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Exploring the presence of core skills for surgical practice through simulation

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40 **Abstract**

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

60

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

63 **COMPETENCIES:**

64 1-Practice-Based Learning and Improvement.

65 2- Systems-Based Practice.

66

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

69 **Introduction**

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

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

83 It is well established that humans can rapidly learn tasks where the control parameters
84 require simple input-output adjustments by some variable amount (e.g. adaptation to
85 different degrees of visuomotor rotation [1–3]). It is also known that acquiring the
86 ability to complete one such task often yields little in the way of general sensorimotor
87 learning that can be applied to another task [4,5]. Nevertheless, in some scenarios,
88 neurologically intact adults display an ability to extract general rules from a task and
89 apply these rules to novel tasks with similar dynamical structures by identifying
90 invariants between input-output mappings. This process is known as ‘structural
91 learning’ [6–8] and it is associated with higher levels of performance in related novel
92 tasks [6,7,9]. For example, it has been established that participants show better
93 laparoscopic skills when trained on multiple ports [10] and across a variety of
94 parameter spaces [11]. However, as previously discussed, skilled motor learning is also
95 marked by specialisation of function - with sensorimotor commands developed and
96 refined through the interaction with, and tailored for, specific environments. If a small
97 change in the context is associated with a large alteration in the learning task, then
98 generalising from prior learning can interfere with learning the new task and impair

99 performance [6,12]. Thus, one of the major challenges for researchers seeking to
100 improve training regimes is identifying the core (structural) elements that underpin a
101 particular class of behaviours and differentiating such elements from the components
102 associated with a specific (specialist) skill.

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

109 **Materials and methods**

110 Simulation has been effectively utilised for education, assessment, and maintenance of
111 various skills across a diverse range of domains. It has been particularly crucial in
112 professions that demand a high degree of precision and safety – such as healthcare
113 education [13,14]. The purpose of simulation is generally agreed to be to replicate or
114 amplify real experiences using analogous tools or settings that imitate real world
115 conditions, with the goal of learning and training, in an immersive and interactive mode
116 [15,16]. In dental and surgical education, intensive theoretical and practical preclinical
117 training is fundamental to bridge the educational gap between preclinical and clinical
118 practice [17–20]. In the context of this experiment, none of the participants had any
119 previous experience of using these two simulators and each participant was allowed to
120 try out the devices as part of the introduction to familiarise themselves with the procedure
121 and the required tasks. The experiment lasted approximately 20-25 minutes in total to
122 perform one attempt on the two assessment tasks.

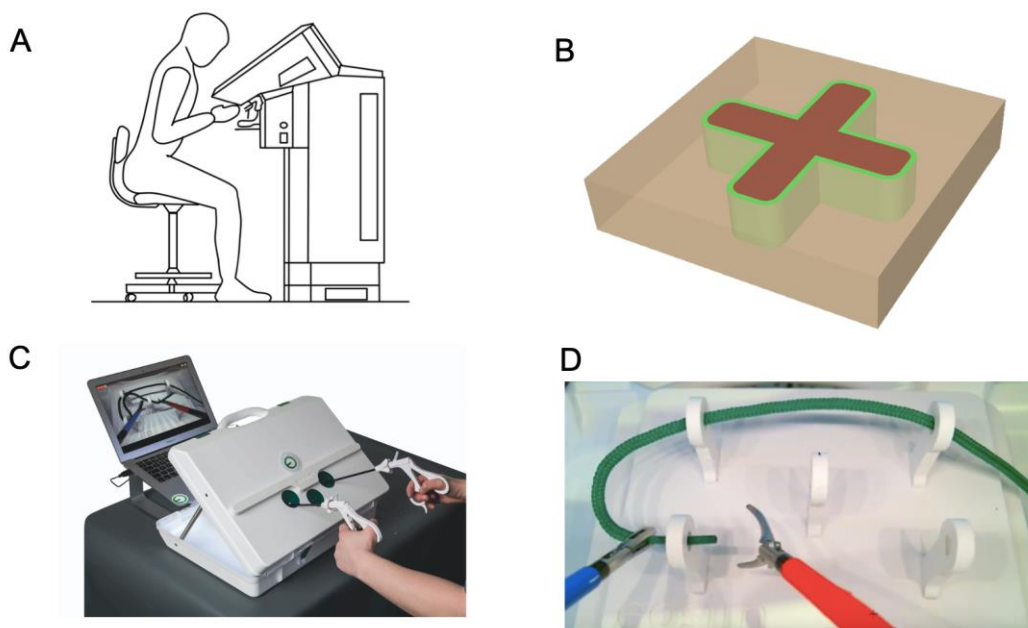
123 We used a high-fidelity haptic virtual reality (VR) simulator (Moog Simodont Dental
124 Trainer® [21,22]) and a laparoscopic box simulator (EoSim®[23–25]) to assess the
125 performance of dentists (N = 19, 7 females, M = 4.7 ± 1.27 years of experience) and
126 laparoscopic surgeons (N = 19; 8 females, M = 5.05 ± 5.79 years of experience) on
127 simulated surgical and dental tasks. We sought to compare the performance of these
128 participants against a surgically naïve control group of participants with an equivalent
129 level of education. Postgraduate psychologists presented a sample of convenience (N =
130 19; 11 females) that satisfied these criteria. The study followed the tenets of the
131 Declaration of Helsinki and was approved by the local Research Ethics Committee at the
132 School of Psychology (reference 17-0166), University of Leeds, United Kingdom.

