Pilot Study on Auditory xR in Laparoscopic Surgery Training: Instruments' Movement Sonification Mapping

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Abstract

This paper presents a pilot study on integrating real-time sonification into laparoscopic surgery training to enhance clinical skills under xReality (*xR*) conditions. Laparoscopic procedures demand high technical proficiency. *xR* can contribute to training such procedures more efficiently. Existing simulation-based solutions often overlook the auditory modality, yet sonification can complement visual cues by mapping instrument movements to sound, potentially reducing cognitive load. We introduce a novel sonification mapping for translating tool placement and proximity data into intuitive audio cues. Through formative design workshops and a summative online survey (N=50) with medical technology/domain experts, we evaluated preferences regarding sound mappings for instrument motion. This work contributes empirical insights into a design case of auditory *xR* applications, allowing us to test if sonification leads to more holistic and effective training in minimally invasive surgery.

Keywords

xReality, Augmented Reality, Sonification, Laparoscopy, Medical Education, Medical Training

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1 Introduction

In recent years, xReality [12] including AR, VR, and others has gained increasing relevance in healthcare for medical planning, real-time interventions, and training [8, 10]. Laparoscopic surgery, a minimally invasive technique that demands high technical skill due to constrained visualization and limited tactile feedback, particularly benefits from XR-based training solutions [11]. Simulation-based systems have proven effective in accelerating skill acquisition and improving patient outcomes [5, 6]. Yet, most focus on visual or haptic cues, while the generally sparsely researched auditory feedback in xR [1] remains overlooked in medical training [2]. Overall, many simulators focus primarily on visual and haptic feedback but lack richer sensory integration. This can limit a learner's ability to deeply understand surgical techniques. Mapping instrument or procedural data to sound (Sonification) can enhance situational awareness, reduce cognitive load, and improve performance [3, 4, 7, 9, 14]. This paper contributes an empirical evaluation of a novel sonification mapping for laparoscopic training, translating tool movements into meaningful audio cues for live feedback and thus expanding HCI design in surgical education.

2 Sonification Design

We designed a sonification for the laparoscopic training device using an iterative approach with formative expert workshops and a summative online survey (cf. Figure 1).

Device and System Setup. We use a *Laparo Analytics*[1] device for the laparoscopic training. It has two cameras that track the position of the inserted instruments, made available via Laparo-API and another PC receives the data and stores it for the sonification. Two additional webcams (Logitech C922 Pre HD) were placed inside the trainer. Colored markers on the inserted instruments were used for tracking via custom software running on an external PC. For the sonification step, MeVisLab [13] UI retrieves the newest instrument data and creates sound configurations accordingly. These are then sent to the digital synthesizer software *midikey2key*[2].

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[1]https://laparosimulators.com/analytic/

[2]https://midikey2key.de

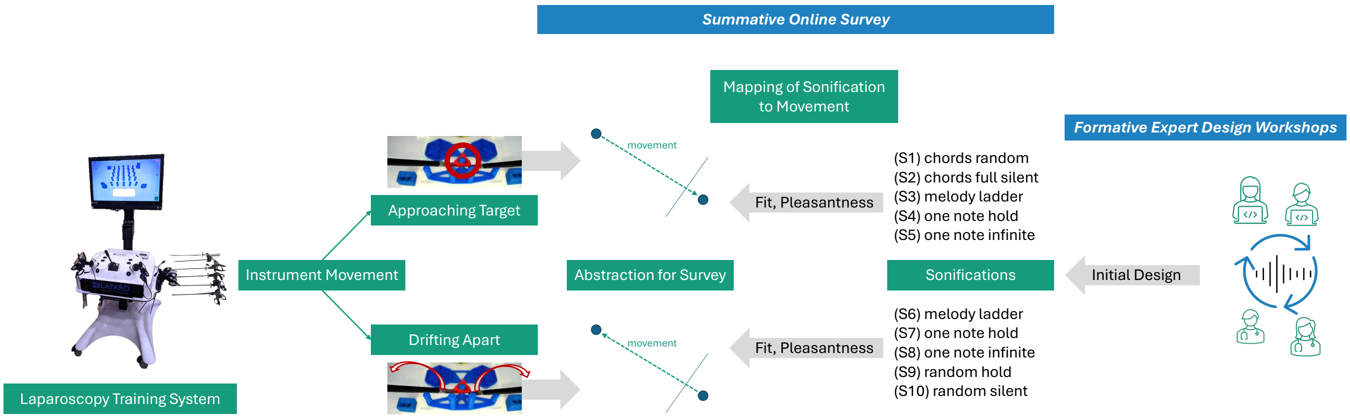


Figure 1: Overview of the Study – To design a pleasant and fitting sonification of the instruments' movement for the laparoscopic training device, we (1) started with multiple sessions of direct interaction between clinicians and sound designers in *formative expert design workshops* , and (2) evaluated the generated sound in a broader *summative online survey* with medical technology and domain experts.

