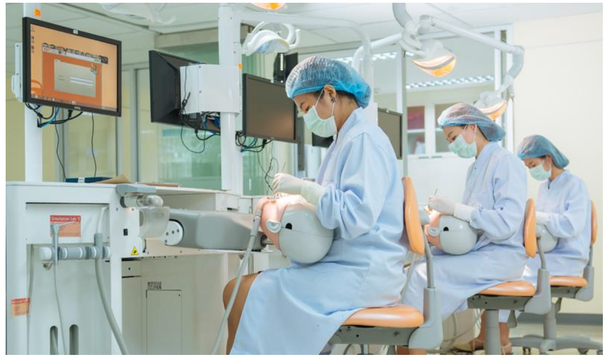
Reflecting on Excellence: VR Simulation for Learning Indirect Vision in Complex Bi-Manual Tasks

Maximilian Kaluschke[1], Rene Weller[1], Myat Su Yin[2], Benedikt W. Hosp[3], Farin Kulapichitr[1], Peter Haddawy[2], Siriwan Suebnukarn[4], Gabriel Zachmann[1]

[1] University of Bremen, Computer Graphics & Virtual Reality, Bremen, Germany
[2] Mahidol University, Faculty of ICT, Bangkok, Thailand
[3] ZEISS Vision Science Lab, University of Tübingen, Tübingen, Germany
[4] Thammasat University, Faculty of Dentistry, Bangkok, Thailand

Introduction

- Dentistry: complex bi-manual tasks
- Traditionally physical dummies, real tools
  - High costs, *or sporadic practice*
  - Limited tooth variations
- Proliferation of VR
  - Reusable, configurable
  - Data logging (performance, behaviour)



Previous Work

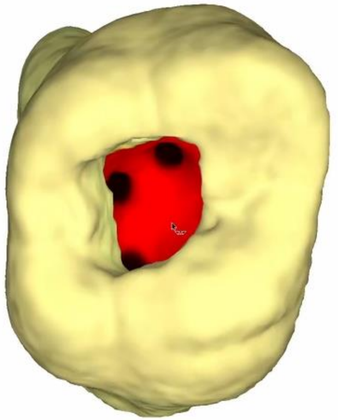
- Studies on learning effect, but without considering eye gaze
  - Learning measured in simulator [Elizabeth 2014] [Wang 2015]
  - Learning measured in real-world methods [Murbay 2020] [Yin 2021]
- Eye tracking studies focus on direct vision tasks and dwell time

  [Jeong 2020] [Yang 2022]
- *No studies so far focused on indirect vision & mirror handling*

