Die Wirkung stereoskopischer Visualisierungen beim Arbeiten mit einer Lernsoftware zur Anatomie des Menschen – Untersuchungen zum Einschätzen und Wiedergeben von anatomischen Strukturen und Proportionen

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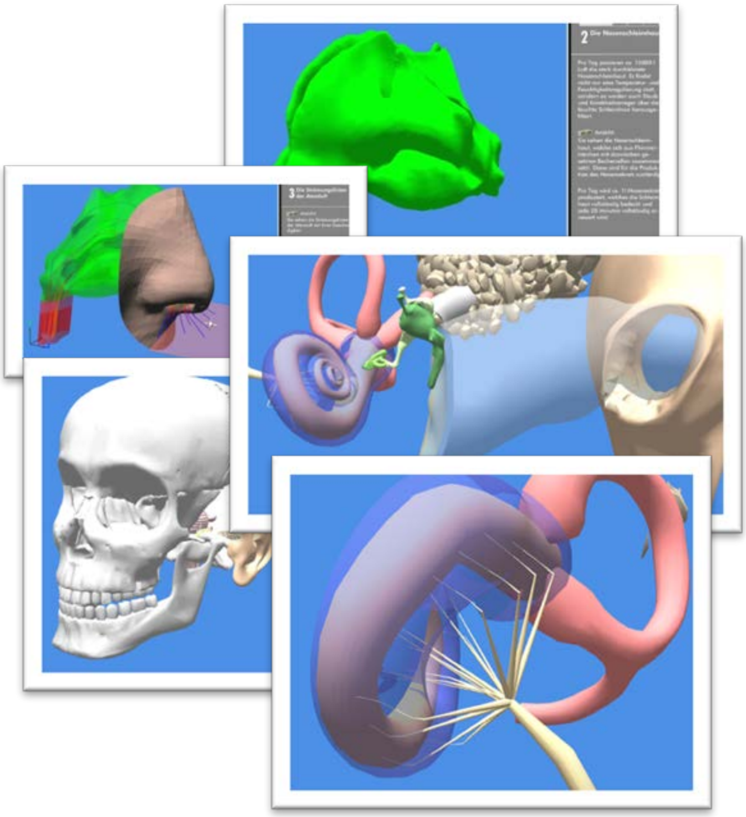

„Gedanken ohne Inhalt sind leer, Anschauungen ohne Begriffe sind blind. Daher ist es ebenso notwendig, seine Begriffe sinnlich zu machen, (d. i. ihnen den Gegenstand in der Anschauung beizufügen,) als seine Anschauungen sich verständlich zu machen (d. i. sie unter Begriffe zu bringen).“

Immanuel Kant

(Kritik der reinen Vernunft, 2. Aufl., Kap. 22)

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Inhalt

Summary

For student teachers and as well for pupils, authentic insights into the human body remain denied. To enable a realistic impression of human anatomy, visualizations displaying human organs should contain template-close information of structures. In contrast to non-stereoscopic visualizations, stereoscopic visualizations convey an impression of three-dimensional structures according to the principle of human binocular vision in everyday life. The present study is taking up this and investigates the impact of stereoscopic visualizations in the context of estimating organic structures within the human body. In doing so, the study focuses on secondary school and biology teacher students as they are typical learners of human biological content. Even though stereoscopy is known as a strong depth cue, there is only little evidence concerning possible effects in context of estimating proportions of organ structures. However, knowledge concerning this is inevitable to enable the development of e-learning environments to transport knowledge about anatomical structures effectively. Because object motion parallax is considered as powerful non-stereoscopic depth cue, research on the application of digital stereoscopic visualizations has to distinguish between the presentations of static or moving images. Because stereoscopic visualizations are said to provoke impairments, especially in the case of dynamic presentation, there is the need to clarify whether students get impaired while working with stereoscopic visualizations. Such possible impairments should be considered when judging the suitability of the application of digital stereoscopic imagery. As sensible measure may function the assessment of the situational visual attention performance. As things stand 2018, the application of digital stereoscopic visualization in most educational institutions is not practiced. Because first application of any technology in any educational setting can function as motivating, research focusing on the impact of stereoscopic representations should investigate whether possible enhancement effects on performance are in context with motivational aspects or independent to it.

Thus, aim of the present study was to evaluate the performance of participants related to tasks referring to structure and proportion of human organs in consideration of different modes of presentation. Moreover, it was intended to assess the impacts of working with stereoscopic representations on the situational attention performance of the visual working memory and also to prove the connection to motivational sensations. The findings of the present study are structured in four sub studies relating to the construction of tangible hands-on representations depicting the nasal cavity (sub study 1 and sub study 2), relating to the role of motivational sensations in this context (sub study 3), and relating to the estimation of anatomical-structural relationships within the middle and the inner ear (sub study 4). In the following, the findings of the present studies are presented in four sub studies. Sub study 1 revealed that digital static stereoscopic representations can be used more successful compared to non-stereoscopic ones to construct template-close haptic representations of the nasal cavity. Sub study 2 found even that advantage for a digital e-learning environment with dynamic picture presentation. Sub study 3 showed that the benefit of stereoscopic representations on constructing detailed haptic representations was independently to situational motivational sensations. Taking the example of the anatomy of the middle and the inner ear, sub study 4 highlighted the value of both static and dynamic stereoscopic visualizations concerning estimating anatomical-spatial relationships. It could be also demonstrated that dynamic stereoscopic visualizations influenced participants' situational visual attention performance individually different. Some got cognitively hindered; some others empowered to reach high situational visual attention performance.

Summarizing it can be stated that estimating anatomical-spatial relationships within digital visualizations as well as constructing template-close representations of human organic structures got more precisely due to stereoscopic imagery. This was true for static as well as for dynamic picture presentation. Because a connection between task performance and motivational sensations could be excluded within study 3, it can be assumed that the technology of stereoscopic imagery can be applied sustainably with more success compared to non-stereoscopic imagery to convey the proportions of anatomic structures. Future research should focus on the individually strongly different impact of combinations of stereoscopic imagery and dynamic picture presentation on situational visual attention performance to find solutions to avoid cognitive impairments. Moreover, it should be clarified whether the enhanced recognition of anatomical structures leads to an enhanced integration performance of picture and text in working memory, and moreover, to and enhanced comprehension of physiological concepts related to those structures. For carrying out such research, evidence-based studies on multimedia learning may provide an adequate framework.

Zusammenfassung

Originale Einblicke in den menschlichen Körper bleiben Lernenden in Schule und Lehramtsstudium versagt. Um einen Eindruck von der Anatomie im Körperinneren liegender Organe zu ermöglichen, sollten Visualisierungen menschlicher Organe proportionsgetreue Informationen über deren räumliche Strukturen enthalten. Digitale stereoskopische Visualisierungen vermitteln im Gegensatz zu digitalen nicht-stereoskopischen Visualisierungen ein Bild über räumliche Strukturen nach dem Prinzip des stereoskopischen Sehens aus dem Alltag. Die vorliegende Arbeit greift dies auf und befasst sich mit der Erforschung der Wirkung stereoskopischer Repräsentationen bei der Einschätzung von anatomischen Strukturen des menschlichen Körpers. Hierbei fokussiert sie auf Schülerinnen und Schüler der Sekundarstufe sowie Studierende des Lehramts Biologie, welche beide durch institutionelle Rahmenbedingungen mit dem Lernen menschlicher Anatomie befasst sind. Obwohl die Stereoskopie als starkes Tiefenkriterium bekannt ist, liegt Stand 2018 wenig Evidenz darüber vor, mit welchen Effekten bei der Verwendung digitaler stereoskopischer Visualisierungen bezüglich des Einschätzens der Proportionen von dreidimensionalen Organstrukturen zu rechnen ist. Wissen darüber ist allerdings hilfreich, um die Eignung der digitalen stereoskopischen Bildgebung für das Ausgestalten digitaler Lehr-Lernumgebungen zur Vermittlung von Wissen über anatomische Strukturen beurteilen zu können. Da Bewegungsparallaxe als starkes nicht-stereoskopisches Tiefenkriterium gilt, muss die Forschung zur Wirkung digitaler stereoskopischer Visualisierungen im Kontext des Einschätzens der Proportionen von Organstrukturen zwischen der Präsentation statischer und bewegter Bilder differenzieren.

Die vorliegende Arbeit fokussiert ferner auf Faktoren, die in Verbindung mit dem Arbeitsprozess mit stereoskopischen Visualisierungen stehen. So liegt etwa Evidenz vor, dass stereoskopische Bilder, besonders bei dynamischer Präsentation, Unwohlsein erzeugen können. Um aber die Eignung digitaler stereoskopischer Visualisierungen zur Vermittlung von Anatomie beurteilen zu können, bedarf es der Klärung, ob das für das Ausführen kognitiver Operationen relevante Arbeitsgedächtnis bei der Verwendung stereoskopischer Visualisierungen beeinträchtigt wird. Als sinnvolles Maß hierfür kann die situative visuelle Aufmerksamkeitsleistung gelten. Darüber hinaus zeigt Forschung zum multimedialen Lernen, dass ein erstmaliger Einsatz einer Technologie in Lehr-Lern-Situationen auf die Probanden stark motivierend wirken kann und dies Performanzeffekte zu beeinflussen vermag. Daher muss bei der Forschung zur Wirkung stereoskopischer Repräsentationen auch ermittelt werden, ob etwaige positive Performanzeffekte im Licht situativer motivationaler Faktoren gesehen werden müssen oder unabhängig davon zustande kommen.

Die vorliegende Arbeit geht von diesen Forschungsdefiziten aus und verfolgt das Ziel, die Performanz von Probanden beim Lösen von Aufgaben mit digitalen stereoskopischen Visualisierungen zu untersuchen. Dabei wird der Fokus darauf gelegt, die Struktur und Proportion menschlicher Organe unter Berücksichtigung verschiedener Präsentationsmodi zu ermitteln sowie die Auswirkungen des Arbeitens mit digitalen stereoskopischen Visualisierungen auf die situative Leistungsfähigkeit des visuellen Arbeitsgedächtnisses und auf die Abhängigkeit von motivationalen Empfindungen zu überprüfen. Die empirischen Befunde der Arbeit sind in vier Studien unterteilt. Diese befassten sich mit dem Erstellen haptischer Repräsentationen der Nasenhöhle bei statischer bzw. bei statischer und dynamischer Visualisierung (Studien 1 und 2), mit der Rolle motivationaler Empfindungen in diesem Kontext (Studie 3) sowie mit dem Einschätzen anatomisch-räumlicher Beziehungen im Mittel- und Innenohr bei statischer und dynamischer Visualisierung (Studie 4). Studie 1 zeigte, dass digitale statische stereoskopische Visualisierungen erfolgreicher zur Gestaltung proportionsgetreuer haptischer Repräsentationen der Nasenhöhle genutzt wurden als nicht-stereoskopische. Studie 2 belegte im selben Kontext den Vorteil stereoskopischer Repräsentationen auch in einer digitalen Lernumgebung mit dynamischer Bildpräsentation. Studie 3 verdeutlichte, dass der Mehrwert stereoskopischer Visualisierungen beim Konstruieren detailreicher haptischer Repräsentationen der Nasenhöhle unabhängig von situativen motivationalen Empfindungen zustande kam. Studie 4 offenbarte den Nutzen statischer und dynamischer stereoskopischer Visualisierungen beim Einschätzen anatomisch-räumlicher Beziehungen am Beispiel der Anatomie des Mittel- und Innenohrs. Studie 4 zeigte auch, dass dynamische stereoskopische Visualisierungen die situative Leistungsfähigkeit des Arbeitsgedächtnisses individuell unterschiedlich stark beeinflussten und manche Probanden kognitiv hemmten, anderen dagegen zu hoher situativer visueller Aufmerksamkeit verhalfen.

Zusammenfassend kann festgestellt werden, dass sich in den Studien sowohl das Einschätzen anatomisch-räumlicher Strukturen in digitalen Repräsentationen als auch die eigene Umsetzung durch stereoskopische Visualisierungen erworbener Raumeindrücke in Knetrepräsentationen präziser darstellte als bei der Verwendung nicht-stereoskopischer Visualisierungen. Dies betraf sowohl die statischen als auch die dynamischen Bildpräsentationen. Da eine Verbindung der Performanz zu situativen motivationalen Empfindungen in Studie 3 ausgeschlossen werden konnte, ist davon auszugehen, dass die Technologie der digitalen stereoskopischen Visualisierungen unabhängig von motivationalen Faktoren und daher nachhaltiger bei der Vermittlung der Proportionen räumlicher Strukturen eingesetzt werden kann als die der digitalen nicht-stereoskopischen Visualisierung. Künftige Forschung sollte die individuell unterschiedliche Wirkung von Kombinationen von stereoskopischer Visualisierung und Bewegung auf die situative visuelle Aufmerksamkeit näher untersuchen, um Wege zu finden, wie sich individuelle Beeinträchtigungen vermeiden lassen. Ebenso sollte geklärt werden, ob die verbesserte Wahrnehmung anatomischer Strukturen auch zu einer verbesserten Text-Bild-Integration im Arbeitsgedächtnis und letztendlich zu einem tieferen Verständnis von mit den Strukturen verbundenen physiologischen Konzepten führen kann. Evidenzbasierte Studien zum multimedialen Lernen liefern für eine diesbezügliche Anschlussforschung den adäquaten Rahmen.

Ausführliche Zusammenfassung

Prolog

(Biologie-) Unterricht findet in einem Spannungsfeld personaler, kognitiver, sozialer, affektiver, emotionaler, motivationaler und curricularer Faktoren (Shuell, 1996, S. 726) statt, welche im Zusammenhang mit dem Handeln der Lehrkraft und dem Lernerfolg der Schülerinnen und Schüler stehen. Wissen für erfolgreichen Unterricht in diesem Spannungsfeld erstreckt sich dabei auf die Bereiche des pädagogischen Wissens, des Fachwissens und des fachdidaktischen Wissens (Baumert & Kunter, 2006; Abell, 2007; Blömeke et al., 2009; Kunter et al., 2009; Blömeke et al., 2010; Kunter et al., 2011; Voss et al., 2011; Baumert & Kunter, 2013). Forschung zur Wirkung eines Mediums wie der digitalen stereoskopischen Visualisierung – in der vorliegenden Arbeit zur Repräsentation anatomischer Strukturen – muss folglich in diesem Gefüge verortet werden, um Erkenntnisse für die Aus- und Weiterbildung von Biologielehrkräften gezielt nutzbar zu machen.

Dabei klammert pädagogisches Wissen nach Grossman (1990) Fachwissen aus und umfasst vielmehr überfachliche Kompetenzen. Kunter et al. (2011) und Tepner et al. (2012) operationalisieren pädagogisches Wissen unter anderem als Wissen über bildungswissenschaftliche Grundlagen (z.B. Wissen über Lernen und Motivation) unabhängig von einem bestimmten Schulfach. Fachwissen und fachdidaktisches Wissen haben dagegen ein konkretes Unterrichtsfach als Bezug. Sowohl tiefgehendes Fachwissen der Lehrkraft als auch deren fachdidaktisches Wissen (Loucks-Horsley & Matsumoto, 1999; Blömeke et al., 2009; Baumert et al., 2010; Cauet et al., 2015; Kulgemeyer & Riese, 2018) beeinflussen den Erfolg von Lernenden. Das Konstrukt des fachdidaktischen Wissens wurde von Shulman (1986, 1987) begründet und stellt bis heute kein einheitliches Konstrukt dar. Trotz unterschiedlicher Definitionen gibt es einen breiten Konsens bezüglich zweier Komponenten von fachdidaktischem Wissen (Schmelzing et al., 2012; Jüttner & Neuhaus, 2013; Kirschner, 2013). So wird deutlich, dass zahlreiche Studien hierunter das Wissen über Verständnis und Verständnisprobleme von Schülerinnen und Schülern sowie das Wissen über die Wirkung von Instruktionsdesigns bzw. Repräsentationen fassen (Olszewski, 2010; Kunter et al., 2011; Tepner et al., 2012).

Da pädagogische Forschung das Wissen um Lehr-Lernprozesse allgemein im Fokus und Professionalisierungsforschung das Lehrerhandeln und -wissen generell im Blick hat, erscheinen mögliche Forschungsansätze aus diesen beiden Perspektiven als zu umfangreich für eine Integration in eine Forschungsarbeit, welche im Kontext der Verwendung stereoskopischer Visualisierungen Neuland in biologiedidaktischer Forschung betritt und werden daher nicht weiter verfolgt. Die vorliegende Forschungsarbeit möchte vielmehr evidenzbasierte Erkenntnisse darüber liefern, ob angehende Biologielehrkraft sowie Schülerinnen und Schüler der Sekundarstufe 1 durch stereoskopische Visualisierungen anatomische Strukturen und Proportionen vorlagengetreuer einschätzen können als durch nicht-stereoskopische Visualisierungen. Eine verbesserte Wahrnehmung relevanter bildhafter Informationen kann dabei Ausgangspunkt für eine erfolgreiche Integration zugehöriger sprachlicher Information (Scheiter et al., 2009; Imhof et al., 2011; Moreno et al., 2011; Scheiter et al., 2014; Scheiter & Eitel, 2015; Scheiter et al., 2016) und damit letztendlich Ausgangspunkt für tieferes Verständnis sein (Eitel et al., 2013a; Eitel et al., 2013b; Butcher, 2014; Scheiter et al., 2016). Daher haben Erkenntnisse aus dieser Arbeit einerseits Implikationen für die Genese von Fachwissen von Lehrkräften über Humanbiologie, andererseits aber auch für deren fachdidaktisches Wissen: Ein Wissen um ein etwaiges verbessertes Erkennen von anatomischen Strukturen durch Schülerinnen und Schüler muss zwangsläufig einen Einfluss auf die Beurteilung der digitalen stereoskopischen Repräsentation als instruktives Mittel seitens der Lehrkraft haben. Dies eröffnet dieser die Möglichkeit, Entscheidungen über Methoden und Instruktionsformate im eigenen Unterricht zu Humanbiologie bewusster zu treffen. Erkenntnisse zur Wirkung stereoskopischer Visualisierungen auf Schülerinnen und Schüler sollten somit aus fachdidaktischer Sicht in die Ausbildung von angehenden Biologielehrkräften einfließen.

