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Periodic Kinesthetic Guidance Cannot Expedite Learning Surgical Skills

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Abstract

Introduction. Connecting multiple haptic devices in a master-slave fashion enables us to deliver kinesthetic (haptic) feedback from 1 person to another. This study examined whether inter-user feedback delivered from an expert to a novice would facilitate skill acquisition of the novice in learning laparoscopic surgery and expedite it compared to traditional methods. *Methods.* We recruited fourteen novices and divided them into 1 of 2 training groups with 6 half-hour training sessions. The task was precision cutting adopted from one of the tasks listed in Fundamentals of Laparoscopic Surgery using laparoscopic instruments. In the haptic feedback group (haptic), 8 subjects had the chance to passively feel an expert's performance before they started to practice in each training session. In the self-learning group (control), 6 subjects watched a video before practicing. Each session was video recorded, and task performance was measured by task completion time, number of grasper adjustments, and instrument crossings. Cutting accuracy, defined as the percentage of deviation of the cutting line from the predefined line, was analyzed via computer analysis. *Results.* Results show no significant difference among performance measures between the 2 groups. Participants performed similarly when practicing alone or with periodic haptic feedback. *Discussion.* Further research will be needed for improving our way of integrating between-person haptic feedback with skills training protocol.

Keywords
haptic interface, skill acquisition, task performance and analysis

Introduction

Haptic devices, like SensAble™ Phantom® Omni (SensAble Technologies, Inc, Woburn, Massachusetts), allow us to feel the texture and density of virtual objects displayed on a computer screen.[1] Such technologies generate force according to the different texture and tissue properties and subsequently feedback the signal to the hands of a human user. The ability to feel virtual objects through haptic feedback has significantly enhanced the realism of the interaction between the human and the virtual object. This capability has been utilized in a multitude of different fields including music,[2] as well as health care. Examples, where this has been helpful, include guiding arterial catheterization,[3,4] promoting physician navigation and identification and characterization of tissues,[5,6] as well as enhancing surgeon performances while taking a biopsy from a patient.[7]

Besides connecting a human user to virtual objects within a computer, haptic devices can also deliver kinesthetic feedback from 1 individual to another when we connect multiple haptic devices. In the Surgical Simulation Research Lab (SSRL), we connected 4 Phantoms to build a complex master-slave system that allowed the movement from both hands of 1 individual to the hands of another.[8] This system was coined as "What-you-feel-is-what-I-feel" (WYFWIF)[7] and has been proven to have significant benefits for skill training outside of health care.[9]

WYFWIF also provides a unique opportunity in healthcare education where we can incorporate haptic guidance to enhance training, especially in the field of surgery. Since the early 1900s, laparoscopic surgery provided a novel way of performing procedures while minimizing incision size and enhancing healing times. By the 1970s, modern laparoscopic surgery using cameras and insufflation became more and more popular.[10] Now, its widespread use in all surgical fields means that all

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surgical residents have to demonstrate proficiency with laparoscopic techniques and be able to master the Fundamentals of Laparoscopic Surgery (FLS) before they can be licensed and function as an independent practitioner.[11]

Traditionally, methods of training residents have primarily consisted of passive learning from watching a video or demonstration of a task and subsequently practicing that task. Trainees repeat the task until they reach some proficiency that meets the FLS standard.[12] This training method can often be time-consuming and may not result in the most efficient or best way of performing the task depending on what their skill levels are and what the video or demonstration showed. In other words, it lacked expert guidance, and it required significant time commitments. Both of which are hard to acquire in a practice setting, given clinical obligations of both trainee and physician teachers.

However, by creating a system where we can record an expert completing a task and translate their kinesthetic movement and techniques to the novice in real-time, we can effectively enhance the training period through haptic feedback. Learners will not only be able to see what the expert has done but also feel the movements as well. Using the WYFWIF system, we intend to test whether between-person haptic feedback can help expedite the process of skill learning in a surgical setting.

We hypothesize that the between-person haptic feedback would facilitate the learning of laparoscopic skills more than the self-learning alone, quantified as a measure of shorter task performance time and fewer performance errors.

Methods

The research was performed in the SSRL of the University of Alberta. Methods used in the study were reviewed and approved by the University of Alberta Health Research Review Board.

Apparatus

We connected 4 Phantom Omni interfaces in parallel using the Simulink (Mathworks, Palo Alto, California) platform to build a master-slave system. Simulink is a graphical programming environment for a simulation that runs on MATLAB. Details of the haptic communication system can be found in our previous article.[1,2] Briefly, the master-slave system was able to translate 6 degrees of freedom from both hands of 1 person on the master side to the second person on the slave side.

