Serious games in surgical education
Graafland, M.

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Training situational awareness to reduce surgical errors in the operating room

Maurits Graafland, Jan Maarten C. Schraagen, Marja A. Boermeester, Willem A. Bemelman, Marlies P. Schijven
ABSTRACT

Background: Surgical errors result from faulty decision-making, misperceptions and the application of suboptimal problem-solving strategies, just as often as they result from technical failure. To date, surgical training curricula focus mainly on the acquisition of technical skills. The aim of this review is to assess the validity of methods improving situational awareness in the surgical theatre.

Methods: A search was conducted in PubMed, Embase, the Cochrane Library, and Psychinfo using predefined inclusion criteria, up to June 2014. All study types were considered eligible. The primary endpoint was validity for improving situational awareness in the surgical theatre at individual or team level.

Results: Nine articles were considered eligible. These evaluated surgical team crisis training in simulated environments for minimally invasive surgery (MIS, n = 4) and open surgery (n = 3), and training courses focused at training non-technical skills (n = 2). Two studies showed that simulation-based surgical team crisis training has construct validity for assessing situational awareness in surgical trainees in MIS. None of the studies showed effectiveness of surgical crisis training on situational awareness in open surgery, whereas one study showed face validity of a two-day non-technical skills training course.

Conclusions: To improve safety in the operating room, more attention is needed on situational awareness in surgical training. Simulation training is viewed as the mainstay to improve situational awareness in the context of the surgical theatre. To date, few structured curricula have been developed and validation research remains limited. Strategies to improve situational awareness can be adopted from other industries.
INTRODUCTION

Modern teaching curricula aim to produce competent professionals in educationally efficient and safe environments\(^1\). It is commonly assumed that a high level of technical skills predicts the ability of surgeons to perform safe surgery. Training technical skills is therefore often seen as the most important strategy to reduce adverse events in surgery\(^2\,\,^3\). Use of structured assessment scales has improved the objectivity of assessing technical skills\(^4\,\,^5\). Furthermore, laparoscopic\(^6\) and endovascular\(^7\) virtual reality simulators have shown to be effective tools for teaching technical surgical skills.

To date, teaching curricula do little to incorporate cognitive factors. An omission, as errors in the surgical theatre are in fact more likely to result from perceptual or judgmental errors, than from poor surgical technique\(^8\). Procedural outcome of supervised residents is not associated with more complications than that of skilled surgeons\(^9\,\,^10\). Surgical errors are often caused by errors of judgement, carelessness\(^11\), incomplete understanding of the situation\(^11\), failure of vigilance\(^8\) and misperceptions\(^12\). Impaired recognition during surgery frequently results in errors, even though the surgeon's technical skills are of high standard\(^11\,\,^13\,\,^14\). From a psychological perspective, functioning in complex situations is related to an individual's perception of key elements in that situation, comprehension of these key elements in the procedural context and the individual’s expectations towards the future course of the procedure\(^15\). Failure of this situational awareness inevitably lead to inaccurate decisions.

The surgeon’s situation assessment results from a multitude of information sources within the modern surgical theatre. Our perception of reality is not always accurate in such complex, continuously evolving situations. This is caused by cognitive, com-

**Box 1**

**Misperceptions in dynamic environments**

The surgeon's perception of reality is not always accurate in complex, evolving situations. This is caused by inherent information-processing limitations of the human mind under specific circumstances (e.g. time pressure, conflicts of interest). *Inattentional blindness* refers to an individual's failure to recognize objects in the visual field. Our attention is limited and focuses mainly on objects of interest\(^49\), while giving us the false impression that we are able to see everything in detail. Depending on where one's attention is allocated, every individual thus perceives the same environment differently\(^50\). A recent study shows that 83% of experienced radiologists fail to notice a picture of a gorilla placed over a computed tomography of the chest, when asked to look for malignant nodules. The radiologists focus only on what they have been told to look for and fail to recognize unexpected objects\(^51\). Secondly, *change blindness* refers to the failure of our brain to detect substantial changes in the visual field\(^52\). The short-term visual memory tells us that a change has taken place and where, but cannot tell us what has changed\(^53\). Therefore, the brain's ability to perform a successful comparison and detect subtle changes is compromised. In practice, our ability to detect unexpected events and situational changes is limited, even if the changes are of significance to the procedure itself.
munication, teamwork and environmental factors (Figure 1). The human mind has inherent information-processing limitations under specific circumstances, referred to as *inattentional* blindness and *change* blindness (Box 1). Situational awareness can be viewed as the *product* of an individual’s perception and comprehension of the available information, and expectations towards the future course of the procedure\(^\text{15}\) (Figure 2). Situational awareness is thought to occur both on individual and team level, both heavily relying on teamwork and communication\(^\text{16}\).

