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The impact of intra-operative interruptions on surgeons' perceived workload: an observational study in elective general and orthopedic surgery

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Abstract

Background and aim Surgeons' intra-operative workload is critical for effective and safe surgical performance. Detrimental conditions in the operating room (OR) environment may add to perceived workload and jeopardize surgical performance and outcomes. This study aims to evaluate the impact of different intra-operative workflow interruptions on surgeons' capacity to manage their workload safely and efficiently.

Methods This was an observational study of intra-operative interruptions and self-rated workload in two surgical specialties (general, orthopedic/trauma surgery). Intra-operative interruptions were assessed via expert observation using a well-validated observation tool. Surgeons, nurses, and anesthesiologists assessed their intra-operative workload directly after case completion based on three items of the validated Surgery Task Load Index (mental demand, situational stress, distraction).

Results A total of 56 elective cases (35 open, 21 laparoscopic) with 94 workload ratings were included. Mean intra-operative duration was 1 h 37 min. Intra-operative interruptions were on average observed 9.78 times per hour. People who entered/exited the OR (30.6 %) as well as telephone-/beeper-related disruptions (23.6 %) occurred most often. Equipment and OR environment-related interruptions were associated with highest interference with team functioning particularly in laparoscopic procedures. After identifying task and procedural influences, partial correlational analyses revealed that case-irrelevant communications were negatively associated with surgeons' mental fatigue and situational stress, whereas surgeons' reported distraction was increased by case-irrelevant communication and procedural disruptions. OR nurses' and anesthesiologists' perceived workload was also related to intra-operative interruption events.

Conclusions Our study documents the unique contribution of different interruptions on surgeons' workload; whereas case-irrelevant communications may be beneficial for mental fatigue and stress in routine cases, procedural interruptions and case-irrelevant communication may contribute to surgeons' mental focus deteriorating. Well-designed OR environments, surgical leadership, and awareness can help to control unnecessary interruptions for effective and safe surgical care.

Keywords Interruptions · Distractions · Surgery · Workload · Observation · Operating room

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There is growing interest regarding the potentially detrimental impact of interruptive operating room (OR) environments on surgical performance [1, 2]. Previous investigations showed that interruptions occur frequently in ORs, across various surgical specialties, and bear different severities [1, 3–6]. Potentially, interruptions can negatively impact on surgeon's attention, disrupt surgical workflow, and jeopardize patient care [1, 2, 7]. Additionally, disruptive OR environments may affect the communication among OR staff and the quality of intra-team coordination [8]—with time wasting as a result [6].

Although there have been studies on disruptions in ORs, the evidence base on the intervening variables between an interruptive OR environment and surgical performance or outcomes is unclear. One potential link is surgical workload, a critical variable that links work demands and effective performance [9]. Surgeons' workload is a major determinant of surgical performance in the OR [9]. Workload is generally defined as "the cost incurred by a human operator to achieve a particular level of performance; (…) it emerges from the interaction between the requirements of a task, the circumstances under which it is performed, and the skills, and perceptions of the operator" [10]. Importantly, workload is by definition subjective: The same task may incur lower workload in an experienced surgeon, but higher workload in a novice [10].

Specifically within surgery, subjective workload has been proposed as a link between work demands in the OR and resulting surgical performance [9–11]. One hypothesis that has been proposed is that intra-operative interruptions add to the operating surgeon's workload. In the course of a surgical procedure, surgeons often perform complex tasks that demand undivided attention (e.g., complex dissection). Interruptions have the effect of suspending the surgeon's attention from the task at hand, as he/she attends to the interruption and performs an unplanned task (e.g., responding to a telephone call), eventually resulting in interrupted task performance [12, 13] and potential performance detriment [11, 14]. Previous research has demonstrated that more workflow interruptions are associated with lower performance—in real [2] and simulated procedures, e.g., suturing tasks [11]. The hypothesized pathway to performance detriment here is that interruptions are associated with increased workload [15], fatigue, stress [16], and frustration [17], and that they also negatively affect patient safety [18, 19].

