Retention of mastoidectomy skills after virtual reality simulation training

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IMPORTANCE: The ultimate goal of surgical training is consolidated skills with a consistently high performance. However, surgical skills are heterogeneously retained and depend on a variety of factors including the task, cognitive demands and organization of practice. Virtual reality (VR) simulation is increasingly being used in surgical skills training including temporal bone surgery but there is a gap of knowledge on the retention of mastoidectomy skills in VR simulation.

OBJECTIVE: To determine the retention of mastoidectomy skills after VR simulation training with distributed and massed practice and to investigate the cognitive load during retention procedures.

DESIGN: A prospective 3-month follow-up study on a VR simulation trial.

SETTING: Academic teaching hospital

PARTICIPANTS: A total of 36 medical students: 19 from a cohort trained with distributed practice and 17 from a cohort trained with massed practice.

INTERVENTIONS: Participants performed 2 virtual mastoidectomies in a VR simulator 3 months (2.4–5 months) after completing initial training with 12 repeated procedures with practice blocks spaced in time (distributed) or all procedures in 1 day (massed).

MAIN OUTCOMES AND MEASURES: Final-product performance assessed by 2 blinded senior otologists using a modified Welling Scale. Cognitive load estimated secondary task reaction time integrated in the simulator.

RESULTS: Mastoidectomy final-product skills were largely retained at 3 months (mean change in score 0.1 points, p=0.78) regardless of practice schedule but the massed practice group seemed to need more time to complete the task. The performance of the massed practice group increased significantly from the first to the second retention procedure (mean change 1.8 points, p=0.001), reflecting that skills were less consolidated. For both groups, reaction times in the secondary task reflected that cognitive load during the virtual procedures had returned to the pre-training level.

CONCLUSIONS AND RELEVANCE: Mastoidectomy skills acquired under time distributed practice conditions were superiorly retained. Complex psychomotor skills should be regularly reinforced to consolidate both motor and cognitive aspects. VR simulation training provides the opportunity for such repeated training and should be integrated into training curricula.

Introduction

Surgical training is undergoing a paradigm shift from traditional apprenticeship to increased use of simulation-based training. Patient safety issues, working hour constraints and productivity demands contribute to limited training opportunities under the traditional apprenticeship dogma. Still, a safe performance in high-stakes surgery requires extensive and high-quality training[1] and the complex psychomotor skills of surgery need to be developed both efficiently and reliably. VR simulation-based surgical skills training has in a range of different surgical fields been demonstrated to improve surgical performance and transfer to the operating room.[2]

In temporal bone surgery, VR simulation is primarily used to supplement other training modalities such as cadaveric dissection and current evidence supports the effectiveness of VR simulation in mastoidectomy training of novices.[3–9] However, performance during practice is often the only reported outcome in these studies. Nevertheless, measurement of the retention of acquired skills is a better indicator of actual learning than performance during practice because consolidated skills and consistency of performance are the goals of surgical training.[10] In other words, retention tests *"attempt to remove the effects of temporary modulators on performance such as fatigue, and rely only on the retrieval of skills from memory"*.[10]

Complex psychomotor skills acquired in a VR simulation environment seem to some extent to be retained for several months.[10–14] However, surgical skills are retained heterogeneously and depend on the procedure, the task studied, and time elapsed since training. In addition, several other factors affect the retention and transfer of skills training including deliberate practice, part-task training, task variability, and overlearning after reaching proficiency.[15]

There is also evidence that heavier demands on cognitive functions during motor skills acquisition negatively affect retention.[13,15] Highly complex motor skills could cause substantial cognitive load due to the limitations of working memory and thereby inhibit the capacity for learning.[16] Several instructional designs can modify the cognitive load[17] and we have previously demonstrated that organizing training as distributed practice (practice sessions spaced in time) rather than massed practice (all sessions in one day) provides superior learning curves[18] and reduces cognitive load.[19] However, there is a gap in knowledge on whether such an improvement in performance and reduction in the cognitive load during the procedure are sustained after the training period.

Based on this, we hypothesized that different training strategies affect the retention of surgical motor skills and cognitive load during retention performance. The aims of this study were to 1) determine the retention of mastoidectomy skills after VR simulation training with distributed and massed practice, and 2) to investigate the cognitive load in the retention procedures, with the purpose of informing the optimal organization of temporal bone skills training.