Research Questions

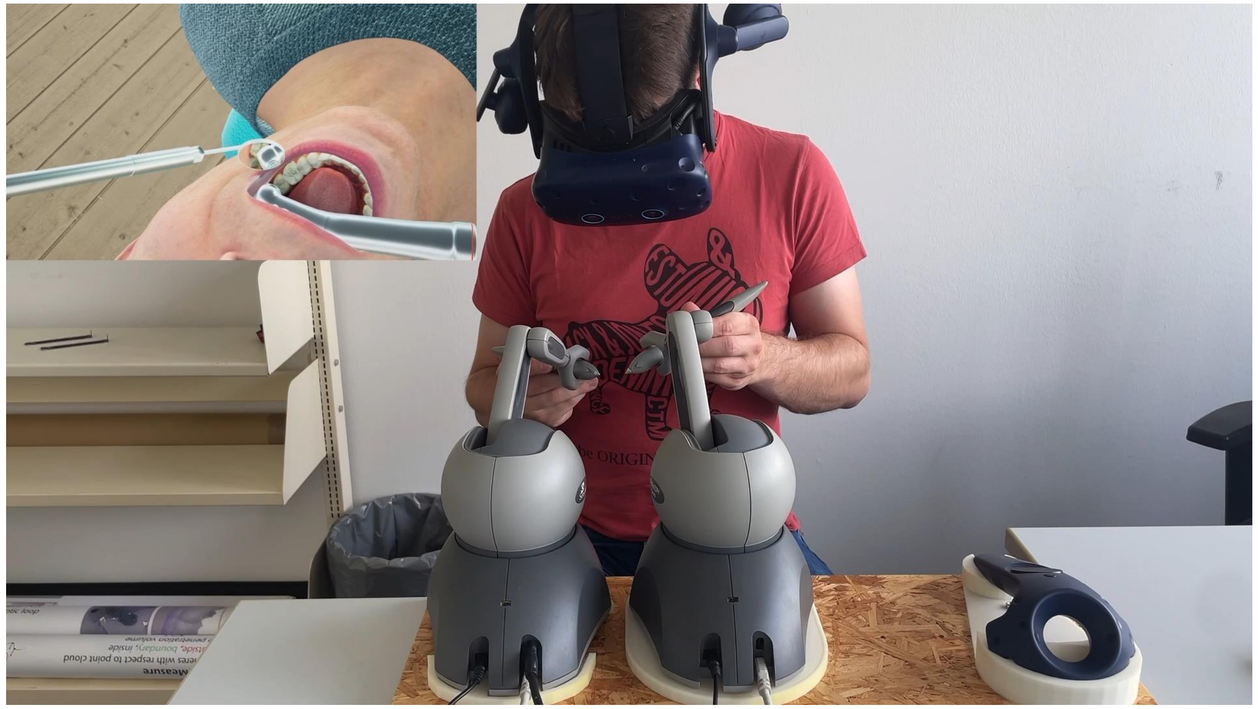
1. Mirror usage predicts performance?
2. Mirror usage predicts learning?
3. Learning effectiveness of simulator?
   - Mirror handling abilities
   - General skill (real-world metrics)

- **Task**: root-canal access opening on upper jaw
  - Requires extensive mirror use



VR Dentistry Simulator

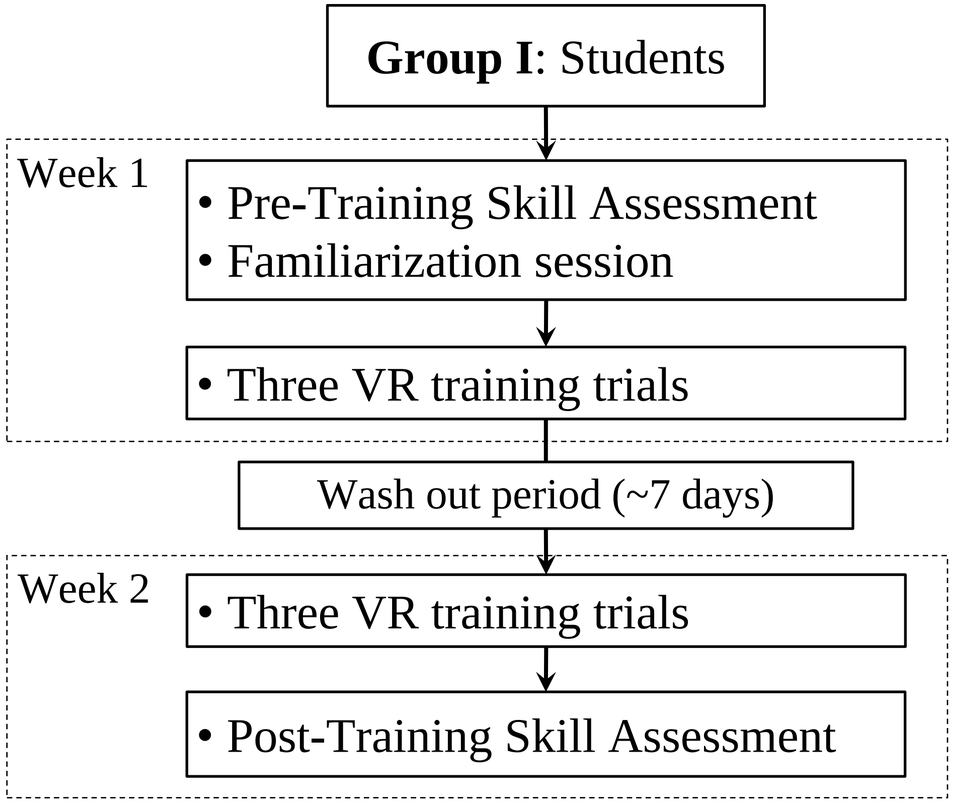
- Our VR-based dental surgery simulator [Kaluschke et al., 2022]
  - HTC Vive Pro Eye, Unreal Engine
  - Haptic feedback (one per tool)
  - Patient: Metahuman + custom anatomical teeth

