Technical, Non-Technical, or Both? A Scoping Review of Skills in Simulation-Based Surgical Training

Amalie Asmind Rosendal, BSc(Med),[*,†] Sigurd Beier Sloth, MD, PhD,[†,‡] Jan Duedal Rölfing, MD, PhD,[*,†,§] Magnus Bie, RN,[*] and Rune Dall Jensen, MSc, PhD[*,†]

[*]Corporate HR MidtSim, Central Denmark Region, Aarhus, Denmark; [†]Department of Clinical Medicine, Aarhus University, Aarhus, Denmark; [‡]Department of Obstetrics and Gynaecology, Randers Regional Hospital, Randers, Denmark; and [§]Department of Orthopaedics, Aarhus University Hospital, Aarhus, Denmark

OBJECTIVE: Technical and non-technical skills are traditionally investigated separately in simulation-based surgical training (SBST). Recent literature has indicated an interrelation of these skills, but a clear relationship is yet to be established. This scoping review aimed to identify published literature on the use of both technical and non-technical learning objectives in SBST and investigate how the entities are related. Additionally, this scoping study reviewed the literature with the aim of mapping how publications on technical and non-technical skills within SBST have changed over time.

DESIGN: We conducted a scoping review using the 5 step framework by Arksey and O'Malley and reported our results according to the PRISMA guidelines for scoping reviews. Four databases, PubMed, Web of Science, Embase and Cochrane Library, were systematically searched for empirical studies on SBST. Studies within surgical training addressing both technical and non-technical learning objectives and presenting primary data were included for further analysis.

RESULTS: Our scoping review identified 3144 articles on SBST published between 1981 and 2021. During our analysis, an emphasis on technical skills training in published literature was identified. However, recent years have seen an immense increase of publications within either technical or non-technical skills. A similar trend is seen in publications addressing both technical and non-technical. In total, 106 publications addressed both technical and non-technical learning objectives and were included for further analysis. Only 45 of the included articles addressed the relationship between technical and non-technical skills. These articles mainly focused on the effect of non-technical skills on technical skills.

CONCLUSIONS: Though literature on the relationship between technical and non-technical skills remains scarce, the included studies on technical skills and non-technical skills such as mental training suggest such a relationship exists. This implies that the separation of the skill sets is not necessarily beneficial for the outcome of SBST. A shift towards seeing technical and non-technical skills as intertwined may enhance learning outcomes from SBST. (J Surg Ed 80:731−749. © 2023 The Author(s). Published by Elsevier Inc. on behalf of Association of Program Directors in Surgery. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/))

KEY WORDS: Surgery, Education, Simulation, Technical skills, Non-technical skills

COMPETENCIES: Professionalism, Interpersonal and Communication Skills, Practice-Based Learning and Improvement

INTRODUCTION

It is well-established that simulation-based surgical training (SBST) enhances patient safety, as it offers an opportunity for improving surgical performances outside the operating room (OR).[1] A frequent cause of medical error lies in communicative errors in the OR, testifying to the importance of the multifaceted set of both technical and non-technical skills (TS and NTS) a surgeon must master to provide safe patient care.[2−4] Research conducted in both clinical settings and simulation-based settings shows that TS and NTS should be recognized as

Correspondence: Inquiries to Amalie Asmind Rosendal, Corporate HR MidtSim, Central Denmark Region, Palle Juul-Jensen Boulevard 82, 8200 Aarhus, Denmark, Phone: 0045 25776479; e-mail: amalieasmind@gmail.com

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intertwined.[5,6] Studies by Cleland et al. and Tsuda et al. demonstrate how the acquisition of TS always happens in relation to other learners and teachers, making the distinction between the 2 skill sets arbitrary.[6,7]

The studies emphasize that learning of TS is influenced by interpersonal and cognitive skills. This is supported by socio-cultural educational studies emphasizing that the dispositions of the learner and the affordances of the environment form the outcome.[5,8,9] These studies are explorative and point towards a relationship between TS and NTS. Similarly quantitative studies including both TS and NTS are present in the surgical literature.[10–12]

These studies challenge the traditional viewpoint where TS and NTS are seen as separable, especially in SBST. Consequently, the traditional way of focusing on either TS or NTS in SBST may hamper the transfer of skills acquired through training into the clinical setting. To our knowledge there is no consensus on whether a correlation between TS and NTS exists in surgery. Hence, this scoping review aims to map published literature within SBST to investigate how TS and NTS are used and related in SBST.

Establishing the most efficient approach for training surgeons has been an ongoing endeavour since Halstead's introduction of the apprenticeship model more than a century ago.[13] This model submerged the surgeon in the clinical setting, using the "see one, do one, teach one" approach.[7] In the 1970's, however, SBST was introduced as a means for training TS before applying and refining the skills in clinical practice.[7,14]

Moving surgical training outside the OR and into a simulated learning environment, allowed surgeons to practice deliberately without endangering the patients. However, this development has also contributed to surgical training being divided into 2 separate entities: the training of either TS or NTS.[15,16] Although this focus on certain aspects of the surgical skill set may be desirable at some stages of training, a general disintegration of TS and NTS in SBST may inhibit the aim of training surgeons to perform in complex situations and interactions in the OR.

Definitions of Technical and Non-Technical Skills

While the initial focus of SBST literature was on TS, a growing body of evidence suggests that NTS are crucial for optimal surgical performance.[17] Consequently, training NTS has gained increasing interest in the past decades. Currently, no clear definition of NTS exists. Previous definitions entail skills and behaviours such as teamwork, communication, leadership, situational awareness, and decision-making as defined by Yule and colleagues.[18] Others have taken a 3-fold approach separating NTS into personal resource skills, interpersonal skills, and cognitive skills.[19] Regardless of previous definitions, no clear consensus remains as to what defines NTS. TS can, on the other hand, be defined as body-kinetic skills, and as such, this paper operationalizes NTS as all skills which refrain from this definition.[20]

While the separated training of TS and NTS has been well-established, recent literature on the development of expertise in surgery has suggested that surgeons rely on both skill sets simultaneously.[5] Thus, a holistic approach to SBST, integrating the 2 well established entities of surgical education, may be needed for developing surgical expertise.[21]

To the best of our knowledge, there is currently no agreement in the literature, as to whether an interdependence of TS and NTS exists and how their relationship should be analysed.