Methods

The ethics committee for the Capital Region of Denmark deemed this study exempt (H-4-2013-FSP-088). All trainees provided written informed consent; participation was voluntary, and participants did not receive financial compensation.

Virtual reality simulation platform

In brief, the Visible Ear Simulator is a PC-based temporal bone simulator featuring 3D-stereo graphics, force feedback for drilling using the Geomagic Touch™(3D Systems, USA) haptic device, and the option of simulator-integrated tutoring with greenlighting of the volume to be drilled in each step of an anatomical mastoidectomy.[20,21] The simulator software is academic freeware that can be downloaded from our group's website[22] and is currently in use at many training institutions worldwide.

Participants

This study was designed as a 3-month follow-up study on a study of the learning curves of VR simulation training of mastoidectomy with distributed and massed practice.[18] Participants were medical students from the Faculty of Health and Medical Sciences, University of Copenhagen, Denmark, and they were complete novices regarding temporal bone surgery. Participants volunteered for the VR simulation training as an extracurricular activity.

Study design

In the initial study, two cohorts of novices completed self-directed training with either distributed or massed practice of 12 identical mastoidectomy procedures in the Visible Ear Simulator (flowchart, Figure 1). For each of the repeated procedures, participants were allowed 30 minutes to perform a complete mastoidectomy with entry into the antrum and a posterior tympanotomy. In distributed training, practice blocks consisted of two repeated procedures and the six practice blocks were spaced by at least three days. In massed practice, all 12 repetitions of the procedure were completed in a single practice block. Participants in both groups were further randomized for initial simulator-integrated tutoring and thereby an identical tutoring intervention. However, by the end of the study, the effect of initial tutoring had faded and end-of-training performances were similar.

For this study, participants who had completed training in the previous study were invited back for retention testing after three months. A total of 36 participants accepted the invitation for this follow-up study: 19 out of 21 participants in the distributed practice cohort and 17 out of 19 participants in the massed practice cohort completed the retention procedures. None of the participants had practiced the procedure in the intervening period. The follow-up retention testing was scheduled at the convenience of the individual participant and consisted of two procedures identical to the 30-minute procedures of the initial study. During retention testing, the participants had access to the standard on-screen instructions and received no other assistance.

Outcome and statistics

The virtual mastoidectomy was auto-saved by the simulator every ten minutes and performances were later assessed by two blinded expert raters (PCT and MSS) using final-product analysis.[23] In addition, participants were reaction time tested on a secondary task provided by the simulator at several times during the procedure and at baseline to estimate the cognitive load by the increase in reaction time during simulation relative to individual baseline measurements.[19] The outcomes (final-product performance and relative reaction time for cognitive load estimation) were analyzed exactly as previously described to ensure comparability with previous studies.

Supplemental analyses of the volume removed during VR simulation sessions were performed for this study.

The means of the two retention procedures (session 13 and 14) and the last two procedures (end-of-training procedures, session 11 and 12) of the initial study were compared. Data were analyzed using SPSS (SPSS Inc., Chicago, IL) version 22 for MacOS X with Analysis of Variances (ANOVA), paired samples t-tests, and Pearson's r for correlations.

Ethical approval

The regional ethics committee deemed this study exempt (H-4-2013-FSP-088). All participants signed informed consent for participation.

Results

Loss to follow-up was 10 % for the distributed practice cohort and 11 % for the massed practice cohort and participant characteristics were therefore similar to those reported in the initial study: participants in the distributed practice group were significantly older, more often male, and had a higher gaming frequency than participants in the massed practice group (Table I). As previously, these factors could not be demonstrated to be associated with the outcomes.

The mean number of days between the end-of-training sessions of the initial study and the retention sessions in this follow-up study was comparable for the two practice groups (Table 1). In addition, the number of the days for follow-up was not found to be associated with neither final-product nor relative reaction time performance.

For both practice groups, the difference in mean final-product performances of the end-of-training sessions and the retention sessions were without statistical significance (Table II). The slightly lower performance during retention procedures was related to the anatomical boundaries of the procedure such as adequately removing cells in the sinodural angle, along the tegmen, and in the mastoid tip; not over-exposing the facial nerve; and expanding the facial recess.

We also found that the final-product performance of the massed practice group increased significantly from the first to the second retention procedure ($p=0.001$) whereas the performance of distributed participants remained stable and unchanged during the retention procedures (Figure 2). The two practice groups had equal mean retention final-product performances (p=0.89).

