International Journal of Surgery 10 (2012) 80–86

Contents lists available at SciVerse ScienceDirect

International Journal of Surgery

journal homepage: www.theijs.com

Original research

Spatial awareness in Natural Orifice Transluminal Endoscopic Surgery (NOTES) navigation

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A R T I C L E I N F O

Article history:
Received 11 December 2011
Accepted 21 December 2011
Available online 28 December 2011

Keywords:
Natural Orifice Transluminal Endoscopic Surgery
Translumenal surgery
NOTES
Spatial awareness
Navigation
Surgical navigation

A B S T R A C T

Objective: To characterise navigational patterns in the abdominal cavity associated with different spatial awareness status of the operator during navigation of Natural Orifice Transluminal Endoscopic Surgery (NOTES). It is hypothesised that poor spatial awareness will manifest as erratic navigational patterns and poor performance.

Subjects and methods: Ten endoscopic novices navigated a defined course in a NOTES phantom (NOSsE) simulating the path of peritoneoscopic examination. Subjects performed the task three times without and once with an additional laparoscopic camera. Electromagnetic tracking was used to trace the tip of the endoscope during the navigation. Metrics of performance included the number of correctly visualised course targets, between targets localisation time and path length, and total completion time. Spatial awareness was explored by means of topological modelling of the navigation trace. Spatial navigation maps were generated from the tip trace footprint, differentiated using the Earth Movers Distance (EMD) and captured in a two dimensional chart where proximity in the projected space reflects similarity of navigation behaviour. Groups were identified displaying idiosyncratic target to target transitions in endoscopic navigation behaviour.

Results: No significant differences were found between four sessions in terms of the path length. Time was statistically improved when using supplemental visualisation ($p < 0.05$). Four awareness groups were identified based on the subjects exhibited navigation footprint over the frontal plane, namely: (1) consistent navigation and performance; (2) inconsistent navigation and performance; (3) improvements in navigation and performance despite undifferentiated behavioural signatures; and (4) inconsistent navigation with improvements in performance.

Conclusions: Tracking the tip of the endoscope permits reconstruction of the navigation path during extraluminal navigation. The spatial location of the tip of the endoscope during navigation was used to unveil the operator's spatial awareness. Navigation routes in this study have been projected onto a 2D scene, related to performance and classified according to exhibited spatial awareness. Our assessment of this relationship suggests that poor spatial awareness is accompanied by erratic manoeuvres, often leading to poor performances, and vice versa. Tracking the location of the tip of the endoscope is an important issue in NOTES, and similarly understanding the spatial awareness of the operator is crucial in terms of the safety in NOTES. This work may have significant implications for training and assessment of new NOTES or minimally invasive surgeons. It may also lead to the new designs of endoscopes for NOTES.

1. Introduction

NOTES is explored as a Minimally Invasive Surgery (MIS) modality driving towards even less invasive or "incisionless" procedures. With this approach, the abdominal cavity is accessed through a body natural orifice (e.g. via the mouth, vagina, anus). Before the technique can be considered in routine clinical practice, a number of issues must be considered including the improvement of existing surgical instruments, intra-operative imaging guidance, surgical ergonomics and visual perceptual factors.[1] In practice, this surgical modality is affected by a narrow field-of-view, lack of depth perception and tactile feedback, as well as restricted mobility and instrument

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doi:10.1016/j.ijsu.2011.12.005

management.[2] The Natural Orifice Surgery Consortium for Assessment and Research (NOSCAR) recognized the aforementioned issues as potential barriers to safe clinical implementation of NOTES, together with spatial orientation, surgical navigation and performance, management of complications, and training.[3]

Awareness of the position of the endoscope within a cavity is essential both for navigation and safety. When an operator performs a NOTES procedure, because of the modality's inherent characteristics, spatial awareness is challenged. Operating under conditions of reduced spatial awareness increases the risk of injury. In current NOTES practice, the endoscope tends to be retroflexed in order to determine its position using the forward facing camera. This is to ensure that it is not in the vicinity of a visceral organ with the potential of causing significant injury, as well as to determine the appropriate position of the endoscope for navigation. Lacking luminal constraints has the potential to cause disorientation within a spatial cavity.

Spatial awareness (SA) in surgery can be defined as '*the operator's knowledge of the spatial orientation and location of the instrument(s) with regard to the anatomical environment in which it is operated*'. SA provides the primary cue for subsequent decision making and performance in the operation of complex and dynamic systems.[4]

The current paper is concerned with understanding SA in a simulated NOTES environment inferred from the subjects' navigational paths reconstructed from the localisation of the endoscopic tip with regard to the abdominal cavity and intra-abdominal organs. It is hypothesised that behavioural performance will reflect to a degree the SA of the operator. However, traditional metrics alone such as time or path length of navigation are not indices of SA. Rather the succession of erratic manoeuvres, interpreted as poor spatial navigation, is hypothesised to be associated with poorer SA during NOTES. Gaining an appreciation of the spatial challenges inflicted by NOTES procedures through novel quantitative assessments of spatial navigation and SA, may form the basis of ergonomic assessments of innovative technology designed to counteract disorientation and enhance clinician SA. Visual navigational and spatial orientation cues incorporated into NOTES technologies may augment behavioural performance and shorten the learning curve for skills acquisition.