Hence, this scoping review aimed to identify literature published on SBST that included both TS and NTS learning objectives or assessments. We sought to map how the publication of studies concerning SBST has changed over time and investigated the association between TS and NTS in existing SBST literature.

METHOD

This scoping review was guided by the 5 step framework described by Arksey and O'Malley.[22] In brief, the framework consists of the following stages: 1) specifying the research question, 2) identifying relevant literature, 3) selecting studies, 4) extracting and charting the data, and 5) summarizing and reporting the results.[22] An initial charting of studies was needed in order to select studies that included both learning objectives. Hence, we do not sequentially follow the 5 steps in the methods section. The results are reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-Scr).[23]

Defining Technical and Non-Technical Skills

As stated in the introduction, this paper defines technical skills as body kinetic skills. Due to the lack in consensus on a definition of non-technical skills we chose to take a broad approach and define non-technical skills as all skills that are not body kinetic. This approach allowed the inclusion of publications addressing cognitive skills as well as intra- and interpersonal skills. These skills are not included in all definitions of NTS and may be missed if the used definition was limited to specific assessment tools. The choice of a broad definition thus aligns with

the purpose of the scoping review, which aims to map all relevant literature within a field.[22]

Inclusion Criteria

Publications included in this review had to meet several inclusion criteria. First, publications had to address both technical and non-technical learning objectives as defined above. Second, publications had to be centered around SBST. As such, studies in both pre- and post-graduate education with a surgical focus were included. These studies either concerned the individual surgeon or addressed the OR team if this included at least one surgeon. Third, publications must be written in English. Last, only publications presenting primary data were included in this scoping review.

Search Strategy

A systematic search of PubMed, Web of Science, Embase, and Cochrane Library was conducted. For identification of articles the following search string was used in PubMed: Simulation(Title/Abstract) AND Assessment (Title/Abstract) AND Surgical(Title/Abstract) OR Surgery (Title/Abstract) OR Surgeon(Title/Abstract) AND Training(Title/Abstract) OR Learning(Title/Abstract) OR Education(Title/Abstract). The same terms and boolean terms were subsequently used to search title and abstract in the remaining databases. The search was conducted on September 8th, 2021, and included all publications published in English before this date. Additional publications were identified by screening of reference lists.[24]

Charting Data

Abstracts of all identified publications were imported into the EndNote 20 reference manager system.[25] Duplicates were removed after initial screening. Title, abstract, and full text were screened, and publications were tabulated according to author, year of publishing, population, study type, purpose, conclusion, and learning outcomes, categorised as either technical, non-technical, both, or neither.

Selecting Studies

An interrater consensus on a sample of 100 publications addressing both TS and NTS learning objectives was conducted. The publications were uploaded to Rayyan[26] and screened on the basis of title and abstracts by 4 authors (AAR, MB, RDJ, SBS). After consensus, the remaining publications were screened by the first author (AAR). Publications were included for final analysis based on the inclusion criteria listed above.

Hence, only publications written in English reporting original data with both TS and NTS learning objectives in surgery were included. TS and NTS assessment tools, as well as training sites, were identified for the included publications.

Finally, publications addressing the relationship between TS and NTS learning objectives were identified by full text screening.

Summarizing and Reporting the Results

First, a numerical analysis of publications per year within SBST was made. Data was displayed in 3 figures showing: 1) the general change in publications within SBST per year (Fig. 2), 2) the frequency of SBST publications including both TS and NTS (Fig. 3), and 3) publications investigating the relationship between TS and NTS learning objectives (Fig. 4), respectively.

According to Arksey and O'Malley we prioritized and subsumed 3 theoretical positions in the identified literature in order to provide an overview of the included publications and give examples of how the literature unfolds. Here we choose to synthesize central aspects of the discussion on NTS in SBST. Specifically, mental training, communication, and self-assessment are included as they are the most frequently addressed NTS in the included publications (Table 1), the most frequently operationalized component of NOTSS (Table 1), and well-established components in post-graduate medical education [27–29] that was often addressed in the included publications.

RESULTS

Trends in Publications on SBST

From our systematic literature search we identified 3062 publications. The publications were sorted into categories according to learning objectives. An additional 82 publications were subsequently identified by hand search. Hence, in total we identified 3144 publications on SBST (Fig.1). As seen in Figure 2 an immense increase in SBST publications has occurred in the last decades. The focus of these publications remains largely on TS learning objectives alone, which were addressed in 71% of publications. NTS by contrast, was investigated independently in just 11% of publications on SBST. The increasing tendency to educate the surgeon outside of the OR was reflected in the exponential increase of SBST publications addressing either TS or NTS training, with almost half (48%) of all publications on SBST being published within the past 5 years.

Further discussion of publications addressing solely either TS or NTS learning objectives is beyond the scope of this review, as we aimed to review SBST literature

TABLE 1. Publications Addressing the Relationship Between TS and NTS Learning Objectives*

Publications Addressing the Relationship Between TS and NTS Learning Objectives					
Title	**Author**	**Year**	**Findings**	**Technical Assessment Tool**	**Non-Technical Assessment Tool**
The effect of verbal feedback, video feedback, and self-assessment on laparoscopic intracorporeal suturing skills in novices: a randomized trial	Halim & Jelley	2021	The video feedback group showed the largest improvement in checklist and global score followed by self-assessment. Combining self-assessment and expert video feedback should increase skills acquisition.	PSC, OSATS	
Long-Term Effects of Mental Training on Manual and Cognitive Skills in Surgical Education – A Prospective Study	Kaulfuss & Kluth	2021	Mental training can improve procedural times and performance strategies and has a long-term effect on surgical skills.	GRS, PSC	TOPS
Development and validation of a porcine organ model for training in essential laparoscopic surgical skills	Higuchi & Abe	2020	Repeated simulation training decreases mental workload and may lead to a plateau of technical skills acquisition. Excessive cognitive workload might increase fatigue and have a negative impact on surgical performance.	GOALS	NASA-TLX
One Step at a Time: Step by Step Versus Continuous Video-Based Learning to Prepare Medical Students for Performing Surgical Procedures	Nazari & Van De Graaf	2020	The mean extraneous cognitive load was lower in a group taught by step-by-step approach rather than continuous video demonstration. The surgical performance was not significantly different, yet the step-by step group made fewer procedural errors.	OCHRA	Questionnaire on the perceived intrinsic cognitive load and extraneous cognitive workload using Likert-like-scale
The effect of structured self-assessment in virtual reality simulation training of mastoidectomy	Andersen & Guldager	2019	Structured self-assessment increased the performance, accelerated the learning curves, and reduced time for training while providing a safer performance with significantly fewer collisions with critical structures.	SBM	Self-assessment form based on modified welling scale

