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a pilot study

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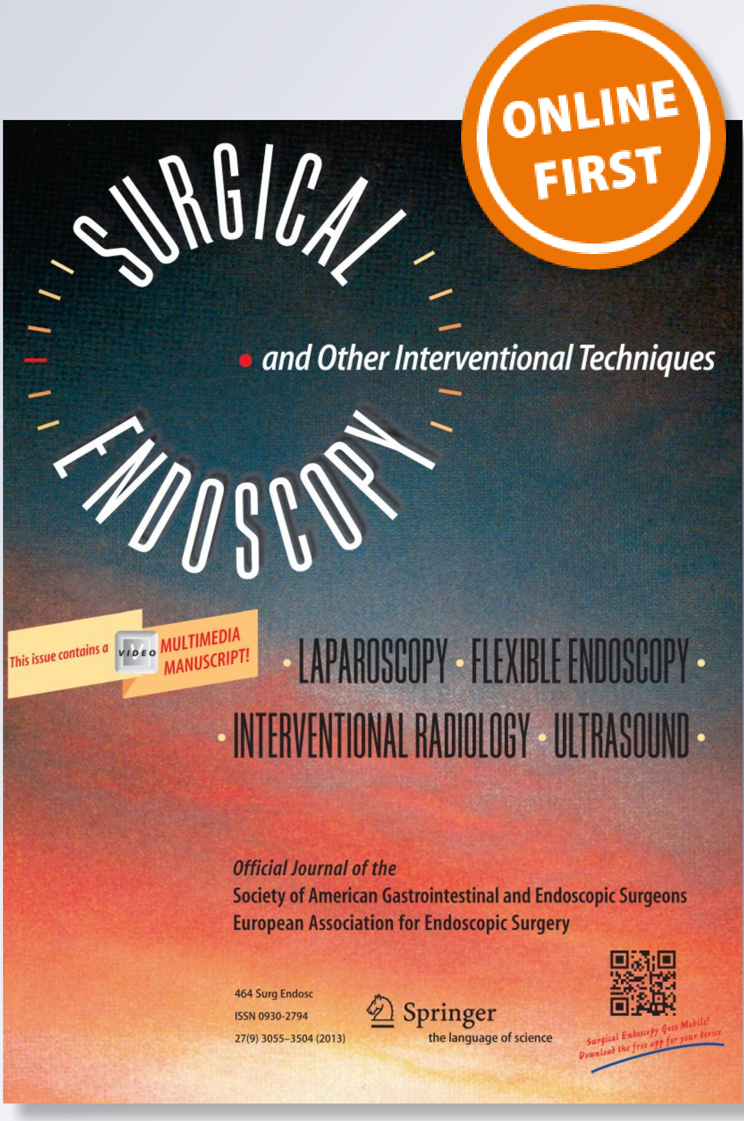

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Effects of surgical flow disruptions on surgeons' resources: a pilot study

B. C. G. van Houwelingen[1] · A.-F. Rutkowski[1] · S. Ganni[2,3] · P. S. Stepaniak[4] · J. J. Jakimowicz[5]

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Abstract

Background Minimally invasive surgery requires surgeons to allocate more attention and efforts than open surgery. A surgeon's pool of resource is affected by the multiple occurrences of interruptions and distractions in the operating room. Surgical flow disruption has been addressed from a quantitative perspective. However, little is known on its impact on the surgeons' physiological resources.

Methods Three physiological markers, heat flux (HF), energy expenditure in metabolic equivalent of tasks and galvanic skin response were recorded using body sensor monitoring during the 21 surgical operations. The three markers, respectively, represent: stress, energy mobilization and task engagement. A total of 8 surgeons with different levels of expertise (expert vs. novice) were observed performing 21 surgical procedures categorized as short versus long. Factors of distractions were time-stamped, and triangulated with physiological markers. Two cases illustrate the impact of surgical flow disruptions on the surgeons.

Results The results indicate that expert surgeons' mental schemata are better organized than novices. Additionally, the physiological markers indicate that novice surgeons display a higher HF at the start (tendency $p = .059$) and at the end of procedures ($p = .001$) when compared to experts. However, during longer procedures, expert surgeons have higher HF at the start ($p = .041$) and at the end ($p = .026$), than at the start and end of a short procedure.

Conclusion Data collected during this pilot study showed that interruptions and disruptions affect novice and expert surgeons differently. Surgical flow disruption appears to be taxing on the surgeons' mental, emotional and physiological resources; as a function of the length and nature of the disruptions. Several training curricula have incorporated the use of virtual reality programs to train surgeons to cope with the new technology and equipment. We recommend integrating interruptions and distractions in virtual reality training programs as these impact the surgeons' pool of resources.

Keywords Surgical flow · Distractions · Physiological markers · Mental and physiological resources · Team training

Classical literature in the field of surgery demonstrates that minimally invasive surgery (MIS) is more demanding on the surgeons' resource than open surgery [1–4]. Surgery is a stressful profession [5]. MIS enhance treatment capabilities, placing, however, an ever-increasing pressure on the surgeons [6, 7]. Resources are an individually possessed form of physical, emotional or cognitive energy required in processing information [8, 9]. Resources are limited; thus, they form a pool and affect each other through a feedback loop [10, 11]. The complexity of technologies in the OR requires surgeons to allocate their resources mindfully to reach optimal surgical results [3]. Particularly, overloaded surgeons may lose their abilities to maintain patient safety in the operating room [12].

