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Exploring the presence of core skills for surgical practice through simulation

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Abstract

OBJECTIVE: The ability to simulate procedures in silico has transformed surgical training and practice. Today's simulators, designed for the training of a highly specialized set of procedures, also present a powerful scientific tool for understanding the neural control processes that underpin the learning and application of surgical skills. Here, we examined whether two simulators designed for training in two different surgical domains could be used to examine the extent to which fundamental sensorimotor skills transcend surgical specialty. **DESIGN, SETTING & PARTICIPANTS:** We used a high-fidelity virtual reality dental simulator and a laparoscopic box simulator to record the performance of three different groups. The groups comprised dentists, laparoscopic surgeons, and psychologists (each group n = 19). **RESULTS:** The results revealed a specialisation of performance, with laparoscopic surgeons showing the highest performance on the laparoscopic box simulator, whilst dentists demonstrated the highest skill levels on the virtual reality dental simulator. Importantly, we also found that a transfer learning effect, with laparoscopic surgeons and dentists showing superior performance to the psychologists on both tasks. **CONCLUSION:** There are core sensorimotor skills that cut across surgical specialty. We propose that the identification of such fundamental skills could lead to improved training provision prior to specialization.

KEY WORDS: Surgical Training; Core Surgical Skills; Sensorimotor; Learning Transfer; Simulation

COMPETENCIES:

1-Practice-Based Learning and Improvement.

2- Systems-Based Practice.

Conflicts of Interest: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Introduction

If you needed to choose between a dentist and a psychologist to perform an emergency appendix removal, who would you opt for? Similarly, if there was no dentist available and you needed a tooth extraction, would you use a social scientist or a surgeon specialising in hepato-pancreato-biliary procedures? These thought experiments reveal the widely held intuition that there are core skills that transcend specialty (and the corollary, that there are specialist skills that are experience-specific).

Advances in technology and the emergence of surgical simulation provide the means of supporting this intuition with scientifically rigorous, empirical evidence (without venturing into ethically reprehensible territory). Nevertheless, there seems little benefit in establishing empirically that psychologists are best avoided when hepato-pancreato-biliary procedures are required. But there would be great benefit in starting to understand the core skills that are common to all surgical specialties as this could streamline the selection and training of prospective surgeons.

It is well established that humans can rapidly learn tasks where the control parameters require simple input-output adjustments by some variable amount (e.g. adaptation to different degrees of visuomotor rotation [1–3]). It is also known that acquiring the ability to complete one such task often yields little in the way of general sensorimotor learning that can be applied to another task [4,5]. Nevertheless, in some scenarios, neurologically intact adults display an ability to extract general rules from a task and apply these rules to novel tasks with similar dynamical structures by identifying invariants between input-output mappings. This process is known as 'structural learning' [6–8] and it is associated with higher levels of performance in related novel tasks [6,7,9]. For example, it has been established that participants show better laparoscopic skills when trained on multiple ports [10] and across a variety of parameter spaces [11]. However, as previously discussed, skilled motor learning is also marked by specialisation of function - with sensorimotor commands developed and refined through the interaction with, and tailored for, specific environments. If a small change in the context is associated with a large alteration in the learning task, then generalising from prior learning can interfere with learning the new task and impair performance [6,12]. Thus, one of the major challenges for researchers seeking to improve training regimes is identifying the core (structural) elements that underpin a particular class of behaviours and differentiating such elements from the components associated with a specific (specialist) skill.

The purpose of this experiment was to explore the generalisability of surgical skills across different contexts. To this end, we examined the extent of sensorimotor skill transfer across healthcare specialties by asking trained laparoscopic surgeons and dental surgeons to complete simulated versions of laparoscopic surgery and dental surgery tasks and compared their performance on these tasks against a group of surgically naïve participants.