2. Materials and methods

2.1. Subjects

Ten subjects (8 males and 2 females) without prior surgical or endoscopic experience were recruited from Imperial College London. Informed consent was obtained according to the ethical approval (Ref: 08/H0712/104) prior to experimental task execution. Subjects were aged between 23 and 39 years (mean 27 years).

2.2. Equipment and task paradigm

The task was carried out using a natural orifice surgical simulated phantom construct validated for endoscopic experience,[5,6] providing a transluminal environment in which to carry out NOTES target navigation (Fig. 1A). Subjects were required to navigate through sequentially numbered targets along a predefined course using a single channel video colonoscope (Karl Storz, Tuttlingen, Germany). The course simulates the path of a hypothetical transrectal peritoneoscopic examination, with targets labelled numerically, and placed in surgically relevant positions along the proposed path (Fig. 1B). Prior to the task execution, each subject was shown a 5-min presentation on the workings of the endoscope equipment and proposed task. Participants were then allowed five minutes to familiarise themselves with the endoscope and simulator. Each subject carried out the task four times (sessions); the first three sessions – under a standard single monitor setup, displaying the video stream from the endoscopic camera, and the final session under a dual camera conditions, where a second camera was mounted on a laparoscopic port attached to the top left side of the phantom. Successful completion of the course entailed navigating the 10 targets in the correct sequential order.

Participants were informed that to successfully reach a target they had to view the target so that it occupied 50% of the screen size marked by tape strips on the screen edge and indicating a distance of 2–3 cm from the target, a distance felt appropriate if in real terms intervention would be required. The participant verbally informed the investigator every time he/she felt they had reached the target. An independent reviewer judged whether the subject had successfully visualised each target and recorded the time taken. Up to 1 min was allowed to progress between any two targets before the subject was asked to move to the next target. Subjects were not required to memorise the course, but instead were encouraged to ask the investigator when unsure of the exact position of the next target. The subject was told the geometric location of the target within the box, but not the manoeuvres required navigating to it.

2.3. Data acquisition

A single coil from an Aurora EM tracking system (NDI, Canada) was attached to the colonoscope for tracking the position of the tip of the tool. Tracking was performed at maximal modulation rate of 115200 kBauds. The EM sensor consists of small coil connected to the sensor interface unit. Each sensor is 0.8 mm in

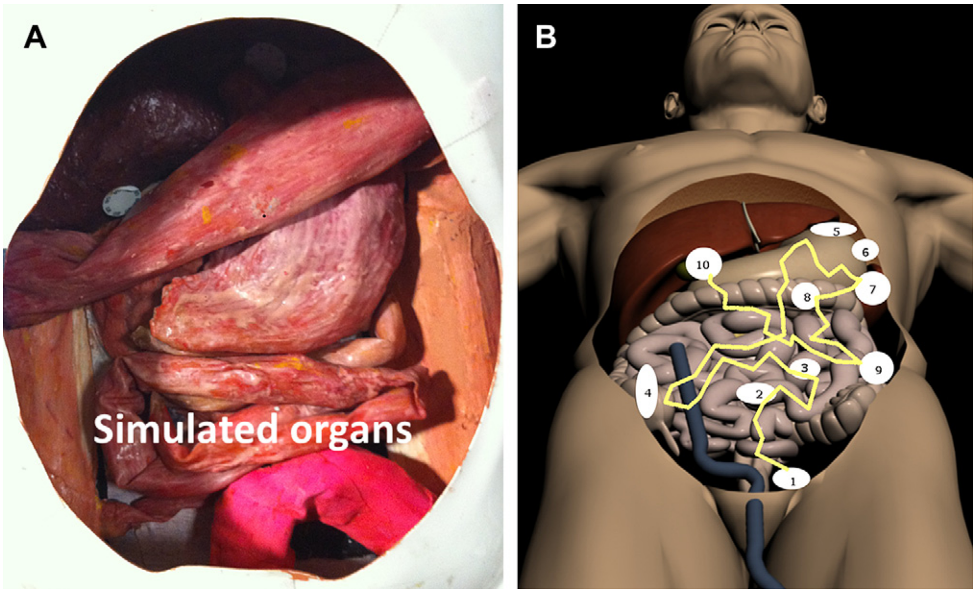

Fig. 1. A) Top view of NOTES simulator where the gallbladder target spot (numbered 10) can be appreciated; (B) schematic presentation of the targets position and artistic representation of the navigation task over imposed on a 3D model.

diameter and 180 mm in length. The typical positional accuracy of the sensor ranges 0.9–1.3 mm longitudinally and 0.3–0.68 mm angularly. The system's working volume is 500 × 500 × 500 mm. This volume is sufficient to cover the area of interest during abdominal interventions. For the experiment, the magnetic field generator was located under the NOTES simulator. Contents of the phantom are ferromagnetically neutral and do not distort the electromagnetic field of the EM tracking system. Performance outcome measures were the number of targets successfully reached during each task, time taken between targets, time taken to fulfil the task and the total path length travelled by the endoscopic tip during the navigation.

