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PsT1: A Low-Cost Optical Simulator for Psychomotor Skills Training in Neuroendoscopy

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Key words
- Angled optics
- Box trainer
- Degrees of freedom
- Metrics
- Neuroendoscopy

Abbreviations and Acronyms
DOF: Degrees of freedom
USB: Universal serial bus

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BACKGROUND: **Well-developed psychomotor skills are important for competence in minimally invasive surgery. Neuroendoscopy is no exception, and adaptation to different visual perspectives and careful handling of the surgical instruments are mandatory. Few training systems, however, focus on developing psychomotor skills for neuroendoscopy. Here, we introduce a new training system called PsT1 that provides visual feedback via the use of simple optics that emulate the endoscope at 0° and 30°. Time and error metrics are generated automatically with integrated software to ensure objective assessment.**

METHODS: **Neuroendoscopic optics were emulated with a low-cost, commercially available universal serial bus 2.0 camera and a light-emitting diode light source. Visual feedback of 30° was obtained by displacing the optical axis of the universal serial bus camera by 30°, and metrics (time, precision, and errors) were generated automatically by the software. Three evaluation modules were developed (spatial adaptation, depth adaptation, and dissection), and 35 expert and nonexpert neurosurgeons performed an initial evaluation of the system.**

RESULTS: **A total of 81% and 90% of surgeons agreed that the visuals were satisfactory and movement and control were accurately replicated, respectively. The advantages and disadvantages of the system were compared.**

CONCLUSIONS: **Here, we present a novel, low-cost, and easy-to-implement training system for developing basic neuroendoscopic psychomotor skills. The use of objective metrics, surgical instruments, and emulation of the neuroendoscope at 0° and 30° are competitive advantages of the current system.**

INTRODUCTION

Most minimally invasive neuroendoscopic surgical training focuses on learning anatomy, surgical planning, and procedural and decision-making skills (9, 24, 26). Well-developed psychomotor skills are essential for mastering minimally invasive techniques and optimizing patient outcomes (22, 31, 32). Perhaps even more than in other minimally invasive disciplines, neuroendoscopy requires extremely careful handling of the surgical instruments and neuroendoscope and exemplary psychomotor skills because of the precise nature of the procedures (3, 18).

As a consequence, neuroendoscopy trainees must develop a range of non-innate skills, including navigation, depth perception, visuospatial orientation, and mental interpretation of the 3-dimensional space from 2-dimensional visual feedback. Adaptation to visual perspectives of 0° and other angles and loss of haptic feedback compound learning difficulties (18), and training in the management of the optics is an essential step that needs to be mastered. In addition to this, the difficulty is increased when the surgical space or geometric scale is reduced, as is the case in pediatric surgery. To our knowledge, however, there are no systems that allow the development of essential basic skills without relying on the neuroendoscopic tower.

Recent studies in adult learning theory, specifically applied to neurologic surgery, emphasize the need for curricula that address multiple learning needs via a variety of methods and formats (3). As part of the multimodal approach, interactive learning via the use of simulation is known to be effective, not least because practical experience is inseparable from the learning process (28, 30). To this end, several options exist for developing neuroendoscopic skills outside the operating room, including practice on cadavers or animals and the use of trainers. Although practice on cadavers is most commonly used (1), training is expensive because of the required labor, infrastructure, and facilities, which are not always available or considered when calculating training costs (24, 26), and there are ethical barriers in many jurisdictions when cadavers or animals are used. However, training opportunities are increasingly becoming limited because of restrictions in working hours (e.g., the European Working Time Directive in the European Union), the increasing cost of operating room time, and ethical concerns surrounding patient safety (17). These factors have encouraged learning environments outside the operating room (31), but economic and technical factors often limit their use in developing countries.

Virtual training systems (e.g., Dextroscope [BRACCO AMT, Inc., Princeton, New Jersey, USA] (23); cranial base surgical simulators (5); ImmersiveTouch (ImmersiveTouch Inc., Chicago, Illinois, USA) (25); BrainTrain (ETH, Zurich, Switzerland) (29); IO Master 7D (Centre Karlsruhe, Germany) (36); burr-hole simulation (Val G.Hemming Simulation Center, USA) (2); NeuroTouch (National Research Council Canada) (11); and virtual endoscopy (vE) (37) represent significant innovations for surgical training. The most sophisticated of these systems include acquisition of multiple training metrics, modeling of deformation of tissue, and real-time haptic feedback, but their high costs have limited their academic impact (10, 26). Meanwhile, physical trainers (e.g., S.I.M.O.N.T.; Pro Delphus Surgical Dimlator, Pernambuco, Brazil) (15) and Endoscopic Sinus Surgery (SurgTrainer Ltd., Tsukuba City, Japan) (7) are considered to be excellent low-cost alternatives. However, the use of physical trainers is limited by the need to use neuroendoscopy equipment, which in developing countries in particular usually is committed to clinical use. In addition, these systems generally do not track metrics, decreasing their usefulness for training evaluation. Similarly, animal models have similar limitations to the physical trainers (14), not least the need to commit neuroendoscopic equipment to training.

