Notes from the field: Secondary Task Precision for Cognitive Load Estimation during Virtual Reality Surgical Simulation Training

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Abstract

Cognitive load (CL) theory suggests that working memory can be overloaded in complex learning tasks such as surgical technical skills training, impairing learning. Valid and feasible methods for estimating the CL in specific learning contexts are needed before the efficacy of CL-lowering instructional interventions can be established. This study aims to explore secondary task precision for the estimation of CL in virtual reality (VR) surgical simulation and the effects of CL-modifying factors such as simulator-integrated tutoring and repeated practice. Twenty-four participants were randomized for visual assistance by a simulator-integrated tutor function during the first five procedures of a total of 12 repeated mastoidectomy procedures on a VR temporal bone simulator. Secondary task precision was found to be significantly lower during simulation compared with non-simulation baseline, $p<0.001$. Contrary to expectations, simulator-integrated tutoring and repeated practice did not impact on secondary task precision. This suggests that even though considerable changes in CL are reflected in secondary task precision it lacks sensitivity. Secondary task reaction time could potentially be more sensitive but needs substantial post-processing of data and the pros and cons of different secondary task measurements should be weighed in future studies on the effect of CL modifying interventions.

Keywords: cognitive load; dual-task paradigm; virtual reality simulation; technical skills; surgical training

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INTRODUCTION

In medical education, one of the leading learning theories is the cognitive load theory (CLT). The theory posits that limitations of the working memory need to be considered in learning and a cognitive overload could be detrimental to learning. The CLT framework proposes educational design strategies that can be used to reduce the CL (Van Merriënboer & Sweller, 2010). Feasible and valid methods for measuring CL in specific learning situations—such as surgical skills training—are needed to establish the effect of CL-lowering interventions.

The dual-task-paradigm is a well-established, direct-objective method for measuring CL: a secondary task is performed simultaneously with the primary task and the CL is estimated by performance on the secondary task (Brünken, Plass & Leutner, 2003). Secondary task reaction time measurement has been investigated for estimating CL in non-virtual surgical skills training (Rojas, Haji, Shewaga, Kapralos, & Dubrowski, 2014). However, reaction time is highly individual and variable and could prove difficult to implement because of the need for considerable post-processing and normalizing of data.

In this study, we wanted to investigate secondary task precision as an estimate for CL in virtual reality (VR) surgical simulation. In addition, we wanted to explore the effects of simulator-integrated tutoring and repeated practice in relation to secondary task precision because these factors could potentially modify CL.

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Methods

The primary task consisted of VR simulation of the mastoidectomy procedure: this involves drilling of the temporal bone in order to gain access to the middle ear. The procedure places high cognitive demands on the learner because it involves visuo-spatial and complex psychomotor skills in addition to the learning condition itself. VR simulation training is increasingly being incorporated into otorhinolaryngology resident training and the Visible Ear Simulator (VES) provides a freeware PC-software platform for temporal bone surgical simulation (Sorensen, Mosegaard, & Trier, 2009). A modified version of the simulator was developed for this study to provide a secondary task for CL estimation.

In addition to the primary task, all participants were asked to simultaneously perform a secondary task integrated in the VR simulator. This secondary task was unrelated to the primary task and consisted of a visual monitoring task: participants had to respond to the appearance of a colored box presented above the instruction panel with a random letter by pressing on the correct key corresponding to the displayed letter. The secondary task was presented three times during each simulation session in 60-second test rounds. Non-simulation baseline precision was determined by similar 60-second test rounds before and after each session without the primary simulation task.

Participants completed a total of 12 identical procedures in the simulator with every other procedure separated by at least three days (distributed practice). The initial procedure served as a longer pre-practice session for familiarization with the simulator. Participants were allowed 30 minutes to complete each of the following procedures.

Twenty-four medical students from the Faculty of Health and Medical Sciences, University of Copenhagen, Denmark, were recruited for this study and signed informed consent. The study was organized as a voluntary extracurricular activity and the only exclusion criterion was previous VR temporal bone simulation training.

The simulator software provided all participants with written, on-screen, step-by-step instructions on the procedure. Participants were randomized to receive supplementary simulator-integrated tutoring during the first five sessions (group 1) or not (group 2). The simulator-integrated tutor function color-codes the volume to be drilled in each procedural step. Participants received no instructions or feedback from human instructors.