2.4. Data processing and analysis

A MATLAB software tool (developed in-house) was used for the visualisation of data collected from the magnetic tracker. This software tool permits 3D visualisation of the markers positions either on its original frame space or registered against a reference scene. The software incorporates a timeline tool where experimental stimulus or conditions and events can be recorded. A scene registration protocol requires locating five control points with the EM sensor. The original coordinates are then rotated and translated to the scene space by rigid registration.

2.5. Spatial awareness analysis

A novel algorithm is proposed for exploration of '*navigational paths*' as a proxy of SA. The endoscope tip positional data along the frontal plane was subjected to a low pass Gaussian filter. The smoothed spatial distribution of the endoscopic tip path then conformed to a 2D histogram. For convenience, we refer to the 2D histograms as "*Navigation maps*" (NM). These spatial navigation maps (histograms) allowed qualitative assessment of the endoscopic navigation skills of the operator. The histogram similarity was computed using the Earth Mover's Distance (EMD),[7,8] a metric designed to match human perception.

In computing the difference between two multivariate distributions, EMD distance represents the minimum amount of energy necessary to transform one into the other. To find the optimum solution the associated minimization problem is conceived as a transportation problem where a set of piles of earth representing the first distribution must be optimally reallocated to best fill a set of holes representing the second distribution. Pairwise similarities were evaluated with classical Multi-Dimensional Scaling (MDS),[9] which then represented the data geometrically in a 2D chart so that interpoint distances embody experimental similarities. MDS is a data projection technique which from a table of pairwise distances affords an optimum spatial distribution of the points so that distances are best preserved. Finally, changes in the navigational behaviour exhibited along the sessions were quantified by means of the Euclidean distance between consecutive session points in the chart.

2.6. Statistical analysis

Dexterity data such as time and path length was statistically analysed using SPSS (SPSS v16, Chicago, USA) by employing non-parametric tests of significance after checking assumptions of normality.

The Friedman Test was conducted to determine whether statistically significant fluctuations in time and path length data had occurred in target navigation across the four sessions for all subjects. A value of $p \leq 0.05$ was assumed to be statistically significant.

3. Results

3.1. Performance analysis

Fig. 2A and B illustrate improvements in performance across sessions and as a result of successful target localisation. The average navigation path length was significantly shorter ($p < 0.05$) when targets were correctly visualised (507.68 A.U.) as compared to visualisation failure (1788.80 A.U.). Practice across sessions lead to significant reductions in the time to complete the target course (mean time 365 s, session 1 versus 275 s, session 4).

Subjects visualised more targets correctly during the 4th session (median 5.5 vs 5.0), however this parameter did not reached statistical significance ($p = 0.084$). Data from subject 1 was discarded due to technical errors.

The relationship between time and path length as illustrated in Fig. 3, can be appreciated as a 'diverging cone'. When a target (e.g. target 1) was readily reachable, this cone converged with data close to the origin, reflecting rapid location time and comparatively short navigation path. If the target (e.g. target 8) proved challenging to locate, the performance cone broadened as the navigation time and path length to reach that target increased. A general trend of longer path length requiring longer time is apparent. However, these metrics do not share a linear relationship.

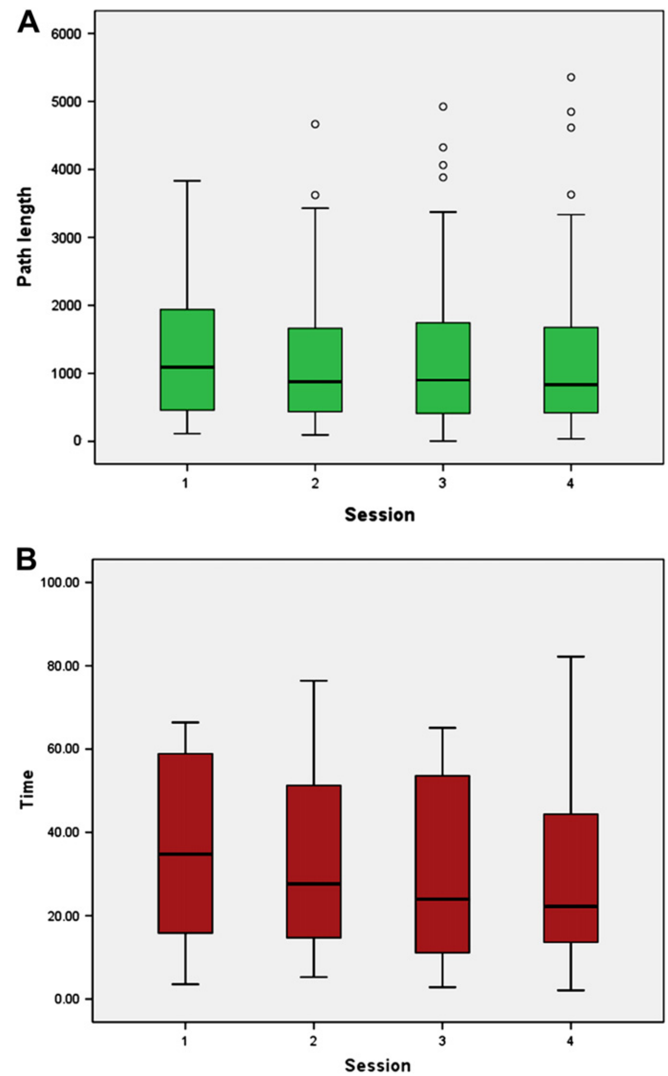

Fig. 2. Performance metrics; (A) total path length in A.U. and (B) time in seconds required to complete across the four sessions.

