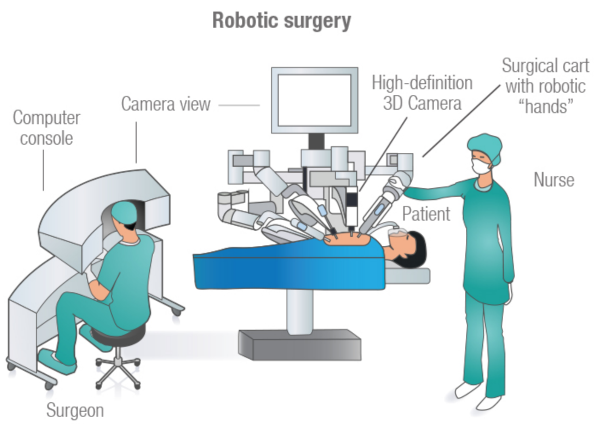

Figure 1: Graphic Representation of Operating Room during RAS (16)

The measurement of workload can include both objective physiological indicators such as heart rate variability (HRV), electroencephalogram (EEG) measurements or electromyography (EMG) measurements, as well as subjective measurements like the NASA Task Load Index (NASA-TLX) or its specialized adoption known as the Surgery Task Load Index (SURG-TLX). The NASA-TLX comprises six dimensions: mental demand, physical demand, temporal demand, own performance, effort and frustration (17). Similarly, the SURG-TLX includes six domains, with the first three mirroring those of NASA-TLX and the last three being distinct and more relevant to surgical tasks - specifically task complexity, situational stress and distraction (18). Participants in both the NASA-TLX and SURG-TLX rank their perceived levels of workload per domain on a 20-point Likert Scale, where 1 indicates low demands and 20 signifies high demands. The scores are aggregated and averaged to generate a total score out of 100. Although literature lacks clear benchmarks for what values are considered harmful (19), some studies suggest that surgeons' performance decreases with workloads approaching 50 or higher (20; 21). Mazur et al. (20) report an increased amount of errors at subjective NASA-TLX scores around 50. Furthermore, physical demand scores over 50 could lead to musculoskeletal injury risks.

1.2. Goal and structure

The primary objective of this study is to examine the impact of robot-assisted surgery on the workload of the surgical team. Through a systematic analysis of workload variations across roles and specialties, and an investigation into the reported factors influencing this workload, this study aims to identify opportunities for workload optimization. The ultimate goal is to provide advice for the improvement of the overall work experience of surgical team members through insights gained from a comprehensive literature study. The central research question guiding this study is: how does RAS influence the cognitive and physical workload of different surgical team members?

First of all, the method of scientific literature search is reported. In the results section, a comprehensive overview of workloads per team member and per specialty is presented. Subsequently, the factors that have the potential to influence experienced workload are described. The results section culminates with a description of possible optimization strategies aimed at achieving a more optimal workload.

2. Methods

2.1. Design

The design of this study is a comprehensive review. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were used for a standardized approach of the review (22).

2.2. Search Strategy

On the 17th of October 2023, a scientific literature search was conducted using two broad academic databases (Scopus and Web Of Science) and one medical database (PubMed). As the aim of this study was to find the impact of robot-assisted surgery on the workload experienced by the surgical team members, the search query was organized into three main aspects: the type of procedure, the surgical team member and the workload. These three had to be present in the paper in order to be included and were therefore connected using the AND operator. The first aspect refers to all types of robot-assisted surgery. A range of terms can be used to describe this type of surgery (e.g. robot surgery, robot-assisted laparoscopy, Da Vinci). The term related to the surgical team refers to all possible team members present during the procedure including nurses, surgeons, anesthesia providers and assistants. The term related to workload encompasses a variety of associated terms that could be used to describe workload such as demand but also to commonly used workload assessment methods as the NASA-TLX and SURG-TLX. The terms within one aspect were connected using the 'OR' operator. This operator necessitates the presence of at least one term on each side of the operator. In Figure 2 a schematic representation of the search query is shown.

The final search string was as follows:
(”Robotic Surgery” OR ”Robotic-assisted Surgery” OR ”Robotic-assisted Laparoscopy” OR ”Robotic-assisted Minimally Invasive Surgery” OR ”Da Vinci” OR ”Robot-assisted Surgery” OR ”Robot-assisted Laparoscopy” OR ”Robot-assisted Minimally Invasive Surgery” OR ”Robot Surgery”) AND (nurse OR surgeon OR assistant OR anesthesiologist OR

Appendix G: Literature Review

anesthetist OR "Surgical Team" OR "Operating Room Team" OR "surgical technician") AND (workload OR demand OR nasa-tlx OR surg-tlx OR teamwork OR cognitiv* OR mental* OR physical* OR ergonom*)

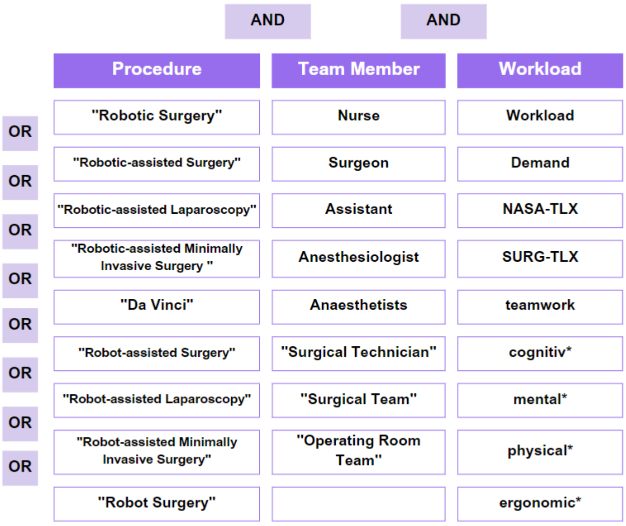

Figure 2: Schematic Representation Of Search Query
The three columns represent the three main aspects connected using the AND operator, and the rows represent associated terms connected with the OR operator.

In order to search for two words that must appear together, quotation marks were used. The asterisk (*) was used as a wildcard, matching all words that contain the search term with any other letter appearing before or after the asterisk.

All three aspects had to be present in the title and/or abstract of the publication in order to be included in the search results since the essence of the publication is encapsulated in those elements and including full text and keywords in the search would lead to too many publications. No filters were applied in any of the databases. In addition, a manual cross-reference search of the cited references in each final included article was conducted.

2.3. Eligibility Criteria

Several eligibility criteria were applied to ensure the relevance of the study during the selection of articles. First of all, duplicate articles and articles that were not written in English were excluded from this research. Moreover, studies of which full text was not available were also excluded. Study protocols and theses were also excluded from this comprehensive review as they often present preliminary or unproven results. The focus was placed on established findings, with only publications from 2014 onwards being included to capture the latest developments as RAS is rapidly advancing. Furthermore, the emphasis of this literature review was placed on real-life situations for greater relevance. Consequently, studies utilizing simulated tasks or involving medical students as subjects were excluded to prioritize findings from real-world scenarios. The primary focus of this literature review centered on examining the impact of RAS on the workload of surgical team members. Therefore, only studies that specifically assessed workload as one of their primary outcome measures were included in this analysis. Additionally, studies that did not pertain to RAS were excluded from the analysis. Finally, it is noteworthy that extensive research has been conducted on the influence of RAS on the ergonomics of surgeons, but there is a gap in understanding its impact on the surgeons' cognitive load and the cognitive load and ergonomics of other surgical team members. To maintain the relevance of this analysis, studies specifically addressing surgeon ergonomics during RAS were intentionally excluded. Studies concerning RAS's influence on the workload of one or multiple surgical team members were included in this analysis. Moreover, studies concerning any type of RAS procedure were included. To be included in the analysis, studies were considered regardless of whether they presented qualitative or quantitative data. In Table 1 the eligibility criteria are depicted.

Table 1: Eligibility Criteria

Inclusion Criterion	Exclusion Criterion
Studies written in English	Studies not written in English
Full text available	No full text available
Published after 2014	Published before 2014
Mentioning any member of the surgical team as subjects	Only mentioning medical students as subjects
RAS procedures performed in real-life situations	Subjects need to perform simulated task
Observational studies, comparative research studies, case studies, (systematic) reviews	Study protocols, theses
Studies concerning any type of RAS procedure	Studies not pertaining to RAS procedures
Workload as primary outcome measure	Solely about ergonomics of surgeon
Studies with qualitative and/or quantitative data	Duplicate articles

2.4. Selection process and data extraction

The titles and abstracts for all search results were screened by one reviewer (CV). Duplicate publications were removed automatically by using a tool in EndNote X9.3.3 (Bld 13966). Remaining duplicates were manually removed. After initial screening, the remaining publications underwent a full-text review. The same reviewer (CV) examined the complete text of each article to verify that the selected publications satisfied the eligibility criteria. A summary of the data provided by the included publications was recorded in a database.