Secondary task precision was analyzed and performance on the primary task was not considered in this study. Simulator records of the registered keystrokes and displayed letters were compared and errors noted. To quantify the degree of precision, errors were categorized as either 'minor error' when the pressed key was immediately next to the displayed key or as 'major error' when further away.

Data were analyzed using SPSS version 22 (SPSS IBM, NY, USA). Results were considered significant if $p<0.05$.

The ethics committee for the Capital Region of Denmark deemed this study exempt (H-4-2013-FSP-088).

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RESULTS

A total of 21 participants (88 %) completed all 12 simulation sessions and were included for study: 11 participants received both simulator-integrated tutoring and on-screen written instructions (group 1) and 10 received only on-screen written instructions (group 2). Three participants did not schedule further simulation training after the first sessions due to time considerations and withdrew early.

Overall, we found that participants made significantly more errors in total during simulation (mean 7.3 %) compared with baseline (mean 2.9 %)(independent samples t-test, $p<0.001$). There was no significant difference in the distribution of minor and major errors between simulation and baseline (Chi Squared test of association, $p=0.90$ and $p=0.18$, respectively), meaning that the degree of secondary task precision was not related to whether the participants were engaged in the primary task or not.

Simulator integrated-tutoring was not found to affect the secondary task performance because no significant difference (using ANOVA) in the total number of errors ($p=0.22$) or the distribution of minor ($p=0.79$) and major errors ($p=0.18$) between the two groups was found.

Secondary task precision did not increase with repeated practice because the number of total errors was not found to correlate with the session number (Pearsons' $r=-0.046$, $p=0.49$)(Figure 1). In addition, the degree of precision in the secondary task (minor or major error) did not increase with repeated practice (Pearsons' r, $p=0.55$ and $p=0.70$, respectively).

DISCUSSION

In this study on secondary task precision for estimation of CL, we found that secondary task precision could discriminate between participants being engaged in the primary task (simulation) or not (non-simulation baseline). Secondary task precision could not detect changes in CL relating to potential CL-modifying factors such as additional assistance by the simulator-integrated tutor function or repeated practice.

Precision performance has been demonstrated to be higher in a motor-only condition than in a combined motor and cognitive condition (Guillery, Mouraux, & Thonnard, 2013). VR mastoidectomy simulation is a combined motor and cognitive task and this could therefore adversely affect secondary task precision in our study. The secondary task itself places some CL on the learner because it draws on the same visual working memory as the primary task (Brünken, Plass & Leutner, 2003). Other factors could cause additional CL such as the written on-screen instructions because it adds another source of information, drawing on the same (limited) visual working memory resources. However, this can be addressed by letting participants study the instructions beforehand (Van Merriënboer & Sweller, 2005) or by pre-training (Mayer & Moreno, 2003) such as the pre-practice session in our study.

In general, VR mastoidectomy simulation contains a high level of element interactivity because written theoretical knowledge and visuo-haptic perception need to be integrated, leading to an

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inherent high CL. Simulator-integrated tutoring could alleviate this by visually guiding directly in the procedural field. Also, repeated practice would be expected to lower CL because more mental resources would be freed as experience accrues. In contrast to expectations, secondary task precision did not demonstrate effects of simulator-integrated tutoring or repeated practice, which could reflect a lack of sensitivity.

In conclusion, secondary task precision can be used in the context of considerable changes in CL (baseline vs. simulation) but other measurements are needed for finer discrimination. Secondary task reaction time (Rojas, Haji, Shewaga, Kapralos, & Dubrowski, 2014) could potentially be a more sensitive estimate of CL but reaction time data need more post-processing and future studies should weigh the pros and cons of precision measurement over reaction time measurement in the study of CLT-based instructional interventions.

REFERENCES

Brünken R., Plass J.L., & Leutner D. (2003). Direct measurement of cognitive load in multimedia learning. *Educational Psychologist*, 38, 53-61.

Guillery, E., Mouraux, A., & Thonnard, J.-L. (2013). Cognitive-Motor Interference While Grasping, Lifting and Holding Objects. *PLoS ONE*, *8* (11), e80125.