It is anticipated that the navigation times and path length between targets in close geometric proximity will be relatively short (e.g. targets 5 and 6, or targets 7 and 8 – see Fig. 1). For example, navigating from the target 2 (a point on the simulated central surface of the greater omentum) to target 3 (positioned on the inner abdominal wall in the umbilical region), only requires bending the tip of the scope upwards (Fig. 4). Subjects aware of the position of the endoscopic tip managed to navigate between these targets without unnecessary gestures. However, navigational behaviour in disoriented subjects or those who were "*spatially lost*" was characterised by erratic paths and inefficient gestures resulting in slow visualisation times and even localisation failure.

In the last session of the current experiment an additional camera view was used to augment SA. Theoretically, this may provide the endoscopic surgeon with enhanced visualisation and inform the precise location of the endoscope inside the abdominal cavity during the entire procedure. Our results suggest that

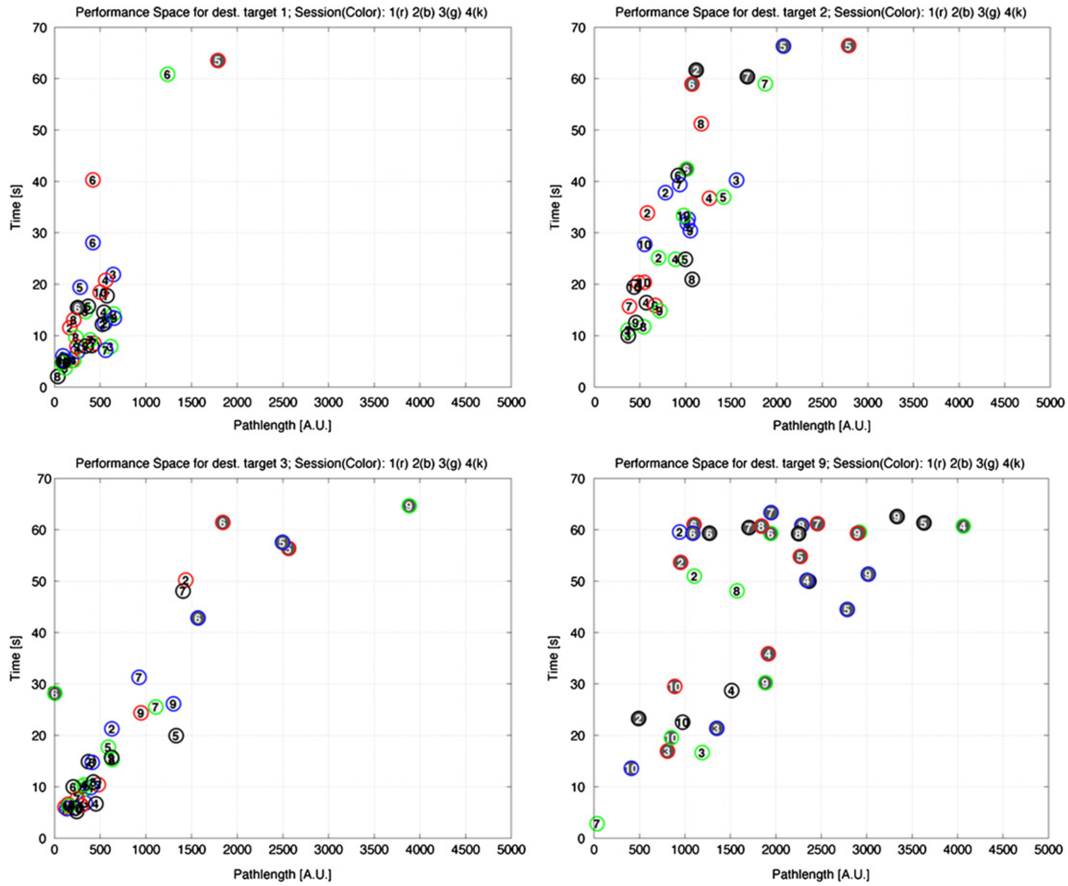

Fig. 3. The relationship between performance metrics in exemplary targets 1, 2, 3 or 9. Scatter plots demonstrate the overall navigation performance of all ten subjects from target 1 to 10 in consecutive order. Filled markers indicate whether the target was (black circles) or was not (empty circles) visualised. Marker edge colour represents the session (1st session, diamond; 2nd session, triangle; 3rd session, square; and 4th session, circle). Numbers within the circles correspond to different subjects.

objective performance metrics are improved with an additional visual display, although it must be acknowledged that the effect may equally be explained by learning.