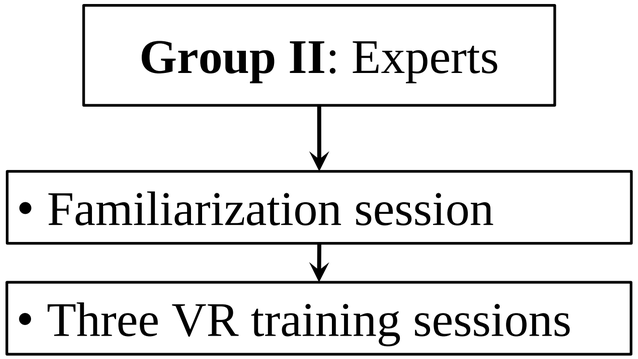


- Extended by new features
  - Eye-tracking (speed 120 Hz, accuracy 1.2°)
  - VR zoom (modifying projection matrix)

User Study

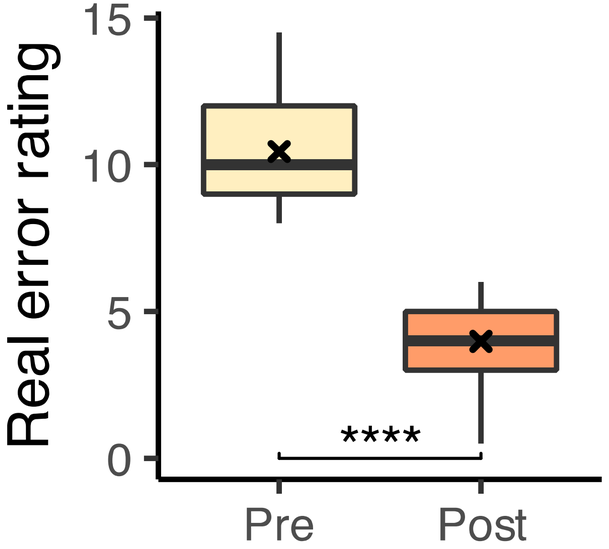
- 30 dental students
  - Training: 3+3 trials
  - Pre- & post-test
    - on plastic teeth
    - ⇒ real-world performance
- 6 expert dentists
  - each 3 trials

