Learning Curves of Virtual Mastoidectomy in Distributed and Massed Practice

Steven Arild Wuyts Andersen, MD; Lars Konge, MD, PhD; Per Cayé-Thomasen, MD, DMSc; Mads Sølvsten Sørensen, MD, DMSc

**IMPORTANCE** Repeated and deliberate practice is crucial in surgical skills training, and virtual reality (VR) simulation can provide self-directed training of basic surgical skills to meet the individual needs of the trainee. Assessment of the learning curves of surgical procedures is pivotal in understanding skills acquisition and best-practice implementation and organization of training.

**OBJECTIVE** To explore the learning curves of VR simulation training of mastoidectomy and the effects of different practice sequences with the aim of proposing the optimal organization of training.

**DESIGN, SETTING, AND PARTICIPANTS** A prospective trial with a 2 × 2 design was conducted at an academic teaching hospital. Participants included 43 novice medical students. Of these, 21 students completed time-distributed practice from October 14 to November 29, 2013, and a separate group of 19 students completed massed practice on May 16, 17, or 18, 2014. Data analysis was performed from June 6, 2014, to March 3, 2015.

**INTERVENTIONS** Participants performed 12 repeated virtual mastoidectomies using a temporal bone surgical simulator in either a distributed (practice blocks spaced in time) or massed (all practice in 1 day) training program with randomization for simulator-integrated tutoring during the first 5 sessions.

**MAIN OUTCOMES AND MEASURES** Performance was assessed using a modified Welling Scale for final product analysis by 2 blinded senior otologists.

**RESULTS** Compared with the 19 students in the massed practice group, the 21 students in the distributed practice group were older (mean age, 25.1 years), more often male (15 [62%]), and had slightly higher mean gaming frequency (2.3 on a 1-5 Likert scale). Learning curves were established and distributed practice was found to be superior to massed practice, reported as mean end score (95% CI) of 15.7 (14.4-17.0) in distributed practice vs 13.0 (11.9-14.1) with massed practice (P = .002). Simulator-integrated tutoring accelerated the initial performance, with mean score for tutored sessions of 14.6 (13.9-15.2) vs 13.4 (12.8-14.0) for corresponding nontutored sessions (P < .01) but at the cost of a drop in performance once tutoring ceased. The performance drop was less with distributed practice, suggesting a protective effect when acquired skills were consolidated over time. The mean performance of the nontutored participants in the distributed practice group plateaued on a score of 16.0 (15.3-16.7) at approximately the ninth repetition, but the individual learning curves were highly variable.

**CONCLUSIONS AND RELEVANCE** Novices can acquire basic mastoidectomy competencies with self-directed VR simulation training. Training should be organized with distributed practice, and simulator-integrated tutoring can be useful to accelerate the initial learning curve. Practice should be deliberate and toward a standard set level of proficiency that remains to be defined rather than toward the mean learning curve plateau.
Virtual reality (VR) simulation training is increasingly being used in surgical training, including in temporal bone surgery where evidence of the efficacy and validity of VR simulation training of novices is emerging. Virtual reality simulation training can address some of the concerns and constraints of traditional dissection training and supervised surgery, for example, regarding patient safety issues, reduced working hours, and costs of facilities and instructors.

Acquisition of surgical skills requires repeated and deliberate practice regardless of the training modality, and the organization of this practice is also of importance: distribution of practice is more efficient for psychomotor skills learning compared with massed practice. Nevertheless, initial mastoidectomy training is frequently offered to trainees or residents as participation in a temporal bone course in places where facilities for frequent dissection are not readily available. Temporal bone skills courses are often organized with a single, massed block of practice. In contrast to this arrangement, VR simulation offers the possibility of repeated training spaced in time to the needs and at the convenience of the individual trainee.

The learning curve of repeated practice of any surgical procedure is crucial because of the implications for training and organization. For operating room performance, approximately 13 procedures are needed for technical competency in all the major steps of a complete mastoidectomy, with performances being assessed using a validated task-based checklist; for VR simulation training, performance (measured by a simulator-generated total score) plateaus after just 4 mastoidectomy procedures. Little is known regarding the learning curves in different practice programs and with other performance measurements, such as final product assessment.