3.2. *Spatial awareness study*

Hotspots in NM originate at either revisited locations or more often points where the operator struggled to achieve smooth navigation. An example of the output charts of MDS for the manoeuvres across targets is illustrated in Fig. 5. It can be observed that the *X*-axis captures the ‘smoothness’ of the motion trajectory. In particular, the more chaotic the motion path, the more likely the data projects to the left of the embedding. In contrast, smoother movements of the endoscopic tip project to the centre of the embedding. The second component (*Y*-axis) captures the anatomical region in which the majority of the motion was conducted. Points located below the horizontal 0 point represent cases whose navigation path position was in the top right area of the phantom, whereas points above zero correspond to cases where the subject’s paths concentrated in the bottom right space of the phantom. Navigation in the central area of the phantom projects towards the 0 ordinate.

Qualitative exploration of these embeddings highlights that certain subjects share similar characteristics in terms of their ability to learn a complex spatial navigation task. Together with the time taken, successful task completion and navigation trajectories, four broad patterns of navigation and learning capability may be deduced as follows:

1. ‘*Consistent navigation and performance*’ – subjects who appear to navigate consistently and smoothly between targets without significant changes in navigation behaviour across sessions (e.g. subjects 2 and 10).
2. ‘*Inconsistent navigation and performance*’ – subjects in whom no clear or co-ordinated pattern of endoscopic navigation was observed (e.g. subjects 5, 6 or 8) often associated with unsmooth manoeuvres.
3. ‘*Improvements in navigation and performance*’ – subjects who demonstrate improvements in objective performance markers of dexterity, target localisation and navigational behaviour across sessions, manifests as within-session consistency (e.g. subjects 3 and 7).
4. ‘*Inconsistent navigation, but improvements in performance*’ – subjects who throughout the sessions improved their performance in terms of time and path length, but were inconsistent in their navigation, made unnecessary gestures and moved the endoscope in a seemingly uncontrolled fashion across the operating site (e.g. subjects 4 and 9).

Quantification of the variation in the navigational behaviour through the sessions is possible by means of comparing the distance travelled on the embeddings (Fig. 6). In this sense, the shorter the travelled distance the more consistent the navigational behaviour from one session to the next. Overall summation of the progression across the four sessions is representative of the general spatial behaviour of the subject. Table 1 summarises the total travelled distance by each subject across the 10 targets. Large

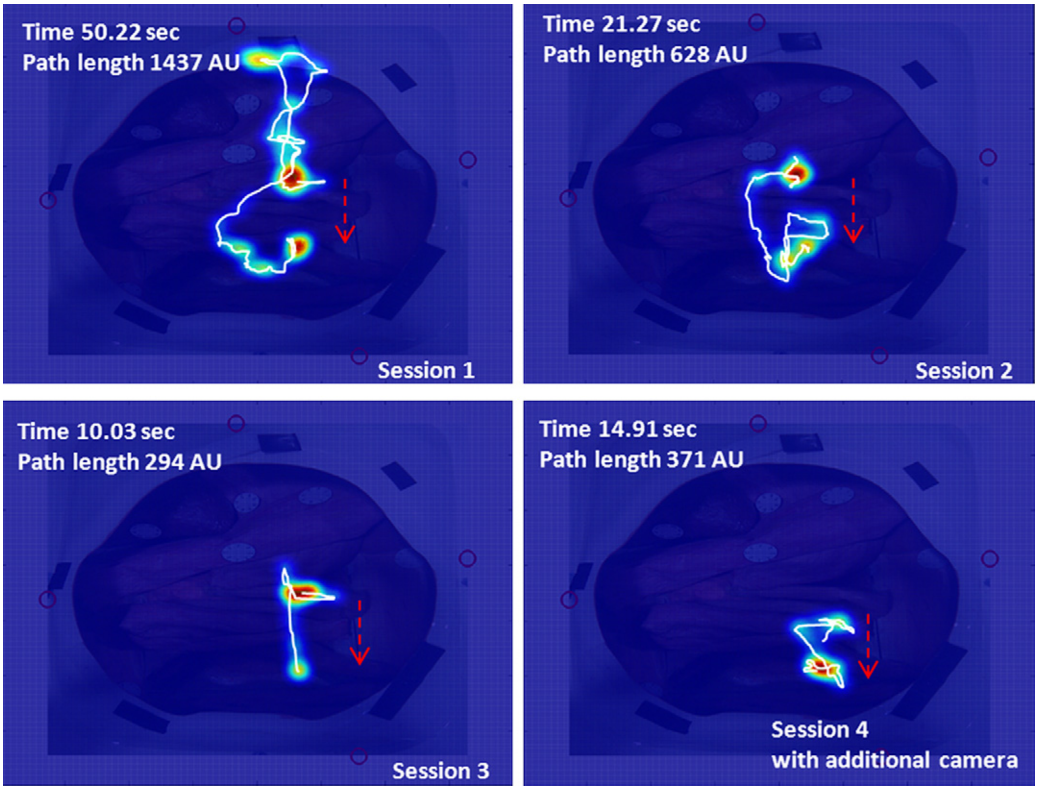

Fig. 4. Navigation maps for subject 2 from target 2 to target 3 for all four sessions. Real trajectory of endoscope tip is highlighted by a white continuous line. Dashed line indicates the "optimal path" for the navigation.