(continued)

TABLE 1 (*continued*)

Publications Addressing the Relationship Between TS and NTS Learning Objectives

Title	Author	Year	Findings	Technical Assessment Tool	Non-Technical Assessment Tool
Simulation-Based Laparoscopic Surgery Crisis Resource Management Training - Predicting Technical and Nontechnical Skills	Goldenberg & Fok	2018	On the BFI personality questionnaire, only conscientiousness correlated with technical GOALS score and successful completion of the scenario. NOTSS score strongly correlated with GOALS score and checklist score.	GOALS, PSC, Self-assessment	NOTSS, Self-assessment, BFI: multidimensional personality questionnaire
The role of cognitive training in endourology: a randomised controlled trial	Shah & Aydin	2018	Generally cognitive training was shown to have little effect on technical skills acquisition. However, the mental imagery group had fewer laser misfires than the control group and flash card group.	SBM	Different types of cognitive training: flash cards and mental imagery
Mental skills training limits the decay in operative technical skill under stressful conditions: Results of a multisite, randomized controlled study	Anton & Beane	2017	A mental skills curriculum improved residents' performance under increased stress and decreased perceived stress and workload.	ProRO	STAI, NASA-TLX
Hands-on Simulation versus Traditional Video-learning in Teaching Microsurgery Technique	Sakamoto & Okamoto	2017	Students with high extroversion scores completed the suturing task significantly faster than those with average extroversion scores. No relationship between performance and neuroticism, openness, and conscientiousness was identified. Students with high agreeableness score had lower NUMAS scores.	NUMSAS, ProRO: Time to complete task	NEO-five-factor inventory (FFI) personality test: neuroticism (N), extraversion (E), openness (O), agreeableness (A), and conscientiousness (C)
Effectiveness of a comprehensive mental skills curriculum in enhancing surgical performance: results of a randomized controlled trial	Stefanidis & Anton	2017	The performance of laparoscopic suturing improved significantly in the group applying the mental skills curriculum.	ProRo	TOPS-2, STAI, Heart rate

(*continued*)

TABLE 1 (*continued*)

Publications Addressing the Relationship Between TS and NTS Learning Objectives

Title	Author	Year	Findings	Technical Assessment Tool	Non-Technical Assessment Tool
Implementation results of a novel comprehensive mental skills curriculum during simulator training	Stefanidis & Anton	2017	Applying the mental skills curriculum improved participants' laparoscopic and metal skills.	ProRo	NASA-TLX, STAI
Are General Surgery Residents Accurate Assessors of Their Own Flexible Endoscopy Skills?	Vyasa & Willis	2017	The expert observation group became significantly better at self-assessing overall time and efficiency while the practice only group improved overall time and efficiency with training but decreased their ability to self-assessment.	SBM	Questionnaire: self-assessment.
A Randomized Control Trial Exploring the Effect of Mental Rehearsal and Cognitive Visualization on Microsurgery Skills	Chadha & Hachach-Haram	2016	After four days the group which had received a visual rat anastomosis script performed superior to the group which had not received mental training and the group which had received a visual relaxation script.	SAMS	
Do resident's leadership skills relate to ratings of technical skill?	Gannon & Law	2016	Surgical residents giving a high number of directional instructions to their assistant perceived less difficulty in the procedure and less reduction in their decision-making skills.	Operative leadership was defined as component of OSATS element" use of assistant"	Leadership (leadership language used in NOTSS and NOTECHS), Self-efficacy
Relationship Between Technical Errors and Decision-Making Skills in the Junior Resident	Nathwani & Fiers	2016	A negative correlation was found between number of errors during the procedure and anticipated difficulties listed by the residents.	Subclavian central line insertion	Cognitive performance: Anticipated difficulties

(*continued*)

TABLE 1 (*continued*)

Publications Addressing the Relationship Between TS and NTS Learning Objectives

Title	Author	Year	Findings	Technical Assessment Tool	Non-Technical Assessment Tool
The Relationship Between Technical and Nontechnical Skills Within A Simulation-Based Ureteroscopy Training Environment	Brunckhorst & Shahid	2015	All individual non-technical skills parameters correlated strongly with technical parameters. A strong positive correlation between NOTSS and OSATS and task specific checklist scores was found. A strong negative correlation between NOTSS and time to completion was found.	OSATS, ProRO time to completion, Task specific checklist scores	NOTSS
Randomized clinical trial to evaluate mental practice in enhancing advanced laparoscopic surgical performance	Louridas & Bonrath	2015	Trainees receiving mental practice has significantly greater OSATS and BOSATS scores on final assessment than at baseline, which was not seen in the control group. Both groups felt equally stressed, illustrated by STAI scores and blood pressure.	OSATS, BOSATS	MIQ, MIQ-RS, NOTSS, STAI
Thinking it Through: Mental Rehearsal and Performance on 2 Types of Laparoscopic Cholecystectomy Simulators	Paige & Yu	2015	A significant inverse correlation was found between MIQ score and the VR clip and cut task, but not the other tasks assessed.	GOALS, ProRo	MIQ
Effect of Different Warm-up Strategies on Simulated Laparoscopy Performance: a Randomized Controlled Trial	Bronnimann & Hoffmann	2014	No statistically significant correlation was found between warm up and technical outcome scores.	ProRo	Cognitive exercise: points achieved in game
Simulator training and non-technical factors improve laparoscopic performance among OBGYN trainees	Ahlborg & Hedman	2013	Simulator training has a positive effect on self-efficacy. Furthermore, self-efficacy scores were associated with shorter duration of surgery independent of simulator training.	ProRo	Questionnaire calculating self-efficacy, Flow experience index

(*continued*)

TABLE 1 (*continued*)

