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Identification and interference of intraoperative distractions and interruptions in operating rooms

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ABSTRACT

Background: Intraoperative interruptions potentially interfere with surgical flow, contribute to patient safety risks, and increase stress. This study aimed to observe interruption events in operating rooms (ORs) and to measure surgical team's intraoperative interference from interruptions during surgery.

Materials and methods: Sixty-five surgical cases were observed at two surgical clinics in Germany (mainly abdominal and orthopedic surgery). An established observational tool was successfully adapted to German ORs. Various disruptions to surgical work were captured with a predefined coding scheme. In addition, the severity of each observed interruption was rated on behaviorally anchored scale to define the level of OR team involvement. Pilot test supported tools' reliability.

Results: Mean intraoperative duration was 1 h, 23 min (standard deviation = 50:55 min). Overall N = 803 intraoperative interruptions and disruption events were observed. Most frequent were people entering or exiting the OR and telephone or beeper calls. On average, OR teams were distracted or interrupted 9.82 times per hour (standard deviation = 3.97). Equipment failures and OR-environment–related disruptions were rated as the highest interference of OR team functioning. The involved OR professions were differently affected by interruption events. Distribution of intraoperative interruptions within the procedure varied significantly; during early stages of the case, significantly more interruptions were observed.

Conclusions: The study demonstrates the high level of interference in ORs. Furthermore, it provides a useful measure for intraoperative workflow disruptions and their interference of OR team functioning. OR environments need to be well designed to reduce unnecessary interruptions and distractions, so that surgical teams can manage their surgical tasks efficiently and safely.

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1. Introduction

There is a growing interest in surgical workflow with particular focus on interruptions and distractions in operating rooms (ORs) [1–4]. It stems particularly from a holistic systems view that emphasizes the contribution of the OR team and OR environment to safe and effective surgical care [5–7]. Research outside of health care (e.g., aviation, control rooms in high risk industries) demonstrated that interruptions and distractions can have detrimental consequences [8–10]. Similar studies in different hospital environments emphasized the high level of interruptions in health care, for example, in emergency rooms [11,12], inpatient wards [13], or postoperative handover procedures [14]. In regard to ORs, the empirical evidence on interruptions and distractions is still sparse [4,15,16].

ORs are complex working environments with a high cognitive demand and a variety of potential distractions and interruptions of the surgical workflow. There is growing evidence that highly interruptive OR environments contribute to detrimental clinical performance, for example, extended procedure durations, incomplete safety checks, or errors [3,4,16]. Surgical flow interruptions are an obstacle to effective surgical progress and hinder efficient case completion [1,15]. To create efficient and safe surgical care and reduce adverse events, ORs need to be well designed to enable smooth team performance [5,7].

We define intraoperative interruptions and disruptions as events during the surgical procedure that potentially distract the OR team or OR member from a primary task or momentarily interrupt their task [17]. In OR teams, interruptions disturb surgical workflow and are responsible for goal obstruction and detrimental task execution, thus, jeopardizing effective surgery and patient care [3]. In addition, disruptive OR environments may affect the communication among OR staff and the quality of intrateam coordination [15,18]. In regard to surgical quality, one observational study by Wiegmann *et al.* [3] demonstrated that interruptions during surgery are associated with erroneous surgical performance.

To the best of our knowledge, there are few studies that focused primarily on assessing distraction and interruption events in real world ORs. Applied observational studies using valid and reliable assessments within real ORs enable more robust investigation of surgical flow interruptions [4,17]. Capture of perioperative disruptions is a major step in creating an efficient environment for surgical teams [17,19]. Second, there is still limited knowledge of the potential interference of interruption events for surgical team functioning. In regard to the complex dynamics and multiple activities in the OR, some distractions and interruptions may involve only single team members, whereas others involve the whole surgical team [17]. Therefore, research is necessary to identify the degree of intraoperative interference for both single clinicians and the entire OR team.