Failure to maintain SA inevitably leads to impaired judgements with potentially harmful outcome. Mishra *et al.* show a strong and independent correlation between surgeons’ situational awareness and their technical outcome in a series of 26 consecutive laparoscopic cholecystectomies\(^\text{17}\). When information is unavailable, incomplete, or falsely interpreted, surgical errors are more likely to occur. Way *et al.* assessed 252 cases of bile duct injury after cholecystectomies and concluded that the vast majority of bile duct injuries stems from incomplete recognition of abnormal situations\(^\text{12}\).

Structured training and assessment of SA is currently lacking in surgical residency training curricula\(^\text{13,18}\). This systematic review explores the opportunities to improve SA in the context of the surgical theatre. The aim was to assess the validity of the interventions described, according to the customary validation criteria\(^\text{19}\).
METHODS

Search and study selection
A systematic search was performed of peer-reviewed studies on methods to improve or train situational awareness in the surgical theatre. The aim was to assess the effectiveness of the interventions in terms of validity criteria. Methods should specifically include the surgical team and/or the primary surgeon. Studies that included settings other than the surgical theatre were excluded. All study types were considered eligible.

The search included Pubmed, Embase, The Cochrane Library and PsychInfo using the terms “Situational awareness”, combined with “training”, “improvement”, “education”, “surgery” and “operation” up to June, 2014. Hand search of references of relevant articles was performed. No exclusion criteria were applied. All articles deemed relevant, dubious, or unknown were examined in full text.

Review
From relevant studies, data was extracted on study setting, methods for improving SA, study design, outcome assessment, results and conclusions into an electronic database. The predominant question in validity research is the extent to which the training method improves what it intends to improve. Validity was assessed using previously described
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criteria. Five main types are described in a validity process (content-, face-, construct-, concurrent- and predictive validity).

Quality of relevant studies and risk for bias was assessed using the methodological index for non-randomized studies (MINORS), a validated instrument assessing 12 items (8 for non-comparative studies).

RESULTS

The search identified 363 potentially relevant articles. Nine articles were found to be relevant (Figure 3). Seven articles described crisis management training in simulated operation rooms, two described a non-technical skills training course. None of the studies described interventions other than training methods. Eight articles describe prospective cohorts studies and one a cross-sectional survey. None of the studies had a randomized character. The studies were small (minimum 10, maximum 83 participants). Systematic assessment of risk for bias delivered one study with low risk for bias, six with moderate and 10 with high (Table 1). Pooling of data was not performed due to heterogeneity of the study designs, outcome measures and settings.

**Figure 3.** Flow chart of the systematic search and inclusion.
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<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Risk for bias</th>
<th>MINORS scale (points / maximum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdelshied et al. (2013)</td>
<td>Prospective cohort study</td>
<td>Medium</td>
<td>17/24</td>
</tr>
<tr>
<td>Flin et al. (2007)</td>
<td>Cross-sectional survey</td>
<td>High</td>
<td>10/16</td>
</tr>
<tr>
<td>Gettman et al. (2009)</td>
<td>Prospective cohort study</td>
<td>High</td>
<td>15/24</td>
</tr>
<tr>
<td>McCulloch et al. (2009)</td>
<td>Historical cohort study</td>
<td>Medium</td>
<td>20/24</td>
</tr>
<tr>
<td>Moorthy et al. (2005)</td>
<td>Prospective cohort study</td>
<td>Medium</td>
<td>18/24</td>
</tr>
<tr>
<td>Moorthy et al. (2006)</td>
<td>Prospective cohort study</td>
<td>Low</td>
<td>21/24</td>
</tr>
<tr>
<td>Powers et al. (2008)</td>
<td>Prospective cohort study</td>
<td>Medium</td>
<td>18/24</td>
</tr>
<tr>
<td>Powers et al. (2009)</td>
<td>Prospective cohort study</td>
<td>Medium</td>
<td>19/24</td>
</tr>
<tr>
<td>Undre et al. (2007)</td>
<td>Prospective cohort study</td>
<td>Medium</td>
<td>11/16</td>
</tr>
</tbody>
</table>