The main objective of this study was to develop a new system for training basic neuroendoscopic psychomotor skills that: 1) addresses the lack of psychomotor skills training systems in neurosurgery; 2) addresses the lack of training systems that work in the 0° and 30° visual perspectives; 3) does not unduly commit equipment for basic skills training; and 4) addresses the lack of physical trainers with metrics. In our easy-to-implement and low-cost system, visual feedback at 0° and 30° is obtained by a camera that emulates the laparoscope and can be connected to any computer via a universal serial bus (USB) port, with calculation and registration of metrics performed using a Matlab (MathWorks, Natick, Massachusetts, USA) implementation.

MATERIALS AND METHODS

Design Specifications

In general, no defined norms exist for the design of simulators. However, as a frame of reference, we can summarize that our proposal does not alter or limit natural neuroendoscopic movement. With respect to camera handling, the movement of the surgeon's hand is reduced to 4 degrees of freedom (DOF) after passing a pivot point. The basic movements available are in-out, left-right, forwards-backwards, and rotation of the laparoscope on its own axis. Likewise, the visual perspectives of 0° and 30° with visual feedback in 2 dimensions are considered.

Video

Video available at WORLDNEUROSURGERY.org

Visual Feedback

The visual feedback system (which replaces the laparoscope) is a low-cost, commercially available USB 2.0 camera (image resolution 640 × 480, 30 frames per second, f/2,4 lens, dimensions 10 × 40 mm). This mini USB camera, using its native optics, allows visualization of the inside of the test modules (see below) and establishes natural visual feedback at 0°. Visual feedback of 30° is obtained by displacing the optical axis of the USB camera by 30° (Figure 1). The USB camera is connected to a computer with a USB port, and illumination is achieved using light-emitting diode lights that provide cool white light in the same direction as the endoscope.

Description of the Training Modules

Three modules were developed to test: 1) spatial adaptation, 2) depth adaptation, and 3) dissection (see also Supplementary Video). The spatial adaptation module consists of 4 points (Ø = 3 mm diameter) distributed within a cylindrical space: 3 points are positioned proximally and the other 3 points more distally. The aim of the task is to touch each of the points using the simulator to complete a sequence (from point 1 to point 4; see Figure 2). An audible alarm indicates that each point has been touched, and the learner is penalized if an undesignated area is touched or if the points are touched in the wrong order.

In the depth adaptation module, a nonlinear path from point A to point B must be traced using the instruments (Figure 3). A penalty is generated each time the instrument tip touches the walls or the base of the track.

For the dissection module, an 8-mm diameter circle is drawn on a polystyrene sheet. The task goal is to dissect accurately the circle without cutting outside the circle. A penalty is generated if the dissected area differs from the ideal cut (Figure 4), the value of which depends on the degree to which the dissection differs from the ideal dissection. The difference between the ideal cut and cut performed is automatically determined by calculating the circumference in Matlab.

For all 3 tasks, the time (t) is recorded from the time that the instruments are

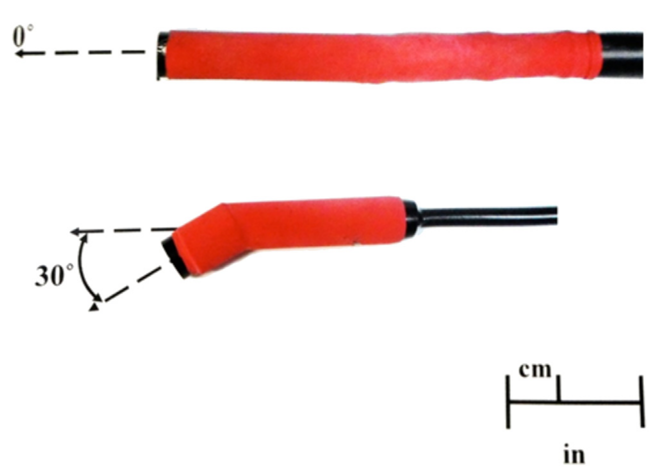

Figure 1. A USB camera that emulates the neuroendoscope and provides visual perspectives of 0° and 30°.