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2.5. Quality check and data analysis

The quality of all included articles was assessed using the checklists of the Critical Appraisal Skills Program (CASP) to enhance the reliability and credibility of this comprehensive literature search (23; 24). The studies were assessed using the corresponding checklist (e.g. systematic reviews were assessed using the systematic review checklist). Studies scoring higher than 75% were considered to be of high quality and were therefore included in the data extraction.

A data analysis was conducted on studies utilizing the same quantitative outcome measure. The mean values and standard deviations (SDs) were extracted from studies. In cases where precise mean values were not explicitly provided but figures containing the mean and SDs were available, the values were determined using WebPlotDigitizer-4.6 (25). Forest plots and other graphs were created using Microsoft Excel (Version 2310 Build 16.0.16924.20054) 64 bits.

3. Results

3.1. Search results

A total of 2411 articles were identified (Figure 3). Five additional articles were identified by checking through references of relevant articles. After the removal of duplicated papers, 230 articles were excluded from the remaining 1155 titles as they were published before 2014. The remaining 925 articles were screened and ranked on their potential resulting in 327 articles. The full text of those 327 articles was read and further assessed based on the eligibility criteria, resulting in a final number of 39 studies that were included in this qualitative synthesis. The 288 studies were excluded due to: not having workload as primary outcome measure (N=169), studying tasks performed on simulated tasks (N=53), only examining the physical workload of the surgeon (N=40), being a study protocol or thesis (N=12), unavailability of the full text (N=6), not pertaining to RAS (N=5) or not written in English (N=3).

3.2. Study characteristics and quality check

The characteristics of the included studies are summarized in Table A.3 in Appendix A. The number of participants in the final 39 studies ranged from 1 to 114 participants. The included studies consisted of a wide range of surgery types (Table A.3) including general, gynecological and urological surgery. Multiple tools were used to examine the cognitive and/or physical workload (Table C.7). These tools were either quantitative measures, objective or subjective, or qualitative measures, based on interviews.

All studies were considered to be of high quality and were therefore included in this systematic review. In Tables B.4, B.5

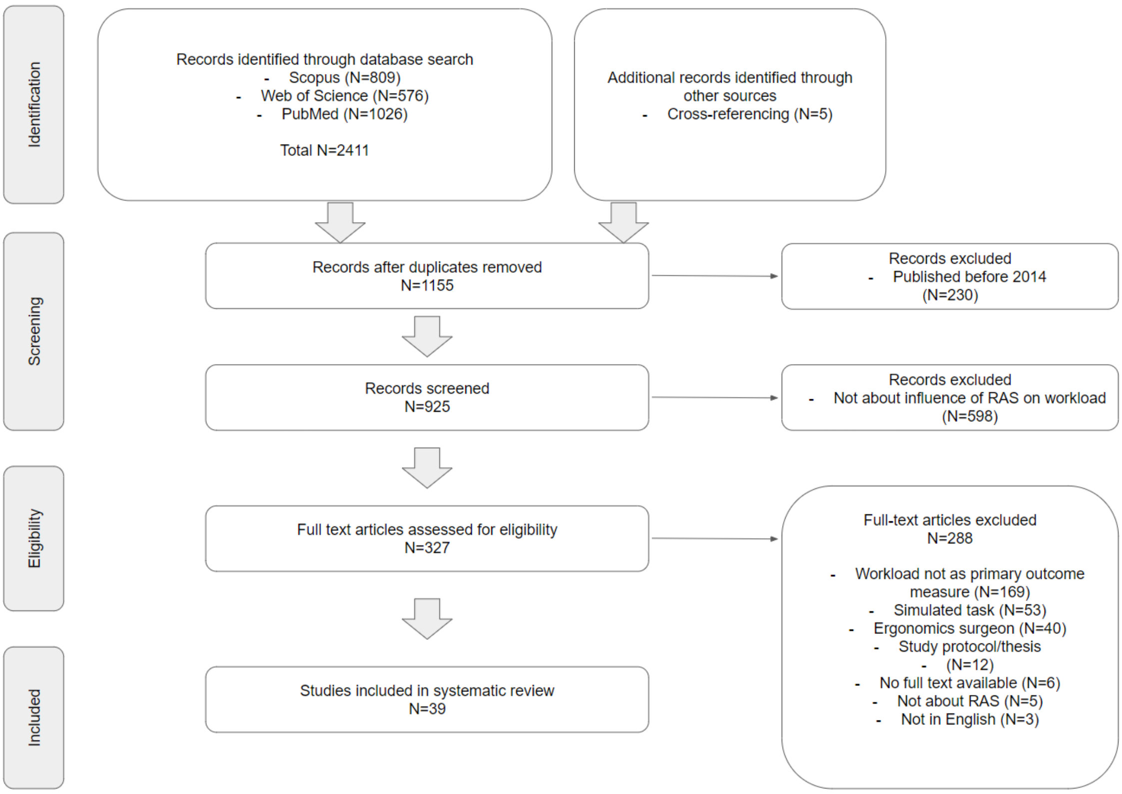

Figure 3: PRISMA flowchart of studies included in this systematic review

and B.6 in Appendix B, the quality check for the qualitative studies, systematic reviews and cohort studies respectively is depicted.

3.3. Physical and mental load assessment tools

In 38 studies the impact of RAS on the cognitive workload was examined and 29 studies investigated the impact of RAS on physical workload. Of these, 28 studies examined both the physical and mental impact on the workload during RAS on either one or multiple members of the surgical team. The tools used in the studies to examine the workload and their scoring can be found in Table C.7 in Appendix C. The most commonly used tool to assess workload was NASA-TLX, which was used by twelve studies. Other common methods were interviews, literature search, SURG-TLX, EMG and EEG measurements. The distribution of tools to investigate workload can be found in Figure 4.

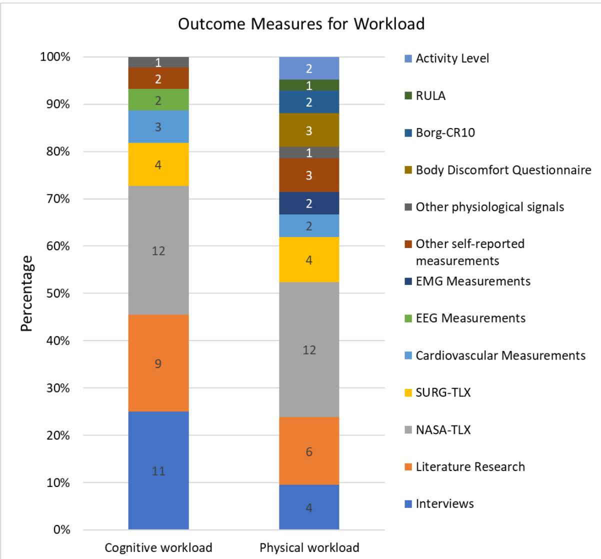

Figure 4: Distribution of tools to assess workload represented with a stacked bar chart

3.4. Demands per team member

There are multiple surgical team members involved during RAS. The most commonly mentioned surgical team members in the studies included in this research are surgeons (N=32), assistants (N=13), nurses (N=17) and anesthesia providers (N=7). As there was no clear distinction in every article between scrub nurses, circulation nurses and their reported workload, the category of nurses entails all different types of nurses involved during RAS. Furthermore, the role of the assistant was not clear in every study, therefore it was chosen that this category entails all kinds of assistants from bedside surgeons to first assistants. Other members, such as surgical technicians, were only mentioned in a few articles (< 3) and were therefore not taken into consideration for this systematic review.

Multiple tools were chosen to measure the cognitive and physical workload respectively, a distribution of these tools per role can be found in Figures D.10 and D.11 in Appendix D.

3.4.1. Surgeon

There were mixed results on the influence of RAS on the cognitive load of surgeons. Eight studies reported an increased cognitive workload, eight studies found a decreased cognitive workload, four studies showed mixed results, two studies reported no difference in cognitive workload and one study indicated an altered cognitive workload.

An increased cognitive workload was determined through various methods including EEG measurements (N=1) (26), interviews (N=3) (15; 27; 28), literature research (N=2) (10; 29) and studies using the NASA-TLX (N=1) (30) or SURG-TLX (N=1) (11). The objective measuring of brain activity during the study of Shugaba et al. (26) indicated increased cognitive demands for surgeons during RAS procedures when compared to laparoscopic procedures. During interviews surgeons state that the distance in RAS procedures might create a feeling of losing control which can elevate levels of stress and therefore lead to an increased cognitive load (28). In addition to the increased cognitive workload, some surgeons also reported feelings of isolation and increased anxiety due to RAS (15; 27; 31; 32). However, other studies offered contrasting results, suggesting that RAS can positively impact the cognitive workload, by workload reduction. These findings were based on cardiovascular measurements (N=2) (32; 33), other physiological signals (N=1) (32), literature research (N=2) (34; 35), interviews (N=1) (36) and NASA-TLX scores (N=3) (37; 38; 39). The objective cardiovascular measurements conducted by Mazzella et al. (32) and Heemskerk et al. (33) both showed lower heart rates for RAS procedures. In addition, Mazzella et al. (32) also examined the cognitive workload using other physiological signals such as saturation levels, respiratory activity, body activity, activity level and body position. A lower cognitive workload was indicated by all of these physiological signals. Three systematic reviews reported mixed results regarding the cognitive demands of RAS (40; 41; 42). Moreover, Krämer et al.(43), found mixed results, as they reported lower cardiovascular measures indicating a lower cognitive workload but contrastingly found higher NASA-TLX scores. Two studies concluded that RAS had no significant influence on the cognitive workload of surgeons, with one study using customized self-reported measures (44) and the other using NASA-TLX and SURG-TLX scores (45). Randell et al. (46) only mention an altered cognitive load based on interviews conducted with surgeons.