Table 1. Strength of included studies. Risk for bias was estimated using the Methodological index for non-randomized studies (MINORS).²²

Training situational awareness in MIS

Four studies describe crisis training for surgical teams in minimally invasive surgery (MIS) [Table 2]. In a simulated surgical environment using high-fidelity simulators and mannequins, critical events are simulated. Abdelshied et al.²³ performed a prospective cohort study in which non-technical skills of nine urology residents were analysed and stratified according to their experience. The senior resident group showed significantly better situational awareness at individual level than the junior group, proving that the training environment has adequate construct validity for assessing SA among trainees. Powers et al.²⁴ performed a prospective cohort study in which 10 surgeons were assessed in a similar setting. Experienced surgeons performed significantly better than inexperienced trainees on SA at individual level, indicating the method’s construct validity for assessing SA in the surgical theatre. Studies by Gettman et al.²⁵ and Powers et al.²⁶ did not provide information on the validity of the training methods applied.

Training situational awareness in conventional surgery

Three studies describe crisis training for surgical teams using a model for a saphenofemoral junction tie procedure. Moorthy et al.²⁷ compared non-technical performances of junior, intermediate, and senior surgical trainees (n = 27) during one surgical bleeding scenario. They found significant differences at individual level in leadership skills, but not in SA. Moorthy et al.²⁸ performed a second study in which they used the same model to train and assess non-technical performances of junior and senior trainees (n = 20) at individual level. In this study once more, no differences in non-technical skills were found. The study by Undre et al.²⁹ using the same training setting to train surgical teams’ non-technical skills at individual level, did not provide information on the validity of the method applied for training SA.
<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Intervention</th>
<th>Study design</th>
<th>Results</th>
<th>Conclusions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdelshehid et al.</td>
<td>MIS teams (9 urology residents, 7 anaesthesia residents)</td>
<td>Surgical crisis training for MIS teams in HF simulator</td>
<td>Prospective cohort study – Non-technical skills junior and senior urology residents compared during simulated lap partial nephrectomy (at individual level).</td>
<td>Individual SA score among senior urology residents was significantly higher than junior residents (2/3 items: 3.8 - 3.9 vs. 2.9 - 3.1 (p 0.04 - 0.24).</td>
<td>Construct validity for training SA at individual level</td>
<td></td>
</tr>
<tr>
<td>Flin et al. (2007)</td>
<td>Surgeons (21 licensed surgeons)</td>
<td>Non-technical skills course for surgeons (lectures, videos), including SA.</td>
<td>Cross-sectional survey – course evaluation on attitudes, relevance and usefulness</td>
<td>Majority indicated course useful, relevant and intended behavioural change</td>
<td>Face validity for improving non-technical skills (incl. SA) at individual level</td>
<td></td>
</tr>
<tr>
<td>Gettman et al. (2009)</td>
<td>19 urology residents</td>
<td>Surgical crisis training for MIS teams in HF simulator</td>
<td>Prospective cohort study – Pre-/ post-test. Non-technical skills assessment on custom scale (5 pt. Likert, at individual level)</td>
<td>Significant increase in 2/6 items related to individual SA (decision 3.1 → 3.9, re-checking 3.4 → 4.1)</td>
<td>Inadequate design for conclusions on validity for SA training at individual level</td>
<td></td>
</tr>
<tr>
<td>McCulloch et al. (2009)</td>
<td>Surgical teams (83 surgeons, anaesthesiologists, OR nurses)</td>
<td>Non-technical skills course for surgical teams hospital-wide (lectures, videos), including SA.</td>
<td>Historical prospective cohort study – team performance compared pre-/post intervention. Outcome measured in OR setting (non-technical skills and technical performance)</td>
<td>No change in surgical team's SA (9.0 → 9.35), Significant improvement in problem-solving, teamwork; Significantly reduced amount of procedural and technical errors during lap cholecystectomies and carotid endarterectomies</td>
<td>Construct validity for improving problem-solving and teamwork; not for SA</td>
<td></td>
</tr>
<tr>
<td>Moorthy et al. (2005)</td>
<td>27 surgical trainees</td>
<td>Surgical team crisis training in vascular surgery teams in HF simulator</td>
<td>Prospective cohort study – performance compared at individual level between junior, intermediate and senior trainees on non-technical skills</td>
<td>No significant difference in individual SA; significant difference in leadership (p = 0.008)</td>
<td>Construct validity for leadership training, no construct validity for SA training at individual level</td>
<td></td>
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<table>
<thead>
<tr>
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</thead>
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<tr>
<td>Moorthy et al. (2006)(^{28})</td>
<td>20 surgical trainees</td>
<td>Surgical team crisis training in vascular surgery teams in HF simulator</td>
<td>Prospective cohort study - performance compared at individual level between junior and senior trainees on non-technical skills</td>
<td>No significant differences in individual non-technical skills (incl. SA) between the groups</td>
<td>No construct validity for SA training at individual level</td>
</tr>
<tr>
<td>Powers et al. (2008)(^{24})</td>
<td>10 surgeons and surgical trainees</td>
<td>Surgical crisis training for MIS residents in HF simulator</td>
<td>Prospective cohort study – performance compared between experienced and inexperienced trainees on non-technical skills at individual level</td>
<td>Significant difference in individual SA between groups (experts 90% vs. novices 50%, (p &lt; 0.05))</td>
<td>Construct validity for SA training at individual level</td>
</tr>
<tr>
<td>Powers et al. (2009)(^{26})</td>
<td>12 surgeons</td>
<td>Surgical crisis training for MIS surgeons in HF simulator</td>
<td>Prospective cohort study – performance compared between experienced and “seasoned” surgeons on non-technical skills at individual level</td>
<td>No significant differences in individual’s non-technical skills (incl. SA) between the groups</td>
<td>Inadequate design for conclusions on validity for SA training at individual level</td>
</tr>
<tr>
<td>Undre et al. (2007)(^{29})</td>
<td>17 surgeons, 17 anaesthetists, 13 ODPs, and 18 nurses</td>
<td>Surgical team crisis training in vascular surgery teams in HF simulator</td>
<td>Prospective cohort study – performance compared between experienced and inexperienced trainees on non-technical skills at individual level</td>
<td>Surgical trainees scored lower on individual SA than other groups (4.1 vs. anaesthetists 4.3; nurses 4.9; ODPs 4.3).</td>
<td>Inadequate design for conclusions on validity for SA training at individual level</td>
</tr>
</tbody>
</table>