In addition to the organization of surgical skills training, the learning environment is important and should be learner-centered and provide both tutoring and opportunity for self-directed learning. In line with this approach, some VR simulators can offer simulation-integrated tutoring and guidance. However, knowledge regarding the effect of this training approach on mastoidectomy performance and skills acquisition is limited and, to our knowledge, has not been investigated in association with the learning curve. It could be hypothesized that simulator-integrated tutoring accelerates skills acquisition and increases performance, but it is equally plausible that ongoing simulator-integrated tutoring impedes learning and that performance drops once tutoring is discontinued.

In this study, we wanted to explore the final product performance learning curves of mastoidectomy in VR simulation training with the aim of proposing an optimal self-directed program for initial mastoidectomy training. We therefore used a 2 × 2 study design to establish the effects of distributed and massed practice of mastoidectomy with and without initial simulator-integrated tutoring.

**Methods**

The ethics committee for the Capital Region in Denmark deemed this study exempt. All trainees provided written informed consent; participation was voluntary, and participants did not receive financial compensation.

**VR Simulation Platform**

The Visible Ear Simulator—a freeware VR temporal bone surgical simulator available for download from the Internet—was used in this study. A modified version 1.3, designed specifically for use in research, supported individual participant log-in with predefined conditions, such as automatic loading of the tutor function and autosaving of the virtual temporal bones. The simulator runs on a personal computer with a graphics card (GeForce GTX; Nvidia) and uses a haptic device (Geomagic Touch; 3D Systems) for drilling with force feedback. An optional simulator-integrated tutor function features greenlighting of the volume to be drilled in each step of a complete mastoidectomy in correspondence to an on-screen guide with text and illustrations.

**Participants**

Forty-three medical students from the Faculty of Health and Medical Science, University of Copenhagen, volunteered for participation in this study, which was organized as an extra-curricular activity. We recruited students from any semester of study for participation, and the only exclusion criterion was previous VR simulation training of mastoidectomy. All participants were novices regarding temporal bone surgery because it is not part of the pregraduate curriculum. Included for study was a group of 21 (of 24) participants who completed time-distributed practice from October 14 to November 29, 2013, and a separate group of 19 (of 19) participants who completed massed practice on May 16, 17, or 18, 2014. Upon enrollment, participants completed a questionnaire on background demographics as well as computer and gaming experience.

**Study Design**

A 2 × 2 study design was used to investigate the learning curves of distributed and massed practice in VR simulation training of mastoidectomy, with randomization within these 2 practice groups for additional simulator-integrated tutoring during the initial 5 sessions (Figure 1). In the distributed practice

![Figure 1. Flowchart](image-url)
group, blocks of 2 procedures were separated by at least 3 days; in massed practice, all of the procedures were completed during 1 course day.

In both practice programs, participants completed 12 repeated procedures consisting of a complete mastoidectomy with entry into the antrum and posterior tympanotomy. All participants had access to the on-screen step-by-step guide to the procedure but were otherwise self-directed. Before the first procedure, all participants received a 30-minute class lecture on the surgical anatomy of the temporal bone and a 5-minute hands-on navigation task in the simulator to familiarize the participants with the simulator controls as well as drilling using the haptic device.

Outcome and Statistical Analysis
The virtual temporal bone final products that were auto-saved at the end of the 30-minute sessions were assessed by 2 expert raters (P.C.-T. and M.S.S.) who were blinded to participant, session number, and practice and tutoring groups (examples of final product progression are shown in Figure 2). The assessment was done using a 26-item modified Welling Scale for final product analysis of performance previously detailed.18 The final product score was calculated as the mean of the scores assigned by the 2 raters. Data were analyzed using SPSS, version 22 (SPSS Inc) for MacOS X with analysis of variance, Pearson correlation coefficient, and nonlinear regression.

Results
The 21 participants in the distributed practice group were older (mean age, 25.1 years), more often male (15 [62%]), and had slightly higher mean gaming frequency (2.3 on a 1-5 Likert scale measured as never, yearly, monthly, weekly, and daily) compared with the 19 participants in the massed practice group (mean age, 23.6 years; male, 5 [26%]; mean gaming frequency, 1.6). However, no significant differences of final product performance scores were found in association with these and other background and computer or gaming factors. In distributed practice, blocks were spaced by a mean of 7.7 days, and there was no correlation of the number of days between sessions with the change in final product scores between sessions (Pearson $r = 0.12; P = .23$).