However, there is also an alternative view of interruptions—namely that depending on the circumstances, intra-operative interruptions may also have benefits; e.g., communication of important information or reducing monotony and/or stress through case-irrelevant communication that lighten the OR atmosphere [1, 4]. Recent studies in hospital physicians have shown that workflow interruptions may be perceived as non-distracting, necessary, or legitimate, depending on their nature and timing [15, 20].

The study that we report here aims to address several shortcomings of the existing evidence base and to contribute to the growing evidence on intra-operative interruptions in several ways.

Firstly, there are few studies examining workflow interruptions in real-world ORs [2, 3, 21]. Many investigations only measure intra-operative interruptions, but do not link them to performance, outcomes, or any patient safety end points. Secondly, to the best of our knowledge, no studies explicitly addressed subjective and cognitive implications of intra-operative interruptions for surgeons in real ORs. Scientific assessment of cognitive detriment due to intra-operative disruptions is a major step in order to create an appropriate surgical work environment [22, 23]. Finally, studies have not yet investigated the differential impact of a singular interruption event on different aspects of a surgeon's workload (e.g., mental load or distractions). Such a multidimensional analysis of interruptions and workload offers useful diagnostic information regarding the impact of various types of disruptions on the surgeon's own experience of workload [9, 11].

Specifically, we sought to:

1. Assess the frequency of intra-operative interruptions and level of surgeons' workload;
2. Identify task- or process-related influences on these interruptions and on surgeons' workload;
3. Analyze associations between intra-operative interruptions and surgeons' workload.

Method

Design

A cross-sectional design was used, combining structured observations of surgical procedures and standardized self-report assessment instruments.

Study setting and sample

Observations were conducted in two surgical facilities of one German University Hospital. All ORs were comparable in terms of work organization, size, equipment, and staffing levels. The Ethics Committee of the Faculty of Medicine, Munich University, gave ethical approval for this study (Nr. 539-11).

Due to confidentiality regulations, we could not collect information on demographic characteristics of the observed cases—including patient or team-member information. Only voluntary information on surgeons' job tenure was collected: $n = 12$ (19 %) reported 0–5 years professional tenure, $n = 14$ (22.2 %) 5–10 years, and $n = 37$ (37 %) classified themselves as having more than 10 years of tenure on their current appointment.

Intra-operative phases that we observed covered the time from incision to closure. The observation dates were selected randomly. Only elective surgical procedures were included carried out under general anesthesia. Excluded were cases with a prospected duration of >4 h as the observational method is particularly demanding on the observer (causing observer fatigue) and increases the risk of bias in the observations.

Surgical procedures from general and orthopedic surgery were sampled. Overall, 56 procedures were observed that included 35 open (62.5 %; abdominal and osteosynthesis procedures) and 21 laparoscopic cases (37.5 %; laparoscopic cholecystectomy and arthroscopic procedures).

Observation procedure and workload assessment

All surgeons were informed prior to the observation (departmental meeting before start of the study and personal email) and provided written consent. Participation was voluntary and consent was obtained from all OR staff members before start of the data collection.

Intra-operative interruptions were assessed via direct expert observation. Two experienced observers (MW, SA) were trained prior to the study and tested for inter-rater agreement (see section below). Observers were present in the OR during the entire surgical procedure and coded workflow interruptions using a previously validated instrument (see section below). They were instructed not to distract OR staff.

Surgeons' self-reported workload was collected immediately after completion of the procedure. Workload ratings were obtained from all surgeons involved in a case—including the operating and assisting surgeons, and any surgical trainee who was actively involved in the procedure (i.e., not just observing). Similarly, we asked OR nurses and anesthesiologists to report their intra-operative workload. Following previous studies on workload assessment, all participants were instructed as follows: "please rate your average workload during the procedure you just completed" [9, 15].