Our study set out to objectively identify distraction and interruption events during surgical procedures and to contribute to the growing intraoperative interruptions evidence base. Specifically, we sought to:

(1) identify and count the type of interruptions that occur during surgical procedures, and measure the interference of those events for the surgical teams;
(2) compare with what extent the various OR professions are individually affected; and
(3) to identify phases with increased interruption levels during surgical procedures.

2. Methods

2.1. Design

Expert observation of surgical procedures was applied, using an established tool. Structured observations have been shown to be useful in various hospital settings [19,20]. Particularly applied to ORs, the detailed identification of workflow interruptions and distractions is a feasible way to obtain information on interruption levels [4,17]. The Ethics Committee of the Faculty of Medicine, Munich University, gave ethical approval for this study (No. 539-11).

2.2. Study setting and sample

Observations were conducted in two surgical clinics of a German University Hospital as part of an internal project on OR teamwork. The study included OR teams from several surgical specialties, including general or abdominal, orthopedic, and plastic surgery.

A total of 65 procedures were sampled from the following surgical disciplines: vascular ($N = 5$, 7,7%), abdominal or general ($N = 33$, 50,8%), orthopedic or trauma ($N = 23$, 35,4%), and plastic surgery ($N = 4$, 6,2%). The observed intraoperative phase of surgery covered the time from incision to closure. The observation dates were selected randomly. Data were collected only during day shifts, and surgical procedures were selected from the departmental case list. Emergency procedures and procedures with a prospected duration of >4 h were excluded (to avoid staff rotation during the procedure and as the observational method is particularly demanding of attention). Team composition varied, as overall eight ORs were available. However, there was generally still some consistency in surgical and nursing personnel, who are consistently assigned to particular ORs. All ORs were comparable in terms of work organization, size, equipment, and staffing levels.

The surgical OR team was considered as the staff assigned to a surgical case, comprising three main professions [17]: (1) anesthetists and their assistants (including anesthesia nurse); (2) nursing group consisting of sterile nurse, circulating nurse, and occasionally any assisting nurse; and the (3) surgical group that comprised the operating and assisting surgeons including any surgical trainee.

2.3. Data collection procedure

All participants were informed before observation through departmental meetings and intranet information. Participation was voluntary, and consent was obtained from all OR staff members before the scheduled observation. Patient consent was not sought as patient identities and details were not gathered.

Two observers (authors SA and MW) were trained before the study. They jointly conducted four pilot observations to gain a shared understanding of recording events and assigning ratings, as well to discuss potential inconsistencies. Before the main study data collection, inter-rater reliability on distraction events, and interference levels were obtained (see the following section). Both observers shadowed OR teams during the procedure and positioned themselves, so that all OR team members could be observed. Before surgery, the OR manager was asked where the observers could watch the case. They were instructed not to distract OR staff or to cause potentially interruptive events.

2.4. Measures: observation of workflow interruptions

An established tool to identify intraoperative workflow interruptions in ORs was applied [4,17,18]. In line with previous research, we considered intraoperative interruption as an intrusion of an unplanned and unscheduled task or event, potentially causing a discontinuation of tasks, a noticeable break, or task switch behavior [3,4,17]. The observational tool was translated and adapted into German. It enables coding of (1) predefined categories of interruptions and distracting events, and (2) the ratings for the extent the interruption event interferes with OR team functioning [4,17,21].

2.4.1. Type of intraoperative interruption

Eleven predefined sources of interruption events were coded: (1) people entering or exiting the OR; (2) phone or beeper calls; (3) radio-related distraction (e.g., radio too loud or noisy); (4) case irrelevant communication (CIC) by surgeons; (5) CIC by anesthetists; (6) CIC by nurses; (7) CIC by external personnel (e.g., patient transport and position staff); (8) equipment (missing or nonfunctioning provisions); (9) work environment (distraction related to OR environment, e.g., diathermy pedals in the wrong place); (10) procedural (distractions intrinsic to surgical work, e.g., surgeon teaching students or waiting for instantaneous sections results); (11) Movement in front or behind laparoscopic monitors (applicable during laparoscopic procedures).

