# Impact of Time Delay on Simulated Operative Video Telementoring: A Pilot Study

Tovy Haber Kamine; Brandon W. Smith; Gladys L. Fernandez

**INTRODUCTION:** As NASA and private spaceflight companies push forward with plans for missions to cis-lunar and interplanetary space, the risk of surgical emergency increases. At latencies above 500 ms, telesurgery is not likely to be successful, so near-real-time telementoring is a more viable option. We examined the effect of a 700-ms time delay on the performance of first year surgical residents on a simulated task requiring significant feedback from a mentor in a pilot study.

**METHODS:** A simulated surgical task requiring precision and accuracy with built-in error detection was used. Each resident underwent two trials, one with a mentor in the same room and one with the mentor using a teleconference with time delay. Outcomes measured included time to complete task, game pieces successfully removed, number of errors, and scores on the NASA Task Load Index by both mentor and operator. Data were analyzed using paired *t*-tests.

**RESULTS:** The time delay group removed significantly fewer pieces successfully than the real time group (3.0 vs. 1.6, $P = 0.02$). There was no difference in the NASA Task Load Index (TLX) scores for the operators between the two groups, but the mentor reported significantly higher scores on Mental Demand (5.6 vs. 12.0, $P = 0.04$) and Effort (6.2 vs. 11.8, $P = 0.05$) during the time-delayed trials.

**DISCUSSION:** A 750-ms time delay significantly degraded performance on the task. Though operator TLX scores were not affected, mentor TLX scores indicated significantly increased mental load. Telementoring is viable, but more onerous than in-person mentoring.

**KEYWORDS:** telementoring, telemedicine, time delay, surgery in space.

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As technological and infrastructure improvements allow for increasingly large amounts of data to be transmitted in real-time, telementoring and telesurgery have increased in interest.[4] Advancements in haptics, visual displays, and networking speed continue to improve this technology. The implementation of these technologies presents many opportunities for development of novel approaches to managing surgical disease and facilitating execution of technical procedures remotely. This is of particular interest in the setting of exploration class spaceflight where a surgeon may not be present on mission.[6] Telemedicine is frequently used in current spaceflight operations and is expected to be used extensively in the future of spaceflight operations for monitoring, support, and consultation.[1] However, while a case report of a simulated Martian time-delay appendectomy has been performed successfully, this required significant prior work, including videos and other visual aides.[10] Since it is not reasonable to expect that all contingencies can be planned for, near real time telementoring for procedures in cis-lunar space is a necessary consideration.

While remote telesurgery using robotics has been considered and even demonstrated, latency in cis-lunar space is a significant issue.[4,8,15] Previous studies have demonstrated that at latencies above 500 ms, telesurgery using robotics becomes increasingly difficult. At delays greater than 1.5 s, many will adopt a move-and-pause strategy.[7,11] In particularly remote or

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austere environments such as battlefields or in space where there may be no surgeon present on site, but a medically trained professional will be on site, telementoring is a more viable option. In this setting, a novice with a solid foundation in the fundamentals of technical procedures may perform a complex or technically challenging procedure for which they have little to no prior training with the assistance of an expert facilitating remotely. The effect of telementoring has been captured in a study evaluating the skills of surgical residents performing Fundamentals of Laparoscopic Surgery tasks with or without a mentor monitoring remotely through a smartphone video chat application, even with a delay of 400 ms.[12] Similar studies have demonstrated the effectiveness of telementoring for teaching laparoscopic skills remotely.[2,9]

As NASA advances the plan to proceed with a lunar base in the Artemis plan, the likelihood of surgical emergency on that lunar base increases. Since telesurgery is not likely to be a viable option given the delays involved, we investigated in a pilot study whether telementoring was viable with a latency of 600–700 ms using an off-the-shelf teleconferencing application. This latency is similar to what might be experienced between the lunar gateway station and a lunar base, though less than the 2-s delay expected from the Earth to the Moon.[6] To test the effects of this latency, we examined its effect on the performance of first year surgical residents executing a simulated task requiring substantial feedback from a mentor in real time vs. receiving feedback remotely with a time delay.

## METHODS

### Establishing Time Delay

Using virtual meeting software and a USB webcam, the time delay on our wireless network was established using a web-based world clock[14] accurate to milliseconds. To determine the mean time delay in milliseconds between the webcam computer (operator) and the observing computer (mentor), 10 screenshots were performed. The time delay averaged around 650 ms with a tight distribution varying by ±50 ms.

