Comparison of Performance Metrics for Real-Time Haptic Feedback in Surgical Skill Training

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INTRODUCTION

Endovascular surgery involves minimally invasive surgical techniques that can result in significantly shorter operation times and hospital stays, lower complication rates, less blood loss, and lower rates of postoperative mechanical ventilation and atrial fibrillation than the equivalent open procedures [1], [2]. Repeated practice is central to skill acquisition, and minimally invasive procedures like endovascular surgery may require more or specialized practice compared to traditional surgery. For example, despite known benefits of endovascular aortic valve replacement compared to traditional surgical methods, Smith et al. attributed observations of higher rates of stroke, transient ischemic attacks, and major vascular complications to a protracted learning curve for the endovascular approach [3].

Virtual reality endovascular surgical simulators can be loaded with a patient's pre-operative CT scan, enabling rehearsal of difficult cases before operating. Simulators are also accessible to trainees, giving opportunities for additional practice in navigating to hard-to-reach vascular structures, or exposure to rare procedures. Still, surgical simulators lack the provision of real-time and objective performance feedback. Instead, feedback is only available after the completion of a surgical task, and often does not provide the trainee with insight into *how* they should change their task performance strategies to achieve performance goals.

Objective measures of skill derived from endovascular guidewire movement kinematics that characterize tool tip movement smoothness have been shown to correlate with expertise [4], [5]. Such metrics have not yet been used during training as real-time performance feedback, despite evidence that providing feedback can improve training outcomes [6].

Our approach to providing real-time performance feedback during surgical skill training is intended to address this gap. We propose to use estimates of spectral arc length (SPARC), idle time, and average velocity to quantify task performance, then encode these measures as vibrotactile cues displayed to trainees in a wearable haptic device (see Fig. 1). We have shown the provision of feedback based on SPARC to be effective for enhancing performance during a mirror-tracing task that emulates endovascular navigation [7]. It was noted that trainees faced difficulties in interpreting and understanding the SPARC-based performance feedback that was provided, likely due to the non-intuitive nature of this frequency-domain measure of movement smoothness. More recently, we have explored alternative performance measures that may be easier for trainees to understand, namely average velocity and idle time, which are time-domain measures of smoothness [8].

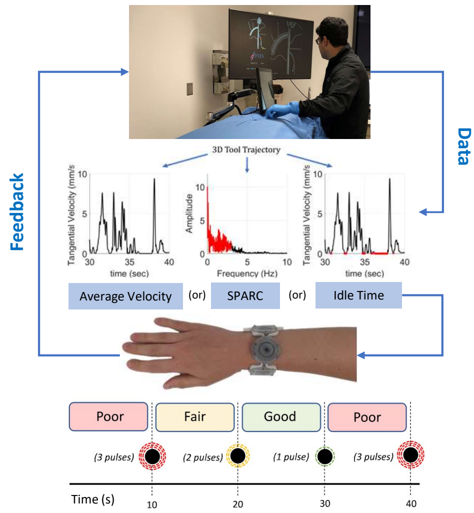

Fig. 1 Our method for providing real-time haptic feedback for training in endovascular surgery. Trainees perform navigation tasks with the AngioMentor. Data are streamed and performance metrics are computed. Metrics are encoded as a haptic cue provided to the trainee with a wearable vibrotactile bracelet.

In this work, we examine trainee performance of an endovascular navigation task using a commercial endovascular surgical simulator. We retrospectively analyze performance that was recorded without real-time feedback, and explore the nature of the real-time feedback that trainees would have received based on online computation of SPARC, average velocity, and idle time. Our goal is to determine the best performance metric on which to base real-time haptic feedback that encodes task performance.

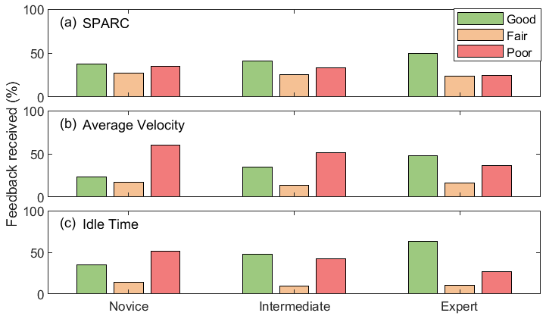

Fig. 2 Distribution of feedback received by novices, intermediates and experts for each performance metric

Average Velocity	SPARC Good	SPARC Fair	SPARC Poor
Good	38%	43%	22%
Fair	15%	17%	15%
Poor	47%	39%	63%

Idle Time	SPARC Good	SPARC Fair	SPARC Poor
Good	48%	59%	36%
Fair	8%	14%	13%
Poor	43%	27%	51%

Average Velocity	Idle Time Good	Idle Time Fair	Idle Time Poor
Good	61%	28%	6%
Fair	18%	28%	9%
Poor	21%	45%	85%

Fig. 3 Mapping of observed feedback for SPARC, average velocity and idle time

MATERIALS AND METHODS

We evaluated guidewire tool tip kinematic data that were collected in a previous study involving 75 participants (57 male, 18 female; 31 novices, 25 intermediates, and 19 experts determined by prior caseload) [8]. Participants were asked to perform four different navigation tasks comprising the FEVS (Fundamentals of Endovascular Surgery) [9] using a commercial virtual reality simulator (AngioMentor, Surgical Science). Real-time performance feedback was not provided to the trainees. Tangential velocity profiles were determined from tool tip data and used to compute the performance measures (SPARC, average velocity, and idle time). Scores were categorized as good, fair, or poor based on performance thresholds computed from prior studies (see Murali et al. [8]). We analyzed the distribution of good, fair, and poor feedback that participants would have received if real-time performance feedback had been provided based on each of the proposed metrics. We also analyzed the agreement in performance feedback between metrics.