Measures: intra-operative interruptions and surgeons' workload

Data were collected on (1) source and severity of intra-operative interruptions and (2) surgeons' intra-operative workload as follows:

1. A well-established tool to identify intra-operative workflow interruptions was applied [4, 7, 8]. This observational tool was designed to record distractions and interruptions in ORs during surgery and to measure the amount of intra-operative interference they add to the work of the OR team. The instrument has validity evidence and has been shown feasible to use in real time in the OR [4, 7, 8]. The instrument defines intra-operative interruptions as non-scheduled events, potentially causing a discontinuation of tasks, a noticeable break, or task-switching (i.e., stopping one task to carry out another: e.g., stopping dissection to take a phone call) [2, 4]. The observational instrument records (1a) the source and recipient of an interruption and (1b) the severity of an interruption, which is defined as the extent of disruption that visibly occurs to an OR team member or to the entire OR team. These are further defined as follows:

   (1a) *Source of intra-operative interruption*: Five pre-defined categories of interruptions were applied: (1) people entering/exiting the OR; (2) phone-/beeper calls-/radio-related distraction; (3) case-irrelevant communication by surgeons, anesthesiologists, nurses, or external personnel (e.g., OR visitors); (4) equipment (missing or non-functioning), movement in front or behind monitors, or work environment related (distraction related to OR environment, e.g., diathermy pedals at the wrong place); and (5) procedural (distractions intrinsic to surgical work, e.g., surgeon teaches students or awaits test results).

   (1b) *Severity/interference with team functioning:* Each observed interruption was rated for its severity on a 9-point scale (Table 1) [4, 7]. Scale points 1–3 refer to observed distraction or interruption to a single member of the OR team (typically of a circulator), whereas in higher scale points two or more OR team members are affected by the distraction.

(2) *Surgeons' intra-operative workload*: To assess surgical workload, an abbreviated version of the validated Surgery Task Load Index (SURG-TLX) was used [9]. This surgery-specific, multidimensional workload measure was derived from the widely used NASA Task Load Index (NASA-TLX) [24]. It enables subjective assessments of load relevant to a specific task, distinguishes between different task complexities, and indicates objective performance [10, 25]. Both the NASA-TLX and the SURG-TLX have been applied to health care [9, 15, 25, 26]. For practical reasons (brevity), for this study, we used three items of the SURG-TLX to capture surgeons' workload: Mental demand ("How mentally tiring was the procedure?"), situational stress ("How anxious did you feel while performing the procedure?"), and distraction ("How distracting was the operating environment?"). The items were selected based on prior expert recommendation as well as literature review [9, 10, 15, 25]. All three SURG-TLX items ranged on a scale from 0 ("very low") to 100 ("very high") [9].

Table 1 Interruptions rating scale

Level	Observable effect to team member or entire team functioning (for assessor to rate)
1	Potentially distracting source (e.g., beeper call but no one responds to it)
2	Interference noticed by floating personnel (e.g., beeper call is noticed by the circulating nurses but not dealt with)
3	Floating member attends to non-case distraction (e.g., the floating nurse responds to the beeper call)
4	Single team member momentarily distracted from the task (e.g., anesthesiologist orients away from the focal tasks of documentation to a beeper call while continuing with the documentation)
5	Team member pauses current task (e.g., surgeon pauses laparoscopy to view surgical instruments tray to select the equipment available while retaining control of instruments inserted in patient's abdomen)
6	Team member attends to distraction (e.g., anesthesiologist responds to queries about the next case)
7	Team distracted momentarily
8	Team attends to distraction
9	Operation flow disrupted: This is the highest scale point, which refers to events when the whole surgical team is interrupted and needs to attend to the break-in event (e.g., equipment failure that stops the surgical procedure or the OR manager enters the room and discusses the case list with the entire team)

Additional information recorded during the observation: specialty (general or orthopedic surgery), type of surgery (open or laparoscopic), number of OR professionals present, training procedure (senior surgeon guides and instructs junior surgeon), time of incision and closure (obtained from the surgical case documentation).