Participating were five first-year surgical residents. Each resident (operator) underwent two trials, the first trial with a mentor in the same room and a second with a mentor monitoring remotely through camera feed with a microphone/speaker in front of the workspace. The board game "Operation™" was chosen to simulate a surgical task requiring precision and accuracy with a built-in system to count errors or "buzzes". Each operator was blindfolded to increase the difficulty of the task and ensure the need for constant communication between the mentor and operator. Each trial was limited to 10 min. In the first trial the mentor and operator stood, facing one another, at opposite ends of a small table. With the operator blindfolded, the mentor verbally guided the operator in navigation of the game board to remove pieces. In the second trial, a webcam was placed in the same position, opposite the operator, as the mentor had stood in the previous trial. The remote mentor then guided the operator through the same tasks through microphone/speaker while monitoring the camera feed with our previously established delay. Outcomes measured included game pieces successfully removed, number of errors, and scores on NASA Task Load Index (TLX)—a subjective workload assessment scale that has been validated for use in measuring workload of healthcare tasks by both mentor and operator.[3] Errors and timekeeping were recorded by an independent observer in the operator's room.

The group of operators' number of errors, pieces removed, and the ratio of pieces removed per error were averaged and compared between the time delay group and the real time group using paired *t*-tests. The group of operators' and the mentor's score for each category of the NASA TLX were averaged and compared between the time delay group and the real time group similarly using paired *t*-tests.

## RESULTS

All five operators completed both 10-min trials. The time delayed telementoring group was able to remove significantly fewer pieces successfully than the real time mentoring group (3.0 vs. 1.6, $P = 0.02$). There was not a significant difference in the number of errors per 10-min period (5.2 vs. 5.0, $P = 0.92$), although there was a trend toward a decrease in pieces removed per buzz (1.9 vs. 0.5, $P = 0.10$). The results are summarized in **Fig. 1**.

There was no difference in the NASA TLX scores for the operators between the two groups, either in overall score (73.0 vs. 80.0, $P = 0.22$) or in any individual measurement. The overall scores for the mentor increased without significance from 47.4 to 64.8 ($P = 0.07$), but scores on Mental Demand (5.6 vs. 12.0, $P = 0.04$) and Effort (6.2 vs. 11.8, $P = 0.05$) individually increased significantly during the time delayed trials. (**Fig. 2** and **Fig. 3**).

The NASA TLX overall scores for the mentor were significantly lower than the operators in the no time delay group (47.4 vs. 73.0, $P < 0.01$), but were not significantly different in the time delayed group (64.8 vs. 80.0, $P = 0.20$).

## DISCUSSION

As previously highlighted, the deleterious result of latency on the effectiveness of telementoring remains a barrier in the development and implementation of this technology. As suspected, the time delay group's performance was inferior to the real time group despite it being their second attempt at the task. Since the operators were blindfolded, the lack of physical presence of the mentor is unlikely to be a reason, suggesting the time delay is a driver of this effect. Our results suggest that this delay significantly impacts the efficiency of the operator at the given task. Interestingly, the number of errors was similar between the two groups. This relationship would suggest that the mentor was able to compensate for the delay at the cost of time and efficiency. This is further borne out by the decrease in almost 75% of the number of pieces removed per buzz. This decrease, though large,