In contrast, there was more consensus on the influence of RAS on the physical workload of surgeons. Sixteen studies reported that RAS decreases the physical workload of surgeons. This conclusion was drawn from a range of measurements and assessments, including cardiovascular measurements (N=2) (32; 33), EMG measurements (N=2) (26; 43), other physiological signals (N=1) (32), self-reported measures (N=2) (44; 47), Body Discomfort Questionnaires (N=2) (32; 48), the BORG-CR10 (N=2) (30; 39), NASA-TLX scores (N=6) (30; 32; 37; 38; 39; 43), interviews (N=2) (28; 36) and literature research (N=4) (29; 34; 41; 42). Lawrie et al. (28) quoted a surgeon stating that RAS is “ergonomically better and comfortable for the surgeons and can prolong their careers”. However, there were exceptions, one systematic review by Park et al. (40) reported mixed results in terms of surgeon ergonomics and the systematic review by Gillespie et al. (10) described altered ergonomics. Talamini et al. (45) found no significant difference in ergonomics for the surgeon based on NASA-TLX and SURG-TLX scores. Despite multiple studies reporting a lower physical workload of the surgeon during RAS procedures, Yu et al. (48) reported that musculoskeletal pain among surgeons was not eliminated by the ergonomic benefits of RAS, as indicated by Body Discomfort Questionnaires, SURG-TLX scores and activity level using Inertial Measurement Unit (IMU) data. The IMU data revealed more static neck, torso and left shoulder postures for the console surgeons when compared to assisting surgeons.

Twelve studies used the NASA-TLX questionnaire of which ten studies explicitly reported NASA-TLX values and four studies used the SURG-TLX questionnaire to assess the overall workload. Forest plots of these overall workloads can be found in Figure 5 and Figure 6 respectively. A score exceeding 50 was considered harmful as it has been associated with errors and impaired performance (1). Moreover, Zamudio et al. (11) noted that in 14 of the 90 instances, surgeons reported a score higher than 50, thereby exceeding the threshold. Yu et al. (48) also reported that the perceived workload exceeded the threshold of 50 in 62% of the observed cases.

3.4.2. Assistant

Twelve studies investigated the workload on the assistants, including bedside surgeons and first assistants. Four studies specifically addressed the influence of RAS on the cognitive workload (27; 31; 38; 46). The literature yielded varying results concerning this cognitive workload of assistants. Two studies conducted interviews and revealed that assistants feel disengaged during RAS procedures as they feel like the robot takes over their tasks (27; 31). Both Avellino et al. (15) and Pelikan et al. (31) report a shift in the role of assistants. Initially tasked with assisting the surgeon, assistants transitioned to supporting the robot as surgeons gained the capability to independently control multiple robotic arms during RAS. Randell et al. (46), however, mention that assistants face new tasks during RAS procedures, increasing their cognitive workload. In contrast, Li et al. (38) found that the cognitive workload of assistants decreased during pediatric RAS procedures, as indicated by lower NASA-TLX scores.

Four studies suggested that RAS increases the physical workload of assistants (8; 29; 30; 47). These conclusions were based on self-reported measurements, such as interviews (N=1) (46), the BORG-CR10 (N=1) (30) or other self-reported measures (N=2) (8; 47), as well as objective assessments like the RULA score (N=1) (8). Observations made by Manuguerra et al.’s experts (47) substantiate these findings, indicating that the assistants were situated in ergonomically unfavorable positions. The literature research of Catchpole et al. (29) similarly found that the neck postures of assistants were more flexed and demanding during RAS. Marçon et al. (30) and Van ’t Hullenaar et al. (8) state that the arms of the robot can cause assistants to work in awkward positions. They also suggest that the preferences of the surgeon and the positioning of the patient determine the final height of the operation table, with no consideration given to the physical workload of the assistant. Moreover, Yu et al. (48) reported that assistants experienced pain during RAS, particularly in their left shoulder and neck, confirmed by IMU data and the Body Discomfort Questionnaire. In contrast, Li et al. (38), reported a lower physical workload for assistants based on the NASA-TLX score.

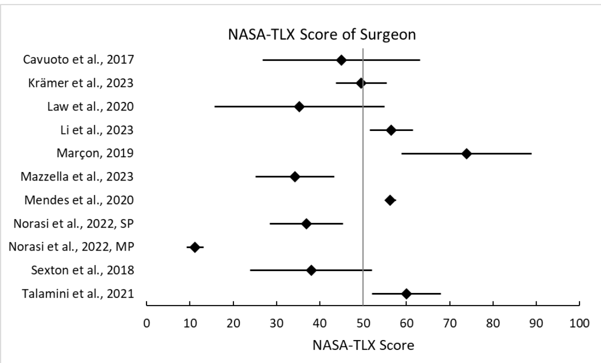

Figure 5: Forest plot of NASA-TLX scores for the surgeon
The diamond shape represents the confidence interval of the mean score while the vertical line at 50 denotes the threshold for possible harmful workloads

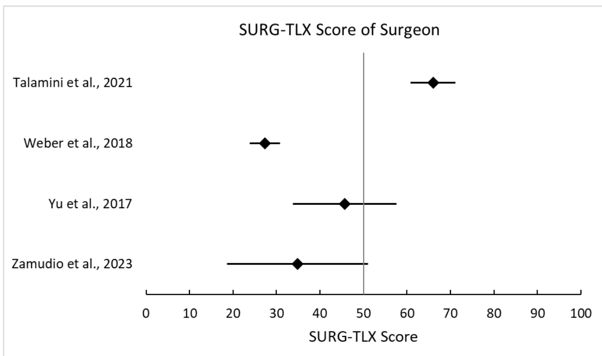

Figure 6: Forest plot SURG-TLX scores for the surgeon
The diamond shape represents the confidence interval of the mean score while the vertical line at 50 denotes the threshold for possible harmful workloads

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To assess the global workload, the NASA-TLX was reported in four studies and the SURG-TLX was reported in one study (48) (M=27.1, SD=10.8). In Figure 7 the forest plot for the NASA-TLX scores is depicted.

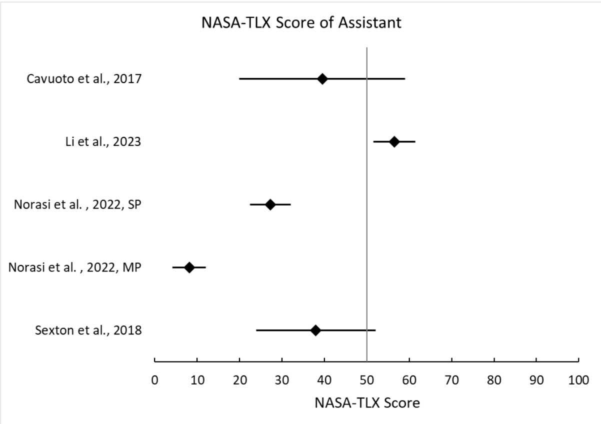

Figure 7: Forest plot NASA-TLX scores for the assistant
The diamond shape represents the confidence interval of the mean score while the vertical line at 50 denotes the threshold for possible harmful workloads

3.4.3. Nurse

There were seventeen studies examining the workload of nurses during RAS. Multiple studies highlighted a significant shift in the role of nurses during RAS. This transition to a new role was often associated with heightened stress and an increase of the cognitive workload as there were more responsibilities to manage compared to non-RAS procedures (49). Seven studies specifically reported an increased cognitive workload (4; 28; 31; 42; 49; 50; 51). Among these, four conducted interviews to gather insights (28; 31; 49; 51), while the remaining three based their findings on a literature review (4; 42; 50). In some interviews, it was revealed that the nurses felt isolated with loss of control (27; 4). Four studies presented differing viewpoints regarding the influence of RAS on nurses' cognitive workload. These studies, with their findings based on interviews, mentioned that nurses felt disengaged as the robot took over their tasks, leading to more side talks (9; 15; 27; 52).