2.4.2. Severity or interference with team functioning

To rate the observed effects for the surgical team, involvement in an interruption event was rated respectively on a nine-point ordinal scale [4,17]. Scale points 1–3 refer to salient events that potentially or actually distract or interrupt the work of a circulating nurse: 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 noncase distraction (e.g., the floating nurse responds to the beeper call). Scale points 4–6 refer to a single member of the OR team: 4, single team member momentarily distracted from the task (e.g., anesthetist orients away from the focal task of documentation to a beeper call while continuing with the documentation); 5, team member pauses current task (e.g., surgeon pauses laparoscopic examination to view surgical instruments tray while retaining control of instruments inserted in patient's abdomen); 6 team member attends to distraction (e.g., anesthetist responds to queries about the upcoming case). Scale points 7 (OR team member distracted momentarily) and 8 (team attends to distraction) include similar events but where two or more OR team members are involved. The highest point 9 (operation flow disrupted) 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).

The following additional information was noted by observers: number of OR professionals present; time of incision and closure (obtained from the surgical case documentation); time of the interruption events; those involved and affected by the interruption event (professional subgroups: surgical, nursing, and anesthesia team); surgical specialty, and open or minimally invasive procedures.

2.5. Observation instrument: pilot testing of reliability

Four pilot observations were conducted before the main study to test the reliability of the tool in terms of interobserver agreement [22]. Four intraoperative observations were conducted by two observers simultaneously (four procedures; range 41–171 min, sum 7 h, 39 min). One hundred seventeen intraoperative interruptions were identified (rater 1: $N = 56$; rater 2: $N = 61$). The resulting Kappa-coefficient based on detecting an interruption event was 0.93 ($T = 20.08$; $P < 0.001$) and the resulting Kappa-coefficient based on the correct categorization for each source was 0.61 ($T = 19.91$, $P < 0.01$). Regarding the interference ratings, observer scores correlated with $r = 0.87$ ($N = 54$). All results indicate substantial inter-rater agreement and support previous reliability tests of the observational tool [17,22].

2.6. Analyses

Observational data were tabulated manually on clipboards, transferred *via* double data entry into a database and checked for errors and implausible values. Statistical tests included Spearman Rho correlation testing the observer agreement on their rating of interference (see the previous section). χ^2 tests were applied for each intraoperative interruption source, tabulated across OR professions. Analysis of Variance was applied to compare interference levels across OR disciplinary groups. For investigating potential differences between the four phases of the surgical procedure, χ^2 and mean difference tests were applied (t-test for paired samples). For all analyses that involved inferential statistics, a P value <0.05 was considered statistically significant.

3. Results

Overall, 65 surgical procedures were observed with an overall observation time of 89 h and 57 min. Mean intraoperative case duration, from incision to closure, was 1 h, 23 min with

Table 1 – Observed intraoperative interruptions and distraction events: frequency and levels of interference for each source (N = 65 surgical procedures).

	Source	Observed intraoperative interruptions and distractions				Interference		Interruptions per hour
		n	*n* (%)	*n* cases	Max count	Mean interference per case (SD)	Sum I-sample	n per h
(1)	People entering OR	248	30.9	59	14	2.95 (1.82)	731	2.76
(2)	Phone or beeper	188	23.4	53	15	3.85 (1.92)	723	2.09
(3)	Radio	5	0.6	4	2	3.40 (1.52)	17	0.06
(4)	CIC: surgeon	71	8.8	34	5	4.48 (1.13)	318	0.79
(5)	CIC: anesthetist	48	6.0	30	4	4.85 (1.38)	233	0.53
(6)	CIC: nurse	35	4.4	21	3	4.20 (1.43)	147	0.39
(7)	CIC: external personnel	19	2.4	15	4	5.42 (1.84)	103	0.21
(8)	Equipment failures	60	7.5	34	5	6.70 (1.78)	402	0.67
(9)	Work environment	47	5.9	30	4	6.11 (1.55)	287	0.52
(10)	Procedural	79	9.8	39	5	5.15 (2.33)	406	0.88
(11)	Movement in front or behind laparoscopic monitors (if applicable)	3	0.4	3	1	4.67 (1.15)	14	0.03
	Overall	803	100	–	–	4.19 (2.13)	3381	9.82