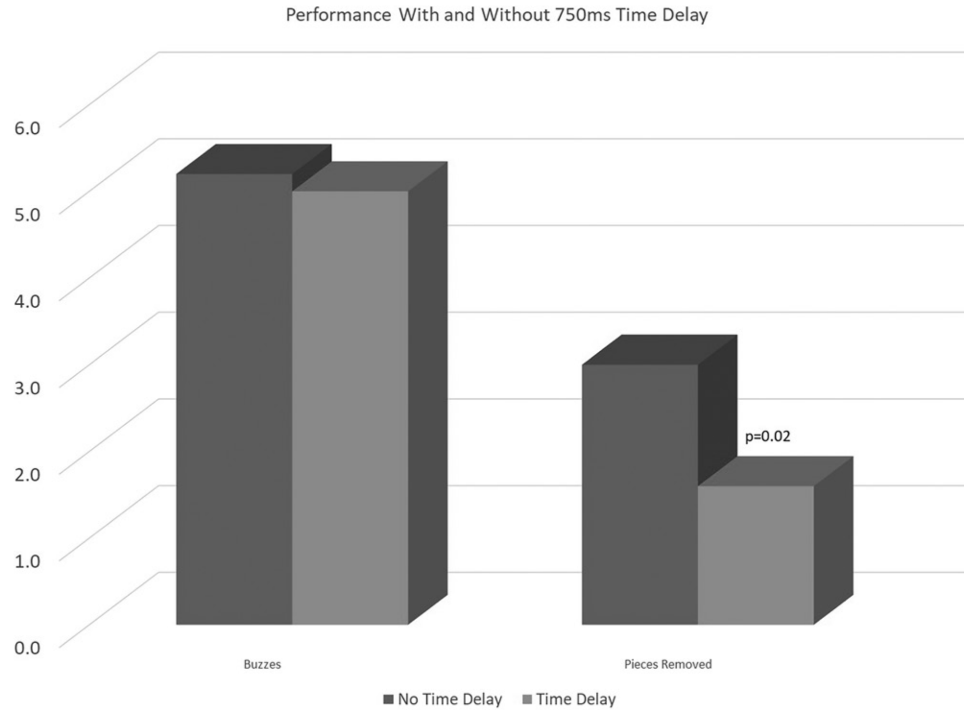


**Fig. 1.** Performance with and without 750-ms time delay.

was not statistically significant, likely because the study was powered only to detect a change in the number of pieces in 10 min, rather than the rate of pieces removed per error.

Review of the NASA TLX scores revealed that the operators' cognitive load was not significantly impacted by the delay. This juxtaposes the mentor's significantly higher rated mental demand and effort, suggesting the strain of the delay was largely overcome by the mentor. The limitations afforded by mentor's fixed vantage point certainly could have contributed to the overall increase in cognitive load reported by the mentor as well. Prior research in remotely piloted aircraft has demonstrated that the lack of normal peripheral visual cues impair