Theoretischer Rahmen

Weil die inneren Organe des Menschen in einem dreidimensionalen Raum verortet sind, ist Wissen über den Aufbau anatomischer Strukturen mit Vorstellungen über Proportionen innerhalb dieses Raums verknüpft (Hilbelink, 2009; Yammine & Violoato, 2015). Um ein möglichst authentisches Bild vom menschlichen Inneren zu transportieren, sollten Lernarrangements zur Anatomie proportionsgetreue Informationen über Strukturen bereitstellen. Da im Kontext Schule eine Sektion von Leichen unmöglich ist und im Kontext universitärer Bildung auf internationaler Ebene selbst Medical Schools zunehmend Schwierigkeiten sehen, ihren Studierenden originale Einblicke in den menschlichen Körper über Sektionen zu ermöglichen (Gregory et al., 2009; Drake et al., 2009; Drake, 2014), ist ein Einsatz von Repräsentationen zur Visualisierung des Körperinneren erforderlich. Diesbezüglich heben Autoren die Bedeutung digitaler Repräsentationsformate hervor (Aziz et al., 2002; McLachlan & Patten, 2006; Tam et al., 2009; Rizzolo et al., 2010; Nguyen et al., 2012; Hackett & Proctor, 2016). Solch digitale Repräsentationsformate umfassen stereoskopische und nicht-stereoskopische Verfahren (Nguyen et al., 2012; Hackett & Proctor, 2016), wobei der Einsatz nicht-stereoskopischer Repräsentationen bisher deutlich weiter verbreitet ist als der Einsatz stereoskopischer Formate (Sergovich et al., 2010; Anderson et al., 2013; Yammine & Violato, 2015; Cui et al., 2016; Hackett & Proctor, 2016). Dennoch geben Meta-Analysen sowohl aus dem Bereich der Anatomie (Hilbelink, 2009; Hackett & Proctor, 2016) als auch über Disziplingrenzen hinweg (McIntire et al., 2012, 2014) Anlass zur Annahme, dass stereoskopische Repräsentationen prinzipiell zur Vermittlung räumlicher Strukturen im menschlichen Körper besonders geeignet sind. Dabei bleibt bislang offen, in welchen Formaten digitaler Bildpräsentation ein Einsatz der Stereoskopie einen Mehrwert gegenüber nicht-stereoskopischen Verfahren erzielen kann. Zur Klärung dieses Sachverhalts fokussiert die vorliegende Arbeit auf Unterschiede in der Wirkungsweise stereoskopischer und nicht-stereoskopischer Tiefenkriterien beim menschlichen Sehvorgang.

Präsentationsformate stereoskopischer und nicht-stereoskopischer digitaler Visualisierungen und ihre Auswirkungen auf die Performanz beim Umgang mit anatomischen Strukturen

Die menschliche stereoskopische Raumwahrnehmung resultiert aus dem Abstand beider Augen zueinander. Beim Betrachten eines Objekts in Greifnähe werden auf der Netzhaut zwei überlappende Bilder des betrachteten Gegenstands aus unterschiedlicher Perspektive abgebildet und vom visuellen System im Gehirn zu einem internen räumlichen Bild verarbeitet (Patterson & Martin, 1992). Die Tiefenwahrnehmung entsteht quasi automatisch. Digitale stereoskopische Bildgebungsverfahren imitieren das alltägliche stereoskopische Sehen, indem den Augen zwei Ansichten eines Objekts aus leicht verschiedenen Perspektiven gezeigt werden. Hierfür werden besondere Hardware-Technologien wie die Polfilter- oder die Shuttertechnik eingesetzt (Urey et al., 2011). Im Gegensatz dazu wird der Raumeindruck bei nicht-stereoskopischen Verfahren über die Wirkung monokularer Tiefenkriterien wie relative Größe, Perspektive oder sich bewegende Bilder („Bewegungsparallaxe“) erzeugt (van Beurden et al. 2012; Hackett & Proctor, 2016). Von den nicht-stereoskopischen Tiefenkriterien wird die Bewegungsparallaxe als das Stärkste mit einer ähnlichen Wirkung wie der Stereoskopie identifiziert (Rogers & Graham, 1982; Sollenberger & Milgram, 1993; Ware & Mitchell, 2005). Dementsprechend schreibt die jüngere Forschung sowohl der Stereoskopie als auch der Bewegungsparallaxe das Potenzial zu, erfolgreich Informationen über anatomische Strukturen zu vermitteln (Nguyen et al., 2012; Cui et al., 2015; Cui et al., 2016). Um die Wirkung stereoskopischer Repräsentationen bei der Vermittlung von Anatomie zu beurteilen, muss folglich zwischen der Wirkung statischer und dynamischer stereoskopischer Visualisierungen unterschieden werden. Dabei kann eine dynamische Bildpräsentation auf zwei Arten erzielt werden: einerseits durch das passive Betrachten sich selbst bewegender Bilder oder durch das Interagieren mit der Visualisierung mittels einer Eingabehilfe und dadurch das eigenständige Induzieren von Bewegungsparallaxe (Nguyen et al., 2014).

Eine explizite Unterscheidung der Tiefenkriterien Stereoskopie und Bewegungsparallaxe beim Generieren einschlägiger experimenteller Settings weisen nur wenige Studien auf. Im Hinblick auf das Nutzen statischer Bilder schnitten Probanden beim Identifizieren von Lungenknoten und markierten Arterien besser ab, wenn diese in stereoskopischer anstelle von nicht-stereoskopischer Visualisierung gezeigt wurden (Abildgaard et al., 2010). In der Studie von Hilbelink (2009) kam ein Lernarrangement über den menschlichen Körper zum Einsatz, welches ein nicht-stereoskopisches Video sowie entweder Computer-basierte statische stereoskopische oder statische nicht-stereoskopische Visualisierungen operationalisierte. Es zeigte sich, dass stereoskopische Visualisierungen den Probanden zu einer besseren Performanz bezüglich des Identifizierens von Strukturen und des Einschätzens von räumlichen Beziehungen zwischen diesen Strukturen verhalfen.

Dynamische Visualisierungen waren Gegenstand einer Untersuchung von Luursema und Kollegen (2008). Die Probanden dieser Studie befassten sich mit Proportionen und Lage von Organen des menschlichen Körpers unter Zuhilfenahme von dynamischen stereoskopischen oder dynamischen nicht-stereoskopischen Visualisierungen. Die Probanden, welche mit den stereoskopischen Repräsentationen arbeiteten, schnitten anschließend besser beim Lokalisieren der Strukturen in nicht-stereoskopischen Bildern ab. Damit übereinstimmend sind die Erkenntnisse von Rosenbaum et al. (2000). Diese zeigen, dass Probanden besser in der Lage waren, Strukturen des vaskulären Systems und des Skeletts zu identifizieren, wenn sie dynamische stereoskopische Visualisierungen im Vergleich zu dynamischen nicht-stereoskopischen Visualisierungen nutzen. Ferdig und Kollegen (2015) verglichen die Wirkung interaktiver stereoskopischer und nicht-stereoskopischer Visualisierungen beim Lernen verschiedener anatomischer Strukturen. Ihre Befunde legen nahe, dass Unterschiede in der Wirkung interaktiver stereoskopischer und nicht-stereoskopischer Visualisierungen von der jeweiligen thematisierten Struktur abhängen. Es konnte lediglich eine Studie mit 2x2 Multi-Matrix-Design identifiziert werden, welche sowohl den Faktor des Visualisierungsmodus (stereoskopisch vs. nicht-stereoskopisch) als auch den Faktor des Präsentationstyps (statisch vs. bewegt) variierte Nelson et al. (2008) konnten im Kontext des Identifizierens fetaler

Knochenstrukturen einen Mehrwert der stereoskopischen Visualisierung nur für den Fall einer Präsentation statischer Visualisierungen nachweisen, nicht aber für den Fall einer dynamischen Bildwiedergabe.

Als Fazit bleibt festzuhalten, dass lediglich eine dünne Faktenlage zur Wirkung stereoskopischer im Vergleich zu nicht stereoskopischen Visualisierungen im Falle des Umgangs mit Aufgaben mit Bezug zu anatomischen Strukturen bekannt ist. Während ein Mehrwert der stereoskopischen Visualisierung bei statischer Bildpräsentation gegeben scheint, zeigen die Studien zu dynamischer Visualisierung heterogene Befunde. Die in den zitierten Studien operationalisierten Aufgaben ähnelten sich in ihrer Ausrichtung; es ging vorwiegend um das Interpretieren von Strukturen in gegebenen Visualisierungen. Dabei gehen die Autoren übereinstimmend davon aus, dass über das Interpretieren gegebener Repräsentationen hinaus das Konstruieren eigener Repräsentationen lernförderlich wirkt (diSessa, 2004; Yore & Hand, 2010; Prain & Tytler, 2012, 2013). So gilt das Konstruieren haptischer Knetepräsentationen als etabliertes Instrument zur Vermittlung von Kenntnissen über anatomische Strukturen (Estevez et al., 2010; DeHoff et al., 2011; Bareither et al., 2013; Kooloos et al., 2014). Der Nutzen stereoskopischer Visualisierungen für den Erfolg der Anfertigung proportionsgetreuer haptischer Repräsentationen ist bis dato unerforscht. Befunde hierüber könnten helfen, Arbeitsphasen zur Konstruktion eigener Knetepräsentationen durch die Wahl einer angemessenen Visualisierung als Arbeitsvorlage effektiver zu gestalten und somit die Aneignung von Wissen über anatomische Strukturen zu fördern.

Situative motivationale Empfindungen und visuelle Aufmerksamkeit im Kontext des Arbeitens mit stereoskopischen Visualisierungen

Stereoskopische Visualisierungen werden nur zögerlich in naturwissenschaftlichen Lehr-Lern-Kontexten eingesetzt (Hackett & Proctor, 2016). Es ist bekannt, dass die Einführung neuer digitaler Medien in Lehr-Lern-Arrangements zu einer kurzzeitigen Steigerung situativer motivationaler Empfindungen führen kann und dies auch eine kurzzeitige Steigerung von Leistung zu implizieren vermag (Jonassen, 1996; Liu et al., 2009; Hew & Cheung, 2010). Es stellt sich daher die Frage, ob die durch stereoskopische Visualisierung erzielte Performanz in Verbindung mit situativen motivationalen Faktoren wie situativer intrinsischer Motivation und wahrgenommener Kompetenz (Deci & Ryan, 2003) steht oder unabhängig davon erzielt wurde. Eine Unabhängigkeit der Performanz von diesen Faktoren wäre ein Indiz dafür, dass die

Technologie längerfristig von Lernenden genutzt werden kann, ohne dass mit einem Absinken der Performanz aufgrund von sinkenden motivationalen Empfindungen zu rechnen ist.

Studien berichten von potentiellen Beeinträchtigungen des situativen Wohlbefindens beim Arbeiten mit stereoskopischen Visualisierungen, bedingt durch eine teilweise Entkoppelung von Vergenz und Akkommodation beim Betrachten stereoskopischer Visualisierungen (Lambooij et al., 2009; Alaraimi et al., 2014; Hackett & Proctor, 2016). Lambooij et al. (2009) weisen auf diese Gefahr speziell beim Betrachten von dynamischen Bildern hin. Dabei ist unklar, ob stereoskopische Visualisierungen im Rahmen einer kurzen Lerneinheit auch die situative Leistungsfähigkeit des für die Verarbeitung von Informationen wichtigen Arbeitsgedächtnisses zu beeinträchtigen vermögen (Mayer, 2003; Chandler & Sweller, 2003). Ein probates Maß für die situative Leistungsfähigkeit im Kontext des Arbeitens mit digitalen Visualisierungen ist die Leistung der situativen visuellen Aufmerksamkeit (Luck & Vogel, 2013; Tas et al., 2016). Sollte eine geringere situative visuelle Aufmerksamkeit nach einer Arbeitsphase mit stereoskopischen Visualisierungen und somit eine situativ niedrigere Leistungsfähigkeit des Arbeitsgedächtnisses diagnostiziert werden, müsste dies bei der Beurteilung der Eignung der Technologie in Lehr-Lern-Arrangements mit berücksichtigt werden.

Ziele und Fragestellungen

Die vorliegende Arbeit stellt das Interpretieren von stereoskopisch visualisierten im Vergleich zu nicht-stereoskopisch visualisierten anatomischen Strukturen aus dem Bereich der Humanbiologie in den Vordergrund. Daneben fokussiert sie auf das Konstruieren haptischer Repräsentationen anatomischer Strukturen auf der Basis von stereoskopischer und nicht-stereoskopischer Visualisierungen Dabei wird eine Unterscheidung in statische und dynamische Visualisierungen vorgenommen. Darüber hinaus finden die Auswirkungen der stereoskopischen und nicht-stereoskopischen Visualisierung auf das visuelle Arbeitsgedächtnis ebenso Berücksichtigung wie etwaige Zusammenhänge der Visualisierungsform mit Empfindungen von situativer intrinsischer Motivation. Aufgrund der Breite der Fragestellungen erschien es sinnvoll, diese auf mehrere Studien zu verteilen und anhand verschiedener humanbiologischer Sachverhalte („Die Nase“ und „Das Ohr“) und Probandengruppen (Schüler und Studierende) zu erforschen.

Studie 1

Der bisher unerforschte Nutzen statischer stereoskopischer Visualisierungen für das Erstellen proportionsgetreuer haptischer Repräsentationen der Nasenhöhle stand im Fokus von Studie 1. Somit wurde für Studie 1 folgende Forschungsfrage formuliert:

(1) Unterscheidet sich die Wirkung statischer stereoskopischer und statischer nicht-stereoskopischer Visualisierungen beim Konstruieren einer haptischen Repräsentation der Nasenhöhle?

Studie 2

In Erweiterung zu Studie 1 wurde in Studie 2 zusätzlich zu statischen Visualisierungen auch der Einfluss der Bewegungsparallaxe auf das Konstruieren haptischer Repräsentationen der Nasenhöhle – jeweils in Präsenz und Absenz von stereoskopischer Bildgebung – untersucht. Folgende Fragen waren handlungsleitend:

(1) Unterscheidet sich die Wirkung dynamischer stereoskopischer und dynamischer nicht-stereoskopischer Visualisierungen beim Konstruieren einer haptischen Repräsentation der Nasenhöhle?
(2) Unterscheidet sich die Wirkung statischer und dynamischer Visualisierungen beim Konstruieren einer haptischen Repräsentation der Nasenhöhle?

Studie 3

Die Probanden in Studie 1 und 2 arbeiteten zum ersten Mal mit stereoskopischer Visualisierung im Kontext Schule. So war es von Bedeutung zu ermitteln, ob Performanzeffekte bei dieser Experimentform im Zusammenhang mit situativen motivationalen Faktoren wie situativer intrinsischer Motivation und wahrgenommener Kompetenz zu sehen sind (Deci & Ryan, 2003). Die Forschungsfragen in Studie 3 lauteten daher:

(1) Unterscheidet sich die situative intrinsische Motivation der Probanden in Abhängigkeit des Visualisierungsmodus?
(2) Unterscheidet sich die wahrgenommene Kompetenz der Probanden beim Erstellen der Knetrepräsentation in Abhängigkeit des Visualisierungsmodus?
(3) Lassen sich Zusammenhänge zwischen situativer intrinsischer Motivation, wahrgenommener Kompetenz und der Performanz beim Erstellen einer Knetrepräsentation nachweisen?

Studie 4

In den Studien 1 bis 3 wurden Performanzeffekte über das Konstruieren eigener Repräsentationen gemessen. Studie 4 dagegen ermittelte direkt die Performanz beim Einschätzen anatomisch-räumlicher Beziehungen in digitalen Visualisierungen über einen Fragebogen und fokussierte somit auf den des Konstruierens einer eigenen Repräsentation vorgelagerten Moment des Interpretierens der visuellen Vorlage. Auch in Studie 4 wurde zwischen Kombinationen von stereoskopischer und nicht-stereoskopischer sowie statischer und dynamischer Präsentation unterschieden. Anders als in den Studien 1 bis 3 handelte es sich in Studie 4 um Lehramtsstudierende als Probanden. Den fachlichen Gegenstand bildete das Innen- und Mittelohr. Folgende Forschungsfragen wurden in Studie 4 untersucht:

(1) Unterscheidet sich die Wirkung stereoskopischer und nicht-stereoskopischer Visualisierungen beim Interpretieren anatomisch-räumlicher Beziehungen im Innen- und Mittelohr?
(2) Unterscheidet sich die Wirkung stereoskopischer und nicht-stereoskopischer Visualisierung auf die situative visuelle Aufmerksamkeit?
(3) Welchen Einfluss hat Bewegungsparallaxe im Kontext von (1) und (3)?