Reliability analyses of observational assessments

Prior to data collection, training observations were conducted to test the tool's reliability in terms of inter-observer agreement: Four cases were simultaneously observed by two blinded observers (total observation duration = 459 min). A total of 117 intra-operative interruptions were identified and the resulting Kappa coefficient based on total number of interruptions noted was 0.93; Kappa for correct classification was 0.61. Concerning the severity ratings, high and positive correlation was obtained between the 2 raters ($r = 0.87, N = 54$). These data show substantial inter-rater agreement [4, 27].

Analyses

Observational as well as self-reported data were checked for errors (i.e., due to incorrect data transfer) and implausible values (e.g., values entered that exceeded the scale range). Aggregated mean workload scores were computed if multiple surgeons contributed to an observed procedure. For descriptive statistics, we computed sum and mean values for the variables of the study. For inferential statistics, analyses of variance (ANOVAs) were performed to explore group differences. To examine associations between interruptions and surgeons' workload, we applied partial correlation analyses. This approach is recommended to take into account potential influence of third variables on the statistically assessed relationship. All analyses were performed using SPSS 20.0. For all analyses that involved inferential statistics, $p < 0.05$ was considered significant.

Results

Overall 56 observations were conducted with an overall duration of 77.1 h (4,626 min). The average procedure duration was 1 h 37 min (SD = 1 h 38 min; range 0.2–3.67 h). There were no significant differences in procedure duration between general versus orthopedic cases ($F = 0.20$, $p = 0.66$), open versus laparoscopic cases ($F = 0.12$, $p = 0.73$), or teaching versus non-teaching cases ($F = 1.00$, $p = 0.76$). A total of 94 workload evaluations were collected from the surgeons involved in these procedures. In 19 cases, we received one evaluation, in 36 two, and in one three workload evaluations (mean = 1.7 evaluations per case). Eighty-one workload evaluations were collected from OR nurses and 54 from anesthesiologists in the same procedures.

Workflow interruptions and perceived workload: descriptive analyses

A total of 725 intra-operative interruptions were identified. A mean of 12.36 interruptions were recorded per case (SD = 7.49; range 2–32). This means that OR teams were on average disrupted 9.78 times per hour (SD = 4.07; range 2.82–20.57)—or once every 6 min.

Table 2 presents how often each interruption source was identified (frequency analysis). Most interruptions were caused by people entering or exiting the OR ($n = 222$; 30.6 %). The remainder were attributed to telephone, beeper calls, or noisy radio ($n = 171$; 23.6 %) and to case-irrelevant communications ($n = 155$; 21.4 %).

Surgeons' average workload ratings were as follows (SURG-TLX scale range 0 = very low, 100 = very high): mental fatigue was $M = 32.9$ (SD = 20.28, range 0–85), situational stress during the procedure was $M = 31.47$ (SD = 19.62, range 2.5–79.4), and self-reported distraction was $M = 24.65$ (SD = 15.54, range 2.5–64.4). Statistical analyses on these data (t test for paired samples) revealed that mean reported intra-operative distraction was significantly lower than mental fatigue [T(55) = 3.05, $p < 0.01$] or situational stress [T(55) = 2.47, $p = 0.02$].

Table 2 Frequency and severity per intra-operative interruption source ($N = 56$ procedures)

Interruption event sources	Observed interruptions			Severity ratings
	Frequency (%)	Min; max	Interruptions per hour (M, SD)	Mean (SD)
People enter/exit OR	222 (30.6 %)	0; 14	3.63 (5.34)	2.70 (1.69)
Telephone/beeper	171 (23.6 %)	0; 15	2.61 (3.51)	3.81 (1.89)
Case-irrelevant communication	155 (21.4 %)	0; 13	3.02 (6.18)	4.63 (1.36)
Equipment-/environment-related interruptions	108 (14.9 %)	0; 9	2.23 (5.99)	6.33 (1.67)
Procedural disruptions	69 (9.5 %)	0; 5	1.24 (2.75)	5.09 (2.43)
Overall	725 (100)	2; 32	9.78 (4.07)	4.16 (2.13)