65 observations with overall observation time = 89 h, 57 min, 01 sec; CIC = Case irrelevant communication; I-sample = sum interference ratings from each source for cases where those events were recorded; max count = shows the maximum count of a recorded event for each source in a single case; mean interference per case (SD standard deviation) = the mean interference rating from each source to cases where those events where recorded (SD) scale 1 (potentially distracting event) to 9 (operation flow disrupted); n = number of interruptions; n cases = number of cases where a particular source was recorded; SD = standard deviation.

a range from 12.0 min to 3 h and 40 min (standard deviation, SD = 0:50:51).

The open procedures (N = 44, 67.7%) included four vascular operations (11.4%), 17 visceral (38.6%), 15 orthopedic or trauma (34.1%), three plastic or hand (6.8%), and four nonclassified operations (e.g., change of vacuum bandage material, performed by different surgical specialties); minimally invasive procedures (N = 21, 32.3%) included 16 visceral (76.2%) and five orthopedic or trauma cases (23.8%).

3.1. *Sources of intraoperative surgical flow disruptions*

Overall, 803 intraoperative interruptions and distractions were identified. On average, 12.35 interruptions were coded per surgical procedure (SD = 7.35; range 2–32). This means that surgical teams were on average disrupted 9.82 times per hour (SD = 3.97; range 2.82–20.57). Table 1 presents total count and sum interference per interruption source from sampled 65 procedures.

Of all observed interruptions, most were caused by people entering OR (N = 248, 30.9%). The rest were attributed to phone or beeper interruptions (*n* = 188, 23.4%) and to procedural delays (N = 79; 9.8%).

Additionally, Table 1 reports respective interferences for observed intraoperative interruptions sources. Comparatively, low interference levels were rated for the events people enter the OR (M = 2.95) and radio distractions (M = 3.40), whereas high interferences of team functioning were evaluated for equipment failures (M = 6.70) and work environment disruptions (M = 6.11). In addition, the last column in Table 1 presents the average prevalence for each interruption source. These prevalence numbers support that people entering the OR and phone or beeper interruptions were most frequently observed. In conclusion, all predefined interruption sources were observed and summed up to an overall interruption prevalence of *M* = 9.8 intraoperative interruptions per hour (cf., Table 1).

3.2. *Interruptions and interferences: relationships to OR professions*

We also coded which OR profession was affected by the observed interruptions. In the following analysis we analyzed if a single member (anesthetist, surgeon, or nurse) or the entire OR team was affected by the interruption. Table 2 displays the frequencies.

With regard to single intraoperative interruption, the results reveal that the OR professions are affected differently (cf., Table 2). The surgeons' sub-team (i.e., surgeons and assistant surgeons) is significantly more often affected by intraoperative interruptions compared with their colleagues from nursing and anesthesia. The entire team is particularly affected if the OR environment causes the disruptions (cf., Table 2).

With regard to mean interference caused by interruption events, we found significant differences between the involved OR professions. As Table 3 displays, interruption events that affected the entire team interfered most severely with OR team functioning. Furthermore, if surgeons' and anesthetists' intraoperative workflow was disrupted, interference ratings were higher compared with their nursing colleagues. *Post hoc* analyses for mean group differences showed that discrepancies were significant.

3.3. *Intraoperative interruptions during the procedure: variation of time*

Furthermore, we were interested in the extent to which interruptions vary across procedure. With regard to the count

Table 2 – Sources of observed intraoperative interruptions and distraction events and OR group (65 surgical procedures).