A different pattern was observed for the relative reaction time (Figure 3): both groups had an increase in relative reaction time when comparing retention sessions with end-of-training sessions—even though this was only statistically significant for the distributed practice group ($p<0.01$)—and both practice groups had equal mean reaction times in the retention sessions (Table 2).

We performed a supplemental analysis of the total volume removed during the VR simulation sessions to explore whether the fixed 30-minute time-frame masked differences between the groups in time used to complete the task. This demonstrated that the distributed practice group consistently removed more of the bone than the massed practice group in both the end-of-training sessions and the retention sessions (see eFigure 1 in the Supplement) consistent with the higher final-product performance of the distributed practice group. Also mirroring the final-product performance, a drop in the total volume removed was found in the first retention session. Finally, the massed practice group removed significantly more bone during the last ten minutes of the first retention session (session 13) than their last end-of-training session (session 12)($p<0.002$)(see eFigure 2 in the Supplement) while retaining total volume removed, reflecting time compensation.

Discussion

In this follow-up study on the retention of mastoidectomy training in a VR simulator with distributed and massed practice of the procedure, we found that final-product performance regardless of the organization of training did not deteriorate significantly during a 3-month non-practice period. In contrast to this, the cognitive load estimated by reaction time measurement had returned to pre-training levels. Moreover, the skills of the massed practice group were less consolidated and they seemed to use more time within the allowed timeframe during retention testing to achieve a similar performance. During the retention procedures, the participants in general had a poorer performance compared with end-of-training procedures in adequately defining the outer boundaries of the procedure, often violating the facial nerve, and not exposing the facial recess sufficiently, suggesting that these items could be emphasized in future instructions.

In VR laparoscopic simulation skills training, performance was found to drop in the immediate period following training but no further skills were lost when retention was tested at a mean of 7 months.[14] Similarly, novices retained skills in another laparoscopic simulator for 6 months[11]. However, at 18 months skills had returned to pre-training levels.[11] A limitation to our study is therefore that retention was only tested at a relative early point in time (3 months), which might explain why mastoidectomy final-product skills were largely retained in our follow-up study. Also, the participants had access to the simulator's built-in onscreen instructions on the procedure to have similar and comparable conditions during training and retention procedures and supporting self-directed practice with directed, self-regulated learning.[24] Nonetheless, this would also help increase performance during the retention procedures and even out possible differences between the two practice groups.

Other limitations to our study are the small sample-size and a non-randomized study-design. Sample-size calculations for learning curves are not well-defined and for the original study, we aimed at having a number of participants in each practice group similar to other studies.[10,11] Based on the data on the end-of-training sessions and the included number of participants, a change in final-product score of 2.5 points would be needed to find a statistically significant difference between performance in the end-of-training and retention procedures. A type 2 error is therefore a possibility and our study could be underpowered to detect smaller changes in performance between end-of-training and retention sessions.

In the previously mentioned studies on VR laparoscopic simulation training, practice was organized in a distributed schedule. The retention of surgical skills in distributed vs. massed practice has been studied for physical simulation models in surgery: distributed practice groups significantly outperformed massed practice groups when retention tested at 1-month or 1 year.[10,25] Surgical skills learned under distributed practice settings are therefore suggested to be more robust.[10] Although we found that final product mastoidectomy skills were retained regardless of practice organization, our supplemental analyses substantiate that time compensation was at play: only about 5–15 % of the total volume was removed during the last 10 minutes of the procedure in end-of-training and retention procedures for both groups—except for the first retention procedure of the massed practice group (session 13). This corroborates that the improvement in time to completion gained during repeated training was not retained in the massed practice group and explains why final-product performance did not deteriorate markedly. When considering both the final-product performance and time to completion, our findings support that distributed practice is superior to massed practice for retention of mastoidectomy skills.