Methoden

Alle vier Studien wurden unter Zuhilfenahme desselben Tarox Computer mit Intel Core i5 Processor (3.20 GHz, 4 GB Ram) und einer NVIDIA Quatro 600 Grafikkarte durchgeführt. Als Software wurde der CyberClassroom (Visenso GmbH) mit den Lernmodulen „Die Nase“ (Studien 1 bis 3) und „Das Ohr“ (Studie 4) genutzt. In den Studien 1 bis 3 wurden die Sachverhalte an einem 47‘‘ LCD Monitor vom Typ LD950 mittels der Polarisationsfiltertechnik visualisiert, in Studie 4 mittels eines Sanyo Projector No. PDG-DWL2500 unter Anwendung der Shuttertechnik. In allen vier Studien fand eine Vortestung der Teilnehmenden bezüglich deren Fähigkeit zum stereoskopischen Sehen statt. Hierzu diente der Titmus-Test (Fricke & Siderov, 1997; Stereo Optical Company, 2011). Daten von Probanden mit 3D-Sehschwäche wurden nicht in die Auswertungen mit einbezogen. Bei minderjährigen Probanden wurde im Vorfeld die Erlaubnis der Eltern zur Teilnahme eingeholt. In allen vier Studien kamen jeweils eine nicht-stereoskopische Version und eine stereoskopische Version der Software zum Einsatz. Jeder Proband arbeitete mit nur einer Version. Die Zuteilung zu den entsprechenden Kohorten erfolgte über randomisierte Verfahren. Alle statistischen Auswertungen wurden mit SPSS 19 bzw. SPSS 22 vorgenommen.

Studie 1

Teilnehmer waren 64 Schülerinnen und Schüler der Klassenstufe 8 aus Grund-, Haupt- und Realschulen im Umkreis von Karlsruhe. Alle arbeiteten einzeln mit der Lernsoftware. Die Probanden sahen dabei statische Abbildungen der anatomischen Strukturen der Nasenhöhle, ein Induzieren von Bewegungsparallaxe war nicht möglich. Die Auseinandersetzung mit dem Lerngegenstand am Computer bestand aus dem zwanzigminütigen Betrachten der Visualisierungen und dem Lesen zugehöriger Fachinformationen. Zum Ende der Intervention wurden die Probanden gebeten, eine aus Knetmasse bestehende Repräsentation der Nasenhöhle zu formen. Hierfür standen rund drei Minuten Zeit zur Verfügung. Nach der Fertigstellung der Repräsentation ritzte der Versuchsleiter einen Code in die Masse, der für nicht Involvierte keinen Rückschluss auf die Person beziehungsweise auf eine Kohortenzugehörigkeit zuließ. Nach dem Aushärten der Repräsentationen im Backofen vermaß stets dieselbe Person mit einem Messschieber deren Länge, Höhe und Breite. Um die Proportionen der Repräsentationen mit denen der Vorlage zu vergleichen, wurden sowohl für die Repräsentation als auch für die Vorlage die Quotienten Tiefe/Länge, Höhe/Länge und Tiefe/Höhe gebildet. Anschließend wurden die Abweichungen der Quotienten der Repräsentationen von denen der Vorlage wie folgt berechnet:

$$((\text{Tiefe}_{\text{Vorlage}} / \text{Länge}_{\text{Vorlage}} - \text{Tiefe}_{\text{Repräsentation}} / \text{Länge}_{\text{Repräsentation}})^{0.5})^2$$

$$((\text{Höhe}_{\text{Vorlage}} / \text{Länge}_{\text{Vorlage}} - \text{Höhe}_{\text{Repräsentation}} / \text{Länge}_{\text{Repräsentation}})^{0.5})^2$$

$$((\text{Tiefe}_{\text{Vorlage}} / \text{Höhe}_{\text{Vorlage}} - \text{Tiefe}_{\text{Repräsentation}} / \text{Höhe}_{\text{Repräsentation}})^{0.5})^2$$

Zur Bestimmung anatomischer Strukturen lag der Fokus auf dem Vorhandensein der Nasengänge als dominierender Struktur in der Nasenhöhle. Die Anzahl der Nasengänge wurde auf einer von 0-3 reichenden vierstufigen Skala bestimmt. Die Skalierung basierte auf der Tatsache, dass pro Hälfte der Nasenhöhle drei Nasengänge vorhanden sind. Neben der Anzahl der Nasengänge wurde auch deren Ausgestaltung gemessen. Hier fand eine von 0-5 reichende sechsstufige Skala Verwendung. Diese Skalierung versprach eine Messung feinerer Unterschiede in der Deutlichkeit der Ausgestaltung als dies bei einer vierstufigen Skala möglich wäre. Die Auswertung wurde unter Zuhilfenahme beider Skalen von acht Studierenden des Fachs Biologie vorgenommen, welche alle bereits die Lehrveranstaltungen in Humanbiologie besucht hatten.

Zwischen diesen acht Ratern wurde die Interraterreliabilität (AD_M) nach Burke, Finkelstein & Dusig (1999) und Burke & Dunlap (2002) unter Anwendung folgender Formel bestimmt:

$$AD_M = \sum_{k=1}^{N} \left| x - \bar{x} \right| / N$$

x_k = Urteil des k-ten Raters

$\bar{x}$ = Mittelwert der Urteile aller Rater

N = Anzahl aller Urteile

Für beide Skalen konnten zufriedenstellende Reliabilitäten ermittelt werden ($AD_{Anzahl} = 0.50$ und $AD_{Ausgestaltung} = 0.61$). Beide Kohorten wurden bezüglich aller erwähnten Output-Messungen mithilfe von Varianzanalysen verglichen.

Studie 2

Ausgehend von Studie 1 wurde die Stichprobe von 64 auf 144 Schülerinnen und Schüler erweitert. Da in Studie 2 zusätzlich der Einfluss der Bewegungsparallaxe beim Erstellen der Repräsentationen ermittelt werden sollte, wurde ein 2x2 Multi-Matrix-Design gewählt (Tab. 1). 110 Probanden arbeiteten exakt wie in Studie 1 beschrieben ohne die Möglichkeit der Induktion von Bewegungsparallaxe (Präsentationstyp statisch), 51 davon mit nicht-stereoskopischer und 59 mit stereoskopischer Visualisierung. Die restlichen 34 konnten über eine Fernbedienung das visualisierte Objekt bewegen und drehen und dadurch Bewegungsparallaxe induzieren (Präsentationstyp dynamisch). 18 von ihnen arbeiteten mit nicht-stereoskopischen, 16 mit stereoskopischen Visualisierungen. Die übrigen Bedingungen für beide Kohorten waren identisch zu Studie 1. Aus organisatorischen Gründen war es nicht möglich, diese Stichprobe zu vergrößern, weswegen die Diskrepanz von 110 bei Präsentationstyp statisch zu 34 bei Präsentationstyp dynamisch zu erklären ist. Die Datenauswertung bezüglich des Vergleichs der Proportionsquotienten von Repräsentation und Vorlage sowie die Bestimmung der Anzahl und der Ausgestaltung der Nasengänge erfolgten identisch zu Studie 1. Auch hier wurden zufriedenstellende Interraterreliabilitäten ermittelt ($AD_{Anzahl} = 0.49$ und $AD_{Ausgestaltung} = 0.62$). In Erweiterung zu Studie 1 wurde in Studie 2 auch das jeweilige Verhältnis der Dimensionen Länge, Höhe und Tiefe zur entsprechenden Dimension der Vorlage berechnet. Zweck dieses Vorgehens war die Beantwortung der Frage, ob diese Dimensionen in den Repräsentationen proportional betont waren.

Tab. 1. Übersicht über das in den Studien 2 und 4 angewandte 2x2 Multi-Matrix-Design.

Visualisierung	**Kohorte 1**	**Kohorte 2**	**Kohorte 3**	**Kohorte 4**
Stereoskopisch	X		X	
Nicht-stereoskopisch		X		X
Statisch	X	X		
Dynamisch			X	X

Studie 3

Zur Messung der situativen intrinsischen Motivation sowie der wahrgenommenen Kompetenz wurden jeweils drei Items in Anlehnung an die Kurzskalen „Interesse/Vergnügen“ und „Wahrgenommene Kompetenz“ von Wilde et al. (2009) adaptiert. Alle Probanden arbeiteten mit statischer Visualisierung wie in Studie 1 und 2 beschrieben, 38 von ihnen mit nicht-stereoskopsicher und 35 mit stereoskopischer Visualisierung. Unmittelbar nach dem Anfertigen der Repräsentation am Ende der Intervention füllten die Probanden den Fragebogen aus. Eine Überprüfung der Reliabilität ergab für beide Kurzskalen zufriedenstellende Werte mit einem Cronbach’s Alpha von .75 für „Interesse/Vergnügen“ und mit einem Cronbach’s Alpha von .77 für „Wahrgenommene Kompetenz“. Als Maß für den Erfolg beim Repräsentieren des Organs wurde die Ausgestaltung der Nasengänge gewählt und wie in den Studien 1 und 2 beschrieben ermittelt. Alle Ouputmessungen wurden in einem ersten Schritt über Varianzanalysen verglichen. Um Zusammenhänge zwischen situativer intrinsischer Motivation, wahrgenommener Kompetenz und der Performanz zu bestimmen, wurden für beide Treatmentgruppen Korrelationen nach Pearson berechnet.

Studie 4

Probanden in Studie 4 waren 171 Lehramtsstudierende an der Pädagogischen Hochschule Karlsruhe. Jeweils zwischen sechs und acht Studierende sahen gleichzeitig eine 14 minütige Präsentation der Lerninhalte. In einem 2x2 Multi-Matrix-Design gab es vier verschiedene Untersuchungsgruppen (Tab. 1). Für die Arbeit mit dem Lernprogramm wurde ein Fragebogen entwickelt. Darin waren vier Items zur Erhebung der Performanz des Einschätzens anatomisch-räumlicher Beziehungen mit geschlossenem Antwortformat enthalten. Zur Messung der situativen visuellen Aufmerksamkeitsleistung kam der d2-R Test (Brickenkamp et al., 2010) zum Einsatz. Eine Testleiterin führte die Probanden durch das Lernprogramm, indem sie via Fernbedienung eine Folie nach der anderen abrief und zusätzlich bei den Kohorten mit dynamischer Bildpräsentation die Bewegungsparallaxe induzierte. Während dieser Interventionsphase wurde der Fragebogen von den Teilnehmern ausgefüllt. Direkt im Anschluss an die Interventionsphase bearbeiteten die Probanden den d2R Test. Die Performanz der Kohorten bezüglich des Einschätzens anatomisch-räumlicher Beziehungen und bezüglich der Konzentrationsleistung wurde mittels Varianzanalysen verglichen.

Ergebnisse und Diskussion

Studie 1

In den Knetrepräsentationen der Probanden der mit stereoskopischen Visualisierungen arbeitenden Kohorte wurde signifikant mehr räumliche Tiefe repräsentiert. Die Quotienten Tiefe/Länge und Tiefe/Höhe glichen damit einhergehend mehr denen der Nasenhöhle im Vergleich zu den entsprechenden Proportionen, die von den mit nicht-stereoskopischen Visualisierungen arbeitenden Probanden geformt wurden. Beim Repräsentieren anatomischer Strukturen am Beispiel der Nasengänge erwies sich der Einsatz von stereoskopischen Visualisierungen ebenfalls als signifikant effektiver. Dies galt sowohl für die Anzahl der modellierten Nasengänge als auch für deren elaborierte Ausarbeitung.

Dies zeigt, dass statische stereoskopische Repräsentationen nicht nur zielführender zur Interpretation visualisierter anatomischer Strukturen eingesetzt werden können als statische nicht-stereoskopische Repräsentationen (Hilbelink, 2009; Abildgaard et al., 2010), sondern auch für das Konstruieren detailreicher haptischer Repräsentationen besser geeignet sind. Da mit dem Konstruieren eigener Repräsentationen eine gesteigerte Verarbeitungstiefe im Vergleich zum bloßen Interpretieren gegebener Repräsentationen einhergeht (diSessa, 2004; Yore & Hand, 2010; Prain & Tytler, 2012, 2013), scheinen statische stereoskopische Visualisierung besser als statische nicht-stereoskopische Repräsentationen geeignet, ein vertieftes Lernen des Aufbaus anatomischer Strukturen zu ermöglichen.

Studie 2

Ähnlich wie in Studie 1 wurde in Studie 2 in den Knetrepräsentationen der Probanden in der mit statischen stereoskopischen Visualisierungen arbeitenden Kohorte signifikant mehr räumliche Tiefe repräsentiert als bei der Kohorte, welche mit statischen nicht-stereoskopischen Visualisierungen arbeitete. Eine dynamische Bildpräsentation führte hingegen dazu, dass sich die Performanz beider Kohorten bezüglich der Quotienten Tiefe/Länge und Tiefe/Höhe annäherten.

Dies belegt die Wirkung von Bewegungsparallaxe als starkes Tiefenkriterium (Rogers & Graham, 1982; Sollenberger & Milgram, 1993; Ware & Mitchell, 2005). Für das Repräsentieren von anatomischen Details in Form der Strukturen der Nasengänge zeigt sich ebenfalls eine positive Wirkung der Bewegungsparallaxe. Es fällt auf, dass sowohl für die Anzahl als auch für die Ausgestaltung der Nasengänge in der Umgebung mit dynamischer nicht-stereoskopischer Bildpräsentation höhere Mittelwerte erreicht wurden als in der Umgebung mit statischer nicht-stereoskopischer Visualisierung, was ebenso die Wirkung der Bewegungsparallaxe als starkes Tiefenkriterium unterstreicht. Besonders geeignet als Vorlage zum Repräsentieren strukturreicher Repräsentationen erwies sich die Wirkung der Kombination der Tiefenkriterien Bewegungsparallaxe und Stereoskopie. Hier finden sich sowohl für das Repräsentieren der Anzahl von Nasengängen als auch für deren Ausgestaltung jeweils die höchsten Mittelwerte. Diese Ergebnisse stehen somit im Gegensatz zu Nelson et al. (2008). Da der anatomische Gegenstand und das Aufgabenformat der Studien unterschiedlich waren, soll über mögliche Gründe hierfür nicht spekuliert werden. Für den Einsatz der Technologie der stereoskopischen Visualisierung kann gefolgert werden, dass den Lernenden die Möglichkeit gegeben werden sollte, bewegte Bilder – am besten in Kombination mit Stereoskopie zu nutzen. Dies kann etwa über das Lernen an Einzelarbeitsplätzen an 3D-fähigen Computern geschehen. Dabei ist jedoch davon auszugehen, dass gegenwärtig (Stand 2018) solche in vielen Schulen kaum vorhanden sind. Dort, wo eine einzige stereoskopische Ausgabeeinheit, zum Beispiel ein Beamer, vorhanden ist, könnten entweder statische Bilder gezeigt oder Bewegungsparallaxe von der Lehrkraft vorgenommen werden. Ganz ohne Möglichkeit einer stereoskopischen Bildpräsentation ist in jedem Falle ein Induzieren von Bewegungsparallaxe anzuraten, um eine angemessene Wahrnehmung und Operationalisierung anatomischer Strukturen anzubahnen.