	Sources	Anesthetists	Surgeons	Nurses	Team	χ^2 (df = 3)	>P
(1)	People entering or exiting	44	27	52	12	28.35	0.001
(2)	Phone or beeper	40	38	44	5	30.63	0.001
(3)	Radio	0	1	0	2	3.67	n. s.
(4)	CIC: surgeon	7	40	4	4	67.26	0.001
(5)	CIC: anesthetist	7	21	0	13	23.29	0.001
(6)	CIC: nurse	0	10	5	14	15.28	0.001
(7)	CIC: external personnel	4	7	2	4	3.0	n. s.
(8)	Equipment failures	3	41	1	12	71.77	0.001
(9)	Work environment	0	10	1	34	66.73	0.001
(10)	Procedural	6	32	9	18	25.15	0.001
(11)	Movement in front or behind laparoscopic monitors (if applicable)	0	3	0	0	4.59	n. s.
Overall		111	230	118	118	68.19	0.001

CIC = case irrelevant communication.

of intraoperative interruptions and distractions, we found a significant effect across the four major phases of the procedure (cf., Fig.). In the initial phase (quartile 1: first 25% of the procedure length) significantly more interruptions and distractions were observed, compared with the consecutive phases of the procedure (χ^{22} [df = 3] = 35.35, $P < 0.001$).

To test the robustness of this finding, we additionally weighted the interruption frequencies for each quartile to the overall length of the procedure respectively for each observation. This is necessary because the duration of the individual quartiles vary between the observed procedures with a mean duration of 20.76 min (SD = 12.72 min; range: 3–55 min). Then we tested the average frequencies of the observed interruptions and found similar patterns: during the first phase significantly more interruptions were observed (M = 3.15 interruptions during weighted quartile, SD = 1.91), compared with the second phase (M = 2.46, SD = 1.51, T [df = 3] = 2.23, $P < 0.05$), the third phase (M = 2.33, SD = 1.86, T [df = 3] = 2.47, $P < 0.05$), and the final phase (M = 1.83, SD = 1.74, T [df = 3] = 4.07, $P < 0.001$). In addition we found a significant difference between the second and fourth quartile (T [df = 3] = 2.36, $P < 0.05$).

In a further step, we tested if this distribution is similar in all three affected OR professions (frequencies not presented): we found a similar significant variation for the surgeons (χ^2 [df = 3] = 9.79, $P < 0.05$) and the entire team (χ^2 [df = 3] = 21.32, $P < 0.001$). For the anesthesia sub-team (χ^2[df = 3] = 3.78, n.s.) and nurses sub-team (χ^2[df = 3] = 0.31, n.s.) the distribution of intraoperative interruptions was nonsignificant across the four OR phases.

Last, we tested if the average interference level differed across the intraoperative phase. Overall, we obtained no significant effect of the mean interference across the four procedure quartiles (F [df = 3] = 0.49; n.s.). Also in a further analysis for the affected OR professions, we obtained no significant differences for surgical team (F [df = 3] = 2.27, n.s.), nursing sub team (F [df = 3] = 1.83, n.s.), anesthesia (F [df = 3] = 0.92, n.s.), and interferences that affected the entire team (F[df = 3] = 0.18, n.s.).

Table 3 – Mean interference for OR professions.

OR professions	Interference level		Test for significance difference (ANOVA)
	Mean	SD	F (df), P
Anesthetists	4.88	1.03	112.97 (3), <0.001
Surgeons	5.21	1.62	
Nurses	2.99	0.63	
Entire team	6.38	1.89	
Overall	4.93	1.81	

ANOVA = analysis of variance; SD = standard deviation.

4. Discussion

This study aimed to investigate the prevalence, character, and distribution of intraoperative interruptions in ORs by applying an expert observation-based design. Overall, drawing on a sample of 65 procedures, intraoperative interruptions and distractions were observed 9.82 times per hour on average. These results illustrate that OR environments are prone to frequent workflow interruptions and match similar observational studies from the UK [17,18].

A closer look revealed that interruptions through people entering or exiting the OR and telephone or beeper calls were by far most frequent, in line with previous findings [17,18].