In this study, we performed retention testing using two repetitions to reveal retention and not re-familiarization with the simulator which lead to another interesting finding supporting the case for distributed practice being superior: the performance of the massed practice group increased significantly from the first to the second retention procedure. Also considering that the performance at the end of initial training was significantly lower for the massed practice group than the distributed practice group, this suggests that the massed practice group still had potential for additional learning whereas the distributed group had already reached an initial plateau during training and did not improve further during the retention testing. A similar pattern was found in a study on VR laparoscopic simulation:[12] one group that had not trained repeatedly to a consistent performance in initial training also improved during retention testing, indicating that some degree of 'overlearning' is beneficial for retention. Even though time spacing of practice is essential for learning we found that it is possible to continue learning even after a considerable period of non-practice. This is in agreement with a study on VR simulation training of endoscopic sinus surgery where novices resumed to follow their learning curves after 11–60 days of not training.[26]

In a study exploring the retention of electrocardiogram analysis skills (a mainly cognitive skill) following a massed practice training course, approximately half of the performance gained during the course was lost after two weeks.[27] In contrast to this, motor skills are consistently found to be less susceptible to decay over longer periods of time than cognitive tasks[15] and basic motor skills in VR laparoscopic simulation are better retained than complex motor skills that placed heavier cognitive demands.[13] In our initial study, we found that cognitive load decreased with repeated and distributed practice and not with massed practice.[19] In the present study, we also measured retention of the performance on a secondary reaction time test. The relative reaction time reflects the cognitive load during the procedure and we found that the cognitive load during the retention procedure had returned almost to the level of the very first procedure. In agreement with current knowledge, this finding suggests that the reduction in cognitive demands with repeated practice of complex psychomotor skills is not retained as reliably as the acquired motor skills. This could have implications for surgical skills training such as mastoidectomy training because the aspect of cognitive learning also should be considered. Training towards (cognitive) automaticity of a surgical procedure requires substantially more training than training towards simulator proficiency alone.[28]

Conclusions

Mastoidectomy skills were largely retained at three months after self-directed VR simulation training when practice was organized with time distribution between practice sessions. The learning curve could, however, be resumed for the massed practice group because they had not reached their full learning potential during initial training. For both practice groups, the cognitive load during the retention procedures returned to the level of the very first procedure. This substantiates that cognitive skills deteriorate more rapidly and this should be considered in the organization of surgical skills training. Surgical skills should be reinforced regularly with a frequency that is sufficient to maintain acquired motor as well as cognitive skills.

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Author contributions: Dr. Andersen had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Andersen, Konge, Sørensen.
Acquisition, analysis, or interpretation of data: Andersen, Konge, Cayé-Thomasen, Sørensen.
Drafting of the manuscript: Andersen.
Critical revision of the manuscript for important intellectual content: All authors.
Statistical analysis: Andersen.
Administrative, technical, or material support: Konge, Sørensen.
Study supervision: Konge, Sørensen.

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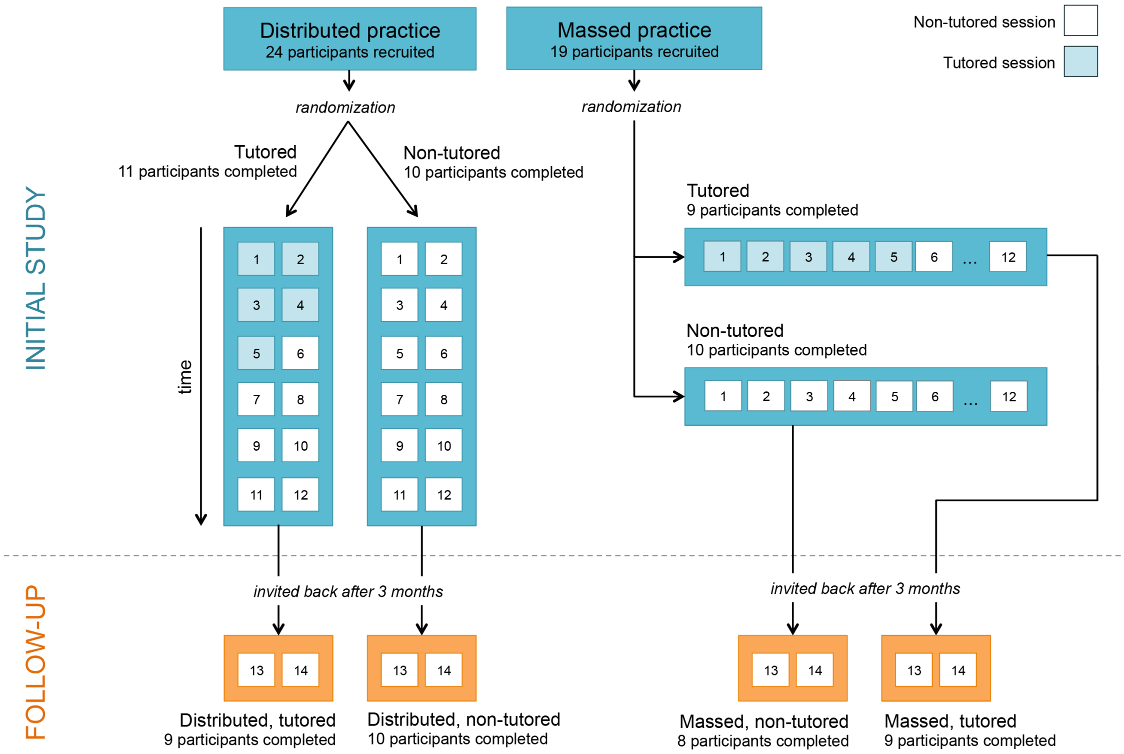