RESULTS

Overall, the frequency of “good" feedback increases as participant expertise increases, as expected (see Fig. 2). Feedback based on average velocity and idle time is more likely to indicate “poor" performance than when based on SPARC. “Fair" feedback is rare when based on average velocity or idle time.

Despite prior studies showing good correlation between SPARC and both idle time and average velocity [8], our analysis shows that the feedback categories based on these metrics are rarely in agreement with those based on SPARC (see Fig. 3). For example, 47% of the “good” feedback for SPARC is mapped to “poor” feedback for average velocity. Similarly, 43% of “good” feedback cues for SPARC are mapped to “poor” feedback for idle time.

DISCUSSION

Studies in motor learning show that while corrective feedback can accelerate adaptation and learning, positive feedback can improve retention of skill [10]. In our study, movement smoothness feedback based on SPARC offers a more distributed set of feedback cues with "fair" and "good" feedback provided more frequently compared to feedback based on average velocity and idle time. Positive feedback has potential for increased self-efficacy [11] and intrinsic motivation [12]. Smoothness feedback based on SPARC has been successfully used to improve performance in endovascular-like tasks [7], and the variability in positive and negative feedback makes SPARC the preferred choice for surgical training.

REFERENCES

[1] M. Prinssen, E. L. Verhoeven, J. Buth, P. W. Cuypers, M. R. van Sambeek, R. Balm, E. Buskens, D. E. Grobbee, and J. D. Blankensteijn, “A randomized trial comparing conventional and endovascular repair of abdominal aortic aneurysms,” *New England Journal of Medicine*, vol. 351, no. 16, pp. 1607–1618, 2004.

[2] F. A. Lederle, T. C. Kyriakides, K. T. Stroupe, J. A. Freischlag, F. T. Padberg Jr, J. S. Matsumura, Z. Huo, and G. R. Johnson, “Open versus endovascular repair of abdominal aortic aneurysm,” *New England Journal of Medicine*, vol. 380, no. 22, pp. 2126–2135, 2019.

[3] C. R. Smith, M. B. Leon, M. J. Mack, D. C. Miller, J. W. Moses, L. G. Svensson, E. M. Tuzcu, J. G. Webb, G. P. Fontana, R. R. Makkar, M. Williams, T. Dewey, S. Kapadia, V. Babaliaros, V. H. Thourani, P. Corso, A. D. Pichard, J. E. Bavaria, H. C. Herrmann, J. J. Akin, W. N. Anderson, D. Wang, and S. J. Pocock, “Transcatheter versus surgical aortic-valve replacement in high-risk patients,” *The New England Journal of Medicine*, vol. 364, no. 23, pp. 2187–2198, 2011.

[4] V. M. Belvroy, B. Murali, M. G. Sheahan, M. K. O’Malley, and J. Bismuth, “In the Fundamentals of Endovascular and Vascular Surgery model motion metrics reliably differentiate competency,” *Journal of Vascular Surgery*, vol. 72, no. 6, pp. 2161–2165, 2020.

[5] S. Estrada, C. Duran, D. Schulz, J. Bismuth, M. D. Byrne, and M. K. O’Malley, “Smoothness of surgical tool tip motion correlates to skill in endovascular tasks,” *IEEE Transactions on Human-Machine Systems*, vol. 46, no. 5, pp. 647–659, 2016.

[6] A. Malpani, S. S. Vedula, H. C. Lin, G. D. Hager, and R. H. Taylor, “Effect of real-time virtual reality-based teaching cues on learning needle passing for robot-assisted minimally invasive surgery: a randomized controlled trial,” *International Journal of Computer Assisted Radiology and Surgery*, no. 15, p. 1187–1194, 2020.

[7] J. L. Sullivan, S. Pandey, M. Byrne, and M. K. O’Malley, “Haptic feedback based on movement smoothness improves performance in a perceptual-motor task,” *IEEE Transactions on Haptics*, pp. 1–1, 2021.

[8] B. Murali, V. M. Belvroy, S. Pandey, J. Bismuth, M. D. Byrne, and M. K. O’Malley, “Velocity-Domain Motion Quality Measures for Surgical Performance Evaluation and Feedback,” *Journal of Medical Devices*, vol. 15, no. 1, p. 011107, 2021.

[9] C. Duran, S. Estrada, M. O’Malley, M. G. Sheahan, M. L. Shames, J. T. Lee, and J. Bismuth, “The model for Fundamentals of Endovascular Surgery (FEVS) successfully defines the competent endovascular surgeon,” *Journal of vascular surgery*, vol. 62, no. 6, pp. 1660–1666, 2015.

[10] D. Sternad and K. P. Körding, “Carrot or stick in motor learning,” *Nature neuroscience*, vol. 18, no. 4, pp. 480–481, 2015.

[11] K. A. Karl, A. M. O’Leary-Kelly, and J. J. Martocchio, “The impact of feedback and self-efficacy on performance in training,” *Journal of Organizational Behavior*, vol. 14, no. 4, pp. 379–394, 1993.

[12] C. Burgers, A. Eden, M. D. van Engelenburg, and S. Buningh, “How feedback boosts motivation and play in a brain-training game,” *Computers in Human Behavior*, vol. 48, pp. 94–103, 2015.