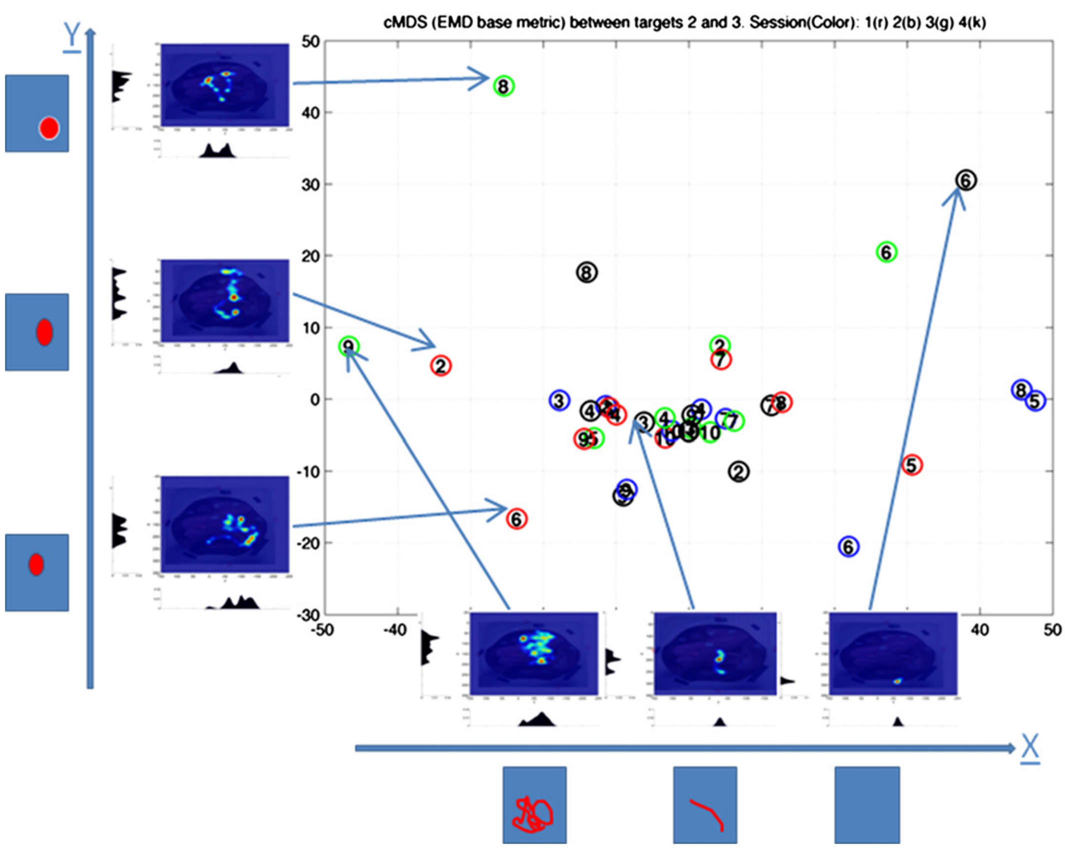

Fig. 5. Multidimensional scaling embeddings representing the SA patterns during NOTES navigation. The example shown corresponds to navigation from target 2 to 3. Axis *X* captures the smoothness of the trajectory and axis *Y* reflects the overall position of the motion trajectory in the phantom. Marker identifies the session; 1st, diamond; 2nd, triangle; 3rd, green; and 4th, circle. Number within marker identifies the subject.