The stylus of each Phantom was modified so that we could attach a laparoscopic instrument to it. Two instruments, a grasper and laparoscopic scissors, on the master side, were inserted into a laparoscopic training box. Inside the box, a piece of fabric was placed on the bottom with a circle drawn within the center. Subjects were required to cut this predefined circle from the piece of fabric. Video recordings of the task were captured by a webcam and displayed to a TV monitor placed on top of the training box, about 75 cm in front of the subject. The same video was simultaneously delivered to a second TV monitor on the slave end (Figure 1). The expert's bimanual movements captured by 2 Phantoms from the master end were then delivered to the 2 Phantoms at the slave end and drove identical movements to 2 laparoscopic instruments. When a learner puts his/her hands on the laparoscopic instruments at the slave end, he/she would be able to see video images the same as the primary operator and receive haptic feedback from the operator.

Figure 1. Overall setup of the kinesthetic guidance system.

Participants

Sixteen volunteers ranging from high-school students to second-year medical students participated in the experiment. No participant had any prior experience in surgery and laparoscopic training. Those with vision and motor control problems were excluded. Written consent was obtained from each participant before entering the experiment.

Baseline Data

Participants were assessed for baseline handedness, depth perception, dexterity, and visuospatial acuity to ensure equal baseline performance between the haptic and control group. Handedness was assessed using the Edinburgh Handedness Questionnaire.[13] Each participant came in for 1 baseline data collection session, where they were asked to complete the questionnaire. All participants included in the study indicated they were right hand dominant.

Following that, depth perception was assessed using Pictorial Surface Orientation (PicSOr) test, a validated, objective test of perceptual skill that predicted laparoscopic technical skill by Gallagher et al.[14] Participants must maneuver the arrow so that the central shaft of the arrow is perpendicular to the surface of the cube. Each participant was given 5 practice rounds, followed by ten real trials. Their accuracy, calculated as the sine of their arrow to the true expected arrow, and time to completion, measured in seconds, for each trial were averaged over the ten trials to provide their composite depth perception score.

Dexterity was measured using the Grooved Pegboard test.[15] Participants were asked to use their dominant hand and place each peg within their corresponding spot on the board. Full instructions are found within the product website.[15] They were then asked to repeat the task using their nondominant hand. Each trial was timed, measured in seconds, and marked according to the product website.

Lastly, participants were assessed for their visuospatial acuity through a mental rotation test. This assessed their ability to mentally manipulate 3D structures in a 2D plane. A mental rotation test was accessed using the free online platform PsyToolKit.[16] It was made based on the original factor-referenced cognitive tests by Ekstrom et al.[17] Participants were asked to follow the instructions on the screen. They were given 5 practice rounds and ten trials. The test recorded time to completion, measured in seconds, as well as the number of questions correct.

Randomization

All baseline scores were recorded and analyzed via Excel. The 6 categories were PicSOr accuracy, PicSOr time to completion, Grooved Pegboard time to completion for the dominant, and nondominant hand, as well as the number of correct answers in mental rotation, and their overall time to complete the task.

The scores were then averaged for all participants in each of the performance categories. Then, going back, each participant who performed above the average received a score of 1 for that category, and those who performed below the average received a score of 0.

These composite scores were then added for each participant to provide a total baseline score that ranged from 0 to 6. Participants on polar opposites of the spectrum were grouped together in the same group, and participants with the same total baseline score were then separated to either the haptic or the control group.

Scores and T-test values for all participants are shown in Table 1. We set a P-value of less than .05 as statistically significant.

Task and Procedure

Participants were assigned to 1 of 2 skill training groups: haptic feedback (haptic) and self-learning (control) group by the previously described randomization section. Precision cutting adopted from the FLS was utilized as the skill task. This involved cutting out a pre-drawn circle

Table 1. Baseline Data for Participants.

Baseline assessment		Group average score		T-test
		Haptic	Control	
Depth perception[a]	SinAvg	.63	.65	.64
	Time (seconds)	10.00	11.10	.65
Dexterity[b]	Right hand (seconds)	61.56	60.33	.71
	Left hand (seconds)	67.22	67.22	1.00
Mental rotation	Time (seconds)	4.89	4.42	.54
Total baseline score		3	2.6	.30

T-test ($P < .05$).

[a] Using PicSOr software.

[b] Grooved Pegboard test.