Sound Metaphors – Sonification. The sonification study aims to find suitable sound metaphors / sonifications for the device instruments' movements. Thereby, we initially focused on the following movements: (1) instruments **approaching** a desired area and (2) instruments **drift apart** from another. In surgical contexts, **real-world movements** can be for example: Laparoscopic knots, instruments' smoothness, ergonomic positioning, reaching a specific area in the body, etc. In this paper, we focus on simulator movements, such as depth perception (especially relevant since the surgeons' monitor only allows for 2D perception), reaching/drifting apart from a target area, etc. – often part of training exercises such as ball passing from one instrument to the other, stitching, or ball placement that aim to improve basic surgical skills such as tissue handling, bimanual dexterity, or depth perception. We investigated different sound parameters to communicate the instruments' movements and their position in relation to the operator's hands.

2.1 Formative Design – Workshops with Medical Experts and Sound Designers

We identified suitable sound parameters in meetings between clinicians and sound engineers over two years and based on previous work of Black et al.. The clinicians' perspective was extremely valuable for the sound engineers because they expressed their preferred sound metaphors and arguments for or against specific sound parameter combinations. Lastly, we had a few possible sound options that were approved by the clinicians for both movements. These sounds represented a **chord** or a **single note** that as soon as a target area is left/reached gets louder/more silent and finally **disappears** (silent) or is played **infinitely**. For the movement **approaching target**, we ended up with: (S1) chords random, (S2) chords full silent, (S3) melody ladder, (S4) one note hold, and (S5) one note infinite. For the movement **drift apart**, we ended up with: (S6) melody ladder, (S7) one note hold, (S8) one note infinite, (S9) random hold, and (S10) random silent. The supplementary materials include all sounds for better understanding.

2.2 Summative Evaluation – Online Survey on Mapping Preferences

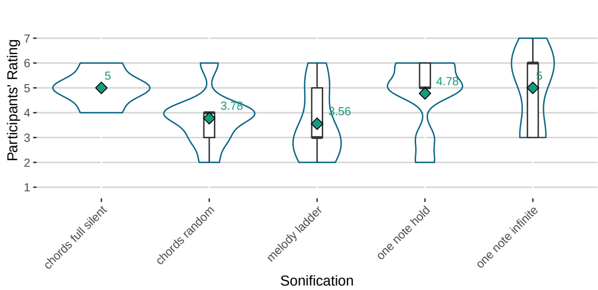
To investigate the preferred mapping between the instrument movements and the sound parameters, we conducted a pre-study with $N = 50$ participants (f=37, m=11, preferred not to answer=2, non-binary=0, other=0). The participants were recruited from two medical product research and development companies (Fraunhofer Institute for Digital Medicine MEVIS[3] and Innovation Center Computer Assisted Surgery ICCAS[4]) internals and from a German University hospital Leipzig[5]. All institutions develop or use medical products, i.e., participants were experts in healthcare and/or technology and on average 38.56±2.1 years old.

We showed an abstracted video (cf. online supplementary material) because we wanted it to fit multiple situations and not to be directly coupled to a particular situation. Nevertheless, we described the purpose with an image of the simulator at the beginning of the study. Participants were asked for both movements to rate the fit and the pleasantness of the presented sonification.

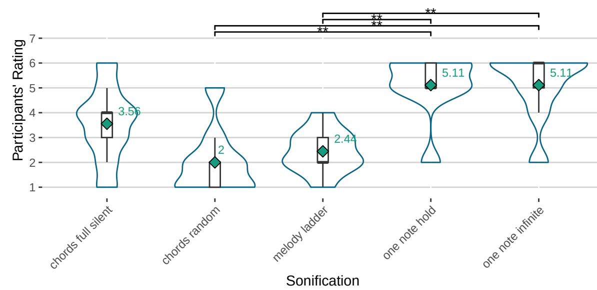
All materials including the sonifications, the questionnaire, and the analysis script are accessible in the online supplementary materials (see Appendix A).