Publications Addressing the Relationship Between TS and NTS Learning Objectives

Title	Author	Year	Findings	Technical Assessment Tool	Non-Technical Assessment Tool
Using the mind as a simulator: a randomized controlled trial of mental training	Eldred-Evans & Grange	2013	The mental training group scored highest across all domains but speed on the box trainer.	SBM	
Stress training for the surgical resident	Maher & Milner	2013	The use of stress-reduction techniques did not significantly improve residents' technical skills.	OSATS	STAI
Learning basic laparoscopic skills: a randomized controlled study comparing box trainer, virtual reality simulator, and mental training	Mulla & Sharma	2012	Mental practice was not as effective in teaching novices new technical skills as other teaching methods.	ProRo	
Mental Practice Enhances Surgical Technical Skills: A Randomized Controlled Study	Arora & Aggarwal	2011	A significant, positive correlations was found between mental imagery score and OSATS score.	OSATS	MIQ
Impact of perceptual ability and mental imagery training on simulated laparoscopic knot-tying in surgical novices using a Nissen fundoplication model	Jungmann & Gockel	2011	Knot tying performance was not improved by additional mental practice.	ProRo	I-S-T-2000 R
Do soft skills predict surgical performance?: a single-center randomized controlled trial evaluating predictors of skill acquisition in virtual reality laparoscopy	Maschuw & Schlosser	2011	A relationship was found between low self-efficacy and poor stress coping, and VR-performance. Upon 3 months of structured VR-training no correlation was found between self-efficacy, stress coping, and VR-performance.	SBM	GSE, SVF78, QCM
Stress Management Training for Surgeons—A Randomized, Controlled, Intervention Study	Wetzel & Akram	2011	Coping strategies and mental rehearsal can improve both technical and non-technical performance.	OSATS, EPA	OTAS, STAI, Observer rating, heart rate
Stress impairs psychomotor performance in novice laparoscopic surgeons	Arora & Sevdalis	2010	Subjective and objective stress impairs technical performance on a VR simulator by increasing time, number of errors and number of unnecessary movements.	SBM	ISAT

(*continued*)

TABLE 1 (*continued*)

Publications Addressing the Relationship Between TS and NTS Learning Objectives

Title	Author	Year	Findings	Technical Assessment Tool	Non-Technical Assessment Tool
Assessment of surgical competence at carotid endarterectomy under local anesthesia in a simulated operating theatre	Black & Nestel	2010	A significant correlation was found between technical and non-technical performance in both the crisis and non-crisis scenarios.	OSATS, ICEPS	NOTECHS
Teamwork Training Improves the Clinical Care of Trauma Patients	Capella & Smith	2010	Simulated, structured trauma resuscitation team training improved efficiency and patient care.	TPOT	TPOT
Mental rotation: cross-talk training and generalization	Stransky & Wilcox	2010	Mental rotation training significantly improved performance on mental-rotation dependent surgical tasks.	SBM	Mental rotation test
The Effects of Stress and Coping on Surgical Performance During Simulations	Wetzel & Black	2010	High experience and low stress had an independent significant effect on non-technical skills and technical skills in a crisis situation.	OSATS, EPA	OSATS, STAI, heart rate, salivary cortisol
Psychometric properties of an integrated assessment of technical and communication skills	LeBlanc & Tabak	2009	Non-technical performance did not correlate significantly with either technical performance scores suggesting that these skills vary independently.	Task specific checklist, OSATS	GRS
Examination stress leads to improvements on fundamental technical skills for surgery	LeBlanc & Woodrow	2008	The stress caused by in-training examination improved junior residents' declarative knowledge, but not their procedural knowledge.	OSATS, PSC	Questionnaire
The influence of non-technical performance on technical outcome in laparoscopic cholecystectomy	Mishra & Catchpole	2008	A strong negative correlation between team situational awareness and technical errors was identified.	OCHRA	NOTECHS
Should we train the trainers? Results of a randomized trial	Murphy & Neequaye	2008	Using a cognitive approach to teaching improved OSATS score and shortened time of surgery.	PSC, GRS, ProRo	

(*continued*)

TABLE 1 (*continued*)

Publications Addressing the Relationship Between TS and NTS Learning Objectives

Title	Author	Year	Findings	Technical Assessment Tool	Non-Technical Assessment Tool
Self-assessment of technical skill in surgery: the need for expert feedback	Pandey & Wolfe	2008	Trainees tend to overestimate their ability according to independent assessment.	OSATS	Self-assessment
Learning basic surgical skills with mental imagery: using the simulation centre in the mind	Sanders & Sadoski	2008	After two mental imagery sessions students performed superiorly to students who had studied the same amount of time from textbooks.	GRS, PSC	
Cognitive training improves clinically relevant outcomes during simulated endovascular procedures	Van Herzeele & Aggarwal	2008	Cognitive skills training significantly improved performance on the VR endovascular simulator.	SBM	
Visual working memory influences the performance in virtual image-guided surgical intervention	Hedman & Klingberg	2007	Visual working memory is related to performance score on MIST-VR and GI Mentor II tasks.	SBM	Robo memo: Visual and verbal working memory span, Borg scale: mental strain
Mental Training in Surgical Education	Immenroth & Bürger	2007	Mental training resulted in better task specific checklist scores than additional physical practice or no additional practice. No difference was seen in results on the GRS.	GRS, Task specific checklist, components of OSATS	
Negative stress-coping strategies among novices in surgery correlate with poor virtual laparoscopic performance	Hassan & Weyers	2006	Negative stress coping correlated positively with time needed to complete a task in a stressful situation on the virtual laparoscopic simulator.	SBM	SVF78
Cognitive skills analysis, kinesiology, and mental imagery in the acquisition of surgical skills	Batahlon & Dorion	2005	Combining mental imagery and kinesiology improved acquisition of an emergency procedure.	OSCE	
Impact of cognitive imaging and sex differences on the development of laparoscopic suturing skills	Donnon & DesCôteaux	2005	The use of cognitive imaging did not benefit technical outcomes in the intervention group during a 1-week interval.	ProRo	

(*continued*)

TABLE 1 (*continued*)

Publications Addressing the Relationship Between TS and NTS Learning Objectives

Title	Author	Year	Findings	Technical Assessment Tool	Non-Technical Assessment Tool
Comparing the effects of physical practice and mental imagery rehearsal on learning basic surgical skills by medical students	Sanders & Sadoski	2004	After an initial physical practice, mental imagery practice was as effective as additional physical practice in improving technical skills.	GRS	