Five studies explored the impact of RAS on the physical workload of nurses (28; 31; 47; 51; 52). Manuguerra et al. (47) found mixed results concerning self-reported ergonomics, with some nurses being positive towards the physical workload during RAS, indicating a decreased physical workload, while others were neutral. During observations by the experts of Manuguerra et al. (47) nurses were assessed negatively on their ergonomics, indicating an increased physical workload. Pelikan et al. (31) highlighted that the nurses faced physical limitations during RAS due to robot arms obstructing their movement and they even reported nurses needing to crawl through under the robot arms, trying to avoid touching the sterile robot arms. Uslu et al. (51) stated that being a nurse during RAS can be rather painful. Additionally, Lawrie et al. (28), underscored the potential risk of nurses being unintentionally hit by the robot. In contrast, Silveira Thomas Porto et al. (52), reported that nurses generally felt more comfortable during RAS procedures.

To assess the global workload, two studies utilized the NASA-TLX questionnaire (M=26.8, SD=20.4; M=12.9, SD=4.9 (SP); M=4.0, SD=1.5 (MP)) (1; 53), and two studies employed the SURG-TLX (M=32.2, SD=20.1; M=30.0 SD=3.0) (11; 54). Zamudio et al. (11) noted that in 11 of the 90 instances, nurses reported a score higher than 50 thereby exceeding the threshold.

3.4.4. Anesthesia provider

Four studies investigated the impact of RAS on the cognitive workload of anesthesia providers. Two of these studies conducted interviews to gain insights (27; 28). El-Hamamsy et al. (27) reported that the staff felt disengaged while Lawrie et al.'s(28) findings indicated a controversy regarding the effect of RAS on the role of anesthesia providers. Some interviewees suggested that the role became more demanding due to RAS, while others argued that the change to their role was less significant. Literature research conducted by the other two studies (29; 41) both reported an increase in cognitive workload for the anesthesia providers.

Notably, there were no studies specifically addressing the physical workload of anesthesia providers in the context of RAS.

The SURG-TLX was used in two studies (M=28.1, SD=17.2; M=39.3, SD=3.5) (11; 54) to examine the global workload. Cavuoto et al. (1) employed the NASA-TLX to assess the overall workload with a mean score of 39.5 (SD=19.6).

3.4.5. Summary of findings per role

In the context of evaluating workload variations among different surgical team members during RAS, six studies utilized either the NASA-TLX or SURG-TLX (1; 11; 48; 53; 54; 55). However, the outcomes across these studies exhibit variability. Yu et al. (48), exclusively examined the workload of surgeons and assistants, discovering that surgeons experienced higher workloads than assistants. Sexton et al. (55) also conducted research among other surgical team members and reported elevated NASA-TLX scores for both surgeons and assistants compared to the rest of the surgical team (M=38 vs M=34). In the literature mixed results about the workload of anesthesia providers in comparison to other surgical team members are present. Zamudio et al.'s (11) findings indicated lower SURG-TLX scores for the anesthesia providers compared to surgeons and nurses, while Weber et al. (54) reported higher SURG-TLX scores for anesthesia providers than for surgeons and nurses. In Figure 8 the mean values of the NASA-TLX and SURG-TLX scores are depicted per role.

Cavuoto et al. (1) delved into the individual domains of the NASA-TLX questionnaire, revealing that assistants had

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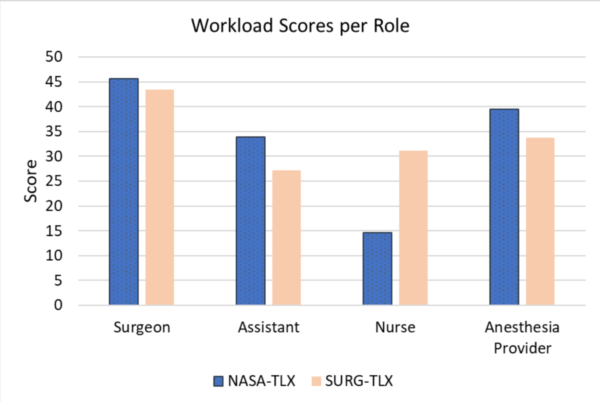

Figure 8: Average NASA-TLX and SURG-TLX scores per role.
Note: These values are illustrative and should not be considered absolute.

the highest physical demand, surpassing surgeons, anesthesia providers and nurses. They also noted that the surgeons experienced significantly higher mental demand and frustration compared to assistants, anesthesia providers and nurses. Moreover, Catchpole et al. (29) found, in their literature research, that the mental demand of anesthesia providers was higher than that of surgeons.

Norasi et al. (53) compared the workload between multi-port (MP) and single-port (SP) RAS procedures. Their findings indicate the lowest workload for nurses (M=4.0; M=12.9) compared to assistants (M=8.1; M=27.2) and surgeons (M=11.2; M=36.9) during both MP and SP RAS.

The main findings, describing the influence of RAS per surgical team member when compared to other types of surgery (e.g. laparoscopic or open surgery), are described in Table 2.

3.5. *Demands per speciality*

There were multiple specialties included in this systematic review (see Figure 9). The most reported specialty was urology (N=19), followed by gynecology (N=9), general surgery (N=6), colorectal surgery (N=5), thoracic surgery (N=3), pediatric surgery (N=3), bariatric surgery (N=2) and other types of surgery (N=3). Other types of surgeries included orthopedics (N=1), endocrine surgery (N=1) and surgical oncology (N=1). Prostatectomies were the most common procedure (N=13).

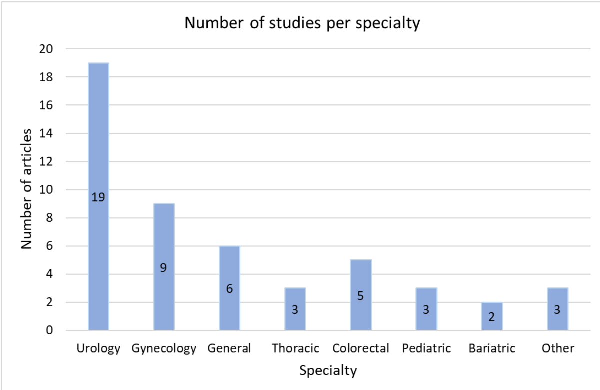

Figure 9: Distribution of the number of studies per specialty

Four studies delved into workload variations across several specialties in the context of different RAS procedures (1; 8; 11; 38). Van 't Hullenaar et al.'s (8) findings indicated that, in comparison to urology and general surgery, gynecology

Table 2: Summary of Main Findings per Role
Description of the influence of RAS on each surgical team member in comparison to other types of surgery

Role	Cognitive Outcome Measures	Physical Outcome Measures
Surgeon	RAS increases cognitive workload (N=8) RAS decreases cognitive workload (N=8) Mixed results (N= 4) Altered cognitive workload due to RAS (N= 1) No difference in cognitive workload (N=2) Surgeons feel isolated (N=4)	RAS decreases physical workload (N=16) Mixed results (N=1) Altered physical workload due to RAS (N=1) No difference in physical workload (N=1) RAS is painful (N=1)
Assistant	RAS decreases cognitive workload (N=1) Felt disengaged (N=2) Altered cognitive workload due to RAS (N=1)	RAS increases physical workload (N=4) RAS decreases physical workload (N=1) RAS is painful (N=1)
Nurse	RAS increases cognitive workload (N=7) RAS decreases cognitive workload (N=1) Felt disengaged (N=4)	RAS decreases physical workload (N=1) Mixed results (N=1) Restricted in movements (N=1) RAS is painful (N=1) Chance to get hit (N=1)
Anesthesia Provider	RAS increases cognitive workload (N=2) Felt disengaged (N=1) Mixed results (N=1)	No specific results

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posed the greatest physical discomfort for assistants. Zamudio et al. (11) similarly reported significant elevated workload scores for gynecology (Mdn=30.0) and urology (Mdn=36.5) compared to general surgery (Mdn=25.0) for the entire surgical team. They also reported nuanced differences in perceived workload across roles and specialties. Surgeons and nurses reported higher scores on average during urology procedures (M= 45.13, SD=15.66; M=38.94, SD=25.12), while anesthesia providers reported higher scores during bariatric procedures (M=33.00, SD=28.61). Additionally, Li et al. (38) found that the gastrointestinal procedures in pediatric surgery imposed a higher overall workload compared to the thoracic pediatric procedures.

In a focused exploration, Cavuoto et al. (1) compared the workload of specific urologic procedures, revealing that cystectomies (M=37, SD=20) and reconstructive surgery (M=36, SD=17) imposed greater workload than prostactomies (M=32, SD=17). Furthermore, cystectomies were rated higher than prostatectomies in terms of temporal demand and frustration.

Furthermore, two studies examined workload differences between single-port (SP) and multi-port (MP) radical prostatectomies (RARP). Norasi et al. (53) found that MP RARP procedures had lower physical and cognitive workload than SP RARP. Conversely, Talamini et al. (45) revealed that the cognitive and physical demands were equivalent between MP and SP RARP procedures.