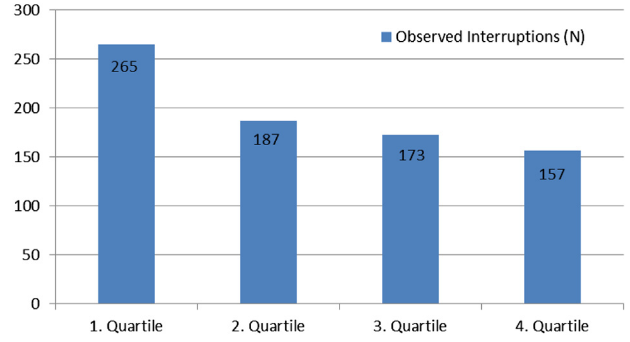

Fig. – Intraoperative interruptions and distractions during the course of N = 65 surgical procedures (procedure length divided into quartiles respectively). (Color version of figure is available online.)

Intraoperative interruptions caused by external staff, telephone or beeper, and irrelevant communication occurred most often. Thus, the study supports the relative contribution of different sources of workflow interruptions previously shown in the literature [18]. Although interruptions attributed to telephone or beeper indicate the high degree of intra- and interprofessional communication among hospital professionals, it also reflects the common tendency of hospital staff to engage in "communication mechanisms" that cause distractions and interruptions [4,18,19,23]. Similar to previous studies, procedure, equipment, and environment events were less frequent than the aforementioned, however, they often involved several OR team members [17].

Drawing on a systems perspective, our study considers the performance of all OR team members and addresses the surgical team as singular units of analysis [5,15,17]. Thus, our study also contributes to the growing evidence that distractions interfere with OR team functioning and effective surgical practice [4]. Although we found a large variation in interference score, surgical cases were included that showed high and intense interference during the procedure (cf., Table 1). Our results also show that frequent interruptions are not necessarily associated with increased interference. Specifically, certain frequent events (e.g., people entering or beeper calls) appeared less interfering because only rotating or fewer team members were affected. This increases the workload of the rotating nurse as she is dealing with extraneous interruption sources while simultaneously supporting the sterile nurse. Notwithstanding, equipment, work environment, and procedural events were responsible for a considerable amount of interference (cf., Table 1). This underlines previous findings, which show that if equipment or procedural problems occur, then surgical teamwork suffers and the surgical flow is disrupted [15,17]. This refers to psychological research on task switching that shows detrimental effects of people switching from a primary to a secondary task [24]. Distractions stretch surgeons' cognitive resources and thus increase the potential for error. This calls for careful preoperative preparation and check ups to prepare equipment and test functioning, particularly in procedures that involve high technology like laparoscopic procedures. Intraoperative interference was especially exacerbated if material and equipment was not at hand or stored closely to the OR. Often we found operating doors opened for an extended time period, which contributes to increased environmental distraction, for example, noise from the hallway or induction room [17].

Aim 2 of our study was to examine potential differences between the OR professions. Our study shows that the frequency of intraoperative workflow interruptions was different for the involved OR professionals. This complements previous literature on OR team members' demands of completing individual and team tasks while dealing with distractions [18]. There is a broad scope of multilayered interruption events during the procedure that may differently affect the involved OR professionals. In addition, our study provides further insights into surgical teams' way of dealing with intraoperative interruptions; for example, the results show that if people enter the OR, mainly the rotating nurse and the anesthetists deal with the event (cf. Table 2). This may perpetuate conflict and stress in certain OR team members, as their primary tasks are compromised and surgeons may eventually recognize compromised performance [17]. This raises potential conflict, as systemic problems of the organization and work environment may be responsible for inefficient practices that eventually increase stress and inefficient collaboration [5,25]. Our results complement previous findings on CIC in OR teams [18]. Surgeons often appeared to be at the center of staff's CICs as they received and initiated CICs, also across professions (which often is 'small talk' or relates to patients not at hand). We cannot conclude on potential consequences for surgical practices, and further research is needed into boundary conditions of harmful CIC. Under stressful surgical demands it could lead to the risk that the efficiency of overall communication is compromised [18,26]. Notwithstanding, small talk could also serve as a mean to establish positive social climate and effective rapport in the beginning of the procedure what may be effective for OR communication.