Figure 1. In the initial study (blue), participants completed 12 repeated mastoidectomy procedures on a VR simulator either with distributed practice (sessions spaced in time) or as massed practice (all session completed in a single day). In this study (orange), participants were invited back for follow-up testing of their virtual mastoidectomy skills.

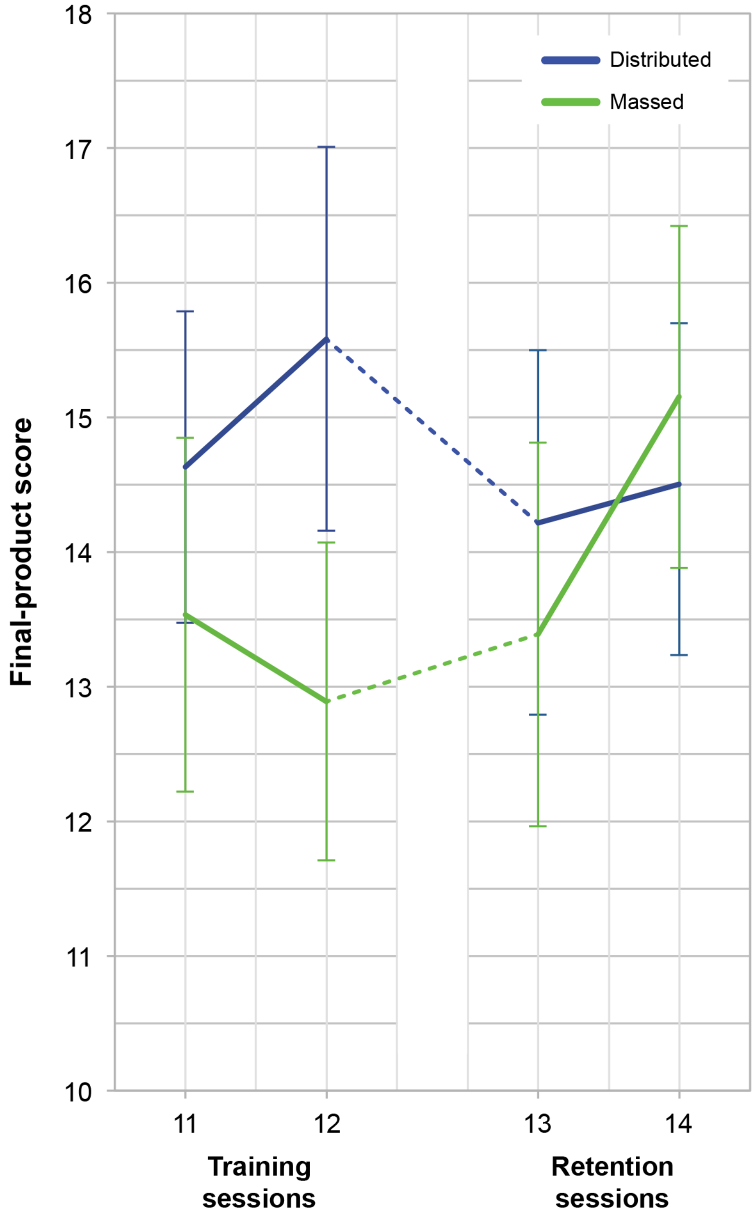


Figure 2. Mean final-product performance of the distributed and the massed practice groups in the last two sessions of training and in the retention sessions. Bars indicate 95 % confidence intervals.