Studie 3

Die Probanden der mit stereoskopischer Visualisierung arbeitenden Kohorte empfanden eine höhere situative intrinsische Motivation als die Kohorte mit nicht-stereoskopischer Visualisierung, allerdings verfehlte die Irrtumswahrscheinlichkeit knapp den Bereich einer statistischen Signifikanz ($p=.062$). Ebenso konnte für die wahrgenommene Kompetenz kein Unterschied zwischen beiden Probandengruppen nachgewiesen werden. In Übereinstimmung mit den Studien 1 und 2 wurden auch in Studie 3 signifikant deutlicher ausgestaltete Nasengänge seitens der Kohorte mit stereoskopischer Visualisierung gefunden. Innerhalb der Probandengruppe, welche mit nicht-stereoskopischer Visualisierung arbeitete, wurde eine signifikante Korrelation ($p=.020$) zwischen der Performanz beim Ausgestalten der Nasengänge und der situativen intrinsischen Motivation gefunden. Innerhalb der Kohorte mit stereoskopischer Visualisierung gab es keinen entsprechenden Zusammenhang. Für beide Kohorten konnten Zusammenhänge zwischen der wahrgenommenen Kompetenz und situativer intrinsischer Motivation gezeigt werden, nicht aber Zusammenhänge zwischen der Leistung bei der Ausgestaltung der Nasengänge und wahrgenommener Kompetenz. Da beide Kohorten ein vergleichbares Maß an situativer intrinsischer Motivation zeigten, kann davon ausgegangen werden, dass die erstmalige Arbeit der Probanden mit stereoskopischer Visualisierung nicht zu gesteigerter situativer intrinsischer Motivation im Sinne eines Neuigkeitseffekts führte (Jonassen, 1996; Liu et al., 2009; Hew & Cheung, 2010). Der Umstand, dass in der vorliegenden Studie kein Zusammenhang zwischen wahrgenommener Kompetenz und der Ausgestaltung der Nasengänge nachgewiesen wurde, mag darin begründet liegen, dass das Aufgabenformat des Knetens neu und für beide Kohorten schwer einschätzbar war. Darüber hinaus hatten beide Kohorten jeweils nur ihren eigenen Visualisierungstyp als Vergleich. Es erscheint möglich, dass dieser damit den jeweiligen Maßstab für die eigene Kompetenz setzte und somit die Einschätzung der eigenen Leistung unter diesem Gesichtspunkt zutreffend war. Obwohl die Kohorte mit stereoskopischer Visualisierung signifikant besser beim Repräsentieren anatomischer Details abschnitt, gab es hier keinen Zusammenhang zwischen Performanz und situativer intrinsischer Motivation, anders als bei der Kohorte mit nicht-stereoskopischer Visualisierung. Da eine Verbindung zwischen wahrgenommener Kompetenz und situativer intrinsischer Motivation nachgewiesen werden konnte, nicht aber zwischen Performanz und wahrgenommener Kompetenz, kann aufgrund dieser fehlenden Verbindung geschlossen werden, dass der Erfolg der stereoskopischen Visualisierung während der Arbeitsphase nicht als Motor für situative intrinsische Motivation dienen konnte. Umgekehrt konnte situative intrinsische Motivation kein Motor für Performanz sein. Daraus kann geschlossen werden, dass der positive Einfluss der stereoskopischen Visualisierung auf das Repräsentieren anatomischer Details unabhängig von den untersuchten situativen motivationalen Empfindungen abläuft, wohingegen in Absenz von stereoskopischer Visualisierung – bei nicht-stereoskopischer Visualisierung – sehr wohl in Zusammenhang mit situativen motivationalen Empfindungen steht. Für die Naturwissenschaftsdidaktik sind diese Ergebnisse ein starkes Argument für den Einsatz stereoskopischer Visualisierungen anstelle von nicht-stereoskopischen Visualisierungen im Unterricht: Einerseits ist die Leistung beim Repräsentieren anatomischer Details besser im Vergleich zu nicht-stereoskopischen Visualisierungen, andererseits wirken sie unabhängig der augenblicklichen Motivation der Schülerinnen und Schüler. So besteht die Möglichkeit, dass auch solche mit geringer situativer Motivation optimale Ergebnisse erzielen.

Studie 4

Die Probanden beider Kohorten mit stereoskopischer Visualisierung waren erfolgreicher beim Einschätzen der räumlichen Beziehungen anatomischer Strukturen als die Probanden der Kohorten mit nicht-stereoskopischer Visualisierung. Ähnlich wie in Studie 2 wurde der Vorteil der stereoskopischen Visualisierung besonders in der Umgebung mit statischer Bildpräsentation deutlich. Im Unterschied zu Studie 2 erwies sich die Kombination von stereoskopischer Visualisierung und dynamischer Bildpräsentation als nicht erfolgreicher im Vergleich zur Verwendung statischer stereoskopischer Visualisierung. Vielleicht stellen die komplexen anatomischen Strukturen des Mittel- und Innenohrs die Probanden vor solche Schwierigkeiten, dass die Kombination beider Tiefenkriterien auch keinen Vorteil bringen konnte. Der Faktor der Dynamik der Bildpräsentation für sich alleine betrachtet hatte in Studie 4 keinen Einfluss auf die Performanz beim Einschätzen anatomischer Strukturen. Somit erwies sich hier die stereoskopische Visualisierung als das stärkere Tiefenkriterium. Dafür konnte in der vorliegenden Studie ein Interaktionseffekt zwischen dem Visualisierungsmodus und der Art der Bildpräsentation nachgewiesen werden, der darin begründet liegen mag, dass die Kohorte, welche mit den vermeintlich schwachen Tiefenkriterien nicht-stereoskopische Visualisierung und statische Bildpräsentation arbeitete, einen Mittelwert erreichte, der deutlich unter dem der anderen Kohorten lag.

Die Mittelwerte der situativen visuellen Aufmerksamkeit der vier Kohorten unterschieden sich weder in Abhängigkeit des Visualisierungsmodus noch in Abhängigkeit des Präsentationstyps. Stereoskopische Visualisierung und statische Präsentation führten zu höchster visueller Aufmerksamkeitsleistung nach der Arbeitsphase. Im Gegensatz dazu resultierte aus der potentiell kritischen Kombination von stereoskopischer Visualisierung und dynamischer Bildpräsentation (Lambooij et al., 2009) die schwächste situative Aufmerksamkeitsperformanz. Auffallend ist, dass für beide mit stereoskopischer Visualisierung arbeitenden Kohorten signifikant größere Standardabweichungen als für deren mit nicht-stereoskopischer Visualisierung arbeitenden Pendants notiert wurden. Offensichtlich reagierten die Probanden auf die stereoskopische Visualisierung individuell stark unterschiedlich – manche wurden in ihrer Aufmerksamkeit behindert, umgekehrt waren andere stärker fokussiert. Im Gegenteil dazu war die Aufmerksamkeitsleistung der Probanden in den Kohorten mit nicht-stereoskopischer Visualisierung deutlich homogener. Es kann gemutmaßt werden, dass Personen mit ausgeprägter räumlicher Vorstellungskraft leichter auf prominente Strukturen fokussieren konnten (Roach et al., 2017) und ihnen das synchrone Interpretieren der in jeder stereoskopischen Visualisierung immanenten stereoskopischen und nicht-stereoskopischen Tiefenkriterien leichter fiel. Umgekehrt mussten Probanden mit schwächer ausgeprägter räumlicher Vorstellungskraft, um die Aufgaben während der Arbeitsphase zu lösen, mehr in das Korrelieren der stereoskopischen und nicht-stereoskopischen Tiefenkriterien investieren, was zu einer stärkeren Beanspruchung des visuellen Arbeitsgedächtnis und damit zu einer schwächeren Aufmerksamkeitsleistung im Test nach der Arbeitsphase führte.

Fazit und Ausblick

Die Ergebnisse der Studien 1-4 zeigen, dass anatomisch-räumliche Strukturen mithilfe digitaler stereoskopischer Visualisierungen proportionsgetreuer eingeschätzt werden können als mithilfe digitaler nicht-stereoskopischer Visualisierungen. Die Ergebnisse der Studien 1-3 verdeutlichen, dass damit auch ein proportionsgetreueres Gestalten eigener haptischer dreidimensionaler Repräsentationen einhergeht. Da besonders das Gestalten eigener haptischer Repräsentationen als lernförderlich für das nachhaltige Wissen um die Strukturen anatomischer Sachverhalte gilt (Estevez et al., 2010; DeHoff et al., 2011; Bareither et al., 2013; Kooloos et al., 2014), dürfen stereoskopische Visualisierungen menschlicher Organe als hierfür besonders geeignet angesehen werden. Bemerkenswert ist, dass der Mehrwert stereoskopischer Visualisierungen auch im Kontext von dynamischer Bildpräsentation nachgewiesen konnte, sowohl dann, wenn die Bewegungsparallaxe selbst oder durch einen Versuchsleiter induziert wurde. Dies belegt die Stärke der Stereoskopie als Tiefenkriterium. Inwieweit die Kombination der Tiefenkriterien Stereoskopie und Bewegungsparallaxe einer statischen stereoskopischen Visualisierung überlegen ist, scheint vom konkreten visualisierten Organ abhängig zu sein. Wichtig ist in diesem Kontext die Feststellung, dass stereoskopische Visualisierungen zu keiner Beeinträchtigung der situativen Leistungsfähigkeit des visuellen Arbeitsgedächtnisses führen und somit diesbezüglich mit keiner Lernbeeinträchtigung zu rechnen ist. Wieso jedoch manche Probanden durch dynamische stereoskopische Visualisierungen mit situativ niedriger visueller Aufmerksamkeit reagierten und andere dagegen eine hohe Leistungsfähigkeit des Arbeitsgedächtnisses zeigten, kann mit unterschiedlicher räumlicher Vorstellungskraft der Probanden im Kontext unterschiedlicher Anforderungen beim Interpretieren stereoskopischer und nicht-stereoskopischer visueller Informationen interpretiert werden (Roach et al., 2017). Da jedoch die räumliche Vorstellungskraft der Probanden nicht untersucht wurde, bleibt diese Annahme im Bereich des Spekulativen. Anschlussforschung sollte diesen Aspekt jedoch aufgreifen, damit sichergestellt werden kann, dass jeder Proband mit der für ihn gemäß der individuellen räumlichen Vorstellungskraft geeigneten Präsentationsform stereoskopischer Visualisierungen arbeiten kann. Da durch Studie 3 gezeigt werden konnte, dass keine Verbindung zwischen der Performanz beim Gestalten eigener haptischer Repräsentationen und situativen motivationalen Faktoren vorliegt, scheint die stereoskopische Visualisierung für einen nachhaltigen Einsatz in Lehr-Lernsituationen geeignet und ein schnelles Verschwinden der gesteigerten Performanz nach Etablierung der Technologie unwahrscheinlich.

Anatomische Strukturen gehen mit bestimmten Funktionen einher (Nguyen et al., 2012; Ferdig et al., 2015). Folglich ist das Wahrnehmen anatomischer Strukturen Voraussetzung für die Auseinandersetzung mit Physiologie, da deren Wirkungsprinzipien auf Struktur-Funktions-Zusammenhängen beruhen. Digitale Lernformate zu physiologischen Aspekten operationalisieren Konzepte von Struktur und Funktion mithilfe von Kombinationen sprachlich und analog-bildhaft kodierter Repräsentationen. Diese werden im Arbeitsgedächtnis der Lernenden aufeinander bezogen und integriert, was idealerweise zum Aufbau eines kohärenten mentalen Modells führt (Kintsch, 1998; Zwaan & Radvansky, 1998; Arndt et al., 2015; Schüler et al., 2015; Scheiter et al., 2016). Eine besondere Relevanz der analog-bildhaften Information wird dabei für Themenkreise postuliert, deren Inhalte sich direkter Beobachtung entziehen und gleichzeitig eine hohe strukturelle Komplexität aufweisen (Larkin & Simon, 1987; Wetzel et al., 1994; Scheiter et al., 2014), wie etwa die Physiologie menschlicher Organe. Dabei ist es für eine erfolgreiche Text-Bild-Integration essentiell, dass Lernende relevante Details innerhalb von Bildern rasch wahrnehmen und klar selektieren können (Scheiter et al., 2009; Imhof et al., 2011; Moreno et al., 2011; Scheiter et al., 2014; Scheiter & Eitel, 2015; Scheiter et al., 2016). Da in der vorliegenden Arbeit gezeigt werden konnte, dass stereoskopische Visualisierungen zu einer deutlich verbesserten Wahrnehmung anatomischer Strukturen verhelfen, darf gefragt werden, ob diese verbesserte visuelle Wahrnehmung relevanter räumlicher Details auch mit einer effektiveren mentalen Integration korrespondierender sprachlicher Information einhergeht. Beim Generieren von Forschungsdesigns zur Überprüfung dieser Frage muss allerdings beachtet werden, dass bei der Gestaltung von multimedialen Lernarrangements eine Doppelkodierung speziell von räumlicher Information über Bild und Sprache zu Interferenzen im Arbeitsgedächtnis und damit zu Interferenzen bei der mentalen Text-Bild-Integration führen kann (Schmidt-Weigand & Scheiter, 2011; Schüler et al., 2012). Ein Mittel zur Vermeidung ist der Verzicht der expliziten verbalen Beschreibung räumlicher Aspekte, die im begleitenden Bild klar zu sehen sind (Schüler et al., 2012). Ebenso können Interferenzen vermieden werden, indem räumliche Information wie etwa Strukturen visuell zeitlich vor der Konfrontation mit sprach-kodierter räumlicher Information präsentiert werden (Eitel et al., 2013a; Eitel et al., 2013b). So wird als künftige Forschungsperspektive die vergleichende Wirkung stereoskopischer und nicht-stereoskopischer Visualisierungen im Kontext der Text-Bild-Integration und Struktur-Funktions-Zusammenhängen sein, jeweils unter der Vermeidung simultaner Doppelkodierungen räumlicher Information. Da eine erfolgreiche Text-Bild-Integration wesentliche Voraussetzung für Verständnis im Sinne eines Anwenden Könnens des erlernten Sachverhalts ist (Eitel et al., 2013a; Eitel et al., 2013b; Butcher, 2014; Scheiter et al., 2016), eröffnet sich eine Möglichkeit für Lernende auch diesbezüglich von stereoskopischen Visualisierungen zu profitieren. Die empirische Überprüfung dieser weiterführenden Perspektive macht jedoch nur unter der Prämisse Sinn, dass ein Vorteil von stereoskopischen Visualisierungen bei der Text-Bild-Integration belegt werden kann.

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Darstellung des Eigenanteils

Remmele, M. & Martens, A. (2016). Stereoscopic representations to pictorially represent a human organ. In M. Roy, M. Kusyk, G. Schlemminger & D. Bechmann (Eds.), Digital Environments and Foreign Language Interaction: Formal and Informal Learning in Real and Virtual Worlds (pp. 217-233). Bern: Peter Lang Verlag.

Autor 1 entwarf das Design und die Messinstrumente der Studie, führte die Datenerhebung durch, vollzog die statistische Auswertung und verfasste den Artikel.

Remmele, M., Weiers, K. & Martens, A. (2015). Stereoscopic 3D's impact on constructing spatial hands-on representations. *Computers & Education*, 85, 74-83. doi:10.1016/j.compedu.2015.02.008

Autor 1 entwarf das Design und die Messinstrumente der Studie, war bei der Datenerhebung bei 110 Probanden der Versuchsleiter, vollzog die statistische Auswertung und verfasste den Artikel.

Remmele, M. & Martens, A. (in preparation for Advances in Physiology Education). Using stereoscopic visualizations as templates to construct a spatial hands-on representation – is there a novelty effect?

Autor 1 entwarf das Design der Studie, entwickelte das Messinstrument zur Auswertung der haptischen Repräsentationen, führte die Datenerhebung durch, vollzog die statistische Auswertung und verfasste den Artikel.

Remmele, M., Schmidt, E., Lingenfelder, M. & Martens, A. (2018). The impact of stereoscopic imagery and motion on anatomical structure recognition and visual attention performance. *Anatomical Sciences Education*, doi: 10.1002/ase.1704

Autor 1 entwarf das Design der Studie und betreute Autorin 2 bei der Entwicklung der Fragebogenitems zum Einschätzen anatomisch-räumlicher Beziehungen, vollzog die statistische Auswertung und verfasste den Artikel.

Bei der Planung, Durchführung und Verschriftlichung aller vier Studien wurde Autor 1 vom Doktorvater beraten.

Im Bearbeitungszeitraum der Doktorarbeit entstanden zu weiteren Themenfeldern folgende Schriften:

Remmele, M. & Lindemann-Matthies, P. (angenommen). Like father, like son? On the relationship between parents' and children's familiarity with species and sources of knowledge about plants and animals. *Eurasia Journal of Mathematics, Science and Technology Education*

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Studie 1

Stereoscopic representations to pictorially represent a human organ.

Remmele, M. & Martens, A. (2016). In M. Roy, M. Kusyk, G. Schlemminger & D. Bechmann (Eds.), Digital Environments and Foreign Language Interaction: Formal and Informal Learning in Real and Virtual Worlds (pp. 217-233). Bern: Peter Lang Verlag.

Abstract

Learning biological concepts goes in line with computing various representations. In present time, stereoscopic 3D visualizations are available to display human organs. However, there is a lack in research concerning the effectiveness of stereoscopic 3D in comparison with 2D for the abbreviation of biological content. Hence, applying an e-learning environment tackling with the nasal cavity, we investigated stereoscopic 3D's impact compared to 2D on constructing a tangible hands-on representation of the displayed organ. As research subjects were conducted 64 eighth grade middle school students. While discovering the nasal cavity by using the software application (visualization type 2D or stereoscopic 3D) the students were asked to construct a representation displaying the nasal cavity consisting of a kneading mass. The 3D cohort succeeded better in forming the nasal cavity down to the last detail.

1. Introduction

How it looks like within the human body is invisible in everyday life. Thus it is hard to imagine how a human organ like the nasal cavity with its special anatomy is structured. To provide help visualizations are obligated to foster student's estimation. Moreover, imagination about proportions of a human organ may be useful to understand its physiology. For instance such a relevant concept for the nasal cavity is breathing air's warming by the mucosa. This physiological process takes place within a three-dimensional space consisting of complicated structures like meatus of the nose. That means providing depictive information including relevant depth cues is inevitable to learn about structures and proportions going in line with physiology aspects such as meatus of the nose. In general for learning science topics in present time a lot of effort is spent in investigating the benefit of constructing external representations in science learning (Prain & Tytler, 2013; Prain & Tytler, 2012; Yore & Hand, 2010; Tytler, Peterson, & Prain, 2006). To date common subject of inquiry in science education are pictures displaying an object or a structure in detail (Bivall, Ainsworth, & Tibell, 2011; Schönborn, Bivall, & Tibell, 2011; Rundgren & Tibell, 2010). Those pictures are called realistic pictures. Constructing such realistic pictures is acknowledged to be useful for showing structural understanding (Ainsworth, Prain & Tytler, 2011).