*PSC: Procedure Specific Checklist, OSATS: Objective Structured Assessment of Technical Skills, GOALS: Global Operative Assessment of Laparoscopic Skills, NASA-TLX: NASA-Task Load Index, OCHRA: Observational Clinical Human Reliability Assessment, SBM: Simulator Based Metrics, NUMSAS: Nagoya University Micro Suturing Assessment Systems, ProRo: Procedure Related Outcomes, NOTSS: Non-Technical Skills for Surgeons, NOTECHS: Non-Technical Skills Scale, BOSATS: Bariatric Objective Structured Assessment of Technical Skills, MIQ: Mental Imagery Questionnaire, MIQ: Mental Imagery Questionnaire, MIQ-RS: Movement Imagery Questionnaire Revised Second Version, STAI: State-Trait Anxiety Inventory questionnaire for adults, BFI: The Big Five Inventory, GSE: General Self-Efficacy Scale, SVF78:Stress Coping Style Questionnaire, QCM: Questionnaire of Current Motivation, TPOT: Trauma Team Performance Observation Tool, GRS: Global Rating Scale, ISAT: Imperial Stress Assessment Tool, ICEPS: Imperial College Evaluation of Procedure-Specific Skills Scale, EPA: End Product Assessment, SAMS: Structured Assessment of Microsurgery Skills, TOPS: Test of Performance Strategies, TOPS-2: Test of Performance Strategies-2, OSCE: Objective Structured Clinical Examination, I-S-T-2000R: Intelligence-Structure-Test 200R

pertaining to the simultaneous training or assessment of TS and NTS.

Based on our inclusion criteria, we ended up including 106 publications addressing both TS and NTS in surgery (Fig. 1). According to the identified publications, training of NTS was first introduced around the turn of the century, with the earliest article addressing both TS and NTS being published in 1998 (Fig. 3). Since then, an increased focus has been directed towards NTS learning objectives within the surgical training literature. However, the simultaneous incorporation of both TS and NTS in SBST is yet to attain the same momentum reflected by the fluctuating yet slowly increasing number of publications addressing both learning objectives.

Assessment of TS and NTS

Constructing reliable and sound studies of surgical skills training and performance development requires selecting suitable assessment tools. Validated tools for assessing TS and NTS skills are essential to create generalizable study results. The included 106 publications applied multiple different assessment tools, i.e. 28 tools assessing TS and 31 tools assessing NTS. TS assessments were dominated by procedure-related outcomes (n = 26) such as time to completion, accuracy, and precision, defined by the individual studies. Validated assessment tools for TS were used in 42% (n = 45) of publications and were dominated by the Objective Structured Assessment of Technical Skills (OSATS) Global Rating Scale, which was used in 18 of the 106 publications. Both procedure specific checklists without the OSATS (n=16) and simulator-based metrics (n = 16) were frequently used for the assessment of TS.

The assessment of NTS was characterized by the use of questionnaires (n = 18) addressing stress, perceived cognitive load, and self-efficacy. Validated assessment tools were, likewise, used in 44% (n = 47) of the publications, and were dominated by the Non-Technical Skills for Surgeons (NOTSS) used in 13 publications, followed by the NASA Task Load Index (NASA-TLX) which was used in 12 publications.

While some publications assessed TS or NTS using separate assessment tool, others only used a TS assessment tool even though they investigated both skill sets. Rather, these studies used a study design where a NTS intervention was intended to improve NTS.

The Relationship Between TS and NTS

Our study found that while 106 publications investigated both TS and NTS, not all investigated the relationship and interaction between the 2 skill sets. These aspects were only addressed in 45 publications (Table 1). While there has been a general increase in publications addressing both TS and NTS in recent years (Fig. 2), this trend does not extend to publications addressing the relationship between the skill sets, which show a more fluctuating pattern, as displayed in Figure 4.

While procedure-related outcomes and OSATS remained the predominant TS assessment tools used in