Average rated severity on a 1–9 scale (1 = potentially distracting event, 9 = operation flow interrupted)

M mean, *SD* standard deviation

Table 3 Intra-operative interruptions and workload: difference test for specialty and diagnosis ($N = 56$ procedures)

	N	Surgeons' intra-operative workload		
		Mental fatigue M (SD)	Situational stress M (SD)	Distractions M (SD)
Task-related characteristics				
Specialty				
General surgery	33	28.75 (18.89)	30.29 (20.07)	24.68 (14.96)
Orthopedic surgery	23	38.91 (21.12)	33.15 (19.28)	24.59 (16.68)
Significance (F; p)		3.56; 0.07	0.29; 0.60	0.00; 0.98
Type of surgery				
Open	35	31.59 (19.35)	29.75 (19.76)	22.39 (14.69)
Laparoscopic	21	35.15 (22.06)	34.33 (19.53)	28.40 (16.54)
Significance (F; p)		0.40; 0.53	0.71; 0.40	1.99; 0.16
Procedural characteristics				
Teaching case				
Yes	10	40.81 (18.95)	45.88 (18.06)	29.69 (15.53)
No	46	31.21 (25.18)	28.33 (20.98)	23.55 (15.35)
Significance (F; p)		1.87; 0.17	7.32; <0.01	1.29; 0.26
Length of procedure	56	0.48**	0.26*	0.30*
Number OR staff	56	0.13	0.07	0.01

N number of procedures; significance testing: ANOVA; *M* mean, *SD* standard deviation; *r* Pearson *r* correlation coefficient

* $p \leq 0.05$; ** $p \leq 0.01$

Relationships of task and procedure characteristics, interruptions, and workload

We analyzed the potential influences of task-related (specialty, type of surgery) and procedural variables (length of procedure, number of staff in the OR) on the frequency of observed workflow interruptions and surgeons' own workload ratings. Table 3 summarizes the findings.

Regarding specialty and type of surgery, we found no significant differences. Regarding procedural variables, we found a significant influence of teaching, such that surgeons self-rated their situational stress during the procedure higher in teaching cases than in the non-teaching cases ($\Delta M = 17.55$; $p = 0.05$). Further, we tested whether the length of the procedure and the number of OR staff influences surgeons' workload. There was a strong association between the duration of the case and all aspects of surgical workload: longer cases were associated with more mental fatigue ($r = 0.48$), more experienced distraction during the case ($r = 0.30$), and more experienced stress ($r = 0.26$; all p's < 0.05).

Furthermore we analyzed the association between observed interruptions and the task-related and procedural variables. Regarding number of interruptions per case, there was no difference between the two specialties (general surgery: $M = 13.06$, SD = 7.41; orthopedic surgery: $M = 11.35$, SD = 7.66; $F = 0.71$, $p = 0.41$), or for type of surgery (open: $M = 12.34$, SD = 8.24; laparoscopic: $M = 12.38$, SD = 6.23, $F = 0.00$, $p = 0.99$), or for teaching/non-teaching cases (teaching: $M = 12.57$, SD = 7.96; non-teaching: $M = 11.4$, SD = 4.97; $F = 0.19$, $p = 0.66$). Severity of interruptions was also not significantly different between specialties or for teaching/non-teaching cases (results not reported). For type of surgery, severity of

Table 4 Associations between interruptions (number and severity) and surgeon's perceived workload (partial correlation analyses)

Intra-operative interruption sources	Surgeons' intra-operative workload					
	Mental fatigue		Situational stress		Distraction	
	Number	Severity	Number	Severity	Number	Severity
Persons enter/exit the OR	0.10	0.01	0.08	0.07	−0.05	−0.04
Telephone/beeper	−0.15	−0.18	−0.01	−0.05	−0.02	−0.10
Case-irrelevant communication	−0.26	−0.25	−0.28*	−0.24	0.26*	0.38*
Equipment-/environment-related interruptions	0.03	0.22	−0.13	0.08	0.00	0.07
Procedural disruptions	0.09	−0.27	0.01	−0.30	0.29*	0.06
Overall	−0.09	−0.11	−0.05	−0.13	0.30*	0.37**