Because the nasal cavity consists of several meatus structured complicatedly within a three-dimensional space it seems to be appropriate to search for a medium to provide depth-related information best. Stereoscopic 3D seems to be suitable to provide such depth-related cues: Note stereoscopic display technologies work with an imitation of stereoscopic viewing in everyday life and thus we expect them to provide enhanced information about spatial structures. Due to the interocular distance while watching something near around us in everyday life humans' eyes display two overlapping retinal pictures. Fusing these two pictures within the brain is the cue to gain spatial information. For stereoscopic multimedia applications there is a simple way to imitate stereoscopic vision in everyday life. Therefore, each eye sees an image of the same object from out a different angle using shutter glasses, polarizer glasses or autostereoscopic displays (Urey, Chellepan, Erden, & Surman, 2011). In this context research in disciplines out of science education reveals stereoscopic 3D's benefit for spatial structure recognition (McIntire, Havig & Geiselman, 2012; van Beurden, Ijsselsteijn & Juola, 2012; Neubauer, Bergner & Schatz, 2010; Aitsiselmi & Holliman, 2009; Ware & Mitchell, 2005). Dealing with the human body studies from the medical domain give relevant information about stereoscopic 3D's impact on depth-related tasks. In the case of estimating structures of veins and arteries Abildgaard, Witwit, Karlsen, Jacopsen, Tennoe & Ringstad et al. (2010) and Faubert (2001) highlighted stereoscopic 3D's benefit compared to 2D. Interestingly, stereoscopic 3D appears to be pretty useful for young medics with low experiences in surgical contexts (Pietrabissa, Scarcello, Carobbi & Mosca, 1994). Note the studies cited above focused on static pictures. However several studies focus on the application of stereoscopic 3D in combination with object motion parallax as additional depth cue and underline research subjects' enhanced performance (van Beurden et al., 2012; van Beurden, Kuijsters & Ijsselsteijn, 2010; Rosenbaum, Huda, Lieberman & Caruso, 2000). Combining 2D representations with the depth cue object motion parallax may be also useful to obtain enhanced transfer of spatial information in the context of discovering the human body (Luursema, Verweij, Kommer & Annema, 2008; Luursema, Verweij, Kommers, Geelkern & Vos, 2006). The bottom line is that studies out of science education focusing on adults as research subjects reveal that stereoscopic applications seem to be advisable for anatomical structure recognition and in no way inadequate. However to us surprisingly there is lack of studies focusing on the impact of stereoscopic 3D compared to 2D in science education. Hence to our knowledge most schools in Europe teaching science do not use stereoscopic multimedia applications for learning biological content yet. Most common are 2D pictures like those in conventional multimedia applications or printed versions. Thus we found the desiderata to evaluate the impact of different visualization types 2D / stereoscopic 3D on creating representations in type of realistic pictures.

2. Research aims

Because human organs consist of spatial structure it is relevant to estimate its spatial proportions best. However, the studies mentioned above focusing on stereoscopic 3D dealt with the interpretation of given representations, not with the forming of own depictive ones. That means it is not investigated yet if – and if so how – stereoscopic 3D impacts this. Thus, with a large-scaled study (Remmele, Weiers & Martens, 2015) applying different depth cue settings in combination with 2D / stereoscopic 3D we aimed to compare stereoscopic 3D's impact in contrast to 2D on the way to represent the nasal cavity in its spatial proportions. Within the present study we aimed to investigate this comparison by forming the nasal cavity out of kneading mass. Therefore to represent student's estimation of spatial depth as well as of spatial structures the construction of real spatial structures appears to be relevant. Hence, our study tackles with the construction of tangible hands-on representations displaying the nasal cavity for investigating the visualization type's impact. With the sample about we report in the present study we expected to gain initial experiences with our measuring instruments and as well expected to gain information about the prospects for success of a comparison between stereoscopic 3D's impact and 2D's impact on constructing a tangible hands-on representation and thus the prospects of success of the large-scaled study. Therefore with the present sample we only focused on the application of a static picture condition without possibility to move those pictures and thus to exclude the depth cue object motion parallax.

3. Materials and methods

For our study we chose a module called CyberClassroom (Visenso GmbH) providing both hardware (Tarox Computer, Intel Core i5 processor, 3.20 GHz, 4 GB Ram, NVIDIA Quatro 600 graphics card, 47" LCD monitor type 47LD950, polarizer glasses) and software. The learning application could be displayed in a stereoscopic as well as in a non-stereoscopic version. The e-learning module tackling with the nasal cavity contained several screen pages (Fig. 1). On each screen page information about the nasal cavity and its mucosa was given depictively and as well descriptively by written language. To estimate nasal cavity's proportions as well as anatomical details as best as possible the nasal cavity was presented in a lateral positioning turned in a small angle towards the learner on each screen page. Three screen pages turned the left and two screen pages turned the right cavity in front (Table 1). Within all screen pages nasal cavity's depth was strongly masked by either the right or the left part of the cavity. Nasal cavity's length was a little masked and nasal cavity's height could clearly be observed within every screen page. Hence, we expected nasal cavity's depth would be hardest to estimate and in contrast its height least. For navigating between the screen pages a remote was used.

In the present study we had visualization type with 2D in contrast to stereoscopic 3D as single factor. Our research measures focused on students' formed representation of the nasal cavity consisting of kneading mass calculating (a) dimensions, (b) proportions, (c) number of kneaded meatus of the nose and (d) elaboration of kneaded meatus of the nose (Fig. 2). As participants we conducted 64 8^{th} grade students of middle school level. The nasal cavity had not been content of their science lessons before, so we expected them to have only little knowledge about this topic. A worksheet was given to the students to instruct them for navigating between the screen pages, for reading relevant information about nasal cavity's anatomy and physiology and to form the tangible hands-on representation. As kneading mass we provided "Pluffy" modeling clay (Eberhard Faber Vertrieb GmbH) each student received half a package (= 120 g /

package). Before starting any working phase students absolved a stereoscopic vision test ('Titmus Test', Stereo Optical Company 2011, Fricke & Siderov 1997). We wanted to make sure that only students with ability of stereoscopic vision could participate to receive comparable results. Then, the instructor drew them by lot to condition 2D or stereoscopic 3D. Subsequently, each student had twenty minutes on a single working place to discover the nasal cavity's anatomy and physiology and to form the hands-on representation of the nasal cavity as solid body.

4. Data analysis

For measuring the representations' dimensions depth, length and height we conducted one person who was familiar with the application of a caliper. Before measuring the models each got a cipher to be anonymous for later analysis. In addition they were hardened in an oven to be preserved. For each dimension means and standard errors were calculated. To investigate the representations' proportions in relation to the template's proportions we proceeded as follows:

1. Calculation of the proportion quotients depth/length, height/length and depth/height for each representation and as well of the template.
2. Calculation of each representation's deviations from the template using the formulas

   $$((\text{depth}_{\text{template}}/\text{length}_{\text{template}} - \text{depth}_{\text{representation}}/\text{length}_{\text{representation}})^{0.5})^2$$

   $$((\text{height}_{\text{template}}/\text{length}_{\text{template}} - \text{height}_{\text{representation}}/\text{length}_{\text{representation}})^{0.5})^2$$

   $$((\text{depth}_{\text{template}}/\text{height}_{\text{template}} - \text{depth}_{\text{representation}}/\text{height}_{\text{representation}})^{0.5})^2$$

3. Calculation of means and standard errors.

For judging number and elaboration of meatus of the nose we recruited eight experts and proceeded as follows:

1. Development and application of a 4-point-scale (0-3) for counting the mean number of meatus of each side of the nasal cavity.
2. Development and application of a 6-point-scale (0-5) for judging the elaboration of meatus of the nose.
3. Calculation of means and standard errors.
4. Calculation of the average deviation (AD_M) between the eight expert raters (Burke, Finkelstein & Dusig 1999; Burke & Dunlap 2002) using the formula

x_k = judgment of k-th rater

$$AD_M = \sum_{k=1}^{N} \left| x - \bar{x} \right| / N$$

$\bar{x}$ = mean of all raters' judgments

N = number of all judgments

For comparing the 2D cohort with the stereoscopic 3D cohort ANOVAs were calculated on each category mentioned above.

5. Results

a. Dimensions

Findings for representations´ dimensions (Table 2) reveal differences between the visualization types (Fig. 3). Concerning depth, there was a significant effect ($F(1,63) = 9.41$, $p < .003$, ${}_p\eta^2 = .132$). Regarding height, also a significant effect could be detected ($F(1,63) = 8.47$, $p < .005$, ${}_p\eta^2 = .120$), too. Analysis of length also revealed no effect of vision modus ($F(1,63) = 0.51$).

b. Proportions

Different deviations from the templates´ quotients in dependency on the factor examined were found (Table 3 and Fig. 3). Analysis of depth/height revealed a significant effect of the vision modus ($F(1,63) = 12.98$, $p < .001$, ${}_p\eta^2 = .173$). Concerning the depth/length ratio, there was no significant effect ($F(1,63) = 2.19$). Regarding the height/length ratio, results reveal an effect of vision modus ($F(1,63) = 7.93$, $p < .006$, ${}_p\eta^2 = .113$).

c. Number and elaboration of shaped meatus of the nose

For numbering of shaped meatus (Fig. 4.), a significant effect of vision modus was found ($F(1,63) = 4.06$, $p < .048$, ${}_p\eta^2 = .061$). Concerning the elaboration of shaped meatus (Fig. 5.) there was also a significant effect ($F(1,63) = 4.25$, $p < .043$, ${}_p\eta^2 = .064$). For judging numbers and elaboration of meatus of the nose we found low average deviations of $AD_{Number} = 0.50$ and $AD_{Elaboration} = 0.61$ between the raters.

6. Discussion

The stereoscopic 3D cohort and the 2D cohort significantly differ in representing the nasal cavity's dimension. As expected the 3D cohort represented significantly increased absolute depth. That points out stereoscopic 3D's relevance for depth perception. Interestingly height as completely visible dimension without having been masked was increased represented by the 2D cohort. However these dimensions measures should be brought into relation with each other to obtain really meaningful results concerning the representation's proportions especially in comparison with the template's proportions. Comparing the quotient depth/height containing most spatial effort ('depth') in contrast to least spatial effort ('height') the stereoscopic 3D cohort's representation appear significantly closer to the template's proportion. Note the result for the quotient containing expected least spatial affordances (height/length) is vice versa. The interpretation may be obvious: For representing proportions with 2D appearance stereoscopic 3D provides no useful information. In the worst case it may confuse the students and thus leads to decreased performance. For physiological learning, e.g. learning about breathing air's warming and moistening the recognition of anatomical structures which go in line with these processes may be important in a special way. Hence regarding the number and elaboration of formed meatus of the nose stereoscopic 3D's benefit appears to be evident. The stereoscopic 3D cohort's students constructed the meatus more successful. However the p-values 0.048 for number of meatus of the nose and 0.043 for elaboration of meatus of the nose barely reach the level of significance. This may be due to the small group of research subjects. Hence further research conducting a bigger sample is strongly needed and thus was intended by Remmele et al. (2015). Obviously a stereoscopically given depictive information containing details about anatomical structures as well as anatomical spatial relations can be interpreted more successful and can be transferred to create a spatial hands-on representation which is closer to the template's structures. Thus on the one hand our findings go in accordance with research from the medical domain for interacting with and interpretation of given depictive information (Abildgaard et al., 2010; Getty & Green, 2007 and Hernandez et al., 1998). On the other hand with the aspect of creating an own concrete representation our findings highlight some new aspects of stereoscopic 3D's benefit which go beyond the perspective of interaction with given pictures. Note we provided an e-learning environment applying static pictures without the ability to move them or to induce object motion parallax. Additionally to the desiderata to have an increased number of research subjects the application of a setting with the possibility of increased interaction, e.g. to rotate the pictures might be useful was intended by Remmele et al. (2015), too. In addition further research is needed concerning the use of such self-formed tangible hands-on representations in deeper learning contexts. It might be interesting to witch degree those models may use to explain physiological contexts. That means it would be relevant to know if a more elaborated formed representation could be better used to explain a concept like the nasal cavity's physiology. Hence this would mean that stereoscopic 3D could also bring benefit for conceptual understanding. After all we have to underline that the present investigations conducted novices as participants. The circumstance of students' enhanced skills impacted by stereoscopic 3D seems to be important for science education at middle school level in general. Hence most of the students are assumed to be novices concerning concrete anatomical and as well physiological concepts. That means they might also be fostered by applying stereoscopic 3D dealing with other content than the nasal cavity. Thus further inquiry should conduct other human biological topics to verify this assumption.

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Table 1

Content-related design of the e-learning application dealing with the nasal cavity.

Screen page	Content	Nasal cavity's positioning
1	Introduction	Turned about 35° towards the student, left cavity in front
2	The nasal mucosa	Turned about 20° towards the student, left cavity in front
3	Breathing air's moistening	Turned about 20° towards the student, right cavity in front
4	Breathing air's warming	Turned about 20° towards the student, right cavity in front
5	Summary	Turned about 35° towards the student, left cavity in front

Table 2

Representations´ mean dimensions (and standard errors) in dependency to the cohorts´ vision modus 2D / 3D.

	Vision modus 2D		**Vision modus 3D**	
Dimensions in cm	M	SE	M	SE
Depth	**2.95**	0.13	**3.60**	0.15
Heigth	**6.50**	0.32	**5.38**	0.23
Length	**10.23**	0.41	**10.66**	0.42
	N = 27		**N = 37**	

Table 3

Representations´ quotients´ mean deviations (and standard errors) from the templates` quotients in dependency to the cohorts´ vision modus 2D / 3D.

	Vision modus 2D		**Vision modus 3D**	
Deviation template	M	SE	M	SE
Depth/Heigth	**0.42**	0.03	**0.25**	0.03
Depth/Length	**0.33**	0.02	**0.29**	0.02
Heigth/Length	**0.14**	0.02	**0.24**	0.03
	N = 27		**N = 37**	

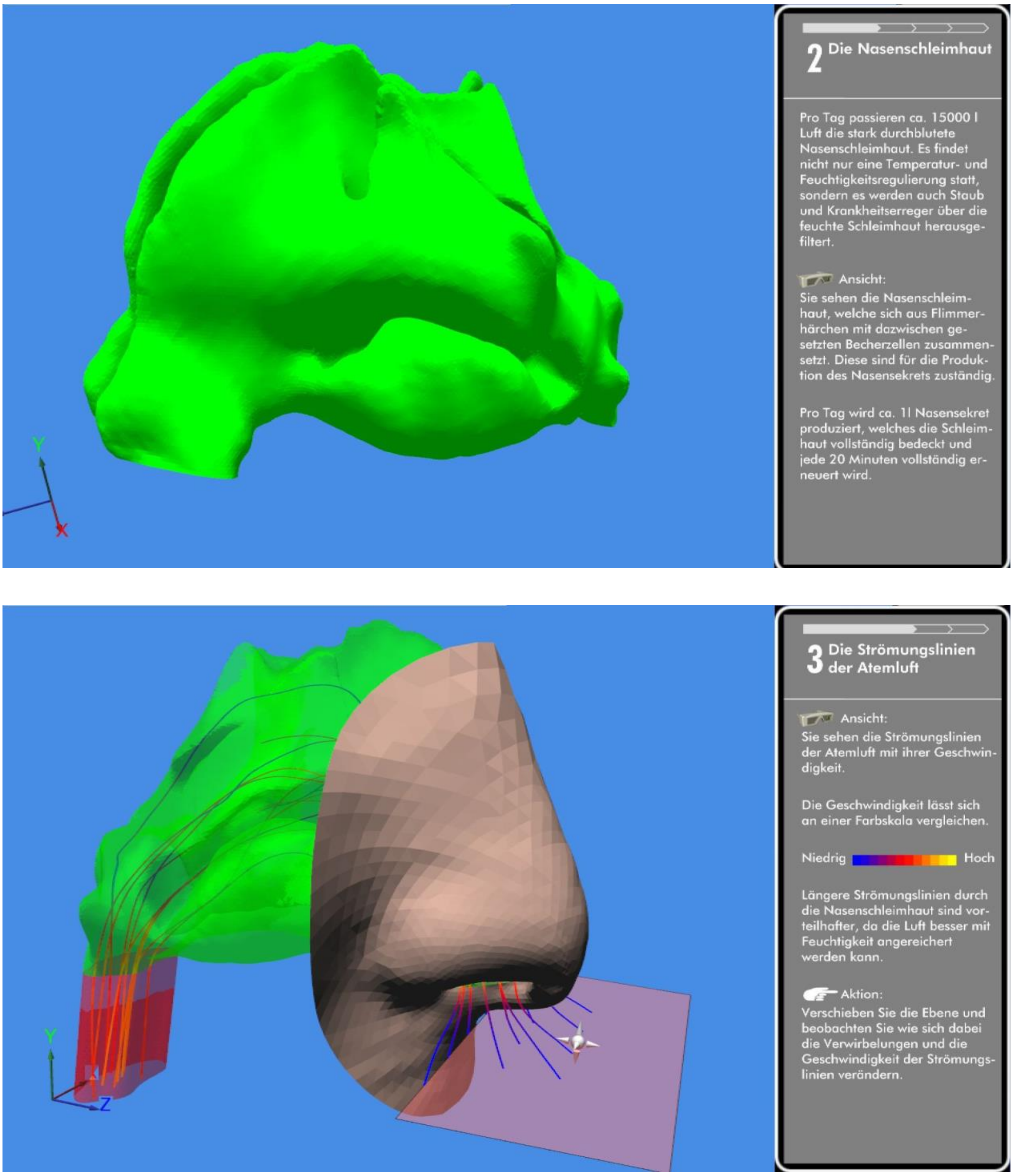

Fig. 1. Screenshots of the e-learning environment offering depictive and descriptive information (Remmele et al., 2015).