**Table 2.** Summary of included studies.  
SA = situational awareness; ODP = operating departmental practitioners; MIS = Minimally Invasive Surgery; OR = operating room
Non-technical skills training courses

Two studies described training courses for non-technical skills, using lectures, videos and discussions. McCulloch et al. applied a hospital-wide non-technical skills program, in which 83 members of surgical teams were enrolled (surgeons, anaesthetists, OR nurses). They evaluated non-technical performances at team level, technical and procedural errors and complications after laparoscopic cholecystectomies and carotid artery surgery before and after the 9-hour training course. They found a significantly reduced amount of procedural and technical errors, predominantly in MIS. Although teams scored significantly better in problem solving and teamwork skills afterwards, SA did not change significantly. Authors did find a high independent correlation between technical errors and surgical team SA ratings.

Flin et al. describe a study in which they enrolled 21 licensed surgeons in a two-day non-technical skills training course, which encompassed lectures on SA. The majority of the surgeons rated the course to be useful and relevant to their everyday work. However, specific outcome measures related to SA were not measured.

Not all articles described training strategies. Two articles described an intervention aimed at improving information displays in the operating room to create improved shared awareness of the surgical team concerning the procedure. One study described methods to improve distributed communication between cardiac surgeons and the OR personnel. Because these articles did not describe a scientific evaluation study, they could not be included in the analysis.

DISCUSSION

Surgeons are ultimately responsible for the patient's safety during the peri-operative process, including possible technical errors as well as errors originating from the operating room environment. Whereas much attention in surgical residency programs is focused on teaching technical skills, a major part in the surgeon's experience is related to decisions and judgments. Which, if inappropriate, threatens safety to a similar extent as technical failure. Surgical team crisis training shows to be an acceptable and reliable method to assess trainees’ situational awareness in MIS. For training situational awareness in open surgical procedures, no validated training methods were found. A possible explanation could be that the simulated single-scenario crisis training in the respective studies, proved insufficient for adequate SA measurement or improvement.