✉ B. C. G. van Houwelingen
berndvanhouwelingen@gmail.com

1 Department of Management, Tilburg University, Warandelaan 2, 5037 AB Tilburg, The Netherlands

2 GSL SMART Lab, Rajahmundry, India

3 TU Delft, Netherlands Faculty of Industrial Design Engineering, Delft University of Technology, Landbergstraat 15, 2628 CE Delft, The Netherlands

4 Health Care Operation Management, Catharina Hospital Eindhoven, Michelangelolaan 2, P.O. Box 1350, 5602 ZA Eindhoven, The Netherlands

5 Department of Research and Education, Catharina Hospital Eindhoven, Michelangelolaan 2, P.O. Box 1350, 5602 ZA Eindhoven, The Netherlands

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Distractions and interruptions are an additional well-known burden on the surgical performance. For example, Wiegmann et al. [13] demonstrated that flow disruptions such as teamwork/communication failures, equipment and technology problems, extraneous interruptions, and training-related distractions led to surgical errors. Environmental factors (e.g., equipment design), social factors (e.g., teamwork, communications), and organizational factors (e.g., scheduling, procedures and policies) are as much potential distractors [12, 14–18]. Disruptions in the OR have mostly been studied from a quantitative perspective in relationship to surgical errors. For example, Zeng et al. [12] studied the frequency and duration of disruptive events (e.g., instrument change, surgeon position change, extraneous interruption) on surgical delay. Using video-aided observations the authors demonstrated that on average, disruptive events performed in the OR caused 4.1 min of delay for each case per hour, corresponding to 6.5% of the procedure time: instrument change (3.4 min/h) generate the most surgical delays. In a recent article Al-Hakim et al. [19] used a similar approach, focusing on the impact of ergonomics factors (e.g., monitor location, level of instruments' handles, and location of surgical team members) on the operative flow disruption. The literature also reports that paying attention and responding to alarm increases the surgeons' mental load and stress level [20]. It creates a competition for attentional resources. These multiple factors disrupt the natural progression of an operation, potentially compromising patient safety [13, 21]. The recurrent disruptions of the surgical flow lead to an increase in surgical errors and impact surgeons' mental strain [22, 23]. Understandably, the more disruptions the more the surgeon must tap into his pool of resources to alleviate potential negative effects. However, surgeons' experience of interruptions and distractions differ in practice. For example, noise is a recognized source of stress, and impairs concentration and communication in the OR. Still, some surgeons may enjoy music in the theater, while others require a quiet environment [24].

Surgeons are able to recognize most disturbing factors, but have a hard time quantifying or sequencing these factors objectively. That is in practice, surgeons report various levels of resistance to disruptions when engaged on the topic. They may experience objective (i.e., physiological level) repetitive stress without consciously identifying it at the subjective level (i.e., verbal report). They are "implicitly" trained in coping emotionally and cognitively with these physiological modifications. Congruently, surgeons do not systematically perceive all distractions and interruptions as consuming their attention. Additionally, they often fail to recognize that they suffer from stress [25, 26]. However, research has demonstrated that excessive and long-lasting stress compromise the surgeons' technical and non-technical skills (e.g., teamwork, decision-making) [27, 28]. Weenk et al. [26] used wearable sensors to collect the heart rate variability (HRV) of surgeons. They concluded that the stress was highest performing an operation in fellows and residents than in consultants. Interestingly, Weenk et al. [26] results showed that the self-reported stress level (i.e., State Trait Anxiety Inventory) did not correlate with the physiological measurements (i.e., HRV).

In this article, we assume that surgeons may not be fully aware of the impact of disruptions and interruptions in the OR on their stress level, and therefore, on the surgical performance. The pilot study presented in this paper focuses on the impact of surgical flow disruptions on the surgeons' cognitive, emotional and physiological resources. We speculate that surgeons who possess high level of expertise and skills (i.e., cognitive resources), nerves of steel when for example dealing with severe bleeding (e.g., emotional resources), after long hours of surgical procedure (i.e., physiological resources) will see their pool of resources particularly challenged when they have to cope with repetitive disruptions of the surgical flow.

Materials and methods

The research was conducted in the department of Surgery and department of research and education at Catharina hospital in Eindhoven (The Netherlands) over a period of 6 months. The surgeons and members of the surgical team were informed of the goal of the research. Consents were collected prior to the procedure. The pilot study was approved by the ethics committee of the hospital.

Procedure

Disruptions, interruptions of the surgical flow as well as surgeons' physiological markers of stress, energy mobilization and task engagement were collected using the SenseWear Pro 3 armband during twenty-one surgical procedures representing approximately 21 h of observation. The surgical flow disruptions reported could be later triangulated with the measurements gathered with the physiological measurements collected with the SenseWear Pro 3 armband.

The surgeon was equipped with the wearable prior to scrubbing and going sterile. Physical activities (e.g., stretching, yawning, laughing, walking, pulling or pushing of tissue or the patient) were consigned in the observation file in addition to the observed distractions and interruptions. Gender, age, weight, handedness and smoking were recorded for reliability purpose. Following the observations, the surgeon was invited for a short debriefing with the observer.