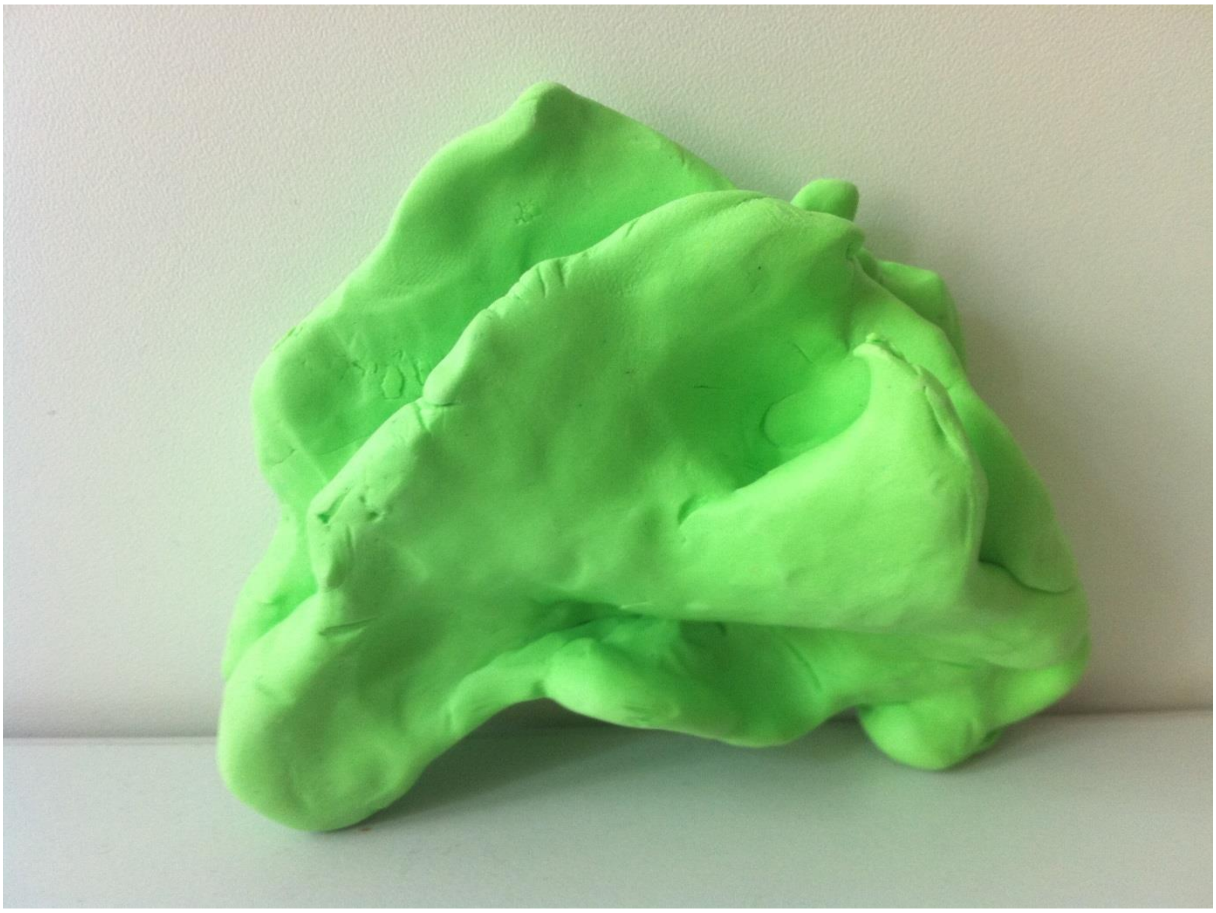

Fig. 2. The nasal cavity formed by a research subject (Remmele et al., 2015).

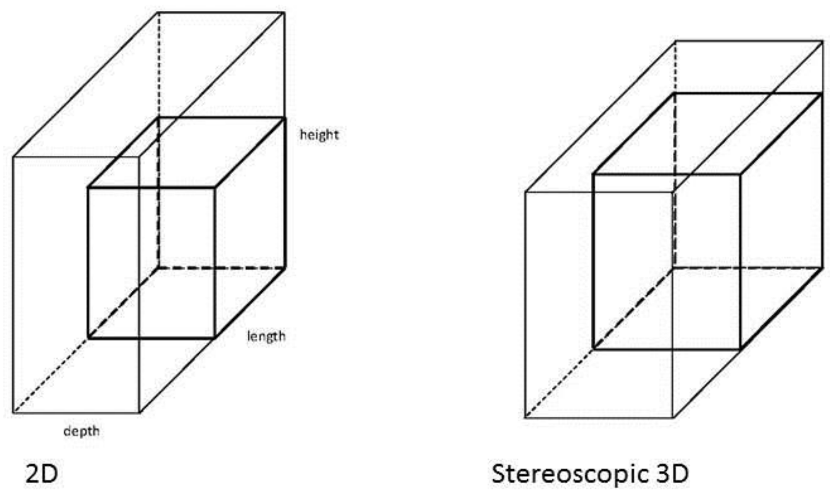

Fig. 3. Cuboids showing the cohorts' representations' mean dimensions. The cuboid representing the template's dimensions (bold) adjusted to the cohorts' representations.

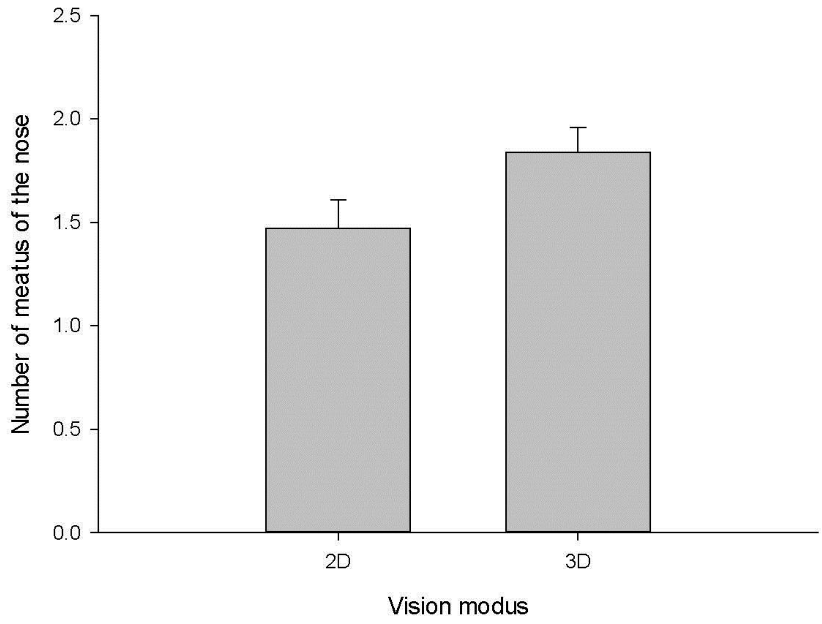

Fig. 4. Number (means and standard errors) of shaped meatus of the nose within the representations in dependency to the cohort's visualization type (2D N = 27, 3D N = 37) rated on a four-point scale (raters N = 8).

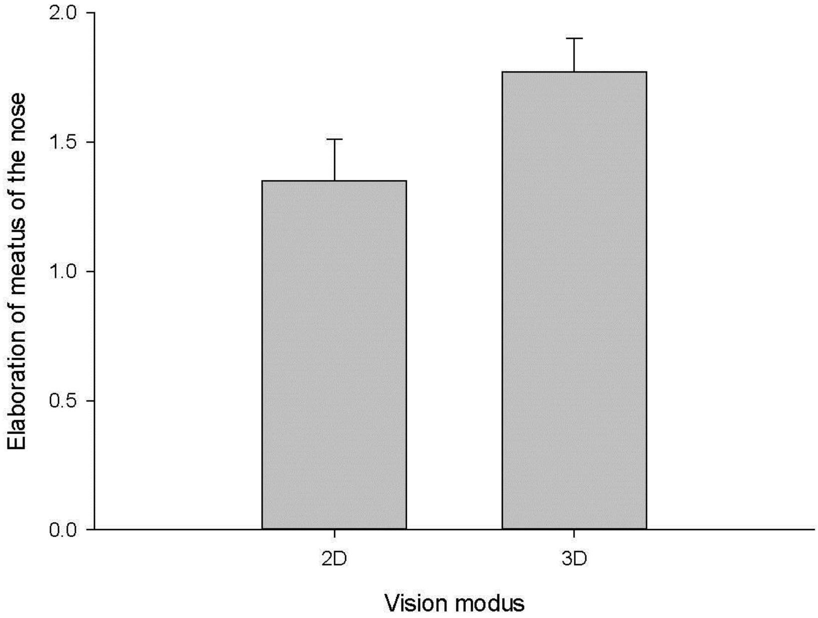

Fig. 5. Elaboration (means and standard errors) of shaped meatus of the nose within the representations in dependency to the cohort's visualization type (2D N = 27, 3D N = 37) rated on a six-point scale (raters N = 8).

Studie 2

Stereoscopic 3D's impact on constructing spatial hands-on representations.

Remmele, M., Weiers, K. & Martens, A. (2015). Computers & Education, 85, 74-83. doi:10.1016/j.compedu.2015.02.008

Abstract

While learning biological topics constructing depictive representations may be the first step to a deeper understanding. The referred to as visualization type as well as interaction type are supposed to have influence on learning with multimedia applications. Comparing 3D and 2D visualizations (both in combination with written text), there is little evidence whether stereoscopic 3D visualisations better support the understanding of biological topics by constructing adequate depictive representations. Likewise, insufficient indication is given of how the interaction type impacts these results (e.g. the ability /disability to move and rotate the displayed object).Therefore, our study focused on an e-learning environment dealing with the anatomy and physiology of the nasal cavity. Here, either (1) text and 2D visualisations or (2) text and stereoscopic 3D visualisations were used - both in combination with two interaction types (interaction / no interaction). Research subjects were 144 eighth grade students at medium stratification level. During a working phase with the different multimedia applications (visualization type 2D / stereoscopic 3D and interaction type 'interaction' / 'no interaction') the students were instructed to form the nasal cavity out of modelling clay. Finally, for both interaction types the 3D cohorts were by far more successful in representing anatomical details. Hence, stereoscopic 3D technology should be implemented in biological e-learning environments.

Keywords: Virtual reality; human-computer interface; applications in subject areas.

1. Introduction

For instance, the question of how it looks like behind the nostrils exemplifies the fact that several topics in science education presumably are out of students` direct viewing. Therefore, these topics require a visualization in order to gain a proper imagination. This may help to get even more familiar with concepts such like the process of breathing air`s moistening or warming in the nasal cavity. These two physiological processes, for example, occur in a three-dimensional cavity. Thus, in order to imagine this phenomenon more accurately information and ideas of what a cavity exactly is and how it can be displayed are needed.

Although various kinds of representations are available, science education at undergraduate level mostly deals with two-dimensional visual representations. For example, pictures in textbooks or common multimedia software are often used to illustrate spatial structures. Learners then are obliged to abstract from these two-dimensional representations so as to generate a three-dimensional internal representation. Precisely this is the point where stereoscopic 3D displays are able to provide spatial information using stereoscopic depth perception – the way we gain spatial information in everyday life. Unfortunately, little evidence is known about the impact of stereoscopic 3D visualizations in educational contexts (McIntire, Havig & Geiselman, 2014, 2012). Thus, applying an e-learning environment, the present study discovers students` ability to represent a human organ in dependency on the vision modus stereoscopic 3D / 2D. Here, the students were given the opportunity to mold an anatomic model consisting of modeling clay.

1.1. Learning science with external representations (ER)

Learning with external representations means interacting with various descriptive and depictive types of representation (Schnotz & Bannert, 2003). This might lead to a deeper understanding (Ainsworth, 2006, 1999). Not surprisingly, information gained by computing ERs plays an important role in learning science. Accordingly, several inquiry (Hubber, Tytler & Haslam, 2010; Tytler, Peterson & Prain, 2006; Prain & Waldrip, 2006) reveal the potential of ERs to foster the acquisition of content knowledge in science subjects. Whereas some older researches interpreted already available representations (Ainsworth, 2008; Gilbert, 2005), recent studies point at the relevance of constructing their own external representations for conceptual understanding (Prain & Tytler, 2013; Prain & Tytler, 2012; Yore & Hand, 2010; diSessa, 2004).

1.1.1. Learning science with realistic pictures

Some research articles particularly pay attention to utilizing realistic pictures. More precisely, utilizing realistic pictures could be described as representations with a high degree of structural accordance with its template (Schnotz & Bannert, 2003), such as pictures displaying human organs or molecular structures. In science education, it is acknowledged that realistic pictures are useful in order to visualize topics which cannot be observed originally. Hence, focusing on research in molecular learning, the alignment of recent inquiry (Schönborn, Bivall & Tibell, 2011; Bivall, Ainsworth & Tibell, 2011; Rundgren & Tibell, 2010; Stieff, 2005; Dori & Barak, 2001) reveals that it is not the question if but in which form or setting realistic pictures should be employed.

Referring to the drawing of a cell that beforehand was observed under a microscope – a realistic depictive representation – Ainsworth, Prain & Tytler (2011) point out the suitability of a drawing in order to construct one's own representations. This simplifies that the process of construction enables students to develop perception, e.g. of relevant anatomical structures. As physiological processes and anatomical structures rely on each other, creating one's own realistic depictive representation offers the possibility of being a starting point for physiological conceptual learning.

1.1.2. Interpreting and constructing realistic depictive representations for learning about the nasal cavity

The nasal cavity, as discussed beforehand, is a well suited topic in order to investigate stereoscopic 3D's impact on interpreting and constructing depictive representations in context with human biology. Here it has to be mentioned that physiological processes within the nasal cavity, e.g. meatus of the nose fostering breathings airs´ warming and moistening by increasing airflow distance, occur within a three-dimensional area depending on spatial structures. These spatial structures need to be realized in order to generate a concept of the nasal cavity's anatomy and physiology. Therefore, accurate depictive imagination of anatomic structures is obligated.

In turn, while interpreting or constructing realistic representations concerning this topic, spatial information has to be computed. Applying multimedia technologies, stereoscopic 3D visualizations are proven to be useful to foster spatial understanding of abstract displayed structures (Neubauer, Bergner & Schatz, 2010; Aitsiselmi & Holliman, 2009; Ware & Mitchell, 2005). This means that stereoscopic 3D might also be suitable for anatomical and physiological understanding. To enable students to pictorially represent a human organ in its spatial proportions, e.g. the nasal cavity, in order to display anatomical structure recognition (because of its three-dimensional structure) the construction of tangible hands-on representations appears to be appropriate. However, according to our knowledge there is a lack of studies in science education. At least, we could not find one single study concerning the construction of external depictive representations using computer-generated 3D visualizations as template. Hence, this study, as a first step, is an investigation of the impact of stereoscopic 3D images compared to 2D images on how students represent the nasal cavity by the aforementioned procedure. Here, the focus lies on the question if 3D enhances the representation of relevant anatomical structures and authentic proportions. Before this research aim will be specified, we review in the following literature concerning 3D applications in human biological contexts.

1.2. Stereoscopic vision in science learning

These days, the term 3D often is used in context with biological education (Keller, Gerjets, Scheiter & Gassofsky, 2004; Huk 2006, Korakakis, Pavlatou, Palyvos, & Spyrellis, 2009). However, all these studies operationalize the term 3D as 3D appearance on the basis of monocular depth cues, such as accommodation, shading, object motion parallax or relative size lacking stereoscopic vision. By means of experience, human´s brain may generate a spatial perception from out a two-dimensional visualization. 3D in context of stereoscopic vision gains spatial perception in another way: The two human eyes are separated by an interocular distance. That means, for seeing an object near around us, that each eye sees a slightly different picture of one and the same object. Two different retinal images arise at the same time. Hereby, the left and the right field of view overlap. Increased overlapping implies an increased chance of gaining spatial information. While calculating stereoscopic depth information, the human's brain fuses both retinal pictures. Thus, the degree of depth perception is impacted by the distance of corresponding points within retinal pictures. However, not every point of a retinal picture can be seen stereoscopically: Fixated points fall onto the horopter. Each point on the horopter got zero retinal disparity and thus cannot be seen stereoscopically. Points in front or behind the horopter got retinal disparity, but only in a small area around the horopter – panum´s fusional area – sensoric fusion is possible (Cutting & Vishton, 1995; Patterson & Martin, 1992). If focused objects move in distance, eyes move to parallel alignment, and stereoscopic depth perception stops. Watching pictures on a flat plane like on leaves of a book or a monitor, fixated points are displayed on a horopter lacking of a panum´s fusional area. Hereby, stereoscopic vision is impossible without technical aids.