Degrees of freedom = 52, controlled for length of procedure and number of OR staff present

* $p \leq 0.05$; ** $p \leq 0.01$

equipment/environment-related interruptions was significantly higher in laparoscopic ($M = 19.53$, SD = 11.26) than in open procedures ($M = 12.16$, SD = 6.98; $F = 6.87$, $p = 0.01$). Further, a strong association was found for length of procedure and rate of observed interruptions ($r = 0.76$, $p < 0.01$). The relationship between the number of personnel present in the OR and the number of interruptions approached significance ($r = 0.25$, $p = 0.06$).

Impact of intra-operative interruptions on surgeons' workload

To identify the unique contribution of each of the intra-operative interruptions on surgeons' workload, we conducted partial correlation analyses. This approach is recommended to remove the influence of confounding variables. We controlled for the length of cases (because longer cases were associated with higher workload and more interruptions) and the number of people in the OR (as it approached significance).

Table 4 presents these analyses. The frequency of intra-operative interruptions was associated with surgeons' reported workload: Case-irrelevant communication was linked to decreased situational stress ($r = -0.28$, $p = 0.04$) but increased surgeons' distraction ($r = 0.26$, $p = 0.04$). Furthermore, procedural disruptions were also associated with the overall distraction experienced by the surgeons ($r = 0.29$, $p = 0.03$). Case-irrelevant communications showed a medium but insignificant association with reduced mental fatigue during the procedure ($r = -0.26$, $p = 0.06$). Moreover, more severely disruptive case-irrelevant communications during the procedure were linked to surgeons' distraction ($r = 0.38$, $p = 0.01$).

Table 4 also reports the associations between the overall summed intra-operative interruptions that were observed and the three workload indicators: The overall number of observed interruptions ($r = 0.30$, $p = 0.03$) as well as their rated severity ($r = 0.36$, $p < 0.01$) were both significantly associated with surgeons' experienced distraction during the cases.

Finally, to further test the robustness of our results, we also controlled for the influence of teaching during procedures—by running partial correlations analyses and controlling for the variable of teaching. We obtained correlations very similar to those above (results not presented).

Impact of intra-operative interruptions on nurses' and anesthesiologists' workload

Similar to the correlation analyses for the surgeons, we also analyzed the contribution of intra-operative interruptions to nurses' and anesthesiologists' reported intra-operative workload. For nurses, more frequent and more severe interruptions through telephone/beeper were negatively associated with reported stress ($r = -0.39$ and $r = -0.47$, respectively; p's < 0.01). For anesthesiologists, increased case-irrelevant communications during the procedure were significantly associated with increased intra-operative stress ($r = 0.31$, $p = 0.03$) and increased perceived distractions ($r = 0.28$, $p = 0.06$).

Discussion

This study firstly aimed to investigate expert-assessed workflow interruptions and self-assessed surgical workload in the OR. Overall, interruptions were observed on average 9.78 times per hour—one every approximately 6 min of intra-operative time. Intra-operative interruptions stemmed from various sources, which replicate previous studies [1, 3, 7]. A closer look revealed that interruptions by people entering or exiting the OR were by far the most frequent, in line with previous findings [4, 5]. In a similar manner, frequent interruptions attributed to telephone/beeper calls as well as case-irrelevant communications indicate frequent communication in and outside the OR during cases—which supports the concept that interruptive "on-the-job" communications are common in healthcare settings [7, 28]. Surgeons' intra-operative workload was overall moderate, and the multidimensional workload scores were comparable to previous findings [9]. However, large variations in these scores were obtained, indicating that individual differences exist and different surgeons experience different levels of workload during procedures.