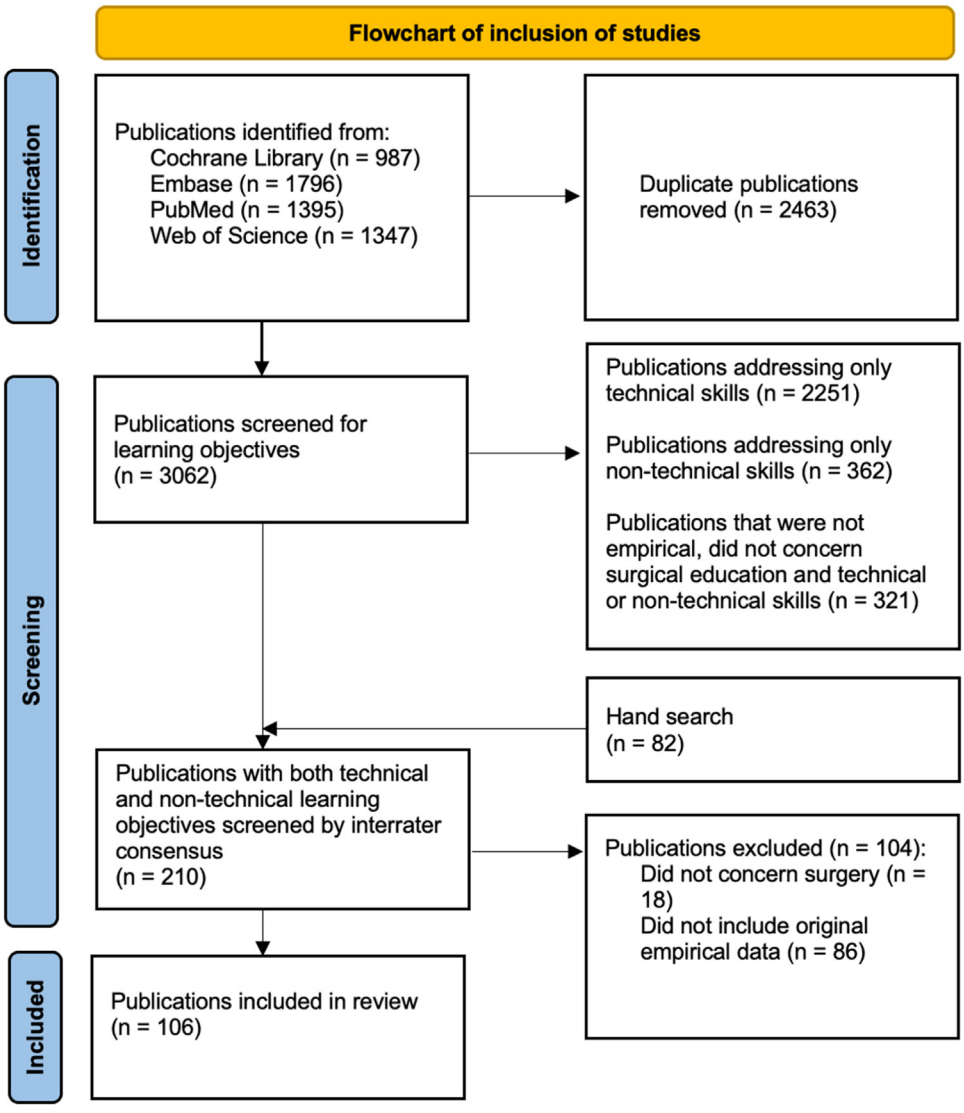

FIGURE 1. PRISMA flowchart of inclusion of studies.

the included publications, a comparatively broader array of NTS assessment tools was used.

Only 1 article investigated the effect of TS on NTS and found that improvements in TS were associated with decreases in cognitive workload and fatigue, which are known contributing factors to poor surgical performance.[30] Most publications (n = 34) focusing on the relationship between TS and NTS investigated the effect of NTS on TS, either by providing an intervention such as mental training or by studying the effect of NTS on TS during simulation-based training. The remaining publications (n = 12) investigated the association between TS and NTS.

Of publications included in the present review, 42% (n = 19) addressed post-graduate medical education, 38% (n = 17) addressed pre-graduate medical education and 11% (n = 5) addressed both pre- and post-graduate education, while the educational level of participants in the remaining 9% (n = 4) of publications was not clearly defined.

A range of specialties were represented in the publications with general surgery (n = 14), vascular surgery (n = 4), and urology (n = 4) being the most frequent. More often though, basic surgical skills such as knot tying or laparoscopic skills which were not specific to a speciality were investigated (n = 12).

Publications investigated themes such as stress management, self-assessment, team dynamics, surgical warm up, communication, and mental training. The influence of mental training on TS was most frequently investigated and will be described further in the following. Likewise, the relationship between TS and communication, self-efficacy, and stress coping, which were all

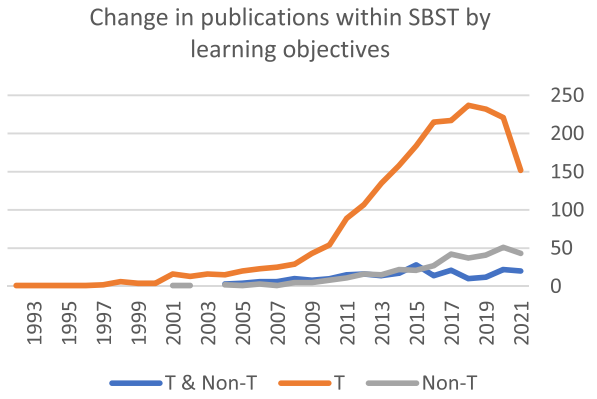

FIGURE 2. Number of publications per year according to main focus.

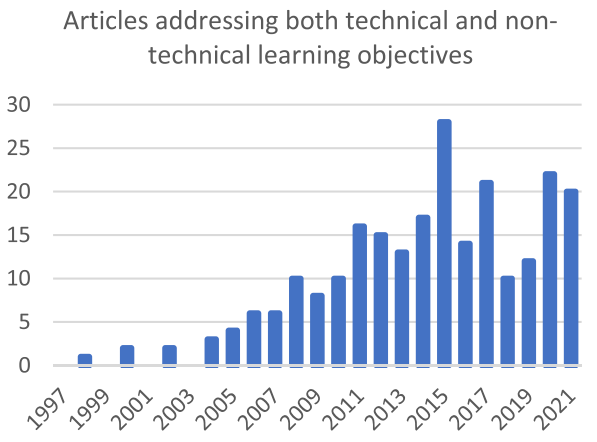

FIGURE 3. Number of publications per year addressing both technical and non-technical learning objectives.

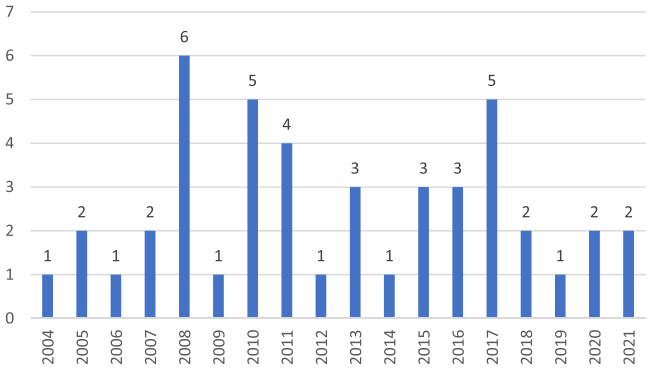

FIGURE 4. Number of publications per year addressing the relationship between technical and non-technical learning objectives.

explored in at least 3 publications, will be further explored.

The Relationship Between Mental Training and TS

The effect of mental training on TS was investigated in 19 publications. Mental training may be defined as the cognitive rehearsal of a task and entails skills such as goal setting, refocusing strategies, attention management, and mental imagery training including memorisation and visualisation of motor skills.[31–33] Most publications reported an increase in technical performance in groups receiving mental training and 3 publications reported significantly better OSATS scores of participants who used a mental training script[34,35] or were trained by a 4 step cognitive method.[36] By contrast, 1 publication reported that knot-tying skills were not improved by additional mental training,[37] while another publication noted that cognitive training resulted in fewer errors but no significant improvement of TS was found.[38]

A study by Mulla et al. sought to identify the most effective way to teach laparoscopic skills and found that participants engaging in mental training without TS training performed similar to or below the control group.[32] Several publications, however, showed a tendency of improved technical outcome when combining TS and mental training[39–42] and 1 publication showed that the addition of mental training had long term positive effects on complicated technical tasks.[43] Furthermore, 3 publications found that, while mental training did not necessarily improve simulator-based outcomes, it was valuable when transferring skills learned during simulation-based training to other environments, such as animal models, or when applying additional stressors.[44,31,45]