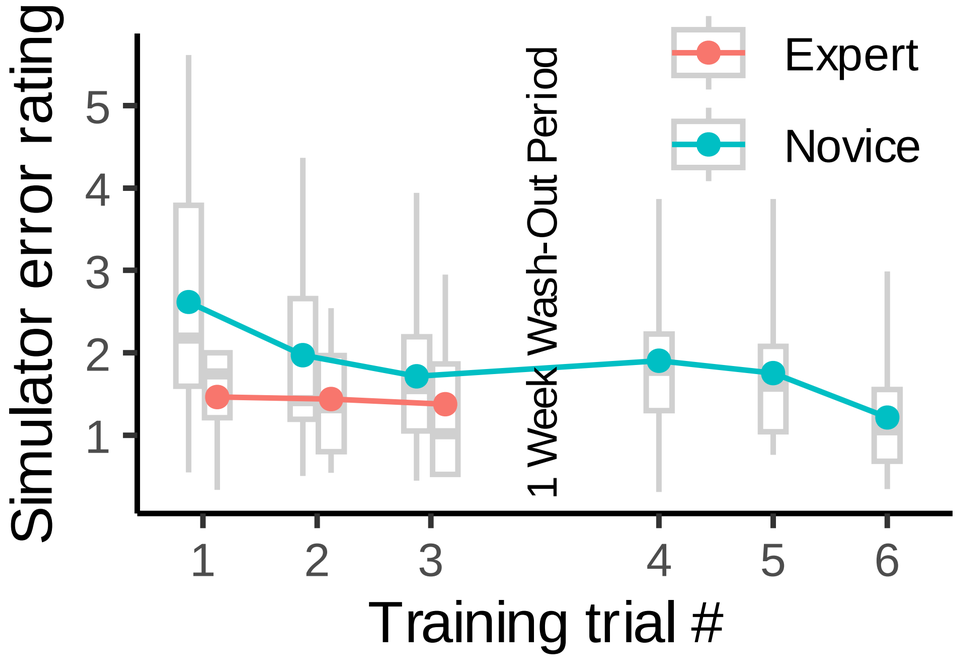




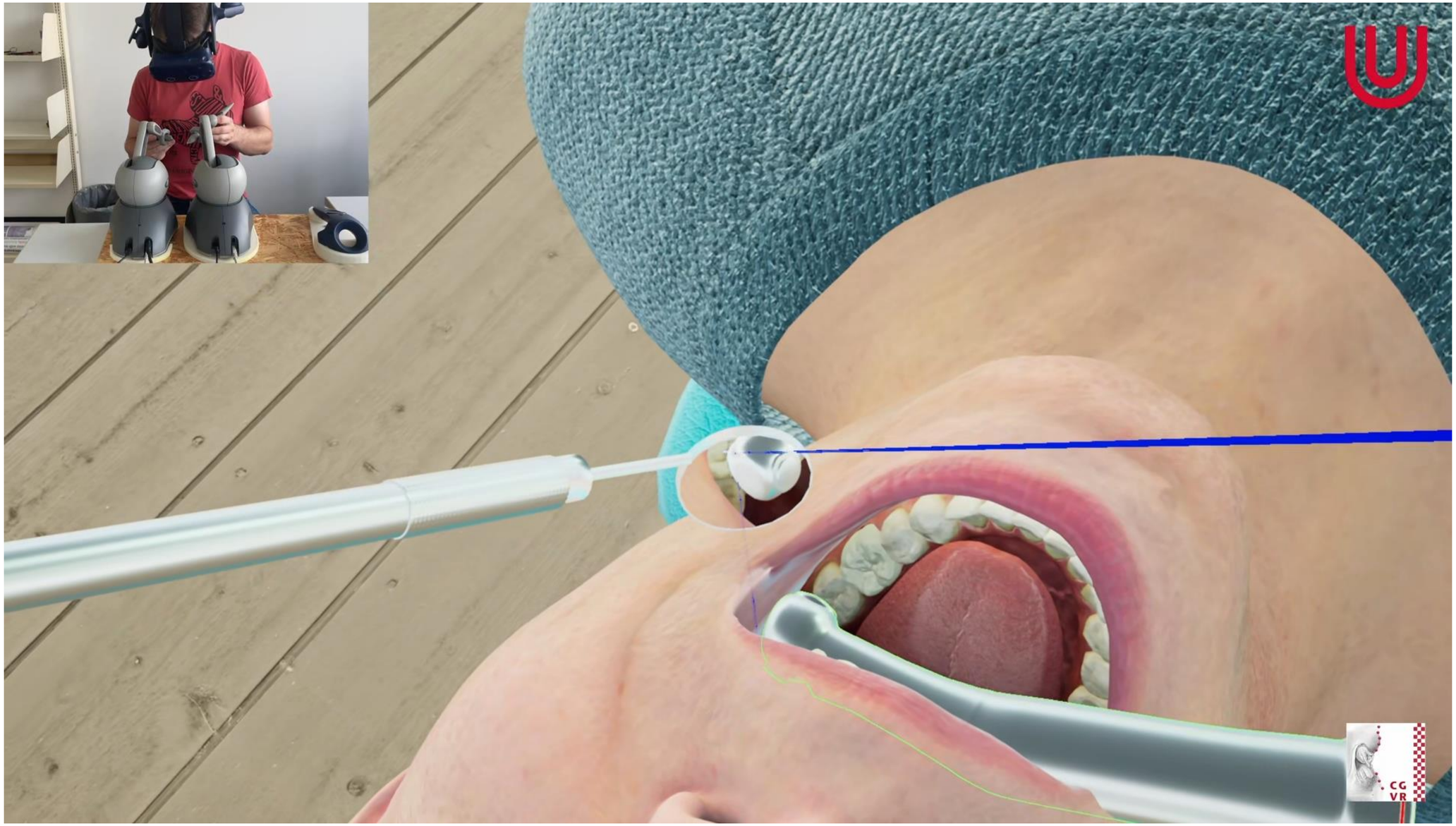
Results – Learning Effect

- Real-world performance (plastic teeth)
  - Error: from 10.4 to 4.1 ($p < .001$)
  - Learning gain: **-63%**
- Simulator performance
  - Error: 2.6 to 1.2: **-52%** ($p < .001$)
  - *Trial #1*: students larger error ($p < .001$)
  - *Trial #6*: students on expert level ($p = .2$)