This study further aimed to examine potential influences of task-related and procedural characteristics on both workflow interruptions and self-reported workload. The level of interruptions was comparable across specialties and type of procedure (open vs. laparoscopic). Situational stress was higher among surgeons that were involved in teaching cases. Previous research has shown that junior surgeons find evaluations from their senior instructors to be stressful [29]. Regarding senior surgeons, intra-operative stress may increase as they seek to align the requirements of a surgical procedure and teaching junior colleagues during the case.

The final objective of this study was to explore whether workflow interruptions are linked to surgeons' workload (aim 3). Controlling for length of procedure and number of OR staff present, significant associations between intra-operative interruptions and workload ratings were identified. This pattern provides validation for both concepts (distractions and workload) in the OR setting. Our study also corroborates that different sources of interruptions affect a surgeon's, a nurse's, and an anesthesiologist's workload differently.

Two findings deserve further attention: First, we found that frequent case-irrelevant communications were associated with less mental fatigue and stress but increased intra-operative distraction. This link may point to surgeons' capability to "allow" themselves to be distracted when they are less busy during the case. Although we observed elective procedures with moderate workload ratings (below SURG-TLX scale midpoint, see Table 3), our findings indicate that surgeons who felt at ease, or had a procedure under full control, tended to get distracted. Drawing on cognitive psychology, we assume that during routine cases surgeons experience "spare capacity" [11, 30]. This allows surgeons to allocate attention resources to other tasks and issues, e.g., administration of surgical case list, discussions about equipment and provisions, OR organization, or discussion of problems [8, 11]. Furthermore, communication among OR staff may reduce tension, boredom, and may help to maintain heightened awareness and address vigilance decrements [8, 31]. Thus, irrelevant communication may serve as "small talk" to reduce stress and fatigue as long as the OR environment is not too saturated with distracting communications [8]. Second, the overall volume of interruptions was significantly associated with surgeons' reported distraction levels during the procedure. This effect was particularly present for procedural interruptions and case-irrelevant communications. Surgeons' attention and awareness is fundamental for decision making, clinical reasoning, and monitoring dynamic intra-operative demands. To enable surgeons to focus their attention on the surgical procedure, OR environments may need to reduce unneeded interruptions. Regarding the overall number of interruptions, our results emphasize that multi-layered disruptions to surgical work are likely to have an effect significantly more pronounced than the effect of individual distracting events [1]—in other words, interruptions can have a cumulative effect. Consequently, increased subjective distraction may degrade attention or memory processes that are important in resuming a previously interrupted task when this is required [22].

Overall, our results point to a more nuanced standpoint to discuss the benefits and costs of intra-operative interruptions. Our results indicate that case-irrelevant communications may be functional to decrease mental fatigue and situational stress [8]. However, intra-operative interruptions potentially impact safety and quality of healthcare delivery [1, 2]. In regard to cognitive alertness of the involved surgeons, interruptions cause additional mental load and may lead to inefficient work practices. A balance between these effects should be sought. While we attempted to address immediate effects in terms of intra-operative interruptions, surgeons' load, and patient safety consequences, our study complements previous research findings that addressed important longer-term effects, i.e., identification of surgical errors [2].