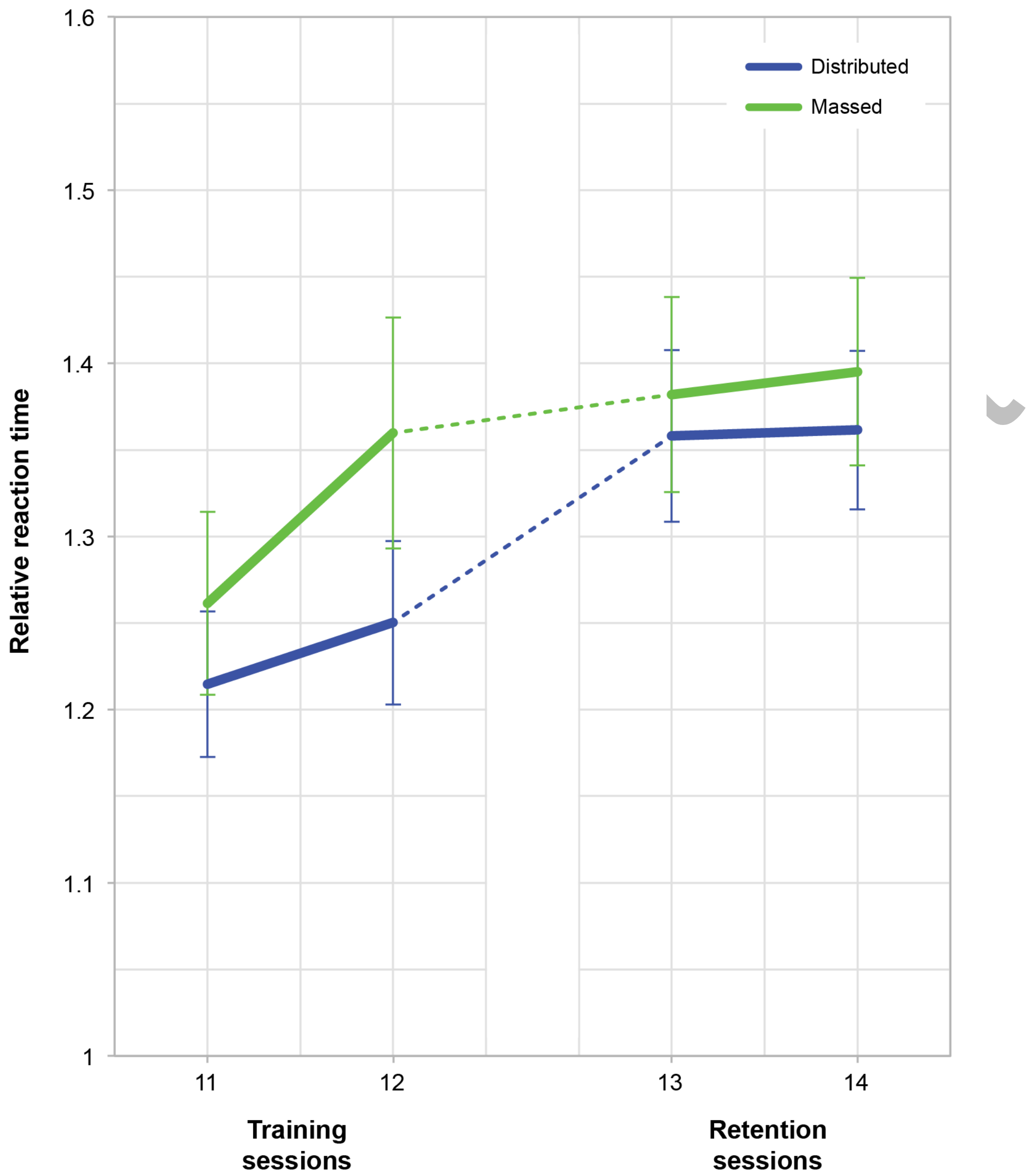


Figure 3. Relative reaction time on the secondary task of the distributed and massed practice groups in the last two sessions of training and in the retention sessions. Bars indicate 95 % confidence intervals.