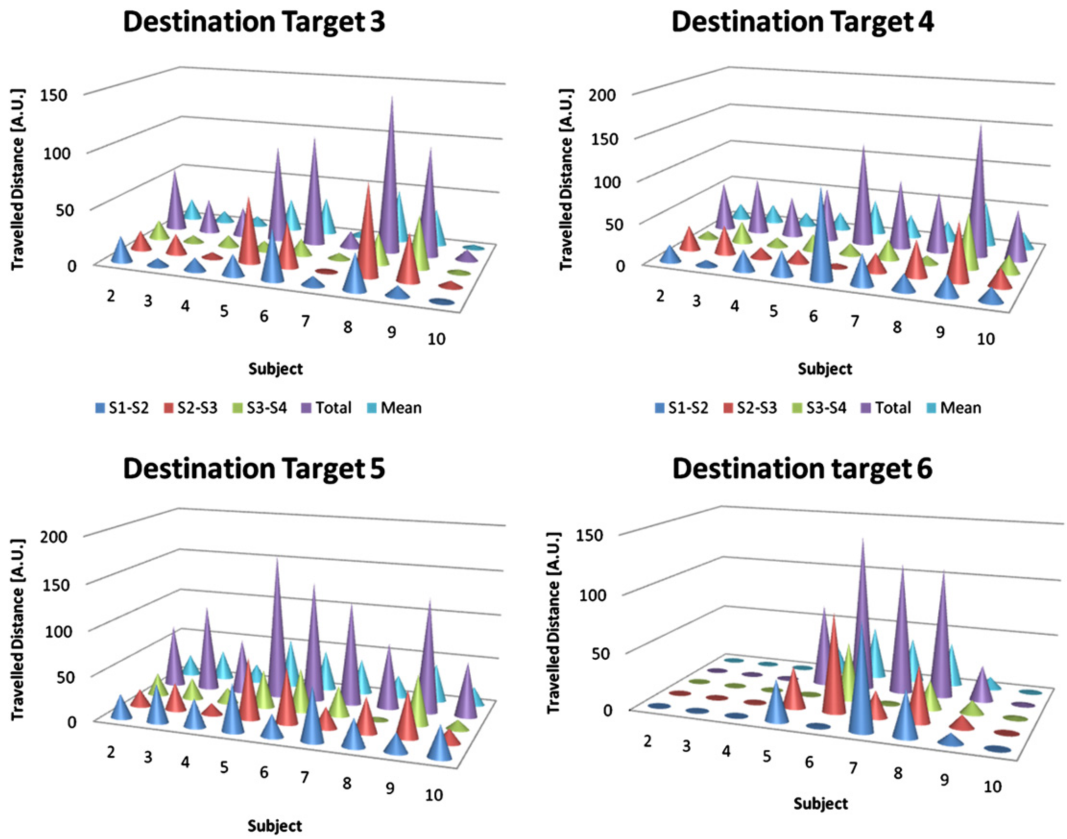

Fig. 6. Examples of quantitative analysis of the performance metrics based on the total and mean distance travelled within the embeddings through the sessions (SX–SY) for targets 3, 4, 5 and 6. The figure highlights consistency (e.g. subjects 2 and 10) and inconsistency (e.g. subjects 8 and 9) in spatial navigation behaviours across sessions amongst study subjects.

session to session variation in the Euclidian distance suggests inconsistent navigation behaviour (e.g. subjects 5, 6 or 8), whereas consistent navigation behaviour is more likely to be manifest smaller fluctuations in the Euclidian distance (e.g. 2 and 10). The quantitative data support the proposed classification of navigation behaviour with regards to SA. From Table 1 it is clear that within the embedded space subjects 2 and 10 do not migrate significantly in their performance and they are considered '*consistent navigators and performers*' (Group 1). Subjects 5, 6 and 8 demonstrate large variation in target to target navigation behaviour and are considered '*inconsistent navigators and performers*' (Group 2). Subjects 3 and 7 are observed to progressively reduce their migratory behaviour in the embedding across sessions and demonstrate consistent improvements in navigation and performance (Group 3). Subjects 4 and 9 exhibit large standard deviations, despite the reduction in mean values of travelled distance within the embedded space, and are considered '*inconsistent navigators with improved performance*' (Group 4).

4. Discussion

SA is deemed a necessary skill for safe deployment of NOTES procedures. Quantification of the surgeon's spatial capabilities during navigation is therefore of utmost importance for the realization of NOTES. Electromagnetic tracking has permitted the navigation paths of the endoscope tip to be reconstructed. Starting from the premise that SA can be inferred from the exhibited navigation path, we have explored the association between SA and traditional performance metrics (i.e. path length, time). As hypothesised, poor SA as characterised by concatenated erratic manoeuvres often lead to poor performance. Unexpectedly, path length did not accompany dexterity progression marked by a reduction in time. The fact that the path length does not improve statistically across sessions suggests that SA demands not only higher dexterity from the operator but also a real understanding of the semantics of the viewed scene. This finding emphasizes the need to further unravel the foundations of operator's SA in transluminal endoscopy, as well as the need to look beyond the traditional metrics of performance to fully characterise SA. In this sense SA is a comparatively difficult construct to measure, but using EM trackers or perhaps other available trackers (e.g. wireless trackers) enables the navigational behaviour to be evaluated, which traditional metrics cannot capture. In addition to the conventional time and path length metrics, navigational performance reveals conduct aspects of the SA of the operator. Incorporating additional more sensitive performance metrics (e.g. motion of the scope, trajectory of the movements) will lead to better understanding of SA and perhaps to novel objective tools to assess navigation skills in surgery.

One factor likely to improve SA during MIS procedures is in the provision of additional spatial cues to augment the surgeon's SA within the peritoneal cavity. There is some empirical evidence that orientation aids are useful. For example, Fowler et al. demonstrated improved spatial orientation and navigation using an EM-based orientation aid during in-vivo NOTES procedure in a pig model.[10] Similarly, Lerotic et al. described a software adjunct to enhance the operators visual field during NOTES; so called dynamic view expansion, a system that it likely to improve SA during NOTES.[11]

Harmonizing patient safety, surgical action and navigation is the operator's responsibility.[12] Enhancing scene visualisation, for

Table 1
Evolution of spatial navigational behaviour as represented by the Euclidean distance travelled by the subject within the embeddings.