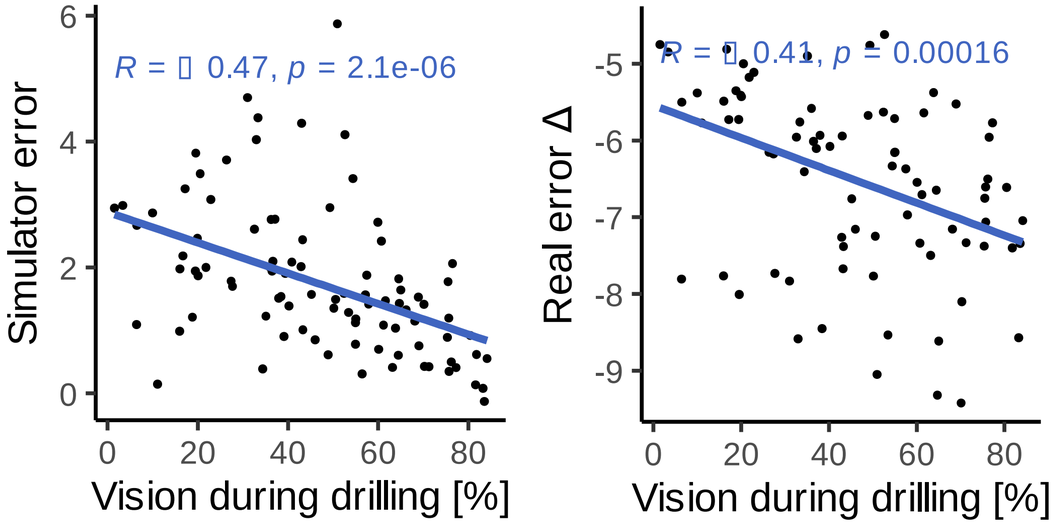


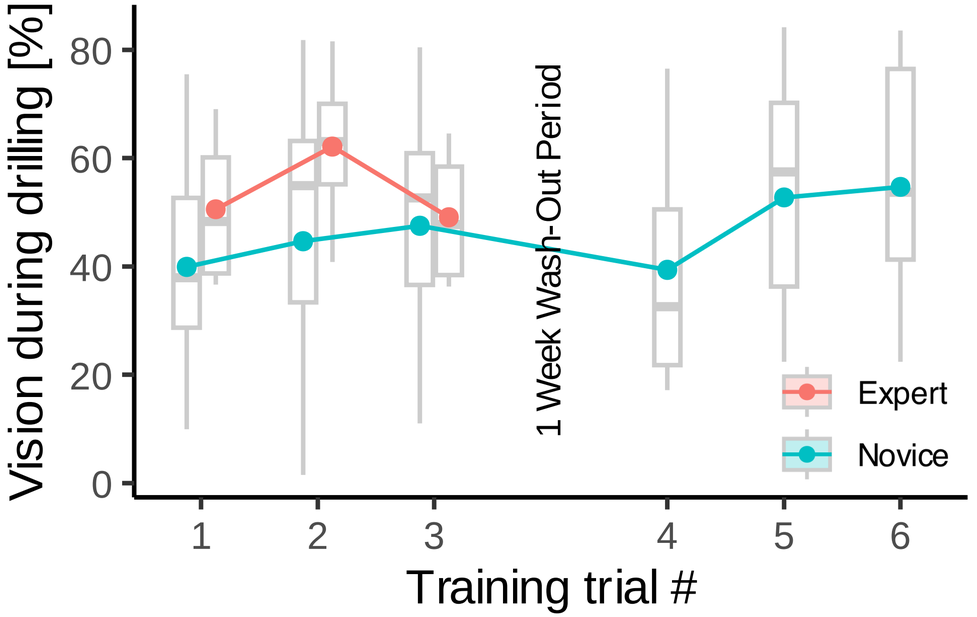
Results – Indirect Vision during Drilling



Results – Indirect Vision during Drilling

- “Vision” requires
  - Mirror correctly positioned
  - Handpiece does not obstruct vision
  - Bur not inserted too deep
- Correlates with performance & learning
- Training improved indirect vision
  - *Week 1*: Novices **44%** vs. experts 54% [*]
  - *Week 2*: Novices **49%** vs. experts 54%





Results – Inspections