3.6. Factors that influence workload

Numerous included articles highlighted factors potentially impacting the perceived workload of surgical team members. Communication emerged as a predominant theme in nineteen articles, underscoring its profound influence on the stress levels of the surgical team (1; 4; 8; 9; 10; 11; 15; 27; 29; 31; 35; 41; 42; 46; 47; 51; 54; 55; 56). The loss of nonverbal communication in RAS due to the large robotic arms occluding sight was frequently cited. Particularly with the surgeon situated at a console, obstructing the view and impairing situational awareness. Additionally, the added noise of the robot makes it more challenging for team members to hear each other (31). Celik et al. (4) underline the importance of positive communication for harmonious teamwork. The lack of non-verbal communication also heightens the difficulty for team members to anticipate the surgeons's instructions (54). Sexton et al. (55) note that anticipation is negatively correlated with operative time, resulting in an overall 8% reduction of OR time and consequently decreasing the workload. Moreover, due to the lack of non-verbal communication and therefore reduced anticipation, surgical team members invest more effort into verbal communication, potentially depleting attention or awareness and elevating their cognitive workload.

Furthermore, seventeen articles reported experience with the robot as a factor of influence on the workload of surgical team members (4; 9; 10; 15; 27; 28; 29; 36; 37; 39; 44; 46; 47; 49; 51; 53; 54). A learning curve for RAS was noted, with increased robotic experience correlating with a reduction in workload found in most studies. Mendes et al. (39) conducted research on the perceived workload differences between young and experienced surgeons, revealing that the cognitive workload, especially the cognitive workload of young surgeons was higher during RAS compared to laparoscopic procedures. Studies by El-Hamamsy et al. (27) and Avellino et al. (15) underscored the significance of assistant experience, emphasizing that experienced assistants alleviate stress for the surgeon. Moreover, heightened experience often translated to shorter operating times, contributing to a lower overall workload. Law et al. (37), however, mention that surgical experience had inconsistent effects on the workload of the surgeon

Six studies delved into the realm of training as an influence on perceived workload, focusing specifically on nurses (4; 9; 49; 50; 51; 52). Nurses expressed a tangible need for training in order to alleviate their levels of stress and consequent cognitive workload. Their role is often not clear right now which leads to confusion and an elevated workload. Also, they can have tasks that they were initially not trained for or did not have sufficient knowledge about. Uslu et al. (51) report nurses stating that technical problems caused them to worry during the procedure as they were concerned about harming the patient but could not solve the technical problem themselves due to their lack of technical knowledge.

Team familiarity has been highlighted as a significant factor affecting workload in seven articles (10; 27; 28; 42; 45; 50; 55). Lawrie et al. (28) emphasize that RAS procedures are frequently carried out with team members who are unfamiliar with each other, leading to an increased workload. Sexton et al. (55) further contribute to this understanding by noting that higher team familiarity scores correlate with fewer inconvenience events. Since a higher frequency of inconvenience events is linked to longer surgery times, which, in turn, are associated with heightened workload, reduced team familiarity results in an increased workload.

Five studies mention flow disruptions as a factor influencing workload, with a higher frequency of flow disruptions leading to an increased workload (10; 29; 41; 45; 54). Weber et al. (54) examined the types of flow disruptions that occur during RAS procedures. They identified that the majority of flow disruptions result from people entering the operating room. Additionally, technology aspects such as equipment issues or camera cleaning, also contribute to flow disruptions. Nurses experienced heightened stress levels with higher disruption rates, leading to higher mental demands. Moreover, anesthesia providers and nurses faced an increased distraction with more flow disruptions, contributing to an impaired situational awareness. Case irrelevant information increased the situational stress and distraction of the anesthesia providers significantly. Additionally, flow disruptions due to equipment issues had a negative impact on the mental demands of the anesthesia providers but a positive effect on the mental demand of nurses.

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Furthermore, the literature presents mixed findings regarding the impact of case complexity on the perceived workload. Four studies suggest that more complex procedures tend to result in a higher overall workload (11; 32; 38; 55). This is attributed to extended operative times and the likelihood of requiring heightened focus, consequently leading to an increased cognitive workload. Conversely, two other studies propose no definitive effect of procedural complexity on workload (1; 37). In Cavuoto et al.'s (1) study, which examined various urological procedures, no significant correlation between workload and complexity was identified. Law et al. (37) discovered inconsistent effects of patient characteristics and disease processes on the surgeon's workload.

3.7. *Workload optimization strategies*

A prevailing optimization strategy, identified in sixteen studies, revolves around the development of tailored training methods for surgical teams engaged in various RAS procedures (4; 9; 10; 11; 28; 29; 41; 42; 45; 46; 47; 49; 50; 51; 54; 55). Six studies underline the importance of team-wide training to enhance communication and anticipation skills (10; 29; 42; 47; 55; 54). The training should not only focus on the technical aspects of RAS but also on the development of non-technical skills (NTS) (e.g. communication and decision making) as stated by Manuguerra et al. (47).

Furthermore, communication is hindered and movements are often restricted due to the design of the workspace. In addition to this, surgical team members are sometimes hit by the arms of the robot or hindered by the robot. Catchpole et al. (41) propose workspace interventions, advocating for clear primary movement pathways and careful management of overhead beams to optimize workload. Van 't Hullenaar et al. (8) recommend optimal hardware settings (e.g. table on optimal height and optimal monitor position) to overcome ergonomic problems for the surgical assistant. De'Angelis et al. (44) align with these recommendations, asserting that overall well-being, particularly of surgeons, is intrinsically tied to the optimization of the surgical environment. Celik et al. (4) further assert that the design of the robotic system itself influences workload dynamics.

Task-related interventions emerge in four studies as viable strategies for optimizing workload with checklists and team briefings highlighted as potential aids (27; 41; 47; 49). These interventions not only contribute to heightened situational awareness but also contribute to the reduction of experienced workload.

4. Discussion

This systematic review aims to comprehensively synthesize the existing literature on the cognitive and physical workload associated with Robot-Assisted Surgery (RAS) across various members of surgical teams. While prior systematic reviews have explored the impact of RAS on patient outcomes (57; 58; 59), a notable gap exists in research focusing on the workload experienced by surgical team members. Recent systematic reviews have exclusively examined the physical workload of surgeons (60; 61; 62), incorporated laboratory-simulated tasks to assess workload (34; 40) or concentrating solely on one specific surgical team member (4; 50). In contrast, this literature review adopts a more inclusive approach. To the best of the author's knowledge, this review represents the first attempt to investigate the workload experienced by diverse surgical team members, utilizing a combination of quantitative and qualitative data, and exclusively relying on real-life scenarios. By considering both quantitative and qualitative data, a nuanced understanding of the cognitive and physical demands placed on surgical team members during RAS procedures is sought. This approach distinguishes this literature review from previous reviews and enhances the overall understanding of the challenges presented by RAS in real-world clinical settings.

4.1. *Summary of Findings*

The influence of RAS on the workload experienced by various surgical team members lacks a definitive consensus. There is considerable heterogeneity of results among the included studies, suggesting that, instead of a reduction, RAS may redistribute the workload among team members.

Surgeons are likely to experience less physical demand during RAS procedures as the console is designed to alleviate the physical workload. This is supported by a majority of the literature in this study. There is, however, no clear consensus on whether the robot also decreases the cognitive workload of the surgeon as literature poses mixed results. The benefits of RAS for other team members are unclear. Assistants often experience increased physical demands due to awkward positions, nurses are likely to experience heightened stress leading to an increased cognitive workload. There is no consensus on the influence of RAS on the workload of anesthesia providers.

According to the literature (11; 20), scores surpassing 50 on NASA-TLX and SURG-TLX suggest an elevated risk of burnouts and muscle-related injuries. Upon inspection of the forest plots (Figure 5, Figure 6, Figure 7), it's evident that not all scores for these team members fall below the 50-point threshold. Furthermore, Zamudio et al.'s (11) mentions that nurses also exceed this threshold in some cases. This suggests an excessive workload during RAS procedures for various surgical team members which may pose potential risks.

Gynecological procedures were deemed more demanding than both general surgery and urologic procedures, as highlighted by Van 'T Hullenaar et al. and Zamudio et al. (8; 11). Given the higher frequency of urologic procedures (28), the surgical team likely acquired considerable experience in this domain, potentially contributing to a reduction in their overall workload. Nevertheless, it's crucial to acknowledge the limited number of studies exploring workload variations across different procedures, making it challenging to reach definitive conclusions in this regard.

Numerous factors were identified as influencing the experienced workload, with communication, experience, training, team familiarity, flow disruptions, and case complexity being the most frequently cited. However, not all studies reached a definitive consensus regarding the extent of their influence.

In order to optimize the workload studies report developing tailored team training methods, workspace interventions and task-related interventions such as team briefings and checklists.