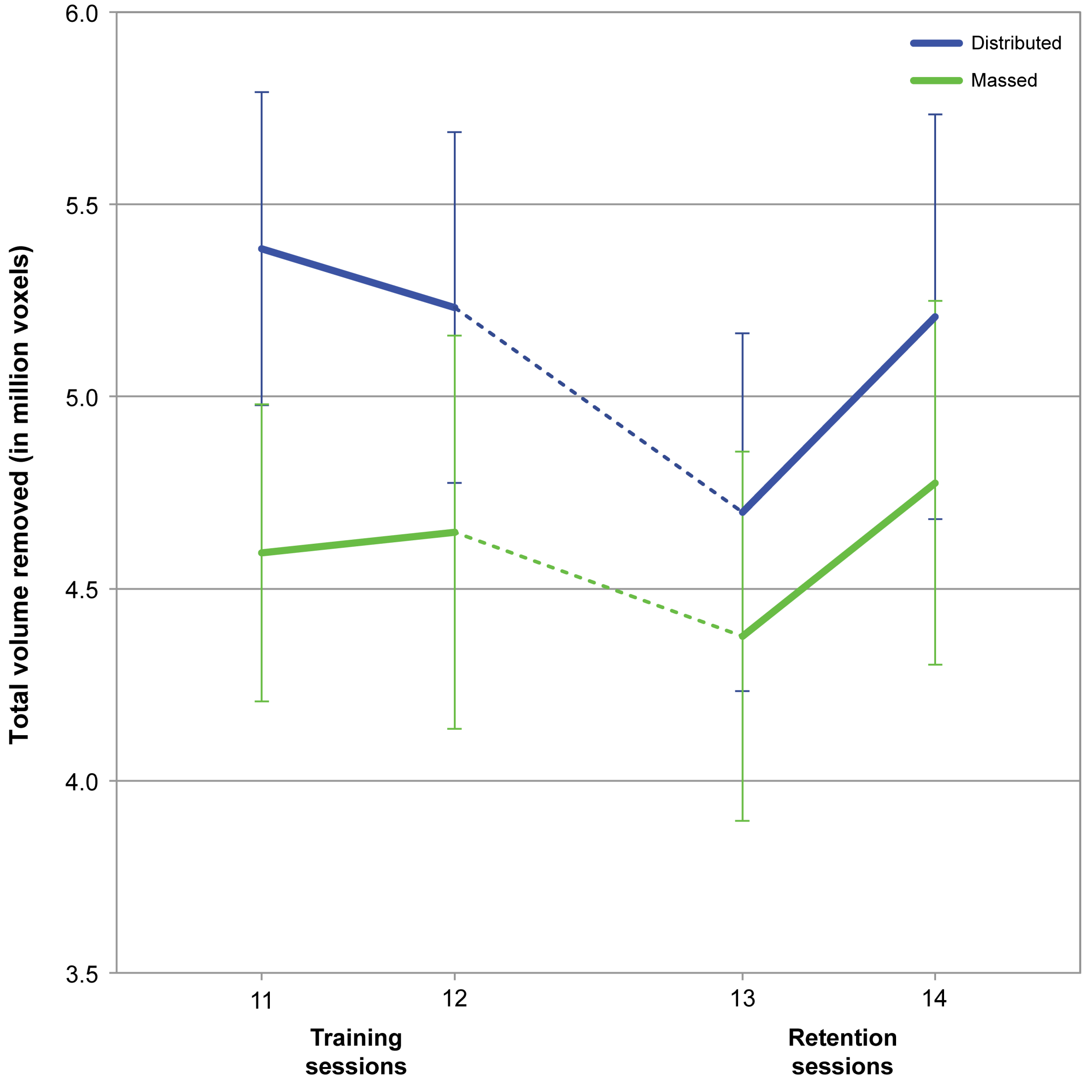
Table 1. Participant characteristics

	Distributed	Massed	Significance of difference
Retention-tested/initially trained, n (%)	19/21 (90 %)	17/19 (89 %)	
Age, years	25.2	23.4	p=0.01
Sex			
Males, n (%)	11 (58 %)	4 (24 %)	p=0.04
Females, n (%)	8 (42 %)	13 (76 %)	
Semesters of study	8.8	7.5	ns
Any previous VR simulation experience	29%	28%	ns
Gaming frequency, 1–5 Likert like scale	2.3	1.5	p=0.02
Computer usage, h/week	18	20	ns
Days between last training and retention sessions, days (range)	101 (74–153)	95 (80–126)	ns

Table 2. Final-product and relative reaction time of the two practice groups in the last sessions of initial training and in the retention sessions.