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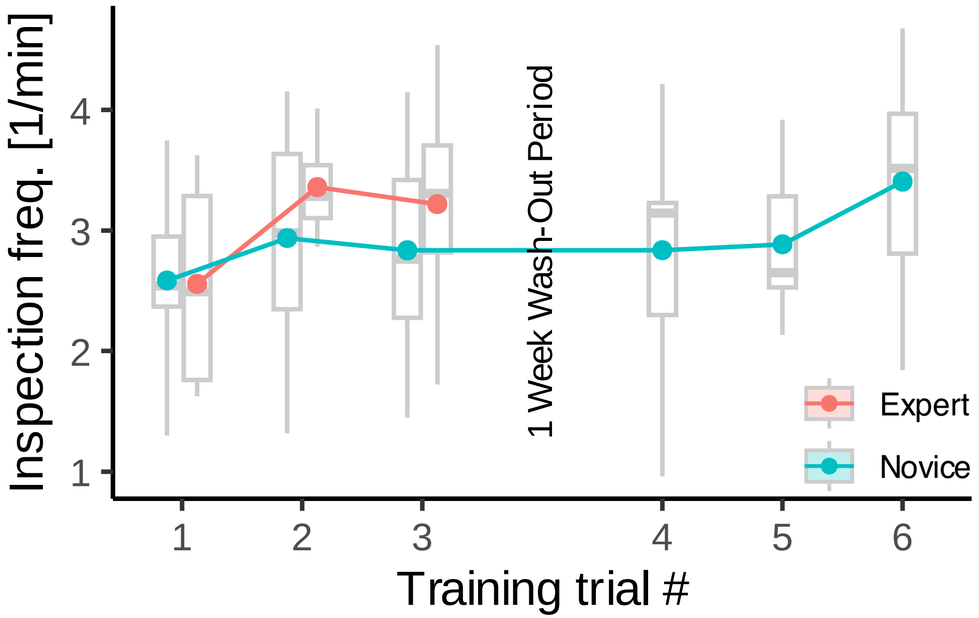
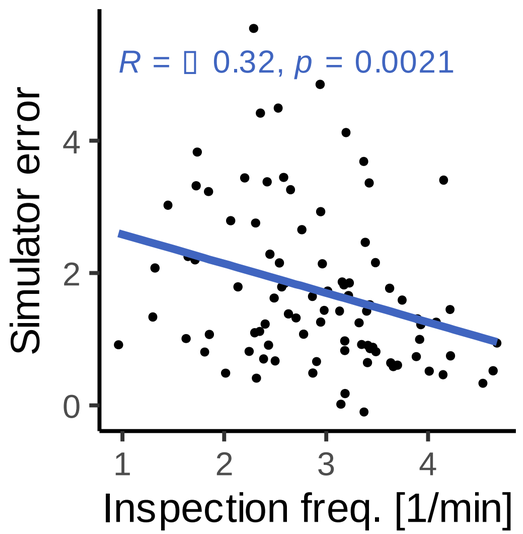
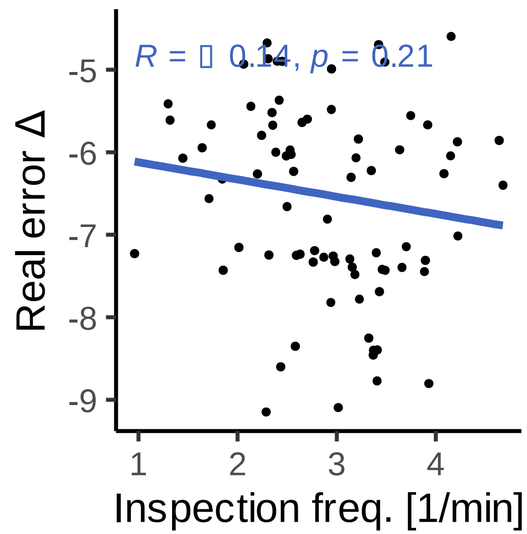
- "Inspection" = looking at tooth w/o drilling
  - Full vision inside tooth
- Experts & novices had similar inspections
  - *Week 1*: **2.6** vs. 3.1 inspections/m ($p = .18$)
  - *Week 2*: **3.4** vs. 3.1 inspections/m ($p = .49$)
- Novices improved sig. during training
- Correlates with performance
  - No correlation with learning gain