133 To examine performance in dental surgery, we asked participants to drill through a
134 virtual 3D shape presented by the Haptic VR Dental Simulator (see Figure 1A). The
135 shape comprised three zones (see Figure 1B): (i) a target zone- which needed to be
136 removed by the participant; (ii) leeway zones (side and bottom) surrounding the target
137 zone which the participants were instructed to avoid removing; and (iii) container
138 zones (sides and bottom) which the participants were also told they must avoid. The

139 participants were informed that they needed to remove 99% of the target zone. For
140 assessing laparoscopic surgery performance, a thread transfer task was used. The task
141 involved inserting a thread in 5 pegs (holes) within 10-minutes, using laparoscopic
142 graspers with both hands (see 1C and 1D).

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

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



153 **Figure 1.** (A) Schematic drawing of the VR dental simulator and the experimental setting. (B) Schematic
154 of the cross-shape dental task presented through a haptic VR simulator, illustrating the location of the
155 target area, the Leeway and Container. (C) The set-up of the surgical simulator showing the laparoscopic
156 task. (D) The peg-threading setup of the laparoscopic task.
157

158 **Statistical analysis**

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

164 The dental composite measure was calculated by multiplying the total error by the time
165 taken, such that lower scores indicate better performance (Equation 1). The
166 laparoscopic composite measure was calculated by multiplying the number of
167 incomplete holes (n) plus one, by the amount of time taken to complete the task within
168 the maximum time period, such that lower scores indicate better performance
169 (Equation 2). A repeated measures analysis of variance (ANOVA) was conducted to
170 compare performance according to specialty for the z-score composite variables in
171 dental and surgical simulators. The statistical significance threshold was set at $p < .05$
172 and we report generalised eta squared (η^2_G) as a measure of effect size and considered
173 $\eta^2_G = 0.02$ to be small, $\eta^2_G = 0.13$ medium and $\eta^2_G = 0.26$ to be a large effect size. All
174 statistical analyses were performed using the statistical analysis package R and R Studio
175 Version 1.1.463 (28).