Information regarding the surgical procedures such as the type of surgical procedure, the start of procedure (i.e., time of the first incision), the end of the procedure (i.e., start of the final stitching) as well as the team composition (i.e., members and roles) were consigned. Table 1 presents the type of procedures and the level of experience of the surgeons in years of practice.

Measurements

A non-exhaustive list of disruptions and interruptions was built based on the literature to report the observations during the 21 surgical procedures [12, 14–18]. The list of factors has been pre-tested with the participation of four expert surgeons, and later complemented by a set of observations conducted in the operating room. Each real-time occurrences of disruptions were reported and time-stamped in an excel file. The list was composed of environmental factors (e.g., operating room environment, environmental hazards), social factors (e.g., teamwork, communications), equipment factors (e.g., technologies and instruments, technical default), organizational factors, training and knowledge factors (e.g., technical factors, training and procedures).The SenseWear provided three physiological marker measurements: (i) the heat flux (HF) that is the amount of heat that is being dissipated from the body via the skin [29]. The heat flux is classically used an indicator of stress. The HF scale ranges from 0.00 to 300 W/m^2. A two-standard deviation range of ± 10.00 W/m^2 at HF was inferior to that of 50 W/m^2. In this pilot study, the heat flux ranged between 40 and 110 W/m^2. Previous research has demonstrated that difficulties during surgeries, e.g. distractions, influence of the stress level increasing the heat flux level [25, 26, 30]; (ii) the METs value that is the physiological measures of energy expenditure in metabolic equivalent of tasks. The METs scale range between 56 and 20 MW. A two-standard deviation range was ± 3.00% of expected value. This measure allows controlling the influence of physical activity on galvanic skin response [29–31]; (iii) the galvanic skin response (GSR) that is the electrical conductivity of the skin. The GSR score range from 20 to 40 °C. A 2 standard deviation range was ± 0.80 °C across the temperature range. Skin conductance level is a reliable indicator for the level task engagement [29]. Increase in task complexity relates to more task engagement [32]. Distractions in the OR increase the complexity of the procedure as it increases the cognitive resources needed to complete the task, potentially increasing the GSR. The GSR spikes allow assessing task engagement at certain point of the procedure. It is related to the METs value providing a good indicator on energy expenditure.

Results

Surgical flow disruption: occurrence of distraction and interruption events

A total of 1541 distracting events were recorded during the 20 h 19 min and exactly 06 s of observation. The three top distractions computed through the 21 surgical procedures were instruments change (30.7%); procedure or patient irrelevant communication (13, 9%); Operating Room door opening (12.8%). Radio conversation, phone communication as well as sounds of alarm represented all together another set of disrupting factors (16%). Most have been reported in the literature [12, 14–18].

Physiological markers: heat flux, METs and GSR

The three physiological markers were collected continuously through the whole duration of the procedure for each of the surgeons. As previously reported, heat flux is an indicator of stress; this measurement may serve as a proxy of the emotional resources required as part of the surgeon profession [26]. METs is related to physical activation; this measurement is an interesting indicator to assess the physiological resources required to perform the surgical tasks. The GSR indicates modifications in task engagement; this measurement concerns mostly the cognitive resources required to deploy efficiently (e.g., effortless) the cognitive schemata required for the surgery. These three measurements combined indicate how the surgeon's body consumes fuel to cope with complex tasks and situations in the OR. The data collected allowed comparisons between expert and novice surgeons engaged in short procedure, as well as long procedure.

Table 1 Types of procedures observed and the level of experience of the surgeons in years of practice

	Expert surgeons (from 5 to 19 years in function)	Novice surgeon in training (from study year 2–5 to 6 months of experience)
Short procedure < 1 h (n = 14)	Gastric bypass (2) Gastric sleeve (1) Hernia (1) Diagnostic laparoscopy (2)	Gastric sleeve (1) Hernia (1) Cholecystectomy (6)
Long procedure > 4 h (n = 7)	Esophagus (5) Tumor resection (1)	Lap Nissen fundoplication (1)

A conservative statistical approach was used to analyze the continuous outcome of the three physiological variables [33]. Non-parametric tests equivalent of parametric tests was selected as the appropriated statistical tools regarding the small size sample, and despite the continuous outcome of the three physiological measurements. Indeed, due to the reliance on fewer assumptions, non-parametric methods are more robust [34]. The Mann–Whitney *U* test is the non-parametric equivalent of the two sample *T* test; the Wilcoxon signed-rank test of the paired *T* test and the Spearman's rho is the equivalent of the Pearson correlation. Tables 2, 3, 4, and 5 present the median values as well as the minimum and maximum values for each of the three markers. Additionally, we present for the sake of readability the mean scores and the standard deviation. Indeed, these parametric values are informative and reliable (e.g., computation of continuous outcome).

First, we compared the average scores of the three physiological markers as a function of the levels of experience during the short procedures. Indeed, in this pilot, we add no situation of novice surgeons involved in long surgical procedure. Second, we compared the average scores of the three physiological markers within each of the three conditions observed. The results of the Mann–Whitney *U* test (equivalent two sample *T* test) show that novices display a higher heat flux at the start of the procedures (tendency $p = .059$) and at the end of the procedures ($p = .001$) than the expert. Table 2 presents the results of the mean, median, minimum, and maximum value of the surgeons' HF at the start and at the end of the short procedure: Novice versus Expert.