Mean (std. deviation)	Session 1–Session 2	Session 2–Session 3	Session 3–Session 4
Subject 2	17.07 (18.93)	17.97 (15.88)	18.67 (16.28)
Subject 3	22.93 (15.62)	19.58 (10.80)	16.87 (14.64)
Subject 4	31.48 (34.76)	26.99 (34.24)	15.48 (13.98)
Subject 5	39.05 (23.41)	31.82 (23.78)	17.59 (12.50)
Subject 6	35.32 (33.19)	58.07 (39.48)	51.69 (37.40)
Subject 7	32.90 (30.05)	29.35 (25.42)	22.55 (26.07)
Subject 8	21.59 (13.32)	30.76 (24.23)	19.51 (12.09)
Subject 9	21.19 (13.92)	34.25 (22.22)	34.62 (24.30)
Subject 10	15.46 (13.44)	7.87 (6.68)	14.03 (12.22)

instance by means of additional viewpoints, seems a feasible strategy for augmenting SA in NOTES. In this study, the additional camera was attached only to the top left upper distal part of the phantom. Further investigation is required to determine whether the position and angle of the additional camera may impact on the SA of the operator. In this study, we have confined ourselves to a 2D projection over the frontal plane. The 3D reconstruction of the deforming scene may provide the surgeon with greater depth information, but the restricted field of view makes navigation more complex. The patterns of SA observed in the current paper should be confirmed in more realistic 3D analysis and bounded by 3D structures including collision analysis.

5. Conclusions

In summary, we have exposed different patterns of navigation assumed to be representative of SA during NOTES navigation, and further qualitatively and quantitatively describe the relationship between navigation capability and traditional performance metrics. To our knowledge, this is the first study of spatial awareness in NOTES. This analysis has revealed distinctive navigational behaviours that would have otherwise gone undetected using current methods for objective assessment and underscores the importance of incorporating markers of SA in assessment performance during NOTES. Our study highlights that traditional metrics of behavioural performance (e.g. time, path length, etc.) do not accurately reflect the idiosyncratic spatial behaviours of individual learners. However, EM motion path analysis facilitates an understanding of the spatial capabilities of the user, on the basis that smooth coordinated navigation is likely to reflect a surgeon with enhanced visual spatial capabilities. Quantification of SA during NOTES procedures may provide the basis of ergonomic assessments designed to evaluate new technologies such as navigational aids, designed to improve the operator's SA.

Conflicts of interest

None.

Sources of funding

None.

Ethical approval

Not acquired.

Author contribution

Vahe Karimyan – study design, data collections, data analysis and writing.

Felipe Orihuela-Espina – data collections and analysis.

Daniel Leff – data analysis and writing.

James Clark – study design.

Mikael Sodergren – study design and writing.

Ara Darzi – study design, data analysis and writing.

Guang-Zhong Yang – study design, data analysis and writing.

References

1. Swanström L, Khajanchee Y, Abbas M. Natural Orifice Transluminal Endoscopic Surgery: the future of gastrointestinal surgery. *The Permanente Journal* 2008;**12**(2):42–8.
2. Karimyan V, Sodergren M, Clark J, Yang G-Z, Darzi A. Navigation systems and platforms in Natural Orifice Translumenal Endoscopic Surgery (NOTES). *International Journal of Surgery* 2009;**7**(4):297–304.
3. Rattner D, Kalloo A. ASGE/SAGES working group on natural orifice translumenal endoscopic surgery. *Surgical Endoscopy* 2006;**20**(2):329–33.
4. Endsley MR. Measurement of situation awareness in dynamic systems human factors. *The Journal of the Human Factors and Ergonomics Society* 1995;**37**(1):65–84. 20.
5. Clark J, Sodergren M, Noonan D, Darzi A, Yang G-Z. The Natural Orifice Simulated Surgical Environment (NOSsE): exploring the challenges of NOTES without the animal model. *J Laparoendosc Adv Surg Tech A* 2009;**19**(2):211–4.
6. Clark J, Orihuela-Espina F, Sodergren M, James D, Karimyan V, Teare J, et al. A quantitative scale to define the quality of endoscopic torque control during translumenal surgery and its potential as an objective measure of endoscopic skill. *Surgical Endoscopy* 2010 [submitted, under review].
7. Rubner Y, Tomasi C, Guibas LJ. A metric for distributions with applications to image databases. In: Sixth international conference on computer vision; 1998. p. 59–66.
8. Rubner Y, Tomasi C, Guibas LJ. The Earth Mover's Distance as a metric for image retrieval. *International Journal of Computer Vision* 2000;**40**(2):99–121.
9. Kruskal J. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. *Psychometrika* 1964;**29**(1):1–27.
10. Fowler S, Hefny MS, Chen EC, Ellis RE, Mercer D, Jalink D, et al. A prospective, randomized assessment of a spatial orientation device in Natural Orifice Transluminal Endoscopic Surgery. *Gastrointestinal Endoscopy* 2011;**73**(1):123–7.
11. Lerotic M, Chung AJ, Clark J, Valibeik S, Yang G-Z. Dynamic view expansion for enhanced navigation in Natural Orifice Transluminal Endoscopic Surgery. In: *Medical image computing and computer-assisted intervention – MICCAI 2008* 2008. p. 467–75.
12. Stüdeli T. Surgical wayfinding and navigation processes in the human body. *Cognitive Processing* 2009;**10**(0):316–8.