The Relationship Between Communication and TS

Communication constitutes 1 of 4 components of the NOTSS assessment tool for NTS assessment.[46] In a publication by Brunckhorst et al. a significant statistical correlation was established between the communication score of NOTSS and OSATS score as well as score on the Rigid-Ureteroscopy Assessment Sheet (RUAS) and time to completion regardless of training received prior to assessment.[10] On the contrary a study by Goldenberg et al. found that the communication component of the NOTSS score did not correlate with Global Operative Assessment of Laparoscopic Skills (GOALS) score, despite finding an overall correlation between NOTSS and GOALS scores and checklist scores.[47] In a study by Gannon et al., enhanced communication between the surgical assistant and resident resulted in less perceived difficulty in the technical aspects of the procedure.[48]

The Effect of Self-Assessment on TS

Four publications investigated the relationship between self-assessment and technical performance. One study found that structured self-assessment accelerated the

learning curve and increased performance based on a virtual reality simulator metrics score.[49] Goldenberg et al. also found that self-assessment of laparoscopic skills correlated moderately with checklist scores and GOALS scores. Additionally, no correlation was found between self-rated communication scores and communication or teamwork components of NOTSS.[47] One study found that participants inaccurately self-assessed their abilities with an overconfidence among low performers.[50]

DISCUSSION

The current study identified an overall increase in publications addressing SBST, with 48% of all 3144 publications being published within the past 5 years. This finding highlights the increasing interest in SBST and its capabilities, e.g. shortening the learning curve, improving OR performance, and contributing to improved patient outcomes.[51–53] NTS training in SBST has seen an increase during the past 20 years. While the importance of NTS training has been established to improve patient outcomes, the majority of publications within SBST continue to concern TS.[4,54]

Likewise, studies examining both TS and NTS have increased. Only few of these studies examined the relationship between the skill sets, indicating a disintegration of TS and NTS in SBST.

Our study used a broad definition of NTS, which allowed the exploration of a diverse range of NTS. While we found ambiguous results in studies investigating the relationship between TS and self-efficacy, and TS and communication, there are indications of a positive association between mental training and TS based on the findings of the present study (Table 2). Such a relationship has previously been identified in other domains of medical education such as anaesthesiology, where studies have suggested that interventions to improve NTS can improve patient outcomes and TS amongst training anaesthesiologists.[27,55] Future research should aim to establish whether this relationship between TS and NTS can conclusively be identified within SBST and be extended to the clinical setting. Such efforts require a common understanding of the concepts of TS and NTS.

While TS are clearly defined, NTS are defined by what they are not. This unspecific umbrella term allows a highly diverse category of skills such as cognitive skills and interpersonal skills to be reduced to an unspecific skill set, complicating the investigation of their relationship. Studies should define NTS by what they are, rather than what they are not to create a more nuanced picture of their influence on surgical skills and patient outcomes.

Stefanidis et al. highlighted flaws in study designs as a gap in SBST literature.[1] This challenge was likewise recognised in the present study where we identified publications with flaws in study designs, as they only assessed either TS or NTS, despite stating that they explored both. For the purpose of this scoping review, only publications addressing the relationship between these skill sets were included. The included publications often investigated this relationship in settings outside of the OR using simulation-based training such as box trainers or VR trainers. While these are validated systems for training TS, they were not able to emulate the intricate interactions between members of the OR team and capture the dynamic nature of the skills. Thus, TS and NTS were often assessed separately and subsequently compared in order to investigate whether a relationship between the level of TS and NTS possessed by surgeons existed. The dynamic nature of the skill sets, however, calls for an investigation of their interaction upon change in either skill set, and should therefore be investigated simultaneously. In this endeavour, in situ simulation and team-based simulation seem promising .[1,55,56] Future studies on the relationship between TS and NTS in SBST may therefore attempt to include several members of the OR and analyse the skills simultaneously to gain a more detailed understanding of how these skills interrelate in the OR setting.

The abundance of tools available for assessing both TS and NTS in SBST underpins the importance of and interest in the training of the surgeon. Many validated assessment tools are currently available for both TS and NTS assessment. The identified publications made use of a range of these, including OSATS, global rating scales, NOTSS, and NASA-TLX. However, just over half of the publications made use of unvalidated tools in their assessments. While the use of unvalidated assessment tools such as questionnaires made for the specific study, procedure related outcomes, and multiple-choice questionnaires may be tailored to investigate 1 aspect of either TS or NTS, the possibilities for interstudy comparisons are limited. Furthermore, validated assessment tools are necessary for the accurate assessment of skills and contribute to preventing an over- or underestimation of the correlation between TS and NTS.[55] Hence, when studies use a NTS intervention without assessing NTS, the possibility to accurately compare the impact of the intervention on TS is hampered.

While validated assessment tools such as OSATS and NOTSS are established within SBST no similar, generic assessment tools for the simultaneous assessment of both TS and NTS are currently being used. Limited studies have investigated if NOTSS and OSATS can be used simultaneously, or if a novel holistic tool is needed. Furthermore, the heterogeneity of studies addressing both

