3D Learning in anatomical and surgical education in relation to visual-spatial abilities

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Summary
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SUMMARY

In **chapter 1** a general introduction on three-dimensional visualization technology (3DVT) and its use in anatomical and surgical education is provided. Additionally, the role of visual-spatial abilities (VSA) in learning anatomy and surgical procedures is described. The overarching aim of this thesis was to gain evidence-based insights to improve anatomical and surgical education by evaluating how various levels of VSA interacts with learning using stereoscopic 3DVT.

In **chapter 2** we performed a systematic review and meta-analysis to compare the effectiveness of monoscopic 3D models with stereoscopic 3D models in teaching anatomy. We included 13 randomized controlled trials. Studies were grouped based on relative between-intervention differences in instructional methods and type of control conditions. When interactive, stereoscopic 3D models were compared to interactive monoscopic 3D models within a single level of instructional design by isolating stereopsis as the only true manipulated element in the experimental design, an effect size of 0.53 ($p < .00001$) was found. Stereoscopic vision had no effect in learning with non-interactive 3D images. With this comprehensive analysis we emphasized the importance of making a distinction between monoscopic and stereoscopic 3DVT.

Based on the evidence of the positive effect of stereoscopic vision, we performed a double-center randomized controlled trial to evaluate the effectiveness of stereoscopic vision in a 3D AR environment in teaching anatomy. In **chapter 3**, sixty (bio)medical students learned anatomy of the lower leg with either stereoscopic 3D AR model, monoscopic 3D desktop model or 2D images from anatomical atlas. As result, an aptitude-treatment interaction caused by VSA, as measured by the Mental Rotation Test, was observed. Students with low VSA achieved significantly higher posttest scores in the stereoscopic 3D AR group (49.2%) as compared to the monoscopic 3D desktop group (33.4%) and similar to the scores in the 2D group (46.4%). Students with high VSA performed equally well in all conditions. These differences were possibly attributed to the absence of stereoscopic vision in the monoscopic 3D desktop group. The findings indicated that VSA is able to compensate for poor instructional method as explained within the cognitive load theory. Since comparisons were made within various levels of instructional design, the true effect of stereoscopic vision in 3D AR environment still needed to be confirmed.

In **chapter 4**, we performed a follow-up study to evaluate the true effect of stereoscopic vision in a 3D AR environment by isolating it as the only true manipulated element between groups. In a double-center randomized controlled trial, sixty (bio)medical students learned anatomy of the lower leg with either stereoscopic 3D AR model or monoscopic 3D AR model. In the monoscopic condition, monoscopic view was obtained technically by projecting identical image to both left and right eyes. Both groups were blinded to the type of condition. As result, no significant differences were found between groups in terms of written knowledge (47.9 vs 49.1; $p = .63$) and specimen test scores (43.0 vs 46.3; $p = .429$), and perceived cognitive load scores (6.2 vs 6.2; $p = .992$). Regardless of intervention, VSA were positively associated with the specimen test scores ($\eta^2 = 0.13$, $p = .003$). These findings strongly suggested that stereoscopic vision was not the only one depth cue that have affected learning. Motion parallax (being able to walk around the model), as another important depth cue, could have compensated for the absence of stereoscopic vision in the control group.

The effect of stereoscopic vision was further evaluated in surgical training. In **chapter 5** we evaluated the effectiveness of watching an instructional video of a spatially complex procedure in 3D. In a randomized controlled trial, 108 surgical residents performed a five-flap Z-plasty on a simulation model after watching the instructional video either in 2D (monoscopically) or 3D (stereoscopically with active 3D glasses). As result, an aptitude-treatment interaction was observed. Overall, both groups performed equally well in terms of perceived cognitive load scores, performance scores and achieved safe lengthening. However, when accounted for VSA, only residents with high VSA benefitted from 3D visualization and achieved safe lengthening significantly more often than low VSA residents (OR = 6.6, $p = .027$). These findings indicate that VSA is able to interact with instructional method and enhance learning, as explained within the cognitive load theory.

The demonstrated aptitude-treatment interaction caused by VSA in learning with 3DVT (**chapter 3 and 5**) brought to light the importance of individualized approach in medical training. **In chapter 6**, we performed a randomized controlled trial and compared two types of intraoperative feedback (task-specific stepwise versus global rating scale) on performing a spatially complex procedure in fifty medical undergraduates in relation to VSA. As result, the task-specific stepwise feedback group performed significantly better than the global rating feedback group in terms of time in seconds (Δ 371 vs Δ 274; $p = .027$) and path length in meters (Δ 53.5 vs Δ 34.7; $p = .046$). However, when results were stratified by VSA, the greater improvement in time ($p = .032$) and path length ($p = .053$) was observed only in students with low VSA. Again, these findings demonstrated the aptitude-treatment interaction caused by VSA. More importantly, the findings demonstrated that alignment between feedback and instructional and learning activities improved learning, especially in students with low VSA.

Lastly, in **chapter 7**, we evaluated whether VSA can be improved by repeated practice of anatomy, starting from the early stages of medical training. In a case-control study, VSA of the first and second-year medical students ($n = 45$) was assessed before and after participation in a dissection course of ten weeks. The improvement in VSA scores were compared to students who did not participate in the course ($n = 65$). After ten weeks, both course participants and controls improved in their VSA scores. However, the improvement was significantly greater in students who participated in the dissection course (*first-year:* Cohen's $d = 0.41$; *second-year:* Cohen's $d = 0.11$). Additionally, the greatest improvement was observed in students with low VSA (Cohen's $d = 0.61$). The findings indicate that VSA can be improved by repeated practice of anatomy, especially in individuals with low levels of VSA.

In **chapter 8,** the results of this thesis are put into a broader perspective and suggestions for future directions are made. The emphasis has been put on recognizing and accounting for the aptitude-treatment interaction caused by VSA in learning with stereoscopic 3DVT and its ability to be improved by repeated practice.