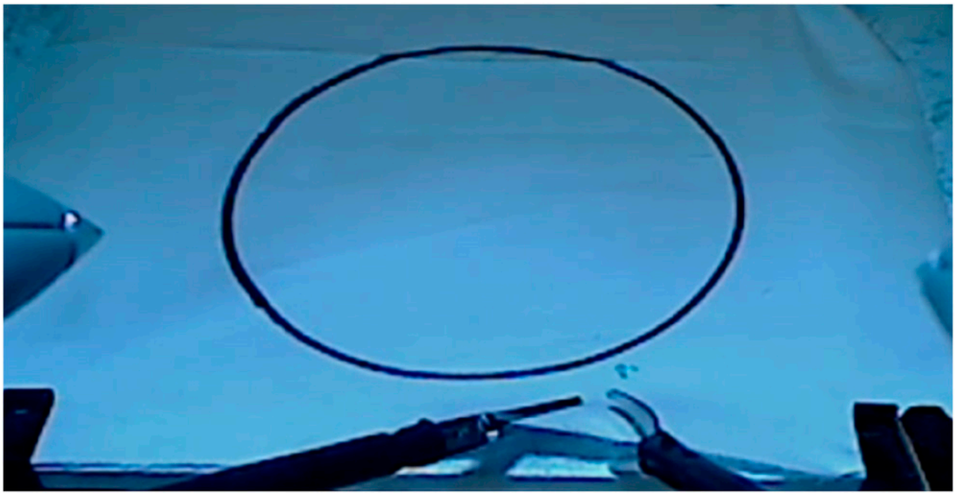

Figure 2. Pattern cutting using laparoscopic instruments and assessment on cutting errors.

within a piece of fabric, using laparoscopic scissors and graspers (Figure 2 and Supplemental Video). Each participant was asked to train for 6 sessions, with each session lasting thirty minutes. All participants viewed an instructional training video before the start of their 6 sessions.

In the haptic group, each participant had a chance to feel movements performed by an experienced operator at the beginning of each training session, followed by self-practice up to 30 minutes. Participants in the control group were given only the first instructional video and then were asked to practice the cutting task with no further aid as per traditional learning methods.

Expert

A research assistant in charge of this project over a 6 - month period practiced the laparoscopic circle cutting task for over 30 trials, sufficient to reach the plateau phase of the learning curve with an average task completion time of 180 seconds. This was considerably shorter than all the selected participants and was deemed sufficient to allow them to deliver the haptic guidance during the experiment.

Measure of Performance

Each complete trial done by a participant was recorded for extracting performance data. The *task completion time* was defined by the moment the laparoscopic instruments touched the fabric to the moment when the circle was out from the fabric.

Bimanual coordination was assessed by the *number of grasper adjustment* and *the number of instrument crossings*. The first is defined by the number of times participants relocated their grasper to provide good counter traction to the scissors held in the right hand. The second measure was defined by the number of times participants crossed their scissors over their grasper in order to continue cutting. Skillful operators often maintain a triangular position between instruments toward the target without letting the instrument crossing the midline. Therefore, instrument crossing leads to invalid bimanual coordination and should be avoided by the participant.

The last performance measure was *cutting accuracy*, which was measured by the deviation from the actual cutting line to the predefined line of the circle. At the end of each valid cutting performance, the cut out circle was scanned. The root mean square was reported to describe the deviation of actual cutting to the predefined line.

Statistical Analysis

The above performance measures were analyzed by the SPSS 22.0 (Chicago, Illinois), using a 2 (training groups) × 6 (Training session) mixed ANOVA with repeated measurements on the second factor. Differences were reported by mean ± standard deviation where $P < .05$ was considered statistically significant. Post hoc analysis was also completed as *Bonferroni* analysis when needed.

Results

ANOVA reported no significant differences between haptic feedback and self-learning group on any of the performance measures. Results are shown in Table 2. Task completion time ($P = .281$), grasper adjustment ($P = .968$), instrument crossing ($P = .694$), and cutting error ($P = .695$) are also given.

Overall, practice over time improved task performance in both groups. Significant differences were found over

Table 2. Statistic Outputs on Task Performance Over 6 Training Session Between 2 Different Training Groups.

		Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	*P* value (session)	*P* value (group)	*P* value (interaction)
Task time	Haptic	308.9 ± 99.6	318.4 ± 98.9	287.8 ± 71.5	264.0 ± 63.1	240.8 ± 41.7	250.0 ± 35.9	.023	.281	.759
(seconds)	Control	280.2 ± 103	274.6 ± 87.7	246.8 ± 56.8	245.0 ± 31.0	228.6 ± 45.9	232.0 ± 64.0			
Grasper adjustments	Haptic	11.8 ± 4.9	13.4 ± 5.9	10.1 ± 3.8	10.2 ± 4.6	8.0 ± 1.8	8.2 ± 2.0	.009	.968	.478
(number)	Control	11.0 ± 4.7	11.3 ± 4.2	10.0 ± 5.4	10.7 ± 5.6	9.9 ± 4.7	8.2 ± 4.2			
Instrument crossings	Haptic	1.2 ± .8	1.2 ± .9	1.2 ± .7	1.2 ± .8	1.0 ± .8	1.2 ± .9	.370	.694	.514
(number)	Control	1.4 ± 2.0	2.0 ± 2.9	1.4 ± 1.9	1.4 ± 1.2	1.2 ± 1.3	.9 ± .8			
Cutting errors	Haptic	22.7 ± 10.8	18.7 ± 4.8	16.1 ± 4.0	15.9 ± 5.2	11.6 ± 2.0	12.6 ± 5.2	.00	.697	.299
(percentage)	Control	21.6 ± 4.6	20.9 ± 5.9	17.5 ± 6.5	11.5 ± 3.0	14.6 ± 4.0	15.8 ± 4.7			

$P < .05$

the 6 training sessions in task completion time ($P = .023$), grasper adjustment ($P = .009$), and cutting error ($P < .001$). However, this was not present for instrument crossings ($P = .370$). Postdoc analysis revealed that the significant drop-in task time occurred between training session 1 and sessions 5 and 6; a significant decrease of grasper adjustment occurred between session 2 and session 6; significant reduction of cutting error occurred between session 1 and sessions 4 and 5.

No significant interaction effects were found between the group and training session on any of the performance measures, that is,, task completion time ($P = .247$), grasper adjustment ($P = .854$), instrument crossing ($P = .672$), and cutting error ($P = .299$).

Discussion

Through our study, it is evident that practice over time did improve task performance. As shown in Table 2, task time, bimanual coordination, and cutting accuracy were improved over 6 training sessions for both research groups (haptic and control). However, adding haptic feedback to a laparoscopic training failed to show benefit in facilitating skill learning compared to self-learning. In other words, our research hypothesis was not supported by our results.

Several factors may contribute to this nonsignificant outcome. The main one being the manner in which we introduced haptic feedback. In the current setting, the haptic feedback was delivered from an experienced operator to the novice at the beginning of each training session to showcase both visually and through haptic feedback on how to complete the task. However, in this scenario, the moment of feedback delivery may not align with the moment of performance difficulty of the novice. In other words, haptic feedback was not present to guide or correct a novice during times of difficulty. Rather, they were able to feel how the expert carried out the task prior to attempting it themselves, but when it came to time to actually perform the task, tricky corners or difficult cuts were still left for the participant to figure out alone. According to the *specificity motor learning* theory, the maximum learning impact would be expected when feedback of performance is given when the performer is struggling with the task.[18] Non-aligned feedback may interfere with skill learning rather than facilitate the process.[19]

A recent article reported a *dual user haptic surgery training system* that will allow 2 surgeons to work side by side.[20] When a novice operator experiences a moment of performance difficulty, the expert in the dyad team can facilitate the performance by delivering a burst of haptic feedback to the novice. We believe this parallel setting of haptic devices will yield observable benefits for skill learning.

Similarly, the degree of haptic feedback provided to the learner may also factor into our results. In our current setting, the amount of feedback is set as a constant in the programing software in order to prevent large jolting movements from being delivered. However, this may sometimes result in subtle movements from the master apparatus not translating to the slave apparatus. Further work in optimizing the programming environment to allow both amplification and reduction in the amount of haptic feedback may benefit future studies so that each haptic delivery is smooth and impactful to the learner.

Another reason for the lack of significant improvement within the haptic group could be our small sample size. We intend to enlarge our sample size to increase statistical power in future studies.

Precaution will also be needed when applying our findings to a clinical setting. The circle cutting task was a simple task that is unrepresentative of a true surgical procedure performed in the operating rooms. The study of surgeons' performance with true surgical tasks, with increased eye–hand, bimanual, and team coordination, may produce different outcomes.

In summary, results from this study failed to show the beneficial effect of learning laparoscopic skills by applying periodic haptic feedback to novices. A future study with an improved design of the haptic system is needed, which allows feedback to be delivered at the moment of learners' performance difficulty. Our ultimate goal is to find an optimal and efficient method of teaching surgical skills.