Based on these findings one can conclude that all surgical team members should be trained and educated properly before conducting RAS procedures as this can reduce their experienced workload. Additionally, interventions in the design of the robotic system and workspace are essential to enhance the physical workload, ensuring optimal functionality for diverse members of the surgical team.

4.2. Strengths and limitations

Several limitations must be taken into account when interpreting the findings of this study, with the most significant being the considerable heterogeneity among the included studies and their respective research approaches. This heterogeneity is evident in variations in study size, methodologies employed, surgical team members assessed, surgical specialties examined, types of robotic modalities utilized, and the tools used to assess both cognitive and physical workloads.

The use of different tools by the studies makes it challenging to compare results. Thirteen different tools were used to assess workload, with only six being objective measurement tools, mainly examining physical workload. Most measurements relied on self-reported subjective measures such as the NASA-TLX, potentially introducing recall bias. Objective measures, such as heart rate variability or muscle activity, were underutilized, particularly in studies focusing on team members other than the surgeon.

An additional concern regarding the NASA-TLX, the most commonly reported tool in the included studies, is its lack in specificity, providing a general impression of mental and physical workload without detailing specific discomfort regions. In contrast, the Body Discomfort Questionnaire used by three studies (32; 43; 48), demonstrated greater specificity in capturing and detailing areas of discomfort.

Moreover, different modalities of the Da Vinci (Multi-Port (MP) and Single-Port (SP)) were used to examine the workload, enlarging this heterogeneity. This difference was, however, not taken into account whereas this could be of influence as stated by Norasi et al. (53). The SP system has only been recently developed and is supposed to reduce problems such as camera swapping and external robotic arms collision.

The heterogeneity among the studies is also portrayed in the types of procedures conducted. All types of procedures were included in this study and there was no distinction when examining the experienced workload per surgical team member. Only a few studies examined the effect of procedure type on workload and some found significant differences. Therefore, it could have been relevant to consider this effect.

Diversity within the surgical teams featured in the studies is evident, reflecting the variation in medical procedures across different countries. The composition of surgical teams varies, with some studies examining procedures performed by specialized robotic teams, while others examined RAS procedures conducted by surgical team members who did not receive prior training. As training and experience emerged as significant factors influencing workload in numerous studies, this is important to take into consideration.

Additionally, there is inconsistency in how studies distinguish between different surgical team members. Some studies explicitly differentiate between roles, such as circulating nurses and scrub nurses, while others address the workload of nurses in general. The same disparity is observed for assistants, who may be classified as first assistants, bedside assistants, or surgical assistants, with inconsistent nomenclature across studies.

It is crucial to acknowledge that not all team members were considered in this analysis. For instance, surgical technicians were only referenced in three studies, which is an insufficient sample size for drawing conclusive insights into their experienced workload whereas initially those members were also included in this review.

Comparisons of workload among team members were affected by the aggregation of mean NASA-TLX and SURG-TLX scores without weighting. This approach treated scores from studies with varying in the number of participants equally, potentially biasing the results. Moreover as visible in the forest plots for NASA-TLX and SURG-TLX scores, there is a lot of heterogeneity between the results of the studies. Additionally, other studies only provided visual representations rather than exact mean NASA-TLX or SURG-TLX scores and standard deviations. Although the values were determined using WebPlotDigitizer-4.6 (25), potential reading errors must be acknowledged. Therefore, it is important not to consider the values for the mean values as absolute truth for absolute workload scores for the team members. Figure 8 was used to illustrate the differences between team members in workload rather than to provide exact values of their experienced workload.

Moreover, there may be inherent bias in the studies themselves. Given that patient outcomes are paramount in the medical industry, the selection of the type of procedure is often influenced by patient and disease characteristics. As noted by Mazzella et al. (32), more challenging cases were conducted using open surgery, resulting in extended operative times and potentially increasing the workload. The ethical constraints associated with conducting randomized controlled trials in the included studies have led to a reduction in the level of evidence they provide.

Despite these limitations, the study's strength lies in its exclusive focus on real-life scenarios, providing a realistic perspective on workload. Only including studies from 2014 onwards ensures up-to-date relevance and encompassing all types of RAS procedures, without exclusion, contributes to a broad understanding of workload during robot-assisted surgeries.

All included studies were considered of high quality, elevating the level of evidence provided.

4.3. Future Research

As most workload measurements studied in this literature review were biased, future research could delve into more objective real-time measurements such as EEG and EMG signals to explore the workload of different surgical team members.

The workload optimization strategies proposed in this literature review are grounded in current healthcare industry practices as only studies examining real-life medical scenarios were included in this research. One suggested strategy involves task-related interventions, such as checklists. However, as highlighted by Urbach et al. and O'Connor et al. (63; 64), checklists are not widely embraced in this industry, and their impacts and effects vary. Consequently, future research should explore novel strategies, potentially drawing inspiration from other industries, to broaden the scope of interventions beyond the medical realm and enhance workload optimization in healthcare.

Moreover, in this literature research, the evaluation of workload using NASA-TLX only considered total scores instead of exploring individual domains. In future research, it would be interesting to consider these individual domains as well for a more thorough analysis in order to provide a more nuanced plan to optimize workload.

5. Summary and conclusions

The aim of this comprehensive literature study was to examine the experienced workload of various surgical team members during RAS procedures. Based on our findings we can conclude that RAS results in a redistribution of workload rather than a reduction. Surgeons experience a lower physical workload during RAS, while there is no consensus about the influence of RAS on their cognitive workload. For assistants, there is a tendency towards an increased physical workload, while consensus on their cognitive workload remains elusive. Nurses, according to the literature, often experience heightened cognitive workload, potentially leading to elevated stress levels, with inconclusive evidence regarding their physical workload. The literature lacks a unanimous stance on the influence of RAS on both the physical and cognitive workload of anesthesia providers. Factors such as communication and robotic experience were commonly cited as influences on perceived workload, with tailored team training frequently recommended to optimize the overall workload in the context of RAS. Future studies should focus on more objective ways of assessing the workload and explore other industries to find new optimization methods.

Acknowledgements

I would like to express my sincere appreciation to Anneke Schouten and John van den Dobbelsteen for their valuable contributions to this literature study. Their provided insightful feedback and expertise greatly enhanced the quality of my research.

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Appendix A. Study Characteristics

Table A.3: Study Characteristics

Author, Year, Country	Study Type	Participants	Specialty	Tool Used	Main Findings
Ahmed et al., 2019, USA (56)	Cohort Study	Surgeons (N=3)	Urology (N=20)	NASA-TLX	When surgeon's non-technical skills scores were found to be high there was a corresponding increase NASA-TLX score of the team, the whole team worked harder to achieve their goals.
Avellino et al., 2019, France (15)	Qualitative Study	Surgeons (N=6)	Gynecology (N=2)	Observations, interviews	Surgeons feel isolated and their cognitive load is increased during RAS.
Catchpole et al., 2019 (29)	Systematic Review	Surgeons, Assistant, Anesthesia Provider (N=not specified)	Not reported	Literature Search	Workload may be reduced for the surgeon, but increased for other team members. Postural stress, rather than being reduced in RAS may simply be relocated.
Catchpole et al., 2022, (41)	Systematic Review	Surgeon, OR Staff, Anesthesia Provider (N=not specified)	Not reported	Literature Search	The surgeon has a lower physical demand but potentially higher mental demand during RAS. Other surgical team members may have higher physical mental demands during RAS. The anesthesia provider has higher mental demand during RAS.
Cavuoto et al., 2017, USA (1)	Cohort Study	Surgeons (N=3), Nurses (N=20), Assistants (N=2), Anesthesia Providers (N=22)	Urology (N=63)	NASA-TLX, additional questionnaires	Surgeons experience highest workload (M: 45, SD=18,2), assistants experience highest physical and temporal demand (M=39,5, SD=19,6), nurses experience lowest workload (M=26,8, SD=20,4) and anesthesia providers report the highest effort (M=39,5, SD=19,6). During cystectomies (M=37 SD=20) and reconstructive surgery ((M=36, SD=17) higher workload was perceived than during prostatectomies (M=32, SD=17)
Celik et al., 2023 (4)	Systematic Review	Nurses (N=not specified)	Not reported	Literature Search	The new roles of nurses are not as clear as they should be. There are different demands during RAS. There is fear and anxiety in nurses.
de'Angelis et al., 2015, USA (44)	Cohort Study	Surgeons (N=12)	Colorectal (N=22)	Self-assessment about psychological stress and pain	There was no difference in surgeon's stress between RAS and laparoscopic surgery. Pain was lower during RAS.