$$176 \quad C_{dent} = t_{dent} \times E_T \quad (1)$$

$$177 \quad C_{lap} = t_{lap} \times (n + 1) \quad (2)$$

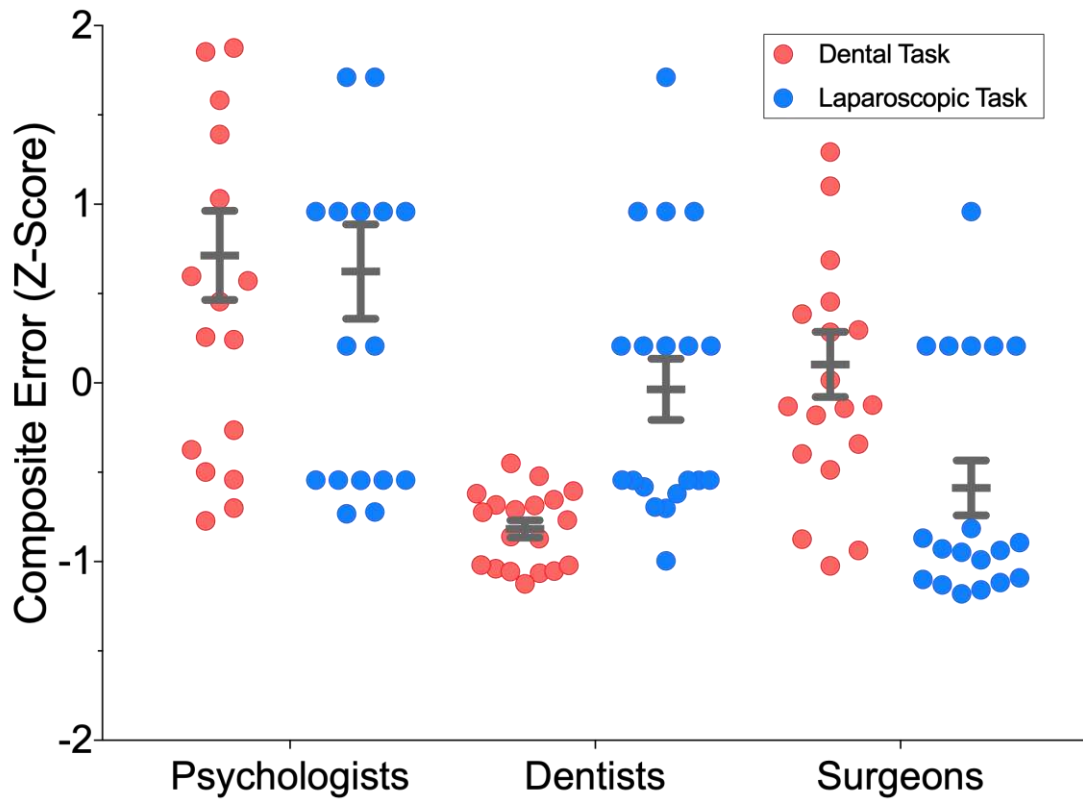
178

179 **Results**

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

185

186 A series of one-way ANOVAs decomposed the interaction by Group. For the Psychology
187 Group, there was no effect of Task Type, [F (1, 18) = 0.058, p =0.81, η^2_G = 0.002],
188 indicating that the Psychology Group produced similar errors in the Dental (M = 0.713,
189 95% CI = [0.333, 1.094]) and Surgical Task (M = 0.623, 95% CI = [0.243, 1.004]). For the
190 Dentists, the effect of Task Type was significant, [F (1, 18) = 24.52, p =0.0001, η^2_G =
191 0.348]], indicating that the Dentists produced fewer errors in the Dental Task (M = -
192 0.817, 95% CI = [-1.197, -0.437]) compared to the Surgical Task (M = -0.036, 95% CI = [-
193 0.416, 0.344]). For the Laparoscopic Surgeons, the effect of Task Type was also
194 significant, [F (1, 18) = 9.05, p= 0.007, η^2_G = 0.189], indicating that the Surgeons
195 produced fewer errors in the Surgical Task (M = -0.587, 95% CI = [-0.967, -0.207])
196 compared to the Dental Task (M = 0.103, 95% CI = [-0.277, 0.484]). Finally, we found
197 that the relative performance of Dentists and Surgeons were not significantly different
198 in their specialities [F (1, 36) = 1.37, p= 0.24, η^2_G = 0.036].



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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.

206 **Discussion**

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

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

228 At this point, it is worth considering why distinct surgical specialties seem to possess
229 core features. Surgery is a complex task where the complexity reflects the integration of
230 both cognitive and sensorimotor processes [27]. In terms of the cognitive processes
231 involved, all surgeons require high-level medical knowledge to make the appropriate
232 assessment and evidence-based decisions. It is relatively easy to identify what cognitive
233 knowledge constitutes core information required by all specialties and this is the
234 foundation of much medical training before career specialization. Likewise, it is a trivial
235 task to identify the specific knowledge required by a given surgical specialty. Integral to
236 all specialist surgical training is the provision of specific knowledge about anatomy and

237 procedures. In contrast, the complexities of sensorimotor control [28] mean that it is
238 much harder to understand the sensorimotor processes that underpin specific surgical
239 procedures and identify the sensorimotor skills that are common to all skilled surgeons.
240 The present study presents, to our knowledge, the first attempt at delineating the
241 sensorimotor surgical skills that can be extrapolated to novel situations.

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

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

257 The road to becoming a highly skilled surgical practitioner is a long (and often arduous)
258 one. It is also the case that there are currently evidence-based approaches to facilitating
259 this learning process. We suggest that detailed investigation into the nature of core skill
260 development that transfers across specialties could inform the development of effective
261 training structures to support learning for surgeons and improve training provision
262 before specialisation. For example, it may be possible to produce generic ‘surgical
263 trainers’ that enable a surgeon of any discipline to learn the fundamental motor
264 behaviours before becoming specialized in one type of surgery. These trainers might
265 not only play a fundamental role in skill learning (and lead to a better understanding of
266 the flexibility and adaptability of the sensorimotor system [6,25]), but may also have the
267 potential to offer new ways to screen and assess prospective surgeons. The increasing

268 prevalence of low-cost virtual and augmented reality technology simulators could
269 present an opportunity for developing such multi-purpose systems[38,39]. The key to
270 maximising their utility for surgical training will be in ensuring that these systems are
271 grounded in the science of human learning.

272 **Conclusion**

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

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386