Learning curves for the mean final product performances were plotted for distributed and massed practice of VR simulation mastoidectomy with and without simulator-integrated tutoring in the first 5 sessions (Figure 3). During the
course of the 12 sessions of repeated practice, participants’ performance increased considerably in both practice groups (Table). As expected, distributed practice was found to increase performance significantly more than massed practice by the end of the training program.

The simulator-integrated tutor function also significantly improved participants’ performance ($P < .01$): the mean for all of the tutored sessions of both practice groups was 14.6 (95% CI, 13.9-15.2) compared with 13.4 (95% CI, 12.8-14.0) for the corresponding sessions of nontutored participants. In both practice groups, performance decreased when tutoring ceased; however, the performance dropped markedly more in the massed practice group than in the distributed practice group (Figure 3). With continued nontutored practice, the tutored participants achieved the same score by the final session as the nontutored participants of their respective practice group.

In nontutored massed practice, initial performance increased faster than in nontutored distributed practice, but the performance started to decline after the fourth session (Figure 3). In contrast to this finding, the performance of the nontutored participants in the distributed practice group asymptotically increased toward a plateau. Nonlinear regression was used to fit a sigmoid function for this learning curve: this analysis suggested a final product performance plateau of 16.0 (95% CI, 15.3-16.7) and that participants statistically reached this level by the ninth session.

**Table.** Mean Final Product Scores of the First and Last Session for the 2 Practice Groups

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean Score (95% CI)</th>
<th>Difference Between Groups</th>
<th>$P$ Value</th>
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<tbody>
<tr>
<td></td>
<td>Distributed Practice</td>
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<td></td>
</tr>
<tr>
<td>Session 1</td>
<td>10.8 (9.3-12.2)</td>
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<td>0.8</td>
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<td>Session 12</td>
<td>15.7 (14.4-17.0)</td>
<td>13.0 (11.9-14.1)</td>
<td>2.7</td>
</tr>
<tr>
<td>Difference between</td>
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<td>NA</td>
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Abbreviation: NA, not applicable.

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In a recent study, an automated and ongoing feedback system was used to improve the drilling performance of novices. However, ongoing simulator-integrated tutoring in repeated mastoidectomy practice has, to our knowledge, not been studied previously. We found that initial tutoring accelerated the learning curve and significantly increased final product performance compared with training using the on-screen instructional guide alone, but we also found that performance dropped considerably when the tutor function was discontinued. Nonetheless, performance at this point was still well above that of the first procedure, indicating that ongoing assistance by the tutor function did not hinder learning and could be useful for novices if applied correctly.

The main aim of this study was to propose an optimized program for self-directed VR simulation training of mastoidectomy on the basis of the different learning curves. The slope of the learning curve of the massed practice groups could suggest that 3 repeated procedures per block of training is more effective than just the 2 we allowed in the distributed practice program. In addition, simulator-integrated tutoring was useful and improved performance but should be used in con-
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Conclusions

Massed practice is often offered in temporal bone courses in places where training facilities do not provide an opportunity for repeated practice at the individual needs of the trainee. However, novices can acquire basic mastoidectomy competencies with self-directed VR simulation training, and repeated and distributed practice can support consolidation of these skills whereas massed practice is suboptimal. Simulator-integrated tutoring can accelerate the initial performance but should be applied in a way that facilitates optimal learning. Individual learning curves are highly variable; thus, the number of training sessions needed to achieve maximum benefit from VR simulation training greatly varies. However, deliberate practice should be aimed toward an evidence-based standard level of proficiency rather than the mean learning curve plateau. Such a predefined proficiency level has yet to be defined but could advantageously be established using future automatic and simulator-based assessment for real-time feedback and evaluation.
Additional Contributions: Peter Trier Mikkelsen, DMSc (Alexandra Institute), developed the experimental version of the Visible Ear Simulator, and Sebastian Roed Rasmussen, BS, Med, and Andreas Pagh Kohl, BS, Med (Center for Clinical Education), assisted with data collection. There was no financial compensation.

REFERENCES