Table 2 Heat flux (i.e., stress) at the start and at the end of the short procedure: expert versus novice

	HF at start of procedure*	HF at end of procedure**
Novice***		
N	8	8
Mean	84.8468	92.6925
Median	87.2830	90.5656
SD	7.62125	8.19507
Min	70.67	82.52
Max	94.03	104.53
Expert ns.		
N	6	6
Mean	70.2812	59.2122
Median	69.7486	57.3030
SD	14.56966	12.43005
Min	53.95	43.95
Max	93.83	76.11

*Ns $p = .059$; **p. < .001; ***$p = .046$; ns. $p = .091$

Table 3 GSR at the start and at the end of the procedure for the three categories of observations

	GSR at start of procedure	GSR at end of procedure
Short novice*		
N	8	8
Mean	0.0767	0.1703
Median	0.0755	0.1701
SD	0.02724	0.05841
Min	0.05	0.11
Max	0.12	0.26
Short expert**		
N	6	6
Mean	0.0567	0.1267
Median	0.0436	0.1301
SD	0.03363	0.04907
Min	0.02	0.07
Max	0.11	0.20
Long expert***		
N	6	6
Mean	0.0401	0.1330
Median	0.0366	0.1297
SD	0.03006	0.02703
Min	0.01	0.10
Max	0.07	0.18

*$p = .012$; **$p = .028$; ***p. = .0281

The results of the Mann–Whitney *U* test did not show significant differences between novice and expert surgeons in METs and GSR. The energy mobilized as well as the overall task engagement appeared to be similar for expert and novice surgeons. The results of the Wilcoxon signed-rank test (equivalent of paired *T* test) indicate that the Heat Flux of the novice surgeons increased significantly between the start and end of the procedure ($p = .046$) while it slightly but not significantly decreased for the expert ($p = .091$). The results indicate that the novice surgeons experience more stress than experts did at the start, anticipating the surgical procedure, as well as during the whole procedure. In addition, the results indicate that the novice surgeons experience more stress than experts did at the start, anticipating the surgical procedure, as well as during the whole procedure. This result is congruent with previous research using HVR as a proxy of stress [26].

Interestingly, the results of the Wilcoxon signed-rank test indicate that the METs remained at constant value for expert surgeons ($p = .753$), while their GSR increased significantly for short ($p = .028$) and long ($p = .0281$) surgical operation. The same analysis conducted for the group of novice surgeons revealed that METs score also decreased slightly but not significantly ($p = .09$), while the GSR increased

Table 4 METs at the start and at the end of the procedures

	METs at start of procedure	METs at end of procedure
Short novice		
N	8	8
Mean	1.5137	1.3514
Median	1.5692	1.2729
SD	0.25100	0.28166
Min	1.01	1.05
Max	1.74	1.74
Short expert		
N	6	6
Mean	1.6267	1.6124
Median	1.6811	1.6164
SD	0.23149	0.13156
Min	1.22	1.45
Max	1.89	1.80
Long expert		
N	6	6
Mean	1.9748	1.5516
Median	1.7243	1.6155
SD	0.49686	0.20094
Min	1.55	1.15
Max	2.73	1.68

Table 5 Expert surgeons' heat flux values at the start and at the end of the procedure: short versus long

	HF at start of procedure*	HF at end of procedure**
Short expert		
N	6	6
Mean	70.2812	59.2122
Median	69.7486	57.3030
SD	14.56966	12.43005
Min	53.95	43.95
Max	93.83	76.11
Long expert		
N	6	6
Mean	87.7887	80.3255
Median	87.5897	79.8751
SD	8.28090	13.22641
Min	79.19	60.87
Max	100.30	98.57

*$p = .041$; **$p = .026$

drastically and significantly ($p = .012$). Table 3 presents an overview of the results of the mean, median, minimum, and maximum value of the surgeons' GSR at the start and at the end of the procedure.

The energy mobilization measured through METS remained mostly constant for both novice and expert surgeons. This result is not surprising as surgeons operate in a static position. Table 4 presents the values for the METS. NO significant effects have been found for this physiological marker.

It appears clearly that the METS values are to be interpreted in light of the GSR. The GSR is a reliable indicator for the level task engagement increased significantly for both groups, and this more drastically for the novice surgeons. These results confirm the assumption according to the levels of expertise impact the amount of stress and task engagement to perform short MIS surgical procedure. Finally, we compared the average scores of the three physiological markers as function of the length of the procedure: short versus long for the group of expert surgeons. The results of the Mann–Whitney U test indicate that the expert surgeons operating on a long procedure have a significantly higher heat flux at the start ($p = .041$) and at the end ($p = .026$), than they do at the start and end of a short surgical procedure. Table 5 presents the results for the expert surgeons' heat flux values for both short and long procedures.

The results indicate that stress by anticipation of expert surgeons is higher for long surgical procedure than in short procedure, and that surgeons end up more stressed at the end of a long procedure than a short one. This result is as previously underlined congruent with the conclusion of Weenk et al. [26] The results of the Wilcoxon signed-rank test indicate that the heat flux of the surgeons remain stable through the procedure ($p = .345$). However, they start from a higher level than they do when engage in a short procedure.