Continued on next page

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Table A.3 – continued from previous page

Author, Year, Country	Study Type	Participants	Specialty	Tool Used	Main Findings
El-Hamansy et al., 2020, UK (27)	Qualitative Study	Surgeons (N=8), Assistants (N=4), Anesthesia Providers (N=5), Nurses (N=5)	Urology (N=13), Gynecology (N=5)	Interviews	There is more stress for surgeons during RAS due to the loss of nonverbal communication. Nurses felt isolated with the loss of control and large equipment was blocking their visual field. Moreover, staff felt disengaged which led to more side talks.
Elek et al., 2021, (35)	Systematic Review	Surgeons (N=not specified)	Not reported	Literature Search	Lower mental demand for surgeons during RAS.
Gillespie et al., 2020, (10)	Systematic Review	Surgical Team (N=not specified)	Urology, Gynecology, Thoracic and General procedures	Literature Search	Due to RAS there are different demands for the different roles.
Guru et al., 2015, USA (65)	Cohort Study	Surgeon (N=1)	Urology (N=51)	NASA-TLX, EEG	Higher EEG-based workload was perceived as more effort exerted by the expert surgeon during RAS. The majority of the workload measured was contributed by motor workload of the surgeon.
Heemskerk et al., 2014, Netherlands (33)	Cohort Study	Surgeons (N=2)	General (N=11)	ECG, HRV analysis	RAS leads to lower HR and LF/HF ratio. RAS reduces total strain (combined mental and physical demand).
Hullenaar van 't et al., 2019, the Netherlands (8)	Cohort Study	Assistants (N=11)	General (N=7), Gynecology (N=5), Urology (N=3)	RULA, questionnaires	RAS is physically demanding for the assistant. Gynecology can be seen as the specialism with the most uncomfortable ergonomic body postures for the first assistant.
Kang et al., 2016, South-Korea (49)	Qualitative Study	Nurses (N=15)	Not reported	Interviews	Nurses felt work-related burden. There are more tasks for nurses during RAS and that requires learning.
Krämer et al., 2023, Germany (43)	Cohort Study	Surgeons (N=5)	Gynecology (N=8)	EMG measurements, ECG measurements, posture, NASA-TLX, Body Discomfort Questionnaire	RAS posed a lower physical demand but higher mental demand for surgeons.
Kumar et al., 2022, India (36)	Qualitative Study	Surgeons (N=93)	Urology (10%), Gynecology (23%), General (62%), Pediatric (5%)	Interviews	There was an improved comfort for the surgeon both cognitively and physically.
Law et al., 2020, USA (37)	Cohort Study	Surgeons (N=7)	Urology (N=13), Colorectal (N=15)	NASA-TLX	Surgeons had a workload of 35,3 (SD=19,5). RAS leads to less mental demand and physical demand, lower frustration and better performance.
					Continued on next page

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Table A.3 – continued from previous page

Author, Year, Country	**Study Type**	**Participants**	**Specialty**	**Tool Used**	**Main Findings**
Lawrie et al., 2022, UK (28)	Qualitative Study	Surgeons (N=11), Nurses (N=2), Anesthesia Providers (n=1)	Urology (N=5), Gynecology (N=1), General (N=2), Thoracic (N=1), Colorectal (N=8), Other (N=3)	Interviews	The surgeon reports better ergonomics but higher cognitive load as it requires higher levels of concentration. Nurses report having a different role, and greater mental effort, especially during early implementation. Also there are more opportunities for distraction and a chance of getting injured by the robot. No consensus on the workload of anesthesia providers, their role might become more demanding.
Li et al., 2023, China (38)	Cohort Study	Surgeons, Assistants (N=not specified)	Pediatric (N=50)	NASA-TLX	Pediatric robotic surgery seems to require less physical and mental work and is less difficult than open surgery
Manuguerra et al., 2021, France (47)	Cohort Study	Surgeons (N=26), Assistants (N=26), nurses (N=13)	Urology (n=26)	Self-assesment and expert observations on ergonomics	Overall all members assessed themselves positively during RAS procedures. Ergonomics, however, was assessed poorly by the experts and the bedside surgeons (assistants) criticized on ergonomics.
Marçon et al., 2019, France (30)	Cohort Study	Surgeons, Assistants (N=not specified)	Urology (N=69)	BORG-CR10, NASA-TLX	RAS appears to be particularly difficult physically for the surgical assistant. RAS has the highest global workload but physical demand is lower for surgeons.
Martinello et al., 2020, (42)	Systematic Review	Surgeons, Nurses, Surgical Staff (N=not specified)	Not reported	Literature search	Surgeons experience a lower physical workload Nurses experience an increased responsibility and a higher demand in roles.
Mazzella et al., 2023, Italy (32)	Cohort Study	Surgeons (N=2)	Thoracic (N=20)	HR, SpO2, respiratory activity, body activity, activity level, body position and the STAI-Y, SAM, NASA-TLX questionnaires	During RAS procedures, the ANS was stimulated to a lesser degree, causing less stress for surgeons and ensuring greater comfort (NASA-TLX: 34,2 RAS VS 59,8 open). Surgeons reported more anxiety for RAS.
Mendes et al., 2020, France (39)	Cohort Study	Surgeons (N=24)	Urology (N=70), Gynecology (N=11), Pediatric (N=8)	BORG-CR10, NASA-TLX	There was a less overall workload for RAS, physical demand was also lower for RAS.
Moloney et al., 2023, (50)	Systematic Review	Nurses (N=not specified)	Not reported	Literature search	Nurses had more stress and felt that role was more demanding.
Norasi et al., 2022, USA (53)	Cohort Study	Surgeon (N=1)	Urology (N=50)	NASA-TLX	Multi-port procedures had lower physical and cognitive workload than single-port procedures.

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Table A.3 – continued from previous page

Author, Year, Country	Study Type	Participants	Specialty	Tool Used	Main Findings
Park et al., 2021,(40)	Systematic Review	Surgeons (N=not specified)	Not reported	Literature search	In literature there are mixed results about the physical demand and mental demand of the surgeon during RAS. Often less physical demand for surgeons and mental demand is unclear.
Pelikan et al., 2018, USA (31)	Qualitative Study	Surgeons (N=6), assistants (N=4), anesthesia provider (N=1), nurses (N=14)	Gynecology (N=10), Bariatric (N=1), Other (N=2)	Interviews, field work	Surgeons feel lonely. RAS brings a reconfiguration of the physical as well as the cognitive distance. The team needs to increase efforts to communicate and team might lose focus. Nurses appear to be stressed.
Randell et al., 2021, UK (46)	Qualitative Study	Surgeons, Assistants, Surgical Staff (N=not specified)	Colorectal (N=21)	Interviews	Surgical team members experienced higher mental demand due to surgeon's reduced situation awareness.
Schuessler et al., 2020, USA (9)	Qualitative Study	Nurses (N=11)	Not reported	Interviews	Nurses are proud to be part of a robot team. There are new demands for nurses during RAS, possibly leading to a greater mental demand.
Sexton et al., 2018, USA (55)	Cohort Study	Surgeons (N=3), Assistants (N=3), Nurses (N=18)	Urology (N=12)	Requests, NASA-TLX	Higher task load of the console surgeon was associated with both increased time spent by other team members fulfilling requests, whereas higher task load of the whole team (driven by increased load on the assistant surgeon) was associated with higher anticipation ratios. More complicated surgeries require more focus which leads to increased cognitive workload on the surgeon and team.
Shugaba et al., 2022, UK (26)	Systematic review	Surgeons (N=not specified)	Various, not specified	Literature research	Physical demand is reduced in RAS, only higher in one muscle. Mental demand is reduced in RAS when compared to laparoscopic surgery.
Shugaba et al., 2023, UK (34)	Cohort Study	Surgeons (N=7)	Urology (N=29)	EMG measurements, EEG measurements	The data suggest greater muscle demands in laparoscopic surgery, but greater cognitive demands in RAS.
Silveira Thomas Porto et al., 2021, Turkey (52)	Qualitative Study	Nurses (N=114)	Various, not specified	Interviews	RAS made nurses feel proud and their role is easier and more comfortable. They do feel they have different duties specific to RAS.
Talamini et al., 2021, USA (45)	Cohort Study	Surgeon (N=1)	Urology (N=40)	NASA-TLX, SURG-TLX, OTAS	Cognitive and physical demands were equal between MP and SP. Effort and task domains were increased in the SP platform. Frustration was lower for SP.
Uslu et al., 2019, Turkey (51)	Qualitative Study	Nurses (N=15)	Not reported	Interviews	Nurses experienced more stress and they had an increased responsibility. They had to work long hours and expressed a need for professional training.