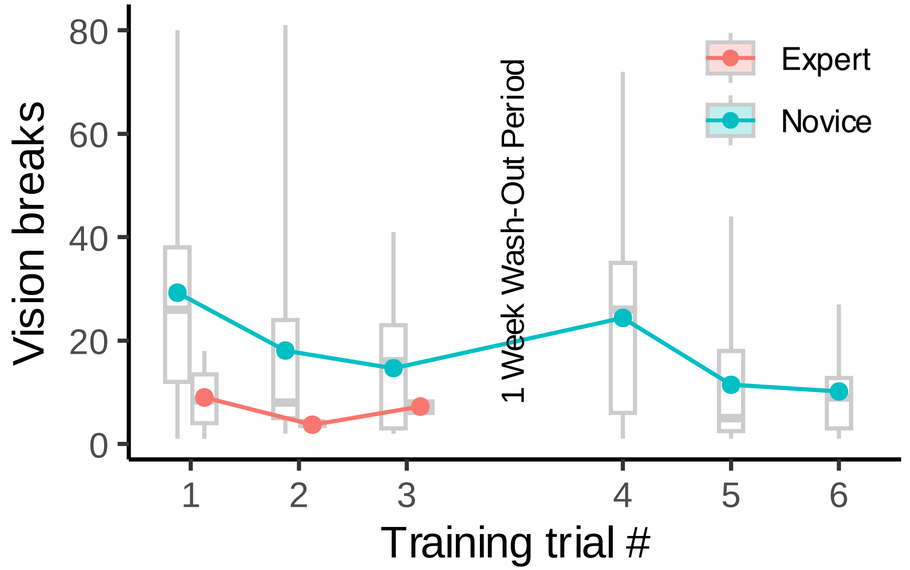


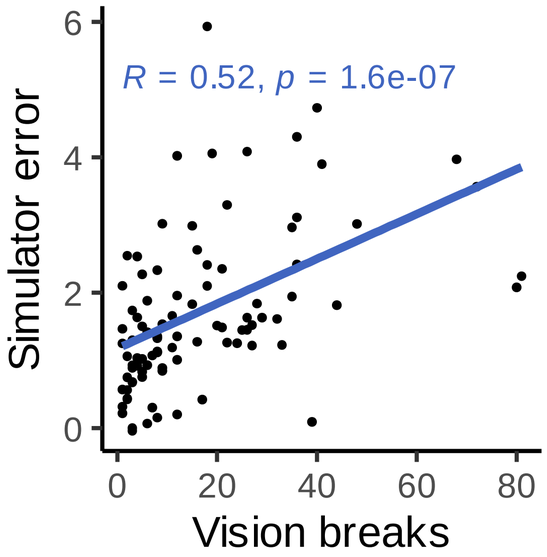


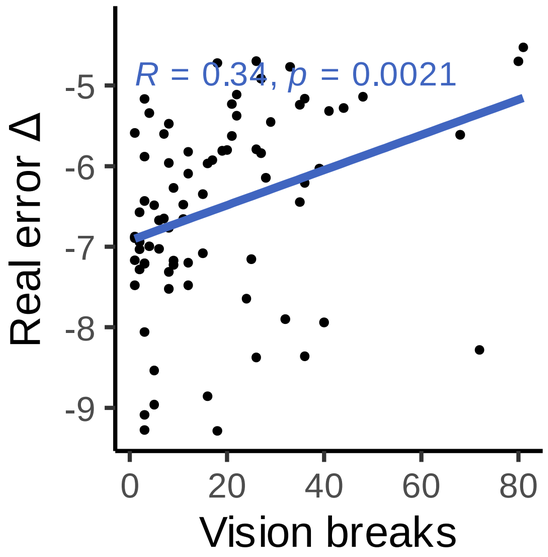


Results – Consistency of Vision

- "Vision break" = 1 sec of cont. vision loss
- Novices have sig. more vision breaks
  - *Week 1*: novice **20.8** vs. expert 6.7 ($p < .001$)
  - *Week 2*: novice **15.7** vs. expert 6.7 ($p < .001$)
- Novices improved sig. during training
- Neg. correlates with performance
  - Same for learning







Conclusion

- Indirect vision predicts performance of manual skills
- Proposal of novel metrics:
  1. Indirect vision during drilling
  2. Inspection frequency
  3. Consistency of vision
- Significant learning effect of manual skills
  (incl. transfer from VR to real-world)
- Novices learn mirror handling during training

Future Work

- Tutoring system: aid learning process
- Deformable physics to improve realism
- Use ML to predict expertise
  - based on tool trajectory & eye gaze

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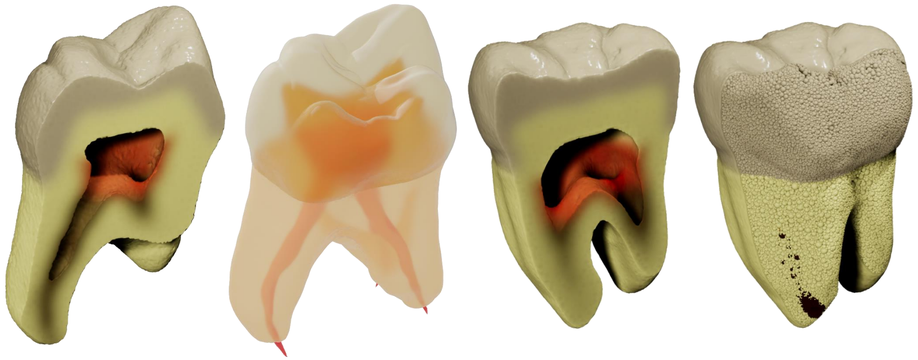

Max Kaluschke mxkl@uni-bremen.de
Computer Graphics & Virtual Reality
University of Bremen