Materials and methods

Simulation has been effectively utilised for education, assessment, and maintenance of various skills across a diverse range of domains. It has been particularly crucial in professions that demand a high degree of precision and safety – such as healthcare education [13,14]. The purpose of simulation is generally agreed to be to replicate or amplify real experiences using analogous tools or settings that imitate real world conditions, with the goal of learning and training, in an immersive and interactive mode [15,16]. In dental and surgical education, intensive theoretical and practical preclinical training is fundamental to bridge the educational gap between preclinical and clinical practice [17–20]. In the context of this experiment, none of the participants had any previous experience of using these two simulators and each participant was allowed to try out the devices as part of the introduction to familiarise themselves with the procedure and the required tasks. The experiment lasted approximately 20-25 minutes in total to perform one attempt on the two assessment tasks.

We used a high-fidelity haptic virtual reality (VR) simulator (Moog Simodont Dental Trainer® [21,22]) and a laparoscopic box simulator (EoSim®[23–25]) to assess the performance of dentists (N = 19, 7 females, M = 4.7 ± 1.27 years of experience) and laparoscopic surgeons (N = 19; 8 females, M = 5.05 ± 5.79 years of experience) on simulated surgical and dental tasks. We sought to compare the performance of these participants against a surgically naïve control group of participants with an equivalent level of education. Postgraduate psychologists presented a sample of convenience (N = 19; 11 females) that satisfied these criteria. The study followed the tenets of the Declaration of Helsinki and was approved by the local Research Ethics Committee at the School of Psychology (reference 17-0166), University of Leeds, United Kingdom.

To examine performance in dental surgery, we asked participants to drill through a virtual 3D shape presented by the Haptic VR Dental Simulator (see Figure 1A). The shape comprised three zones (see Figure 1B): (i) a target zone- which needed to be removed by the participant; (ii) leeway zones (side and bottom) surrounding the target zone which the participants were instructed to avoid removing; and (iii) container zones (sides and bottom) which the participants were also told they must avoid. The participants were informed that they needed to remove 99% of the target zone. For assessing laparoscopic surgery performance, a thread transfer task was used. The task involved inserting a thread in 5 pegs (holes) within 10-minutes, using laparoscopic graspers with both hands (see 1C and 1D).

The kinematic performance measures provided by the Dental Simulator included percentage of target area removal, an error score which included four measurements (leeway bottom, leeway sides, container bottom and container sides), time (seconds) which included time elapsed (the total time taken by the participant to complete the task) and drilling time (the total time taken by the participant to drill the shape), and the total distance the hand moved in meters [22,26].

The kinematic performance measures provided by the Laparoscopic Simulator included time (seconds); distance (m) where lower instrument path distance is taken as a metric of higher control; speed (mm/s); and normalised jerk (mm/s^3) where lower values indicate greater smoothness [23–25].