1.2.1. Stereoscopic display technologies

Stereoscopic display technologies work with an imitation of stereoscopic viewing in everyday life. Therefore, each eye sees an image of the same object. To imitate disparity, the displayed objects differ within the viewing angle. To make the eyes see different images, various techniques are used (Urey, Chellepan, Erden, & Surman, 2011). In the case of passive 3D, polarizer glasses utilize two different permeable glasses for different polarized light, whereas the monitor utilizes these polarized lights in order to generate a left eye picture as well as a right eye picture. In the case of active 3D, shutter glasses alternately open and close for light, whereas the picture source alternately displays the appropriate image. In the case of autostereoscopic 3D, displays address the eyes with distinguishing pictures without glasses.

1.2.2. Interacting with stereoscopic displays in biological contexts

In general, a recent meta-analysis reveals judgment of distances and identification of objects as potential benefits of applying stereoscopic 3D images (McIntire et al. 2012). Accordingly, van Beurden, Ijsselsteijn & Juola (2012) and Holliman (2005) highlight an increased perception of objects and improved relative depth judgment as well as an enhanced surface interpretation, for example the ability to identify concavities as well as convexities within given external representations. In particular, in compliance with Smith, Cole, Merritt & Pepper (1979), van Beurden, Kuijsters & Ijsselsteijn (2010) postulate stereoscopic 3D´s improved value when complex scenes are presented. This indicates the potential benefits of recognizing organs or tissue structures within human biological visualizations as a basis for creating one’s own external representation. Empirical inquiries on the impact of 2D and 3D visualizations within human biological contexts are found within the medical domain. Most of them can be assigned to diagnosis and surgical training. However, hardly any of it can be assigned to the learning or creating of external representations. Hence, how the vision modus 3D impacts the construction of one’s own external representations is unknown. Nevertheless, these studies are suitable for gaining knowledge about interpretations of given depictive 3D representations by examining the accuracy of fine motor movements in the case of surgical training, or examining the performance in recognizing and identifying certain organic structures in the case of diagnosis.

In a surgical training context, research subjects succeed better when working with vein type structures like wire frames (Faubert, 2001). Accordingly, grasping movements succeed better when impacted by stereoscopic 3D (Melmoth & Grant, 2006; Servos, Goodale & Jacobson, 1992). The results exhibit an improved relative depth judgment when impacted by 3D. Not surprisingly, by training minimally invasive skills, especially novices profit from using stereoscopic 3D (Pietrabissa, Scarcello, Carobbi & Mosca, 1994). Focusing on diagnosis, Abildgaard, Witwit, Karlsen, Jacopsen, Tennoe & Ringstad et al. (2010) found 3D to foster even experts´ performance on identifying marked arteries within an angiography simulation when applying 3D. In the same study, 3D was found to facilitate diagnosis performance: Eight experts succeeded best when using stereoscopic 3D for searching 647 lung nodules within 100 CT pictures. For breast cancer diagnosis, Getty & Green (2007) revealed comparable results by applying X-ray imaging. This indicates that 3D enhances perception of anatomic structures. However, high image quality within 2D images seems to relativize 3D´s supposed benefits: Applying three different display types (2D, 3D and 2D HD), Falk, Minz, Grunenfelder, Fann & Burdon, (2001) show similar performances for medics when working with a high quality 2D HD image or a 3D image.

1.2.3. Object motion parallax and interaction type

In compliance with Kuszyk, Heath, Bliss & Fishman (1996) and van Beurden et al. (2012) postulate an increased impact by 3D's if monocular depth cues can hardly be interpreted or if they are unknown. Hence, it is necessary to specify the conditions for a comparison of 2D and 3D visualizations. While the studies cited above utilize static pictures with decreased possibilities of learners´ interaction such as rotating them, other studies demonstrate the significance of increased interaction and object motion parallax as strong monocular depth cues. This is similar to stereopsis (Rogers & Graham, 1982) – by working with depictive representations. Hereby, van Beurden et al. (2012) distinguish between movement parallax and object motion parallax. Movement parallax means that changes in an image perspective correlate with the users´ head movements. However, object motion parallax means that changes in an image perspective are caused by watching moving images or interacting with statically presented images which are manipulated by, for example movement, or rotation. Therefore, an interaction device such as a remote may be useful. Applying 2D/3D ultrasound imaging within two interaction types (decreased interaction / increased interaction) Nelson, Ji, Lee, Bailey & Pretorius (2008) examined medics´ performance in identifying fetal bony structures. Within the decreased interaction condition that means without a possibility to move or rotate the images; and thus without the possibility to induce object motion parallax the 3D cohort succeeded significantly better. Within the increased interaction condition, no difference between the 2D and 3D cohort could be detected. In addition, applying CT, MRT and DSA for imaging skeletal and venal structures Rosenbaum, Huda, Lieberman & Caruso (2000) showed benefits of stereoscopic 3D that was impacted by object motion parallax. Eight physicians succeeded better in identifying structures when seeing the images rotating within the 3D condition instead of the 2D condition. Two other studies dealing with anatomical learning revealed similar results (Luursema, Verwey, Kommers, Geelkern & Vos, 2006 and Luursema, Verweij, Kommers, & Annema, 2008). Research subjects should learn eleven organs of the human body by the aid of using 2D/3D images. In the following, the organs had to be identified by using two-dimensional cross sections, and had to be located within different front views of the human body (Luursema et al. 2006). During the learning phase, the 3D cohort was able to interact with the images by rotating them, whereas the 2D cohort could not do so. In the following study (Luursema et al. 2008) both cohorts were able to rotate the pictures so as to only presence or absence of stereoscopical imaging being the factor between the two groups. The first study (Luursema et al. 2006) revealed significant differences between the cohorts concernig both the identification and the localization task, whereas the second study (Luursema et al. 2008) indicated differences concerning only the localization task.

2. Research aims

Concerning literature, there is an obvious lack of studies which deal with the construction of external depictive representations impacted by 3D. Thus, research is strongly needed. A benefit when working with given external 3D representations appears to be evident. This especially applies when monocular depth cues are ambiguous, or when there is a lack of object motion parallax, e.g. in the absence of a possible movement or rotation of pictures. Therefore, we focus on the impact of stereoscopic 3D compared to 2D while constructing an external spatial hands-on representation. Hereby, concerning the interaction type, we employed two different conditions (the possibility / impossibility to move or rotate the displayed organ to induce object motion parallax). In each condition, cohorts worked in presence / absence of 3D while constructing the hands-on representations. In order to transfer a situation out of the medical sector to a realistic educational situation, we employed high quality pictures by the presence of clear monocular depth cues.

3. Methods

3.1. System description

Hardware as well as stereoscopic 3D software used in the present study presented the virtual reality system CyberClassroom (Visenso GmbH). The software has been installed on a Tarox Computer with an Intel Core i5 processor with 3.20 GHz, 4 GB Ram and a NVIDIA Quatro 600 graphics card. The software was displayed on a 47“ LCD monitor type 47LD950, using passive 3D with also 3D polarizer glasses and was controlled by a remote. Alternatively, the software could be displayed in a non-stereoscopic modus in the same resolution quality. According to Lambooij, Ijsselsteijn, Fortuin & Heynderickx (2009) the screen disparity for displaying the 3D pictures was smaller than 1° to avoid visual discomfort and visual fatigue.

3.2. Description of the multimedia application

The application consisted of five screen pages in order to explain anatomy as well as physiology of the nasal cavity. Each screen page displayed visualizations of the nasal cavity and its surrounding mucosa. These visualizations were simplifications of the original and emphasized realistic shape - for instance proportions and anatomical structures like meatus of the nose. Within these pictures, various monocular depth cues were utilized, e.g. shading, perspective imaging, texture gradients, and relative size. Thus, the interpretation of spatial depth as well as the recognition of anatomic details should be facilitated in absence of stereoscopic vision. Additionally, each screen page employed coherent linguistic information in the form of written text (Fig. 1. A+B). The first two screen pages introduced the anatomy and physiology of the nasal cavity by offering general information. Explicitly, the following two screen pages focused on airflow, moistening, and warming of the breathing air within the nasal cavity and its meatus. Therefore, visualizations of breathing air's changing flow velocities and changing temperature were shown. Each visualization was represented by a different colored airflow line in order to represent those changes. The last screen page made a brief summary. All screen pages displayed the nasal cavity in an original dorsoventral positioning. Furthermore, instead of a real lateral perspective, each screen page displayed the nasal cavity turned around 20° towards the learner into a comparable craniolateral perspective (Fig. 1. A+B). This means that spatial ability was required in order to estimate the nasal cavities´ width and length in relation to its height. Two screen pages turned the left nasal cavity and two screen pages turned the right nasal cavity to the front, so as to offer the opportunity for each student to see both halves of the nasal cavity while working with the multimedia-application. By using the remote learners could navigate between the screen pages. Before starting any working phase, the instructor was able to decide if the student additionally had the opportunity to move and rotate the visualized objects, or not. Thus, the student was able to induce object motion parallax, or not. We called these two opportunities 'interaction' and 'no interaction'. In addition, the instructor had to decide if the application should be displayed in 2D or stereoscopic 3D.

3.3. Design

The study was carried out by using two similar conditions. The first condition we called 'no interaction' (no interaction = no possibility of moving or rotating the visualized organ while working with the application) and the second one 'interaction' (interaction = possibility of moving or rotating the visualized organ while working with the application). In each condition, two cohorts worked by using either 2D or 3D. As independent variable we chose the vision modus with the visualization types 2D or 3D. Otherwise, as dependent variables we chose the objectively representation of the nasal cavity consisting of modeling clay utilizing the categories (a) dimensions in relation the template's dimensions, (b) proportions in comparison with the template's proportions and (c) anatomical details.

3.4. Participants

The participants were 144 8th grade students of medium stratification level. They were taken out of ten classes of five schools near Karlsruhe/Germany. In order to find research subjects with ability for stereoscopic vision 150 students performed a stereoscopic vision test called titmus test (Stereo Optical Company 2011, Fricke & Siderov 1997). Six students without the ability of stereoscopic viewing were excluded from the data collection so 144 students were able to participate. All of them participated voluntarily with permission of their parents. In relation to this issue, they were novices without any previous knowledge about the nasal cavity; also without being explicitly taught beforehand.

3.5. Materials

For molding a tangible representation of the nasal cavity, each student received 60 g "Pluffy" modeling clay (Eberhard Faber Vertrieb GmbH). This kind of modeling clay allows easy kneading, and can easily be hardened in an oven. A worksheet was developed to draw students´ attention to relevant topics within the application and to instruct them to mold the representation of the nasal cavity.

3.6. Procedure

In a first step, with 110 students, we employed the condition 'no interaction'. In a further step, with 34 students, we made use of the condition 'interaction'. Within both interaction conditions, the research subjects were assigned to two cohorts (2D/stereoscopic 3D) by random. Subsequently, each participant worked alone with the application for about 20 minutes; either using stereoscopic 3D or 2D. All participants were asked to watch the pictures, to read the related information, and to navigate from one screen page to another by pressing a button on the remote. Subjects working in the condition 'interaction' were instructed to move and rotate each picture at least once by using the remote. In addition, the students of all conditions were instructed to knead a representation of the nasal cavity as a solid body (Fig. 2) at the end of the working phase by using screen page 2 (Fig. 1 A) as a template.

3.7. Data Analysis

In order to analyze the molded representations' dimensions in relation to the template's dimensions, we measured length, depth and height of each workpiece. Each workpiece had its own code number which did neither allow any direct conclusion to the vision modus nor to the interaction type. For obtaining comparable results, one person measured all model data. Therefore, we called the cranial-caudal axis 'length', the dorsoventral axis 'height', and the medial axis 'depth'. Further, in order to operationalize these data for a later discussion, we expected the learners´ difficulty to estimate these dimensions as follows: The 20° dorsoventral - craniolateral positioning made a perspectival interpretation of the displayed organ inevitable. Hence, the nasal cavities' length and depth had to be estimated in relation to its height (Fig. 1 A+B). In particular, 'depth' was more masked by either the right or the left half of the cavity as 'length'. Thus, it was expected to cause more spatial load by estimating the templates´ dimensions. Thereby, we assume that there was more spatial ability needed to estimate the nasal cavities' depth than to estimate nasal cavities´ length. 'Height' was not masked and could directly be seen. First, we compared the models´ dimensions with the template's dimensions. Therefore, we calculated for each molded representation the quotients depth $_{rep.}$/depth $_{temp.}$ ('rep.' means representation and 'temp.' means template), height $_{rep.}$/height $_{temp.}$ and length $_{rep.}$/length $_{temp}$. Because the template on the screen was bigger than the hands-on representations could be, all quotients were expected to be smaller than '1'. Comparing these quotients to another should give information about which one was the most pronounced. Then, to match the representations' proportions with the templates' proportions, we first used the dimension measures to determine the quotients depth/height, depth/length and length/height. We expected both quotients containing 'depth' to cause increased spatial load. Afterwards, we compared the models' quotients with the template's quotients by calculating deviations. To judge anatomical details within the representations, we focused on the number as well as on the elaboration of meatus of the nose. The mean number of meatus of each half of the nasal cavity was counted by eight expert raters by using a four-point scale. This scale reached from 0 – 3 as each half of the nasal cavity in real contains three meatus. The elaboration of meatus of the nose in each model was rated by the same eight expert raters. Here we chose a six-point rating scale that reached from 0 – 5. This should make it possible to detect fine differences between the elaboration of the meatus within the formed representations. In order to determine the consistency of the raters' decisions, the average deviation (AD_M) between them was calculated (Burke, Finkelstein & Dusig 1999; Burke & Dunlap 2002). Hereby, x_k means the value of the k-th rater on this category, $\bar{x}$ means the mean of all raters on this category and N means the amount of all judgments:

$$AD_M = \sum_{k=1}^{N} \left| \varkappa - \bar{\varkappa} \right| / N$$

For both visualization types in each condition means as well as standard deviations were calculated. Outcome measures were compared by analyses of variances (ANOVAs). Note, for the quotients concerning dimensions as well as proportions, the calculated tests of significance are statistically not clearly independent to another. That means each first two quotients theoretically are independent to another however the results of the third ones automatically are dependent to the first ones. However, we assume this consideration will not reduce the validity of our analysis. Thus, although our special interest lay on quotients containing 'depth' we report about all.

4. Results

4.1. Dimensions in relation to the template's dimensions

For both conditions, the molded representations revealed differences (Fig. 3), hence, we found several significant effects concerning the visualization type. In condition 'no interaction' (Table 1) a significant effect for depth could be detected. Students of the 3D cohort molded this dimension by representing more spatial depth compared to students of the 2D cohort. This was the strongest effect in condition 'no interaction'. In contrast, dimension height was pronounced stronger by subjects of the 2D cohort. For length, there was no difference between the two visualization types in condition 'no interaction'. Interestingly, for both visualization types length was most pronounced (2D 27% of template's dimension vs. 3D 28% of the template's dimension), height second (2D 22% vs. 3D 20%) and depth third (2D 13% vs. 3D 15%). For condition 'interaction' (Table 2) quite different results were found. Length was most pronounced, too (2D 36% vs. 3D 31%) with a significant effect of 2D, for height (2D 18% vs. 3D 14%) and depth (2D 16% vs. 3D 18%) the order of pronouncement seemed to be dependent to the visualization type. At least concerning height there is a significant effect for 2D. For depth, no effect could be found. Note, the representation of depth and length seemed to be stronger in comparison to condition 'no interaction'. In contrast, height seemed to be less pronounced.

4.2. Proportions in comparison with the template's proportions

Looking at condition 'no interaction' concerning depth/height there was a significant effect for 3D. It was the strongest effect in condition 'no interaction'. Analysis of depth/length revealed no significant effect. In contrast, concerning length/height we found an effect for 2D. Focusing on condition ‘interaction’, analysis of depth/revealed a significant effect for 3D. For depth/height and length/height no effect could be detected. Interestingly, the deviations from the template’s quotients for depth/height as well as for length/height obviously are stronger compared to condition ‘interaction’. In contrast, the deviation for depth/length seems to be weaker.

4.3. Anatomical details

For both numbering and elaboration of shaped meatus, significant effects of the vision modus were found for both conditions. Concerning ‘no interaction’, students of the 3D cohort significantly molded more meatus of the nose compared to the 2D group. Additionally, these meatus were significantly shaped more elaborated. Regarding ‘interaction’, similar results were found. Students using 3D succeeded significantly better in molding a realistic number of meatus and as well these meatus were judged by the expert raters as more elaborated. Note, both the number and the elaboration of the meatus of the nose seemed to be more pronounced in relation to condition ‘no interaction’. For both dependent variables, we found average deviations of $AD_{Number} = 0.49$ and $AD_{Elaboration} = 0.62$ between the raters. In accordance with Burke et al. (1999), regarding a four-point scale as well as a six-point scale, these results display a sufficient reliability.