The METs slightly decreased but not significantly, while the GSR significantly increases ($p = .028$) as it does in the case of a shorter procedure (see Table 3). To conclude, the stress level and level of task engagement are affected differently for short or long procedure. These results demonstrate that long surgical procedure impact negatively the amount of stress per anticipation. However, regardless of the length of the surgical procedure, task engagement seemingly increases during the course of the procedure.

GSR, METs, heat flux (HF) and distracting events occurrences

Two specific cases illustrate the impact of surgical flow disruptions on the surgeons' physiological markers; as a function of the length of the operation. We selected these two cases to illustrate from a qualitative rather than quantitative perspective the impact of surgical flow disruption on the surgeons' emotional, cognitive and physiological resources. A coding application allowed reporting with a real timestamp the occurrence of the interruptions and distracting events during the 21 surgical procedures. The real time lapse occurring between the start and end-time of a distracting event served to build sets of instantiations of the surgical flow disruptions. In the next section, we present examples of such instantiations triangulated with the three physiological measurements.

In order to better understand the impact of the distractions on the surgeons' task engagement and stress level, we combined the GSR measurements as well as the Heat Flux with the occurrence of distractions. Interestingly, one can imagine that distracting events are not to be observed under a sequential form. That is often they are observed under multiple, recurring and parallel occurrences as demonstrated in the case of these two surgeons. We purposely selected two representative cases to enlighten the results of the data collected for the overall sample.

Surgeon A: Experienced (6 years as a surgeon), surgical procedure (gastric bypass), length of the operation (59 min), total amount of distraction (91). The energy mobilization and stress level of the surgeon are significantly and positively related. Indeed, the results of the Spearman's rho (equivalent Pearson correlation) indicated that METs and the heat flux (HF) are positively and significantly correlated ($r = .282$, $p = .013$). That is the surgeon deployed energy coping with stress. Interestingly, his level of task engagement was inversely related to his level of stress while performing this short surgery and not related to energy mobilization. Indeed, the GSR is negatively and significantly correlated to the HF ($r = -.476$, $p = .0001$) and not significantly correlated to the METs ($r = .047$). We concluded that while stress impacted energy mobilization during this short procedure, task engagement did not. That is when the surgeon had to pull on his physiological pool of resources it was to cope with stress. He did not have to pull on extra physiological resources attending to the surgical task. This can be mainly explained as a result of his level of expertise. Interestingly, the engagement in the task, was negatively related to the less stress he experienced. Figure 1 presents the *highs* and *lows* in GSR (task engagement) and heat flux (stress) of surgeon A. Between the time-stamp 12:57 and 13:20 that correspond to the highest frequency of *highs* and *low*s observed, a total 35 distracting events were recorded.

The patterns of the task engagement (GSR) and stress (HF) results associated to the distractions indicate that the *highs* observed are mostly related to the changes of instruments, packaging, as well as communication mostly irrelevant to the patient. Interestingly, 3 of the *highs* in task engagement are observed in combination with *lows*, or decreased in stress level. The high level of stress at the beginning may be explained by the fact the expert surgeon does not know what will happen during the procedure (i.e., which difficulties may be encountered). After starting the procedure, the surgeon experienced a form of control of the situation. The surgeon then switched to high focus on the surgical performance and therefore the high level of stress decreased.

As presented in figure b in two points of time was the engagement of the surgeon *highs* as well as his stress level. These points in time correspond to a set of changes of instruments that may have indicated an important point in the procedure. Overall for these patterns of data it seems that the conversation has mostly the role of decreasing stress at the time of *highs* in task engagement. Additionally, experimental studies have shown that stress level can be judged based on the analysis of GSR and speech signals. However, and more probable than not, the state of hyper focus of the expert surgeon resulted in a delayed effect visible after the resolution of the problem. Then conversations took place as a form of outlet of stress.

Surgeon B Experienced (7 years as a surgeon), surgical procedure (esophagectomy), length of the operation (96 min), total amount of distraction (128). The level of energy mobilization and stress were not significantly related for surgeon B. The results of the Spearman's rho indicated that the METs and the heat flux (HF) are negatively but not significantly correlated ($r = -.042$, ns). In the case of surgeon B, it seems he did not have to pull on extra physiological resources to cope with the stress of a long operation. However, his cognitive engagement with the task was clearly related to his stress level. That is contrary to the case of surgeon A. Indeed, the results indicated that the HF is significantly correlated to the GSR ($r = .613$, $p = .0001$). The level of task engagement is negatively related to energy mobilization, however, marginally. Indeed, the results show that the GSR is negatively correlated (tendency) to the METs ($r = -.171$, $p = .072$). As observed in the case of the surgeon A, surgeon B also did not have to pull on extra physiological resources attending to the long surgical task. This is supposedly related to the level of expertise. Striking is that during this long procedure, the more (or less) cognitively engaged the surgeon B was the more (or less) stress he experienced. Figure 2 presents the *highs* and *lows* in GSR and heat flux of an experience surgeon B performing a long surgery. Between the time-stamp 12:05 and 12:20 that correspond to the highest frequency of *highs* and *lows* observed in GSR, a total 26 distracting events were recorded.