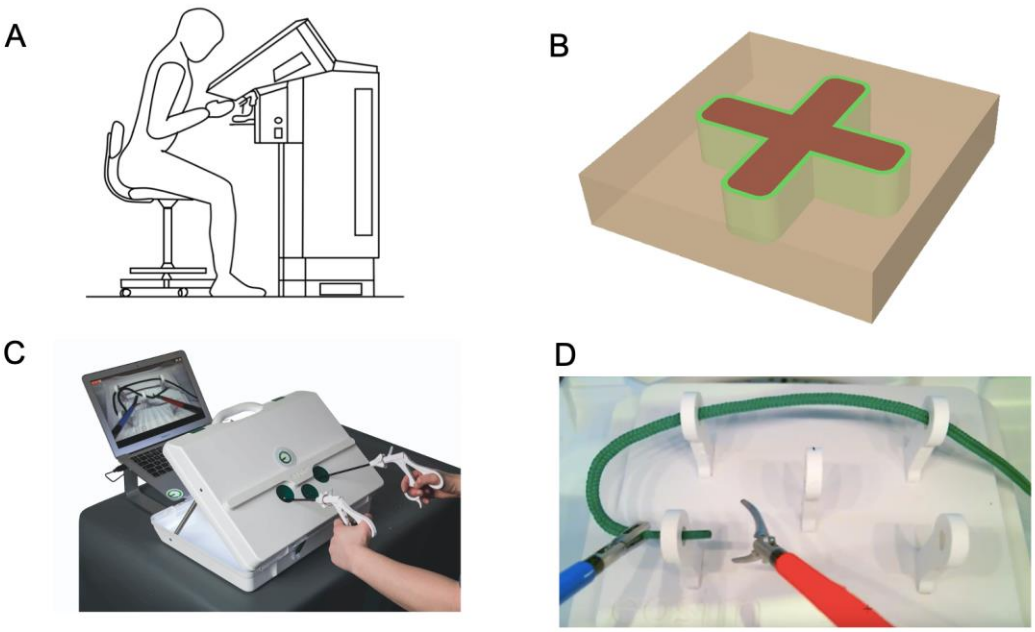

Figure 1. (A) Schematic drawing of the VR dental simulator and the experimental setting. (B) Schematic of the cross-shape dental task presented through a haptic VR simulator, illustrating the location of the target area, the Leeway and Container. (C) The set-up of the surgical simulator showing the laparoscopic task. (D) The peg-threading setup of the laparoscopic task.

Statistical analysis

To asses performance, z-scores of a composite measure that captured speed-accuracy trade-offs in performance for laparoscopic (C_{lap}) and dental tasks (C_{dent}) were compared. Standardising the scores in this way allowed us to make inter-task comparisons, despite the different kinematic performance measures provided by the respective simulators.

The dental composite measure was calculated by multiplying the total error by the time taken, such that lower scores indicate better performance (Equation 1). The laparoscopic composite measure was calculated by multiplying the number of incomplete holes (n) plus one, by the amount of time taken to complete the task within the maximum time period, such that lower scores indicate better performance (Equation 2). A repeated measures analysis of variance (ANOVA) was conducted to compare performance according to specialty for the z-score composite variables in dental and surgical simulators. The statistical significance threshold was set at $p < .05$ and we report generalised eta squared (η^2_G) as a measure of effect size and considered $\eta^2_G = 0.02$ to be small, $\eta^2_G = 0.13$ medium and $\eta^2_G = 0.26$ to be a large effect size. All statistical analyses were performed using the statistical analysis package R and R Studio Version 1.1.463 (28).

$$C_{dent} = t_{dent} \times E_T \tag{1}$$

$$C_{lap} = t_{lap} \times (n + 1) \tag{2}$$

Results

A 2 x 3 ANOVA was conducted to compare the performance of participants on the Task Type (Dental and Surgical) according to the participant Group (Laparoscopic surgeons, Dentists, and Psychologists) for the z-scored composite variables. This yielded a significant main effect for the Group factor, [F (2, 54) = 18.23, p <0.001, η^2_G = 0.250], and a significant interaction, F (2, 54) = 7.36, p < 0.001, η^2_G= 0.121] (Figure 2).

A series of one-way ANOVAs decomposed the interaction by Group. For the Psychology Group, there was no effect of Task Type, [F (1, 18) = 0.058, p =0.81, η^2_G= 0.002], indicating that the Psychology Group produced similar errors in the Dental (M = 0.713, 95% CI = [0.333, 1.094]) and Surgical Task (M = 0.623, 95% CI = [0.243, 1.004]). For the Dentists, the effect of Task Type was significant, [F (1, 18) = 24.52, p =0.0001, η^2_G= 0.348]], indicating that the Dentists produced fewer errors in the Dental Task (M = -0.817, 95% CI = [-1.197, -0.437]) compared to the Surgical Task (M = -0.036, 95% CI = [-0.416, 0.344]). For the Laparoscopic Surgeons, the effect of Task Type was also significant, [F (1, 18) = 9.05, p= 0.007, η^2_G= 0.189], indicating that the Surgeons produced fewer errors in the Surgical Task (M = -0.587, 95% CI = [-0.967, -0.207]) compared to the Dental Task (M = 0.103, 95% CI = [-0.277, 0.484]). Finally, we found that the relative performance of Dentists and Surgeons were not significantly different in their specialities [F (1, 36) = 1.37, p= 0.24, η^2_G= 0.036].