Correct situational assessment and subsequent handling is a key component for the surgeon to manage a complex procedure successfully. The modern surgeon requires the ability to filter relevant information in order to perceive situational deviations correctly and correct errors timely. This is especially relevant to laparoscopic and natural orifice
transluminal endoscopic surgery\textsuperscript{25,36} and it is therefore not surprising that most research has been piloted in the MIS setting. Most misperceptions of anatomical landmarks, equipment failure and physiological state of the patients occur when the mental workload is high. The increase in electronic systems, displays and operating room technology has drastically enlarged the mental workload of the modern surgeon. It is difficult to filter out the relevant signals timely from the ‘data-clutter’ whilst focusing on performing surgery. For surgical residents, gaining proficiency regarding situational awareness currently occurs by gaining experience ‘on the job’. This ‘Halstedian’ approach should be topic of debate to the same extent as with ‘technical’ skills training.

Training for non-routine events (abnormal anatomy, surgical crises and instrumentation problems) could be more effective in improving residents’ vigilance, task management and diagnostic reasoning\textsuperscript{18,38}. Dedy and colleagues\textsuperscript{39} proposed a model for comprehensive simulation training for surgical residents that includes cognitive, technical and non-technical skills training, before commencing surgery in the operating theatre. Furthermore, serious games have also been suggested as promising methods for non-technical skills training. Serious games are video game-based training environments that do not require an extensive simulated operating theatre\textsuperscript{31}.

This study shows that no SA-directed training methods have been fully validated or implemented in surgical curricula. Most of the studies emphasize on situational awareness improvement at an individual level. To enhance surgical crisis management training, strategies from other industries could be of value\textsuperscript{40,41}. Training effective task management strategies\textsuperscript{42}, dealing with non-routine events\textsuperscript{41,43}, planning and preparation strategies\textsuperscript{44} and re-checking information on which a procedural strategy is based, are considered effective ways to prevent or deal with inappropriate perceptions in the airline industry\textsuperscript{41}. Secondly, it has become clear that a surgical team’s situational awareness emerges from coordination and communication processes in the surgical team\textsuperscript{16,45}. More emphasis on teamwork and communication styles should become part of SA-directed training methods.

A different strategy to improve the surgical team’s situational awareness could be to integrate information for all operation team members into one system with one visual display. A ‘surgical radar’ could monitor all relevant data sources in the OR, straightening out interfering information and warnings. Parush et al.\textsuperscript{32} describe the development of an augmentative display for the cardiac surgery theatre, integrating patient information, vital signs, procedure progress and main event taking place - all in one screen. This aims to improve team SA and reduce communication breakdowns. ‘Wearable’ technology using head-mounted displays (such as Google Glass\textsuperscript{TM}) could place this monitor directly in the surgeon’s field of vision\textsuperscript{46}. Although evidence on display design in operation rooms remains scarce in terms of patient-related outcomes, shared displays of this sort significantly reduce decision-making time in teams in aviation\textsuperscript{47}. 
This study has several limitations. First, studies identified only included relatively small study populations. The risk for bias was moderate to high in 8/9 studies. Therefore, the strength of conclusions concerning the validity of the training methods proposed is limited. Practical concerns play a part in small participant numbers, whereas high fidelity simulation ORs are costly in time and money. Additionally, situational awareness can only be measured by structured rating scales and trained assessors, which introduces risk for bias.

Situational awareness in the surgical theatre depends on many individual and team-related factors and should not be confused with a specific ability of the surgeon. Such a viewpoint could potentially result in a renewed ‘blame and shame’ culture similar to aviation, where individual pilots were increasingly held responsible for “losing situational awareness” during calamities. Attention for the aspect of situational awareness should by no means be an attempt to steer away from the process-based approach to safety. It should be applied as framework for improving peri-operative care processes to ultimately improve the operating team’s functioning.

Given the advancements in other areas of medicine, now is the time to set a stronger focus on improving situational awareness both in training and in surgical practice. Improvement of SA in surgery can be accomplished by a two-fold approach. First, surgical team crisis management training in simulators and serious games must be further optimized and integrated into surgical residency programs. Secondly, technological innovations that integrate data from different sources in the OR, could be used to ‘de-clutter’ information to the clues relevant to the procedure and give timely warnings. These techniques should be explored and evaluated. Evidence is mounting that improving SA in surgical theatres leads to better surgical outcomes, and there are plenty opportunities to do so.
REFERENCES

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