As depicted in Fig. 2a, 4 major *highs* are observable in heat flux during this procedure that represent a form of accumulation of about 63 distractions. During that period, the GSR level kept rising steadily. These *highs* in heat flux could be mostly related to set of external bleeding, spilling/dropping items, procedure irrelevant communications, intercom, cleaning of the camera, trocar leakage, as well as sound of alarms. The patterns of observations are different for the case of surgeons A and B. Indeed, the association in term of the combination between *highs* and *lows* in GSR and heat flux are different. However, we can find similarities and

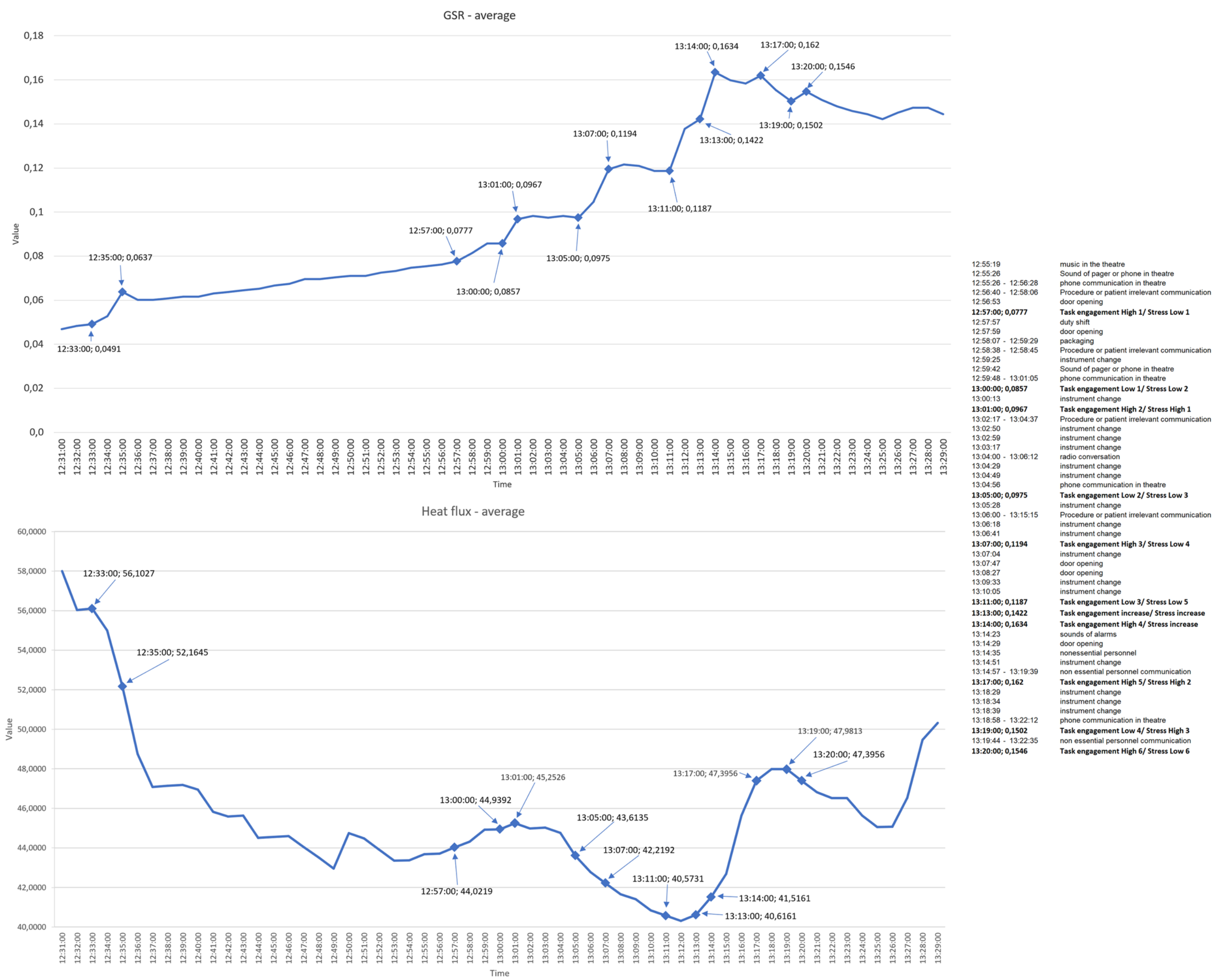

Fig. 1 Surgeon A: GSR, HF and distracting events observed in relation to highs and lows in GSR and HF

point at specifics and interesting events. For example, the observations inform us that the *highs* 1 &2 in task engagement occurred following the surgeon's request to keep quiet in the OR while he was anticipating a difficult point in the surgery (i.e., start of stitching esophagus to stomach). In addition, the results indicate that the task engagement of surgeon B is indeed at a high point when the communication is meaningful to the procedure, and stress increased with unusual and irritating sounds such as the sound of the trocar. As in the case of surgeon A, decreased in stress is observable in association to irrelevant communication even when the surgeon is cognitively engaged. Moreover, we assumed as in Case A, a delay effect in GSR visible after the resolution of the problem, translating into communicative behaviors. Disruptions such as multiple door openings or duty shift led to an increase in the surgeon level of stress. The amount of distractions in relation to HF presented in Fig. 2 demonstrated the clear negative influence of distractions on the surgeon's HF, even when he managed to remain highly cognitively engaged. The case of surgeon B indicated clearly that the task engagement was related to the fluctuation in the level of stress. The impact of combined distractions such as leaking trocar, door opening, or duty shift may have been a burden during the operation. The surgeon mentioned during the debriefing that the sound of the leaking trocar was annoying. As in the case of the surgeon B, irrelevant communication may have served as an outlet of stress, or indicating the end of difficult procedure point requiring high focus.