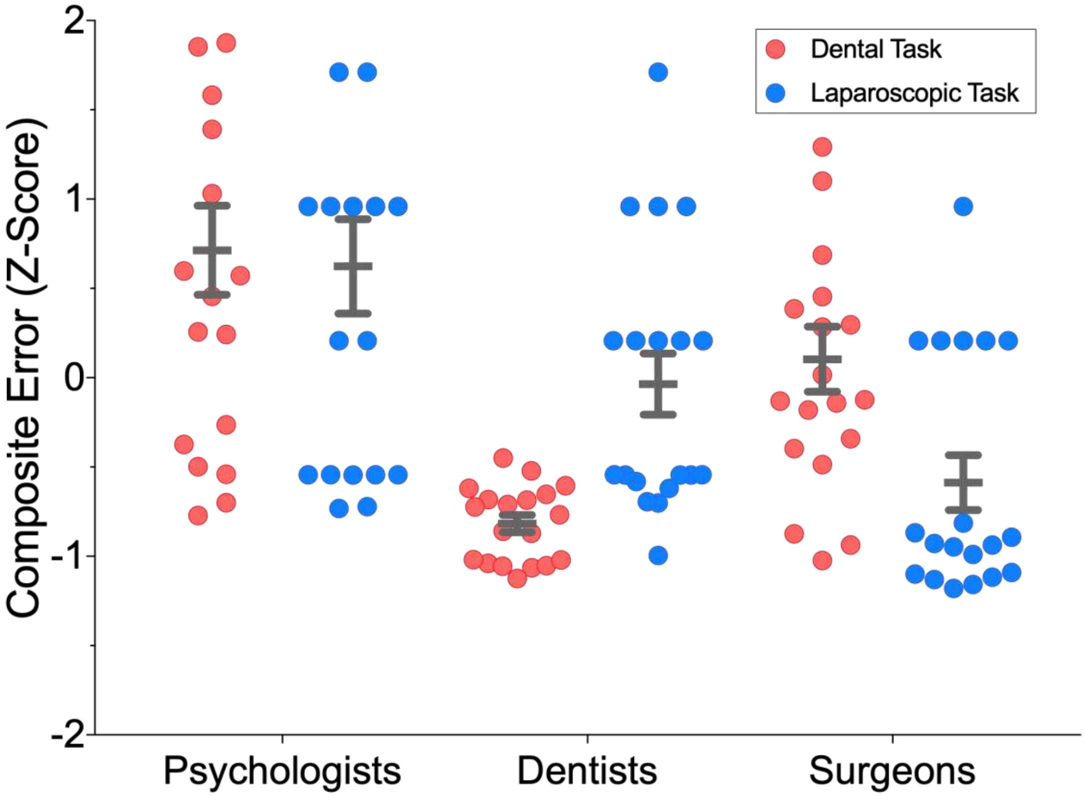

Figure 2. Performance differences on the Dental and Surgical tasks, represented as a z-score of the composite error measures (lower values indicate better performance). The circles represent individual scores, the squares represent the mean and the error bars indicate standard error of the mean. Dentists performed better than psychologists on the surgical task and better than psychologists and laparoscopic surgeons on the dental task. Similarly, the laparoscopic surgeons performed better than psychologists on the dental task and performed better than psychologists and dentists on the laparoscopic task.

Discussion

We explored whether we could identify evidence to support the intuitive notion that there are core surgical skills that transcend speciality (a conjecture that has support from the field of sensorimotor control and the phenomenon of structural learning)[6,7,9]. To address this issue, we monitored the performance of dentists, laparoscopic surgeons and psychologists on dental and surgical simulators. We reasoned that the presence of core surgical skills would be indicated by the dentists and laparoscopic surgeons outperforming the psychologists on the novel surgical procedure presented within these simulators.