Aim 3 was to identify potential variations of interruptions in time during the surgical procedure. The pattern of observed intraoperative interruptions across the respective surgical procedures revealed a significant decrease of disruption events in course of the surgical procedure. A significant peak of interruption events during the initial phases of the procedure was identified, that is, in our case the first two quartiles of the procedure. There is growing evidence that distractions add to the length of the procedure [21]. We assume that particularly during initial stages, where surgeons carry out strategic planning, decision making, and resource planning, there is an increased cognitive demand and need for undisturbed attention. Surgeons value mental readiness and the ability to maintain focus. In the light of our findings, there is a particular risk that distractions in initial phases of the surgical procedure contribute to heightened cognitive load, extended durations for strategic decisions, incomplete check ups, delayed approaches to the target structure, and impaired surgical performance [4]. Furthermore, frequent distractions in the initial stages may be conducive to surgeons' stress and therefore, impact surgical performance during the consecutive phases of the procedure [15]. If interruptions elicit significant levels of stress and impose additional stressful demands upon the surgeons (or an OR team), safety and surgical performance will be compromised [26].

Overall, our results emphasize that interruptions are ubiquitous in ORs. Often, surgical procedures demand undivided attention with high cognitive demands. Consequently, highly interruptive OR environments may interfere with and weaken cognitive alertness or memory processes that are important in carrying out the procedure and resuming the interrupted tasks effectively [2,15].

4.1. *Limitations of the study*

First, our study uses an observational design. Although expert observations in ORs have been shown to be a reliable way to capture interruption events, observational approaches have limitations [7,15,17]. Our prior test of inter-rater agreement showed sufficient reliability for the observational tool. The interference level was defined as the relative involvement of the OR team. Although this is an established approach it cannot capture the subjective or experienced interference in the OR [17]. This raises particular concerns if OR professionals are interrupted during individual tasks that are very sensitive to interruptions or distractions, for example, anesthetists calculates drug dose. Expertise and individual coping strategies to deal with interruptions are not taken into account either [15]. Thus, as our measure is focused towards surgical action, it may not fully account for such qualitative differences [17]. Furthermore, it cannot capture the context of potentially interruptive events during the procedure what refers particularly to CIC. Observation tool's guidelines define to what extent communication events are rated as interruption events, that is, when significant risks for distraction or task switch behavior occur or are observed. CIC behaviors can be positive like for maintaining a good working relationship or reducing monotony during low demanding activities, that is, draping the patient. Notwithstanding, similar behaviors can pose significant risks for patient safety during complex and challenging phases of the case, for example, during a distal anastomosis of a tibial bypass. Future research attempts shall seek to disentangle the inherent cognitive and technical demands during the operation, case complexity, interruptive behaviors, and potential patient- and staffrelated outcomes.

Second, the results are based on a university hospital in Germany. Although we obtained data in two different surgical centers with different ORs, selection bias may have occurred. In regard to surgical disciplines, we focused on mainly general and orthopedic surgery. Further limitations stem from that we only observed procedures from the regular case list. We cannot exclude that specific intraoperative interruptions may be more likely in other surgical specialties and emergency procedures. For this exploratory research, we did not include any information for complexity, type, and length of surgical tasks. Since we observed cases with an anticipated duration <4 h, our findings cannot simply be transferred to longer procedures that inherently have further interruptions because of staff rotation or breaks, for example, rotating staff takes lunch break and is replaced.

Third, potential observer effects may have biased the prevalence of interruption frequencies. In addition, participant observations stress attention resources of the observers [17]. Although we tried to conduct only one observation per day and that during the mornings, we cannot exclude that because of extended observation length, observers' fatigue increases, and interruption events are occasionally overlooked.