Discussion and limitations

The peripheral nervous system regulates homeostatic processes such as body temperature and blood flow. Potential threats of our bodily homeostasis generate stress [35]. The three physiological markers address different psychological

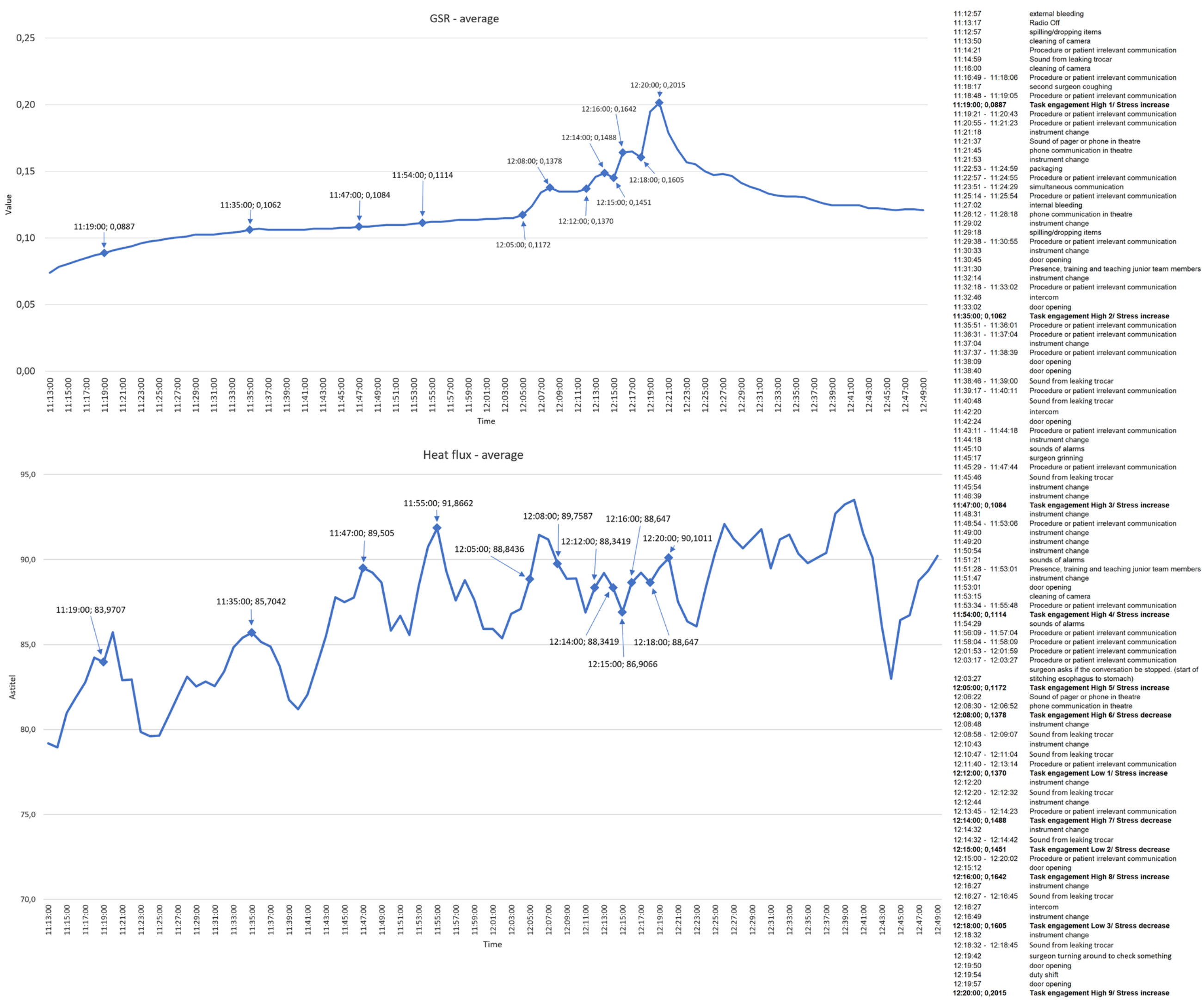

Fig. 2 Surgeon B: GSR, HF and distracting events observed in relation to highs and lows in GSR and HF

phenomena. While we could well relate heat flux to the level of stress, GSR to task engagement, the METs measurement appeared less informative in this research but for novice surgeon. In addition, the stress level and level of task engagement are affected differently for short or long procedure. Long surgical procedure impact negatively the amount of stress per anticipation. However, regardless of the length of the surgical procedure, task engagement seemingly increases during the procedure.