Mayer, R. E., & Moreno, R. (2003). Nine Ways to Reduce Cognitive Load in Multimedia Learning. *Educational Psychologist*, *38* (1), 43-52.

Rojas, D., Haji, F., Shewaga, R., Kapralos, B., & Dubrowski, A. (2014). The Impact of Secondary-Task Type on the Sensitivity of Reaction-Time Based Measurement of Cognitive Load for Novices Learning Surgical Skills Using Simulation. *Studies in health technology and informatics*, *196*, 353-359.

Sorensen, M. S., Mosegaard, J., & Trier, P. (2009). The Visible Ear Simulator: A Public PC Application for GPU-Accelerated Haptic 3D Simulation of Ear Surgery Based on the Visible Ear Data. *Otology & Neurotology*, *30*, 484-487.

Van Merriënboer, J. J. G., & Sweller, J. (2005). Cognitive Load Theory and Complex Learning: Recent Developments and Future Directions. *Educational Psychology Review*, *17*, 147-177.

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Van Merriënboer, J. J. G., & Sweller, J. (2010). Cognitive load theory in health professional education: design principles and strategies. *Medical Education, 44*, 85-93.

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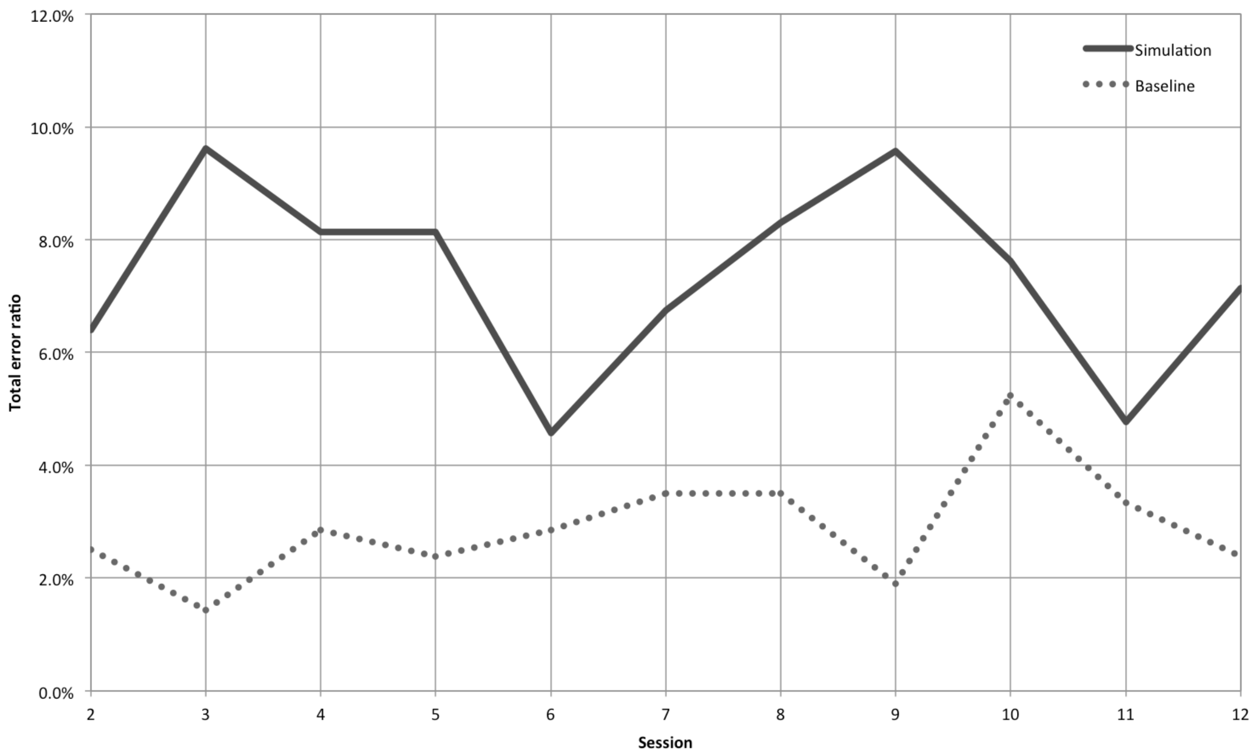

Figure 1 Percentage of total error during the sessions on simulation and baseline.

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