One major issue concerns the 'necessity' or 'legitimacy' of workflow interruptions [27]. A disruption in itself does not necessarily equate with compromised safety. Thus, intraoperative interruptions can be essential for surgical care and may have different effects and safety implications [15]. CIC may reduce boredom, social tension, monotonous work, or help to maintain awareness and vigilance [17,28]. Therefore, a nuanced standpoint to considerably discuss the nature and potential consequences is required. This refers also to 'opportune' moments for surgical flow interruptions, that is, senior surgeon pausing and taking time for teaching. Such an event may be integral to the OR teaching environment and may bring the whole surgical team to the same intellectual point in the case.

We also cannot exclude that intraoperative interruption were subjectively appraised differently among the OR staff, for example, that a surgeon does not acknowledge a specific interruption event or evaluates it as nondistracting. Moreover, there may be interruptive work routines that differ between the involved OR professions, whereas senior surgeons are mostly involved in the procedure, senior anesthetists regularly step into and exit OR to supervise junior anesthetists.

4.2. *Implications of the study*

The results of the present study carry several implications. Clinically, addressing and reducing unnecessary workflow interruptions is a potentially effective option for improving OR surgical performance [15]. Various systemic sources of distractions hinder surgical teams' ability to remain fully mentally engaged during a procedure. To reduce future mistimed workflow interruptions by external staff, an enhanced interprofessional collaboration through better organization of various tasks and deliberate design of joint activities, communication processes, and information transfer is advised. As poor OR teamwork predisposes surgical errors, we suggest team-based interventions to identify and reduce inadequate interruptions to contain interruptibility in ORs [3]. Reducing mutual workflow interruptions and structuring interprofessional collaboration is a promising strategy to enhance clinical safety.

With regard to future research, these study implications address particularly the scope of intraoperative interruptions and potential consequences of frequent distraction events. Future research should address the single and cumulative effect of surgical flow disruptions, using cumulative interruption measures that take into account the multilayered interruptions during surgical procedures [17]. Further research should also investigate the 'ambiguous nature' of interruption events. There are certainly interruptions that are beneficial to OR team functioning such as providing valuable clinical or process-related information, for example, for better clarification, immediate emergency response, acute error capture, or essential information on subsequent tasks [19,29]. Future research needs to investigate which interruptions lead to bad outcomes and unsafe OR practices and which interruption events serve effective surgical care. Last, doctors' individual expertise for coping and subjective appraisal of interruptive events may differ substantially according to severity, temporal duration, or nature of the event [1,17]. Research in ward physicians (including surgical inpatient wards) demonstrates that frequent interruptions add to professionals' subjective workload [27]. To our knowledge, there is no study that investigates the cumulative and prolonged effect of intraoperative workflow interruptions on OR professionals' workload. Investigating the impact of interruptions on stress and performance is a promising avenue for future research, particularly in training of junior surgeons and their coping strategies for demanding and stressful conditions in the OR [30].

5. Conclusions

Surgery is a high-risk activity. This study found that there is considerable distraction and interruption in the OR interfering with the work of surgical teams. Eventually, these events may impact OR team performance and surgical outcome [3]. We found interruption sources extrinsic to operating procedures, particularly people entering or exiting the OR and beeper and phone calls, interfered with the surgical teamwork. However, factors intrinsic to the case at hand like interruptions because of equipment failures, distractions from the work environment and procedural problems, caused more intense interference in OR team functioning.

Our results emphasize that ORs should be well-designed socio-technical systems [5,7]. Future attempts should address efforts for diminishing unnecessary intraoperative interruptions that jeopardize effective and safe surgical performance while maintaining effective and safe communication OR practices. Establishing a low level of interference, through balanced communication, high level of control in the OR environment, and high reliability in technology and equipment is a major avenue to foster surgical teamwork and safe patient care.

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Stefanie Passauer-Baierl was involved in tool development and data collection. She critically reviewed the initial draft and approved the final manuscript as submitted.

Heiko Baschnegger was involved in tool development and preparation of data assessment. He critically reviewed and revised the manuscript, and approved the final draft as submitted.

Matthias Weigl designed the study, obtained funding, and adapted the observational tool. He was involved in data assessment and performed the statistical analyses. He drafted the initial manuscript and approved the final manuscript as submitted.

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