TABLE 2. Publications Addressing the Effect of Mental Training on TS

The Effect of Mental Training on TS Title	Author	Year	Findings
Long-Term Effects of Mental Training on Manual and Cognitive Skills in Surgical Education – A Prospective Study	Kaulfuss & Kluth	2021	Mental training can improve procedural times and performance strategies and has a long-term effect on surgical skills.
Mental skills training limits the decay in operative technical skill under stressful conditions: Results of a multisite, randomized controlled study	Anton & Beane	2017	A mental skills curriculum improved residents' performance under increased stress.
Effectiveness of a comprehensive mental skills curriculum in enhancing surgical performance: results of a randomized controlled trial	Stefanidis & Anton	2017	The performance of laparoscopic suturing improved significantly in the group applying the mental skills curriculum.
Implementation results of a novel comprehensive mental skills curriculum during simulator training	Stefanidis & Anton	2017	Applying the mental skills curriculum improved participants' laparoscopic and metal skills.
A Randomized Control Trial Exploring the Effect of Mental Rehearsal and Cognitive Visualization on Microsurgery Skills	Chadha & Hachach-Haram	2016	After four days the group which had received a mental training performed superior to the group which had not and the group which had received a visual relaxation script.
Randomized clinical trial to evaluate mental practice in enhancing advanced laparoscopic surgical performance	Louridas & Bonrath	2015	Trainees receiving mental practice have significantly greater OSATS and BOSATS scores on final assessment than at baseline. This was not seen in the control group.
Thinking it Through: Mental Rehearsal and Performance on 2 Types of Laparoscopic Cholecystectomy Simulators	Paige & Yu	2015	A significant inverse correlation was found between the mental imagery questionnaire score and the VR clip and cut task, but not other tasks assessed.
Effect of Different Warm-up Strategies on Simulated Laparoscopy Performance: a Randomized Controlled Trial	Bronnimann & Hoffmann	2014	No statistically significant correlation was found between warm up and technical outcome scores.
Using the mind as a simulator: a randomized controlled trial of mental training	Eldred-Evans & Grange	2013	The mental training group scored highest across all domains but speed on the box trainer.
Learning basic laparoscopic skills: a randomized controlled study comparing box trainer, virtual reality simulator, and mental training	Mulla & Sharma	2012	Mental practice was not as effective in teaching novices new technical skills as other teaching methods.
Mental Practice Enhances Surgical Technical Skills: A Randomized Controlled Study	Arora & Aggarwal	2011	A significant, positive correlations was found between mental imagery score and OSATS score.
Impact of perceptual ability and mental imagery training on simulated laparoscopic knot-tying in surgical novices using a Nissen fundoplication model	Jungmann & Gockel	2011	Knot tying performance was not improved by additional mental practice.
Mental rotation: cross-talk training and generalization	Stransky & Wilcox	2010	Mental rotation training significantly improved performance on mental-rotation dependent surgical tasks.
Should we train the trainers? Results of a randomized trial	Murphy & Neequaye	2008	Using a cognitive approach to teaching improved OSATS score and shortened time of surgery.
Learning basic surgical skills with mental imagery: using the simulation centre in the mind	Sanders & Sadoski	2008	After two mental imagery sessions students performed superiorly to students who had studied the same amount of time from textbooks.

(*continued*)

TABLE 2 (*continued*)

The Effect of Mental Training on TS Title	Author	Year	Findings
Mental Training in Surgical Education	Immenroth & Bürger	2007	Mental training resulted in better task specific checklist scores than additional physical practice or no additional practice. No difference was seen in results on the GRS.
Cognitive skills analysis, kinesiology, and mental imagery in the acquisition of surgical skills	Batahlon & Dorion	2005	Combining mental imagery and kinesiology improved acquisition of an emergency procedure.
Impact of cognitive imaging and sex differences on the development of laparoscopic suturing skills	Donnon & DesCôteaux	2005	The use of cognitive imaging did not benefit technical outcomes in the intervention group during a 1-week interval.
Comparing the effects of physical practice and mental imagery rehearsal on learning basic surgical skills by medical students	Sanders & Sadoski	2004	After an initial physical practice, mental imagery practice was as effective as additional physical practice in improving technical skills.

TS and NTS learning objectives complicates the establishment of whether an inherent relationship between these skill sets exists, or whether the relationships identified depends on the study design. In continuation, no tools for the concurrent teaching and assessment of these skills are in place. Developing curricula in surgical education to address both skill sets may provide an opportunity to pursue a more holistic education of the surgeon, rather than focusing on either TS or NTS. However, we do not know whether this norm is due to deliberate choices in training designs, is rooted in the needs and requirements of learners, or in an intention to avoid overloading learners. In this regard, future studies may explore considerations regarding the choices and delineations of learning goals within simulation-based surgical training designs. Furthermore, establishing appropriate tools for the simultaneous assessment of TS and NTS, which has been identified as a current gap in SBST research,[1] may contribute to investigating the relationships between the skill sets while also directing attention to the importance of both. Such an investigation can take its point of departure in validated assessment tools as mentioned above. However, a socio-cultural learning perspective may be beneficial in order to understand how surgical performances may be understood and investigated.[57]

This study has several limitations. Firstly, when conducting a review, the identification of all relevant literature on the subject is of essence. To ensure this, advice on constructing a sound literature search was given by a professional with extensive experience. Furthermore, publications which had not been identified by the initial literature search were subsequently identified through hand search. Secondly, by focusing solely on SBST we potentially excluded literature investigating the relationship between TS and NTS in other areas of medicine, which may be of value to establish how these skill sets are related. Stefanidis et al. called for coordinated research efforts within surgical training in their 2015 paper.[1] To coordinate such efforts in SBST, it must first be established what the different domains within SBST entail. Unclear definitions of what NTS encompass provided an obstacle to the investigation of the relationship between TS and NTS learning objectives in the present study. To overcome this obstacle, we applied a broad definition of NTS defined as all skills that are not body-kinetic skills. Hence, the present study incorporated personal resources skills and cognitive skills in addition to skills such as teamwork and communication which are traditionally defined as NTS.[18,19] Though this definition allowed incorporation of a broad variety of NTS, it also introduced obstacles as mental training may incorporate body-kinetic components such as breathing exercises. Lastly, the broad definition of NTS used in the present study meant juxtaposing measures of interpersonal skills, such as NOTSS, and cognitive skills, such as NASA-TLX. We refrained from further comparing and contrasting these skills sets and measures, as the surgical literature, to our knowledge, has not yet established a clear relationship between cognitive and interpersonal skills in surgery. A final limitation to our study was the exclusion of studies which did not present primary data. We chose to only include studies which presented primary data as these reported a measurable skills assessment. This choice may have excluded qualitative studies which could have added to our understanding of the relationship between technical and non-technical skills in SBST. Table 2

CONCLUSIONS

To conclude, literature on SBST has seen an exponential increase since it was introduced in the 1970's. Within the past twenty years, there has been an increased focus on NTS training in surgery. Our study identified 45 publications investigating the relationship between TS and NTS. Although recent literature suggests that TS and some aspects of NTS such as mental training are interconnected, studies of the relationship remain limited. The identified publications studying this relationship mainly focused on the derivative effects of NTS on TS performances. Due to a broad definition of NTS and a lack of validated assessment tools for both NTS and TS, the present study cannot definitively establish whether a relationship between TS and NTS exists.

Future research may focus on further exploring the relationship between TS and NTS, and if possible, developing an assessment tool covering both aspects of SBST. We suggest studying learning environments where several surgical team members participate, in order to better capture the interplay between the individual TS and NTS and the team performance in the OR.

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