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Table A.3 – continued from previous page

Author, Year, Country	Study Type	Participants	Specialty	Tool Used	Main Findings
Weber et al., 2018, Germany (54)	Cohort Study	Surgeons (N=81), Nurses (N=93), Anesthesia Providers (N=42)	Urology (N=40)	SURG-TLX	Anesthesia providers (M=39, SD=3,5) experienced higher workloads compared to surgeons (M=27,3, SD=3,5) and nurses (M=30, SD=3,0).
Yu et al, 2017, USA (48)	Cohort Study	Surgeons (N=13), Assistants (N=13)	Urology (N=15)	Activity Level (IMU measurements), SURG-TLX, Body part discomfort questionnaire	Console surgeons experienced a higher workload than assistants. Pain was present over all measured regions except the left finger and wrist. The assistants experienced left shoulder and neck pain and console surgeons experienced more pain more often in the right shoulder and neck.
Zamudio et al., 2023, USA (11)	Cohort Study	Surgeons (N=52), Nurses (N=64), Anesthesia Providers (N=30)	Urology (N=25), Gynecology (N=18), General (N=42), Bariatric (N=5)	SURG-TLX	Surgeons (M=34,85, SD=± 16.24) have a higher workload than nurses (M=32.20, SD=± 20.07) and anesthesia providers (M=8.13, SD= ±17.20). Higher aggregate scores for gynecology (Mdn=30.00) (p=0.034) and urology (Mdn=36.50) (p=.006) than for general (Mdn=25.00) were found.

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Appendix B. Quality Analysis

Table B.4: CASP Quality Analysis for Qualitative Studies

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Total Score
Avellino et al. (15)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Medium	95%
El-Hamamsy et al. (27)	Yes	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	Yes	Good	95%
Kang et al. (49)	Yes	Yes	Yes	Yes	Yes	Can't Tell	No	Yes	Yes	Good	85%
Kumar et al. (36)	Yes	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	Yes	Medium	90%
Lawrie et al. (28)	Yes	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	Yes	Good	95%
Pelikan et al. (31)	Yes	Yes	Yes	Yes	Yes	Can't Tell	No	Can't Tell	Yes	Medium	75%
Randell et al. (46)	Yes	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	Yes	Medium	90%
Schuessler et al. (9)	Yes	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	Yes	Good	95%
Silveira Thomas Porto et al. (52)	Yes	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	Yes	Good	95%
Uslu et al. (51)	Yes	Yes	Yes	Can't Tell	Yes	Can't Tell	Yes	Yes	Yes	Good	90%

Table B.5: CASP Quality Analysis for Systematic Reviews

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Total Score
Catchpole et al. (29)	Yes	Can't Tell	Can't Tell	No	Yes	Medium	Good	Yes	Yes	Yes	75%
Catchpole et al. (41)	Yes	Can't Tell	Can't Tell	No	Yes	Good	Good	Yes	Yes	Yes	75 %
Celik et al. (4)	Yes	Yes	Yes	Yes	Yes	Good	Good	Yes	Yes	Yes	100 %
Elek et al. (35)	Yes	Yes	Can't Tell	No	Yes	Medium	Good	Yes	Yes	Yes	80%
Gillespie et al. (10)	Yes	Yes	Yes	Yes	Yes	Good	Good	Yes	Yes	Yes	100 %
Martinello et al. (42)	Yes	Yes	Yes	Yes	Yes	Good	Good	Yes	Yes	Yes	100 %
Moloney et al. (50)	Yes	Yes	Yes	Yes	Yes	Good	Good	Yes	Yes	Yes	100 %
Park et al. (40)	Yes	Yes	Yes	Yes	Yes	Good	Good	Yes	Yes	Yes	100 %
Shugaba et al. (34)	Yes	Yes	Yes	Yes	Yes	Good	Good	Yes	Yes	Yes	100 %

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Table B.6: CASP Quality Analysis for Cohort Studies

Study	Q1	Q2	Q3	Q4	Q5a	Q5b	Q6a	Q6b	Q7	Q8	Q9	Q10	Q11	Q12	Total Score
Ahmed et al. (56)	Yes	Can't Tell	Yes	Yes	Yes	Yes	Yes	Yes	Medium	Good	Yes	Yes	Can't Tell	Yes	89%
Cavuoto et al. (1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	100%
De'Angelis et al. (44)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	86%
Guru et al. (65)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Good	Good	Yes	Can't Tell	Yes	Can't Tell	77%
Heemskerk et al. (33)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	86%
Hullenaar van 't et al. (8)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	86%
Krämer et al. (1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	100%
Law et al. (37)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	86%
Li et al. (38)	Yes	Can't Tell	Yes	Can't Tell	Yes	Yes	Yes	Yes	Good	Good	Yes	Can't Tell	Yes	Yes	89%
Manuguerra et al. (47)	Yes	Yes	Can't Tell	Yes	No	No	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	96%
Marçon et al. (30)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	86%
Mazzella et al. (32)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	100%
Mendes et al. (39)	Yes	Can't Tell	Yes	Yes	No	No	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	96%
Norasi et al. (53)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Good	Good	Yes	Can't Tell	Yes	Can't Tell	93%
Sexton et al. (55)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	86%
Shugaba et al. (26)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	86%
Talamini et al. (45)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Good	Good	Yes	Can't Tell	Yes	Yes	96%
Weber et al. (54)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	100%
Yu et al. (48)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	86%
Zamudio et al. (11)	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	Yes	Good	Good	Yes	Yes	Yes	Yes	96%

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Appendix C. Tools to asses Workload

Table C.7: Description of Tools used in this Systematic Review

Tool	Description	Scoring	Validation	Studies
NASA-TLX	Subjective tool to measure both cognitive and physical workload	6 dimensions, 20-point Likert-scale, 0-20	Yes	Ahmed et al. (56), Cavuoto et al. (1), Guru et al. (65), Krämer et al.(43), Law et al. (37), Li et al. (38), Marçon et al. (30), Mazzella et al. (32), Mendes et al. (39), Norasi et al. (53), Sexton et al. (55), Talamini et al. (45)
SURG-TLX	Subjective tool to measure both cognitive and physical workload, adopted version of NASA-TLX	6 dimensions, 20-point Likert-scale, 0-20	Yes	Talamini et al. (45), Weber et al. (54), Yu et al. (48), Zamudio et al. (11)
Body Discomfort Questionnaire	Subjective tool to measure physical workload	10 point Likert-scale, 0-10	Yes	Mazzella et al. (32), Krämer et al. (43), Yu et al. (48)
BORG-CR10	Subjective tool to measure physical workload	10 point Likert-scale, 0-10	Yes	Marçon et al. (30), Mendes et al. (39)
Electroencephalography (EEG)	Objective tool to measure cognitive workload	EEG peak alpha amplitude	Yes	Guru et al. (65), Shuguba et al. (26)
Electromyography (EMG)	Objective tool to measure physical workload	Maximal Voluntary Contraction (MVC)	Yes	Krämer et al. (43), Shuguba et al. (26)
Electrocardiogram (ECG, Cardiovascular measurements)	Objective tool to measure both cognitive as physical workload	Heart Rate (HR), Heart Rate Variability (HRV)	Yes	Heemskerk et al. (33), Mazzella et al. (32)
Activity Level	Objective tool to measure physical workload	Inertial Measurement Units (IMU)	Yes	Mazzella et al. (32), Yu et al. (48)
Rapid Upper Limb Assessment (RULA)	Objective tool to measure physical workload	Survey based on body posture angles, filled in by experts (66)	Yes	Van 't Hullenaar et al. (8)

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Appendix D. Additional Figures

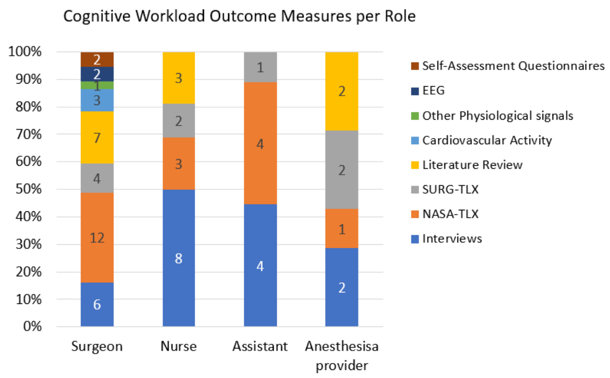

Figure D.10: Outcome Measures for Cognitive Workload per Role represented in a Stacked Bar Chart

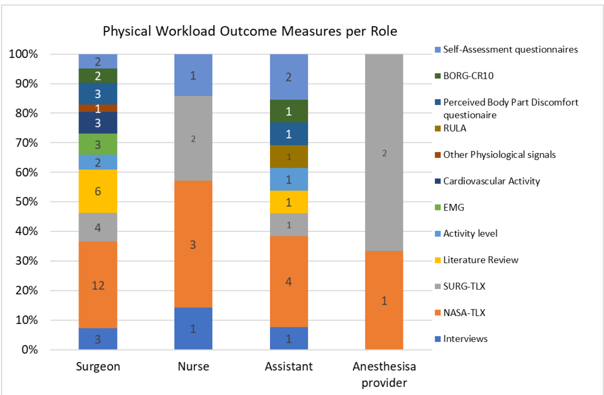

Figure D.11: Outcome Measures for Physical Workload per Role represented in a Stacked Bar Chart

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