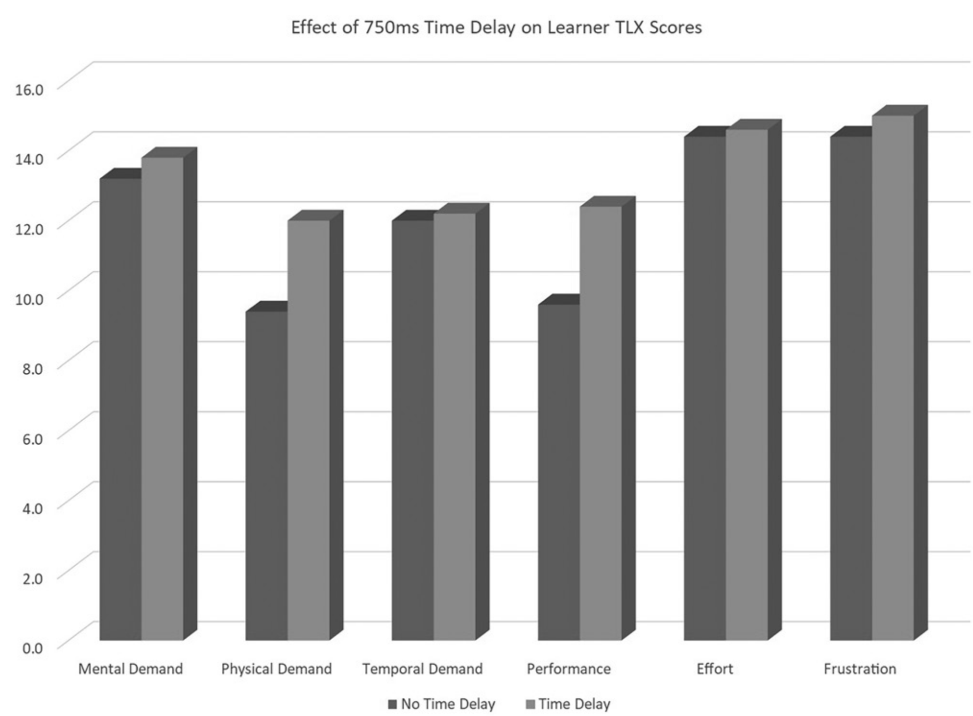


**Fig. 2.** Effect of 750-ms time delay on learner TLX scores.

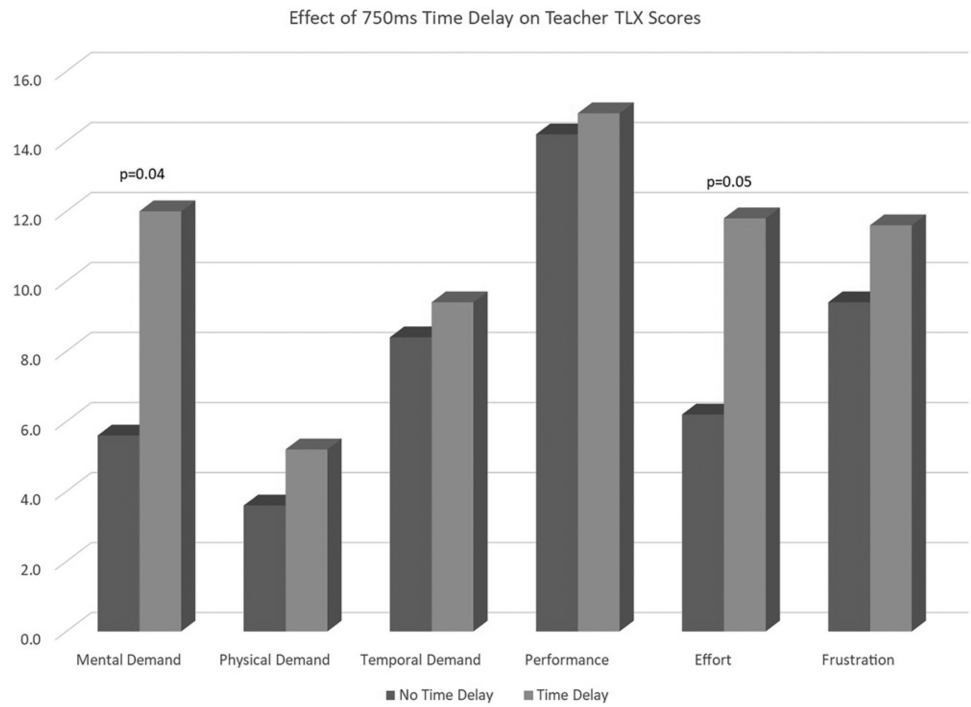


**Fig. 3.** Effect of 750-ms time delay on teacher TLX scores.

the ability to operate the aircraft.[5,13] Similar lack of peripheral vision of the operator and field may have impacted the mentor's ability in this trial. This is a potential concern for future telementoring operations. Our results build on the existing evidence of the effect of latency described in other applications of telesurgery and telementoring. The data do suggest, however, that at a latency of 500–700 ms, telementoring may be a viable option for simple procedures with an acceptable decrease in efficiency and potential increase in errors.

Much of the literature focuses on telesurgical applications in laparoscopy or robotic surgery. In these cases, the mentor is no more disadvantaged by the view than the operator, since both mentor and operator have the same view of the field. Our study design is more representative of a simple, "open" procedure which does not rely on the use of a surgical telescope. This is particularly relevant to the fixed vantage point of the mentor in the time delay trials. In addition, given the simple procedure in this study, it may not be generalizable to other forms of telementoring. In future studies this may be improved upon by incorporation of multiple cameras angles or point-of-view technology, perhaps head-mounted cameras. Our study is further limited by the small nature of the study with only five participants. Despite this, however, our study was adequately powered to identify an effect on our primary endpoint (pieces removed in 10 min) but was not adequately powered to detect a difference in our secondary endpoints (NASA TLX scores, pieces removed per buzz). It is possible that with a larger study we would have detected a significant difference in our secondary endpoints as well.

In conclusion, telementoring appears to remain a viable option for a simple procedural task at simulated latencies of 500–750 s at the expense of time and efficiency. We found that mentors felt guiding the operator was significantly more demanding and required additional effort in the time delay group, suggesting the compensation for the time delay was primarily carried out by the mentor. It is unclear whether this is due to the time delay or the necessity for telepresence via screen. However, it is clear that telementoring is significantly more onerous than in-person mentoring. Ongoing research may aid in development of telementoring curricula for training the trainer in mentor preparation for both graduate education and in-field real-time telesurgery.

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