We conducted a one-way ANOVA to compare the effect of different sonifications (chords random, chords full silent, melody ladder, one note hold, one note infinite) on perceived fit and pleasantness for the instruments' movements *approaching a target* area and *drifting apart*. To that end, participants answered on a 7-point Likert scale (1="Strongly disagree" to 7="Strongly agree") how they agreed to the following statements: (1) "The sonification is fitting" and (2) "The sonification is pleasant". We used Tukey HSD post-hoc tests for individual comparisons. Figure 2 shows the user preferences. For sonifications' *fit* for the movement *approaching a target* (see Figure 2(a)), there was a significant effect of the sonification mappings on

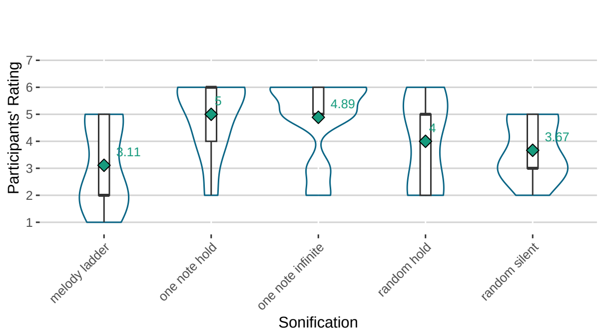
[3]https://www.mevis.fraunhofer.de
[4]https://www.iccas.de
[5]https://www.uniklinikum-leipzig.de



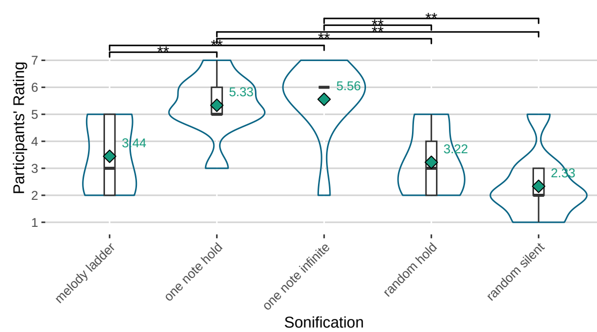
(a) Ratings of how **fitting** each sonification mapping is perceived for instruments' movements **approaching target**



(b) Ratings of how **pleasant** each sonification mapping is perceived for instruments' movements **approaching target**



(c) Ratings of how **fitting** each sonification mapping is perceived for instruments' **drifting apart** from each other



(d) Ratings of how **pleasant** each sonification mapping is perceived for instruments' **drifting apart** from each other

Figure 2: Ratings of how pleasant/fitting each sonification mapping is perceived for instruments approaching or drifting apart from each other.

user ratings of fit (F(4,40)=2.70, p=0.44, η^2=0.21). Post-hoc pairwise comparisons revealed no differences. For sonifications' *pleasantness* for the movement *approaching a target*, there was a significant effect of the sonification mappings on user ratings of pleasantness (F(4,40)=11.49, p<0.001, η^2=0.53). For pairwise comparisons, see Figure 2(b). For sonifications' *fit* for the movement *drifting apart* (see Figure 2(c)), there was a significant effect of the sonification mappings on user ratings of fit (F(4,40)=2.67, p=0.46, η^2=0.21). Post-hoc pairwise comparisons revealed no differences. For sonifications' *pleasantness* for the movement *drifting apart*, there was a significant effect of the sonification mappings on user ratings of pleasantness (F(4,40)=11.09, p<0.001, η^2=0.53). For pairwise comparisons, see Figure 2(d).

3 Discussion and Future Work

Overall, the survey results reveal the most promising sonification mappings that are rated feasible and fitting by experts (one note hold/infinite). Within our future work, we aim to implement these sonifications into the laparoscopic training device (see section 2 – Device and System Setup). We will detail the design of and select different training exercises that train essential surgical skills such as tissue handling, bimanual dexterity, or depth perception – these are implemented in a MEVIS lab interface already (see Figure 3).

Figure 3: Task GUI in MEVIS Lab –– For the later study, we coupled a MIDI interface (sonfications) and the simulator interface (camera, instruments).

The sonifications can communicate the instruments' position when a target is reached, as well as the motion smoothness and ergonomics. Finally, with a set of basic exercises, we want to conduct a randomized controlled trial regarding sonification effects (with/without) on usability and learning success with medical students.

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A Supplementary Material

https://doi.org/10.17605/OSF.IO/W59PG - Files tab