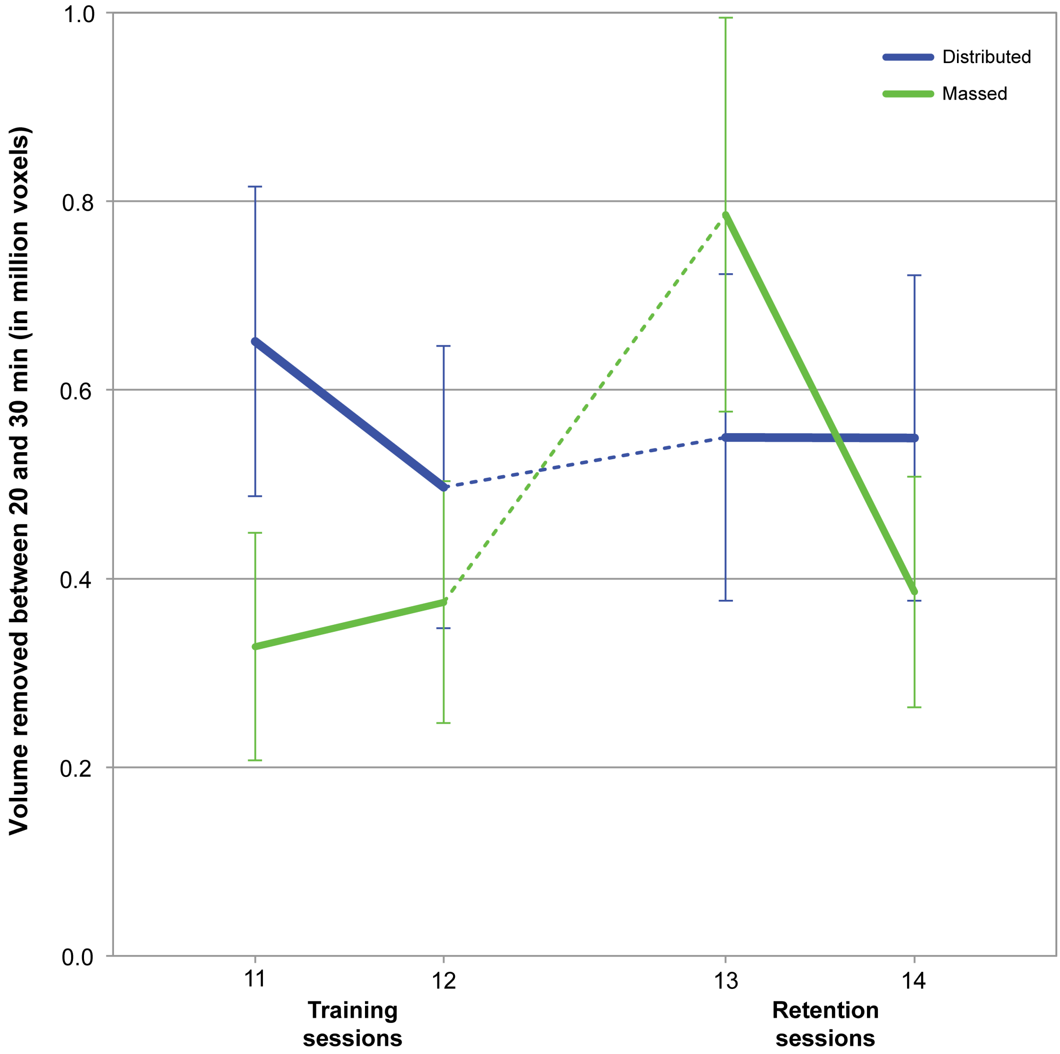
	End-of-training (sessions 11–12)		Retention testing (sessions 13–14)		
	Mean	95 % confidence interval	Mean	95 % confidence interval	Significance of difference
Final-product score					
Distributed practice (n=19)	15.1	14.2–16.0	14.4	13.5–15.1	ns
Massed practice (n=17)	13.2	12.4-14.0	14.3	13.3–15.2	ns
Significance of difference	p<0.005		ns		
Relative reaction time					
Distributed practice (n=19)	1.24	1.16–1.32	1.36	1.30–1.42	p<0.01
Massed practice (n=17)	1.31	1.21–1.42	1.39	1.31–1.46	ns
Significance of difference	ns		ns		

eFigure 1. Mean total volume removed



Mean total volume of bone removed during virtual mastoidectomy procedures for the distributed and massed practice groups in the last two sessions of training and in the retention sessions. Bars indicate 95 % confidence intervals.

eFigure 2. Mean volume removed in the last 10 minutes



Mean volume of bone removed in the last 10 minutes of the virtual mastoidectomy procedures for the distributed and massed practice groups in the last two sessions of training and in the retention sessions. Bars indicate 95 % confidence intervals.