Training in laboratory improves the surgeons' intellectual and technical skills. Furthermore, training plays also a crucial role in preventing surgeon exhaustion caused by numerous interruptions of the surgical flow [36, 37]. Research demonstrated that when there is a lack of training, schemata automation is poorer, leading to a higher risk of failure and increasing the stress level of surgeons [30]. When task complexity increases, trainees use more of their attentional resources concentrating on technical aspects of the task performance rather than on higher level activities (e.g., anticipating, scanning, or attending to instrument read-outs) [38]. The results of the research congruently demonstrated novice surgeons experienced more stress than experts did at the start of the procedure, anticipating potential advert events, as well as during the whole procedure. Both novices and experts mobilized energy and proved high level of task engagement. However, as shown in the two cases of surgeons A and B, the same energy mobilization is used for different purpose. When considering the wellbeing of surgeons, it is important to realize that long procedures are definitively more taxing than short ones. Surgeons deploy more mental and physiological resources in such context. In stressful situation, the body expends energy resources as an attempt to maintain its equilibrium [9]. Interestingly, conversations that are irrelevant to patients mostly have the role to decrease the stress level. However, irrelevant communications occurring simultaneously with highs in task engagement (GSR) correspond to a delay effect of the surgeon hyper focus. These are the verbal signs of the resolution of the problem (i.e., translating into communicative behaviors). Regarding distractions we surely learned that the accumulation or repetitive annoying sounds are increasing the level. These distractions can really get to the nerves of the surgeons when these obviously add up i.e. the one time opening of a door will not exhaust the surgeon's resources, the repetition and association with a leaking trocar may.

We recognize the limitations of this pilot study. First, only eight surgeons took part to this pilot, and the majority were experts. It will be interesting to involve surgeons from other Dutch hospital in other trials. Second, novice surgeons were not eligible to perform long and complex surgery. We therefore could not compare the level of expertise on the length of the operation. Third, we only reported in detail for 2 full observations. In the future, we intend to shadow more operations and propose a better coding of each distractions and interruptions. Indeed, the observations were collected systematically by an observer. In the future, it will be interesting to use video-aided observation to increase the reliability of the observation as a form of manipulation check [12]. Finally, instrument changes have been reported as a distraction but is part of procedure flow rather than disruption. However, it can cause disruptions when the wrong instrument is selected [19]. It will be interesting to address the impact of ergonomics factors on the operative flow disruption in detail. Finally, one may argue that some of the external distractions and interruptions are minimum and not as stressful as a major surgical flow disruption. It is indeed a challenge to assess how disturbing a factor is to surgeons. More research is required.

Conclusion

This pilot study addressed the effects of surgical flow disruptions on the surgeons' physiological resources from both a quantitative and qualitative perspectives. Disruptions and interruptions of the surgical flow disruption have mostly been addressed from a quantitative perspective. This research underlines the importance to consider the effects of such disruptions on the surgeons' pool of resources. In addition, it demonstrates that physiological markers are interesting measurements to assess the disruptive nature of interruption and distraction in the OR. Finally, interest is growing on the potential of virtual immersive training in the medical field [39, 40]. However, little is reported on the importance of realistic team resource management programs in healthcare. Such programs are in widespread use in the military and aviation industries [41, 42]. They are based on simulation and provide training for technical and non-technical skills such as communication and teamwork [43]. As surgeons cannot operate in a bubble, they should not be trained in one [30]. Training is crucial to handle crisis in the OR. Weenk et al. [26] underlined that trainees may benefit from recognizing stressors and stressful situations in real time. Hence, they will learn to cope with or to prevent stress. Training 'in situation', representing more realistically the demands imposed on the surgeons during clinical practice is required to optimize patient safety and preserve surgeons' resources essential to the surgical task. As previously underlined, in "situation" should include disruption of the surgical flow as it repetitively occurs in the OR. Trainees should experience before entering the OR, interruption of their mental flow, competition for their attentional resources, increase level of irritation, while performing surgery on the simulator. Data collected through our observations and then triangulated with physiological markers of body temperature should allow in the future developing realistic scenario, testing in a realistic environment surgeons' nerves of steel.

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Compliance with ethical standards

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Appendix A: Distractions and interruptions observed during the 21 surgical procedures

Environmental factors

Operating room environment

Sound of pager or phone in theater
Sound of pager or phone next to theater
Radio conversation
Sounds of alarms
Music in the theater
Temperature of the airflow
Knocking on the door
Hissing noise with unclear origin
Door opening
Furniture and equipment positioning
Reduced or compromised visibility
Barriers
Surfaces
Wrong lights color

Environmental hazards

Crushing
Sharps

Surgeon touched by unsterile person
Equipment factors
Technology and instruments
Non-electrical surgical tool malfunctioning
Diathermy off or incorrect
Equipment not directly available
Failing table adjustment
Endoscope not working
Electrical point on laparoscopic graspers not working
Spilling/dropping items
Searching activity
Instrument change
Packaging
Orienting the foot pedal
Excessive sound from drawers and equipment
Sound from leaking trocar
Wrong equipment
Buzzing from electrical machine
Cleaning of camera
Technical default
Software not working
Pointing or touch devices not working
Bad image quality
Dead devices
Social factors
Teamwork
Coordination
Personnel not available
Surgeon Position change
Non-essential personnel
Communications
Question on phone to surgeon (surgeon calling)
Intercom
Procedure or patient irrelevant communication
Non-essential personnel communication
Unclear communications
Lack of response
Simultaneous communication
Language issues
Common information not known
Phone communication in theater
Phone communication next to theater
Organizational factors
Organizational
Duty shift
External visitors
Computer data entry
Negative personal information
Training and knowledge factors
Technical (medical) factors
Technical/skill issues
Training and procedures
Presence, training and teaching junior team members
Surgeon leaving to attend beeper message
Protocol failure

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