Author Contributions

Study conception and design: Fangshi Lu, Bin Zheng
Acquisition of data: Fangshi Lu, Betty Wang, Ahmad I. Kathrada
Analysis and interpretation of data: Fangshi Lu, Bin Zheng, and Mahdi Tavakoli
Study supervision: Bin Zheng

Declaration of Conflicting Interests

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Supplemental Material

Supplemental material for this article is available online.

References

1. Çavuşoğlu MC, Feygin D, Tendick F. A critical study of the mechanical and electrical properties of the PHANToM haptic interface and improvements for high-performance control. *Presence Teleoperators Virtual Environ*. 2002; 11(6):555-568.
2. Nichols C. The vBow: A virtual violin bow controller for mapping gesture to synthesis with haptic feedback. *Collected Work: Organised Sound: An International Journal of Music Technology VII/2 (August 2002): Mapping Strategies in Realtime Computer Music*. 2002; 7(2):215-220.
3. Tercero CR, Najdovski Z, Ikeda S, Nahavandi S, Fukuda T. Haptic feedback in endovascular tele-surgery simulation through vasculature phantom morphology changes. Paper presented at 2013 World Haptics Conference (WHC), Daejeon, South Korea, 2013, pp. 359-364.
4. Gobbetti E, Tuveri M, Zanetti G, Zorcolo A. Catheter insertion simulation with co-registered direct volume rendering and haptic feedback. In: *Medicine Meets Virtual Reality 2000 Envisioning Healing: Interactive Technology and the Patient-Practioner Dialogue*. 70: 96-98; 2000.
5. Hu T, Castellanos AE, Tholey G, Desai JP. *Real-Time Haptic Feedback in Laparoscopic Tools for Use in Gastro-Intestinal Surgery.* Berlin, Heidelberg: Springer; 2002.
6. Konstantinova J, Li M, Aminzadeh V, Althoefer K, Thrishantha N, Dasgupta P. Evaluating manual palpation trajectory patterns in tele-manipulation for soft tissue examination. Paper presented at: 2013 IEEE International Conference on Systems, Man, and Cybernetics; October 13-16, 2013; Manchester, UK.
7. Chellali A, Dumas C, Milleville-Pennel I. Haptic communication to support biopsy procedures learning in virtual environments. *Presence Teleoperators Virtual Environ*. 2012;21(4):470-489.
8. Pinzon D. *Learning through Haptics: Haptic Feedback in Surgical education*. [Master's thesis]. Edmonton: University of Alberta; 2016.
9. Feygin D, Keehner M, Tendick R. Haptic guidance: Experimental evaluation of a haptic training method for a perceptual motor skill. Paper presented at: Proceedings 10th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. HAPTICS 20022002; March 24-25, 2002; Orlando, FL.
10. Vecchio R, MacFayden BV, Palazzo F. History of laparoscopic surgery. *Panminerva Med*. 2000;42(1):87-90.
11. Peters JH, Fried GM, Swanstrom LL, et al. Development and validation of a comprehensive program of education and assessment of the basic fundamentals of laparoscopic surgery. *Surgery*. 2004;135(1):21-27.
12. Reznick RK, MacRae H. Teaching surgical skills-changes in the wind. *N Engl J Med*. 2006;355(25):2664-2669.
13. Oldfield RC. The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*. 1971;9(1): 97-113.
14. Gallagher AG, Cowie R, Jordan-Black J-A, Satava RM, Crothers I. PicSOr: An objective test of perceptual skill that predicts laparoscopic technical skill in three initial studies of laparoscopic performance. *Surg Endosc*. 2003; 17(9):1468-1471.
15. Grooved pegboard. https://www.parinc.com/Products/Pkey/122. Accessed December 10, 2019.
16. Stoet G. PsyToolkit. https://www.psytoolkit.org/. Accessed May 5, 2019.
17. Ekstrom RB, Dermen D, Harman HH. *Manual for Kit of Factor-Referenced Cognitive Tests*. Princeton, NJ: Educational Testing Service; 1976: 102.
18. Proteau L, Marteniuk RG, Lévesque L. A sensorimotor basis for motor learning: Evidence indicating specificity of practice. *The Quarterly Journal of Experimental Psychology Section A*. 1992;44(3):557.
19. Richert D, Macnab CJB. Direct adaptive force feedback for haptic control with time delay. Paper presented at: Science and Technology for Humanity, IEEE Toronto International Conference; September 26-27, 2009; Toronto.
20. Motaharifar M, Taghirad HD, Hashtrudi-Zaad K, Mohammadi SF. Control synthesis and ISS stability analysis of a dual-user haptic training system based on S-shaped function. *IEEE ASME Trans Mechatron*. 2019;24(4): 1553-1564.