Limitations

First, our study allows assessment of associations between interruptions and surgeon-specific measures, but an ideal study design to infer causality is a controlled intervention trial. Second, selection bias may have occurred because our results are based on a University Hospital in Germany. Our findings refer to two surgical specialties, general and orthopedic surgery. Other surgical domains with different technological and procedural characteristics may entail different communication and workflow routines. Third, observational results are prone to observer effects, e.g., certain interruptions may occur less often, or surgeons may report their workload differently due to observer presence in the OR. Additionally, although we focused on procedures that lasted maximally 4 h, expert observers' attention can be depleted throughout a case because observers' fatigue increases. Fourth, concerning workload ratings, there is an important limitation that only elective procedures during daytime with mostly routine demands were included—hence, floor effects may have occurred (i.e., low ratings). Other factors that we could not control within the scope of this study could also contribute to surgical workload—notably the complexity of the procedure and the expertise of and familiarity with the entire OR team. We acknowledge that there are multiple such factors that may be responsible for the observed effects—these are problems inherent to observational studies, as there is no single observational technique that can accommodate all potential measures of interest in the OR. Fifth, stress is experienced when demands outweigh subjective resources and capabilities, like in unexpected situation in the OR (e.g., bleeding) [19]. Such rarer events require larger samples to be encountered in surgical practice, or observations within emergency procedures. Finally, for each procedure, only one overall task load rating was collected postoperatively. Our design did not take account of the variation of surgical workload during a case. Future studies may seek opportune ways to collect workload ratings throughout the case—use of ongoing physiological monitoring of stress-related variables (e.g., heart rate) may offer further research options in this direction. Surgical task load ratings were based on established self-report measures. Although the SURG-TLX tool is indicative of objective workload, we cannot exclude subjective bias, hindsight effects, or recall bias in how surgeons, and other team members, reported it to us [9, 10].

Further, we recorded only pre-defined, clearly observable interruption events and rated their impact based on an existing instrument. Although this offers some validation evidence, we cannot guarantee that our taxonomy with pre-defined observable categories covered all potential events in the OR, as this is a dynamic, often fast changing environment [7, 32]. Furthermore, different intra-operative interruptions may have different effects [1, 23, 33]. Future investigations should analyze "appropriate" interruptions that provide valuable information compared to those that are entirely unnecessary [23, 34]. The same may also refer to certain "opportune" moments during the surgical procedure, i.e., moments where an interruption can occur with minimal impact [3, 33]. We did not include any information on surgeons' individual capabilities to deal with interruptive OR environments. Cognitive psychology suggests that particularly working memory capacity is critical for experienced cognitive load [12, 22, 35]. Working memory capacity is known to be a mediator between susceptibility to interruptions and its impact on memory, resumption lags, and detriment to task execution [22, 36].

Implications

For efficient and safe surgical procedures, addressing and reducing unnecessary intra-operative interruptions is a recommended option [1]. Our study indicates that surgeons experience intra-operative interruptions as a source of distraction. Thus, smooth surgical flow needs to be established through enhanced inter-professional communication and better organization of simultaneous tasks. Particularly during demanding and complex parts of the procedure, surgeons should actively manage potential distraction sources in the OR [32]. Additionally, interventions for OR teams that reduce inappropriate intra-operative distractions and interruptions could help surgeons. One promising solution is the "sterile cockpit concept," which involves team members avoiding non-essential talk during key parts of the procedure [37].

Our findings also point to future research directions. Regarding the differential impact of various interruptions, further research should evaluate to what extent different interruptions trigger increased workload, especially during complex or emergency procedures. Concurrent investigations of surgeons' efforts to deal and cope with interruptive OR environments should be conducted, particularly in terms of managing interruption-induced stress, compensatory mental strategies to deal with increased distraction, and maintenance of attention during lengthy procedures [19, 38].

Conclusions

The study found meaningful associations between intra-operative interruptions and subjective workload in surgeons during elective general and orthopedic cases. Whereas case-irrelevant communications were associated with lower mental fatigue and situational stress, the distraction that surgeons experienced during a case increased through case-irrelevant communications. Intra-operative interruptions, and especially procedural interruptions, were also linked to surgeons' reported distraction. Our findings call for efforts to limit unnecessary workflow interruptions in the OR. ORs need to be well-designed socio-technical systems that reduce the impact of harmful interruptions in terms of impaired efficiency and quality and maintain their benefits in terms of communication [23, 39]. Because surgeons value focus and cognitive awareness during procedures, unneeded intra-operative distractions should be actively minimized.

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Ethical standard The Ethics Committee of the Faculty of Medicine, Munich University, gave ethical approval for this study (Nr. 539-11).

Appendix

See Tables 1, 2, 3, and 4.

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