For the dental task, dentists' performance was better than psychologists and laparoscopic surgeons. In the laparoscopic task, the laparoscopic surgeons' performance was better than psychologists and dentists. Finding that each of these simulators was able to discriminate between different levels of real-world skill is not surprising per se- indeed, previous work has established the discriminant validity of each system [22,24]. The novelty of this study comes from contrasting performance on each simulator across groups. Here, we found laparoscopic surgeons' performance was better than psychologists in the dental task and the dentists' performance was better than psychologists in the laparoscopic task. This suggests that surgical training (both dental and laparoscopic) facilitates the development of fundamental sensorimotor skills that transcend their speciality. This is evidenced by surgically trained participants outperforming surgically naïve participants, given the same level of exposure to a novel simulator.

At this point, it is worth considering why distinct surgical specialties seem to possess core features. Surgery is a complex task where the complexity reflects the integration of both cognitive and sensorimotor processes [27]. In terms of the cognitive processes involved, all surgeons require high-level medical knowledge to make the appropriate assessment and evidence-based decisions. It is relatively easy to identify what cognitive knowledge constitutes core information required by all specialties and this is the foundation of much medical training before career specialization. Likewise, it is a trivial task to identify the specific knowledge required by a given surgical specialty. Integral to all specialist surgical training is the provision of specific knowledge about anatomy and procedures. In contrast, the complexities of sensorimotor control [28] mean that it is much harder to understand the sensorimotor processes that underpin specific surgical procedures and identify the sensorimotor skills that are common to all skilled surgeons. The present study presents, to our knowledge, the first attempt at delineating the sensorimotor surgical skills that can be extrapolated to novel situations.

The data from the current study align well with current sensorimotor theories. For example, structural learning accounts of motor learning provide a framework for understanding how humans can adapt and readapt to a sequence of similar tasks[4,7]. This ability to learn the core structures of similar types of movement can lead to higher levels of performance in domains that fall outside a task that has been specifically trained and learned [7,29,30].

A fundamental property of sensorimotor skill is the precision and consistency of the spatial-temporal control of the arms [5,31]. For example, in learning to drill into plastic teeth, the dental student must get their hand to the right place, at the right angle, and apply the appropriate forces to a hand-held instrument. These abilities can become highly precise and consistently repeatable [32–34]. The neural changes associated with practice allow a motor task to be accomplished with increased speed and a reduction in behavioural error [31,35]. It transpires that the trained dentist can then transfer their skills to another (novel) surgical setting. This suggests that learning core skills may leading to faster learning for problems sharing a similar structure [36].

The road to becoming a highly skilled surgical practitioner is a long (and often arduous) one. It is also the case that there are currently evidence-based approaches to facilitating this learning process. We suggest that detailed investigation into the nature of core skill development that transfers across specialties could inform the development of effective training structures to support learning for surgeons and improve training provision before specialisation. For example, it may be possible to produce generic 'surgical trainers' that enable a surgeon of any discipline to learn the fundamental motor behaviours before becoming specialized in one type of surgery. These trainers might not only play a fundamental role in skill learning (and lead to a better understanding of the flexibility and adaptability of the sensorimotor system [6,25]), but may also have the potential to offer new ways to screen and assess prospective surgeons. The increasing prevalence of low-cost virtual and augmented reality technology simulators could present an opportunity for developing such multi-purpose systems[38,39]. The key to maximising their utility for surgical training will be in ensuring that these systems are grounded in the science of human learning.

Conclusion

We set out to examine whether two simulators designed for training in two different surgical domains could be used to examine the extent to which fundamental sensorimotor skills transcend surgical specialty. We found specialisation of performance (each specialty performed better on the surgical simulator designed for their own discipline). Crucially, we also found evidence of transfer learning - with both groups performing better than surgically-naïve participants on the simulator designed for a surgical task outside their domain. These results show that there are core surgical skills that transcend specialty. This opens up the prospect of developing simulators and training protocols that can allow all surgeons to develop fundamental sensorimotor abilities before specialisation.

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