5. Discussion

Stereoscopic 3D led to a different representation of the nasal cavity compared to 2D. In absence of the depth cue object motion parallax, stereoscopic 3D fostered an increased representation of spatial depth within a hands-on representation of the nasal cavity and thus appeared as depth cue. According to the postulations of Cutting & Vishton (1995), van Beurden et al. (2012) and van Beurden et al. (2010), in presence of object motion parallax the pronouncement of spatial depth, expressed throughout the relative ‘depth’ and ‘length’ seems to be higher compared to its absence. In contrast, ‘height’ as dimension with least expected spatial load seems to be representable independent to the interaction type. However, this needs more statistical validation. Moreover, a combination of both strong depth cues stereoscopic 3D and object motion parallax does not lead to a stronger pronouncement of relative spatial depth compared to object motion parallax and 2D. This may appear surprising and indicate that object motion parallax and interaction may appear as stronger depth cues. Interestingly, the most relative pronounced dimension was those with the highest absolute magnitude. Hence, perception of sizes seems to be more essential for pronouncing dimensions compared to depth cues anyway.

However, from a science educator´s view arise desiderata for a nearest possible representation of the template. Thus, it cannot be assumed that a representation of spatial depth or a dimension at all actually corresponds with the template’s exact proportions. Focused on represented depth in relation to height and length, results reveal proportions that are closer to the templates´ proportions within both 3D conditions. Interestingly, for representing depth/length, the quotient containing maybe the highest spatial load, a combination of both depth cues object motion parallax and stereoscopy was best suited. However, proportions concerning length/height – the quotient containing least spatial load – do show advantages for 2D in absence of object motion parallax and interaction. The results indicate that the potential benefit, which 3D may provide in order to represent the proportions within hands-on models, increases with its template´ s spatial load. The explanation might be simple: For representing less spatial depth, spatial information is less important, and therefore is no advantage for the 3D cohorts. Furthermore, computation of stereoscopy – where it is not truly needed – may be additional useless information in order to cope with the short term memory. Thus, it may increase cognitive load (Huk, 2006). This could be an explanation for the 2D cohorts´ success in condition ‘no interaction’ for a better performance representing proportions that contain little spatial load. Note this assumption may be also valid for the depth cue object motion parallax. Hence, condition ‘interaction’ reveals no differences between the visualization types for representing length/height. Not surprisingly, these findings indicate a better performance in estimating distances in depth as well as spatial relations, and thus go in line with Melmoth & Grant (2006) and Pietrabissa et al. (1994). These authors detected 3D´s benefits by training minimally invasive surgery – tasks which as well require estimation of distances and spatial relations. Obviously, there is evidence for a comparable impact of 3D if spatial interpretation of a given external representation has to be transferred to an appropriate motoric movement within the given picture. For instance this is the case when using a virtual surgery tool like in medical studies, or if a given external representation is used to create an own spatial external representation. Strikingly, a combination of both depth cues does not enhance representing the templates proportions in general, but only if one has to deal with proportions containing increased spatial load. In contrast for other cases, in a kind of overestimation it may lead to increased deviations from the templates proportions.

Utilizing the 3D conditions, research subjects represented an increased – a more realistic – number of meatus of the nose as an example for anatomical details. In addition, they manipulated those meatus more in detail elaborately. Thus, 3D seemed to be a relevant predictor for successful representation of special anatomical details. According to Abildgaard et al. (2010), Hernandez et al. (1998), Nelson et al. (2008) and Getty & Green (2007) this may be a consequence of enhanced recognition of surface tissue within given external representations fostered by 3D. However, present results indicate that enhanced recognition of structures within the template can be operationalized for enhanced detailed representation within self-constructed hands-on representations. Obviously, a process of recognition can be successfully transformed into a process of spatial construction, and 3D fosters the outputs´ quality. Interestingly, parallel to representing proportions containing highest spatial load, a combination of both depth cues 3D and object motion parallax led to best performances. Focusing on the decreased interaction type respective static pictures, our findings go in line with Abildgaard et al. (2010) and Getty & Green (2007), who applied arrangements with decreased interaction types without the ability of watching moving pictures. However, in some aspects present results indicate differences from findings of other researches within the medical domain: On the one hand, Nelson et al. (2008), while examining identification skills, merely found differences between 2D and 3D within a decreased interaction condition but not in an increased interaction condition. On the other hand, present studies highlight3D´s benefit also within an increased interaction in order to figure the ground discrimination as well as to construct external representations which may include relevant anatomical details. There is evidence that object motion parallax alone is not predictable for creating the best represented anatomical details. Results reveal that a combination with 3D is more effective. Maybe the expert research subjects within the study of Nelson et al. (2012) used interaction more target-oriented in order to identify structures they were familiar with, and thus did not require stereoscopic images. For representing anatomical details, novice research subjects within the present study required both to perform best. Hence, present results fit better with Rosenbaum et al. (2000) who detected a benefit of 3D for identifying anatomical structures despite of using moving pictures. In contrast to Luursema et al. (2006) and Luursema et al. (2008) the differences between the visualization types 2D and 3D did not diminish within the increased interaction condition.

This means, in order to represent anatomical structures as well as proportions down to the last detail the application of 3D educational software is more advisable than the one of 2D modules. While learning physiology, 3D seems to provide the best chances: Essential processes, specifically the warming and moistening of breathed air, are impacted by the proportions of the nasal mucosa as well as by the meatus of the nose. The more elaborated manipulating of meatus of the nose within tangible representations goes in line with an increased relative depth within the molded representations and thus with a larger surface. Hence, the 3D cohorts´ representations seem to be more suitable in order to take anatomical characteristics up, and connect them with physiological processes. Descriptive representations like written or oral texts may be the most common representations to do so. Thus, further investigations (by further inquiries) should be made. As well, there needs to be a more specialized consideration about the question to which extent the construction of a more detailed representation can be correlated with other external representations e.g. written texts, and if this fact leads to an enhanced concept knowledge.

Within the present study we focused on novices representing anatomical structures that mostly were unknown to them. In contrast, medical studies applying identification tasks focused on experts already knowing specific structures as well as concepts. The expert´s success in utilizing a special technology by working with subjects they were familiar with may not surprise. Due to the test persons' lack of expert knowledge the present study applied high quality images with clear depth cues in order to facilitate the identification of relevant structures with which these students were not familiar. The revealed benefit of stereoscopic 3D for fostering construction of hands-on representations indicates the relevance of utilizing the 3D technology in order to visualize topics out of students` direct viewing. As well, these novices may operationalize 3D images better than 2D images in order to obtain imagination. In science classrooms 3D visualizations should be applied by providing the possibility of increased interaction to receive best imagination. In practice, this might become reality by providing individual 3D desks. Even in an everyday classroom situation, when students watch synchronously static pictures generated by a projector without the ability of interaction, compared to 2D images 3D technology seems to be better suited in order to help gaining imagination about the displayed human organs.

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Table 1

Condition 'no interaction'. Representations' dimensions and proportions in relation to its template and in dependency to the visualization type 2D / stereoscopic 3D. Representations' anatomical details in dependency to the visualization type 2D / stereoscopic 3D.

No interaction		Visualization type (mean $\pm$ SD)				
	dF	2D (N=51)	3D (N=59)	F	P	Partial Eta^2
Dimensions*						
Depth $_{rep.}$ /depth $_{temp.}$	1	0.13$\pm$0.03	0.15$\pm$0.04	10.563	0.002	0.089
Height $_{rep.}$ /height $_{temp.}$	1	0.22$\pm$0.06	0.20$\pm$0.05	6.290	0.014	0.055
Length $_{rep.}$ /length $_{temp.}$	1	0.27$\pm$0.05	0.28$\pm$0.06	0.899	0.348	0.008
Proportions**						
Depth / height	1	0.36$\pm$0.20	0.26$\pm$0.19	8.088	0.005	0.070
Depth / length	1	0.32$\pm$0.12	0.29$\pm$0.11	1.763	0.187	0.016
Length / height	1	0.40$\pm$0.47	0.72$\pm$0.76	6.728	0.011	0.059
Anatomical details***						
Number $_{meatus}$	1	1.51$\pm$0.73	1.89$\pm$0.70	7.896	0.006	0.068
Elaboration $_{meatus}$	1	1.40$\pm$0.84	1.91$\pm$0.82	10.632	0.001	0.090

Dimensions* = Representations' dimensions in relation to the template's dimensions.
Proportions**= Representations´ proportions´ deviations from the templates' proportions.
Anatomical details***= Rated by 8 expert raters using a 4-point (number) and a 6-point scale (elaboration)

Table 2

Condition ‘interaction’. Representations’ dimensions and proportions in relation to its template and in dependency to the visualization type 2D / stereoscopic 3D. Representations’ anatomical details in dependency to the visualization type 2D / stereoscopic 3D.

Interaction		Visualization type (mean $\pm$ SD)				
	dF	2D (N=18)	3D (N=16)	F	P	Partial Eta^2
Dimensions*						
Depth $_{rep.}$ /depth $_{temp.}$	1	0.16$\pm$0.08	0.18$\pm$0.05	1.049	0.313	0.032
Height $_{rep.}$ /height $_{temp.}$	1	0.18$\pm$0.06	0.14$\pm$0.03	6.048	0.020	0.159
Length $_{rep.}$ /length $_{temp.}$	1	0.36$\pm$0.06	0.31$\pm$0.07	5.068	0.031	0.137
Proportions**						
Depth / height	1	0.59$\pm$0.45	0.45$\pm$0.39	0.881	0.355	0.027
Depth / length	1	0.35$\pm$0.13	0.25$\pm$0.10	6.993	0.013	0.179
Length / height	1	1.63$\pm$1.47	1.75$\pm$1.11	0.076	0.784	0.002
Anatomical details***						
Number $_{meatus}$	1	1.69$\pm$0.59	2.19$\pm$0.51	6.922	0.013	0.178
Elaboration $_{meatus}$	1	2.13$\pm$0.66	2.59$\pm$0.61	4.302	0.046	0.118

Dimensions* = Representations’ dimensions in relation to the template’s dimensions.
Proportions**= Representations´ proportions´ deviations from the templates’ proportions.
Anatomical details***= Rated by 8 expert raters using a 4-point (number) and a 6-point scale (elaboration)

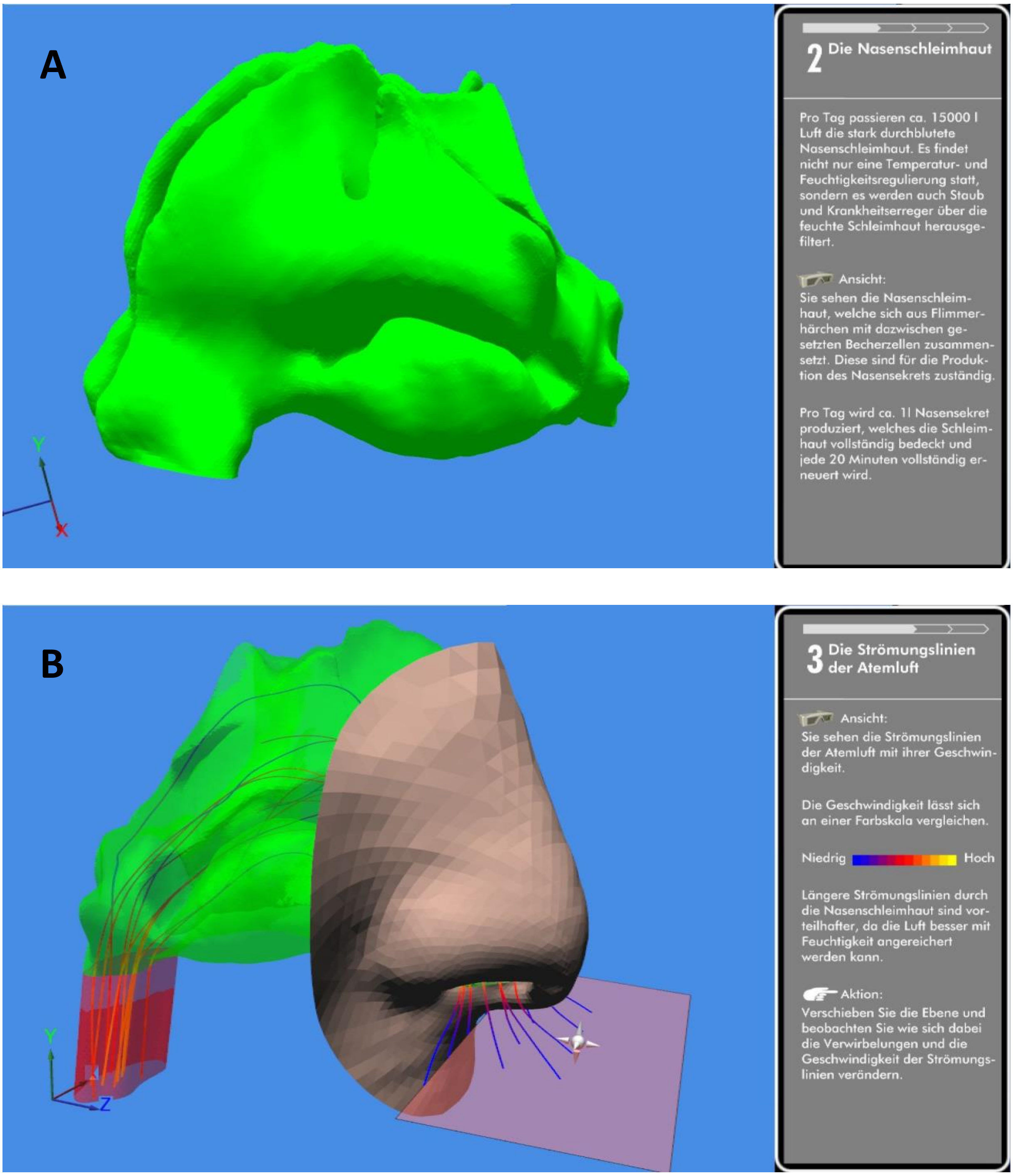

Fig. 1. Screenshots displaying the nasal cavity in the standard adjustment without being rotated. (A) Nasal cavity in a non-translucent surface configuration. (B) Nasal cavity in a translucent surface configuration with airflow lines inside.

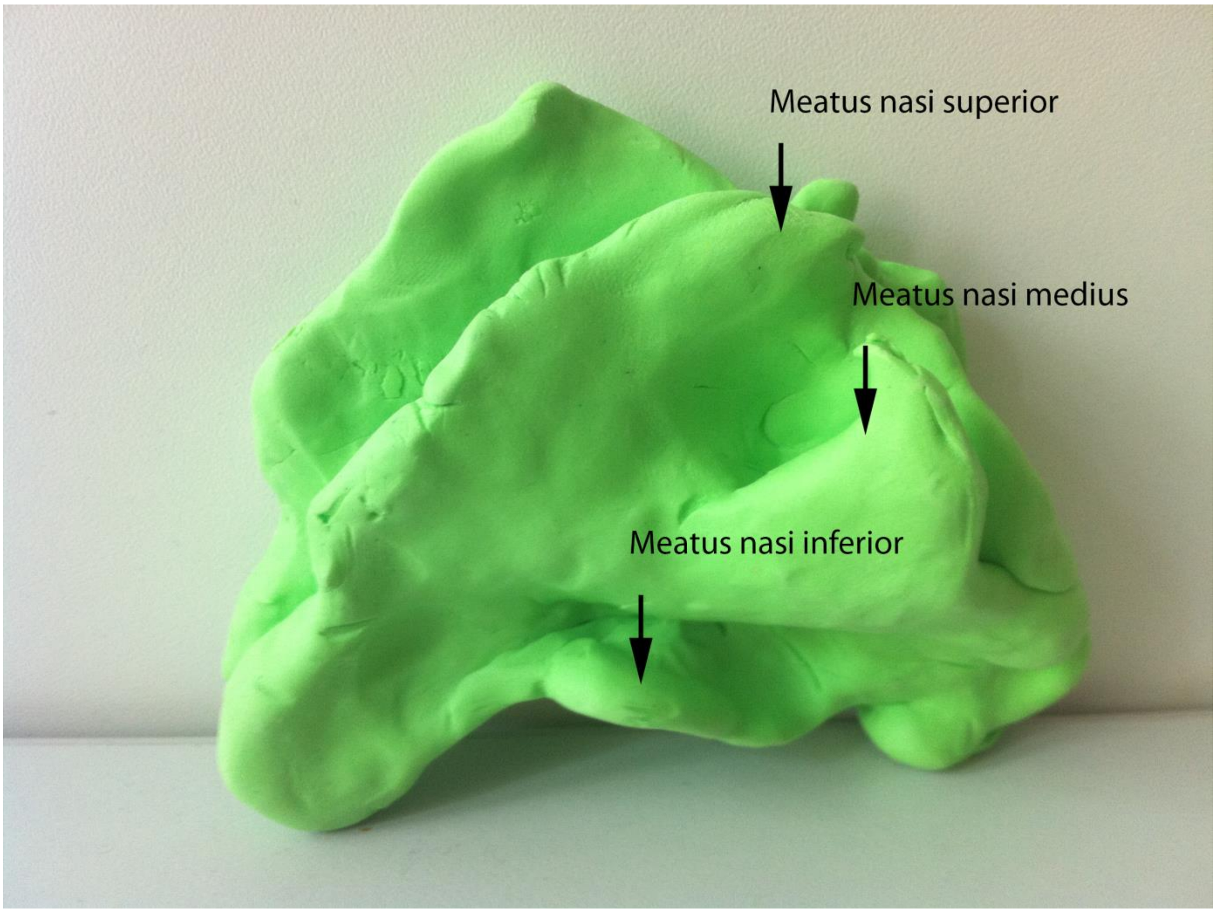

Fig. 2. A student’s hands-on representation displays the nasal cavity.

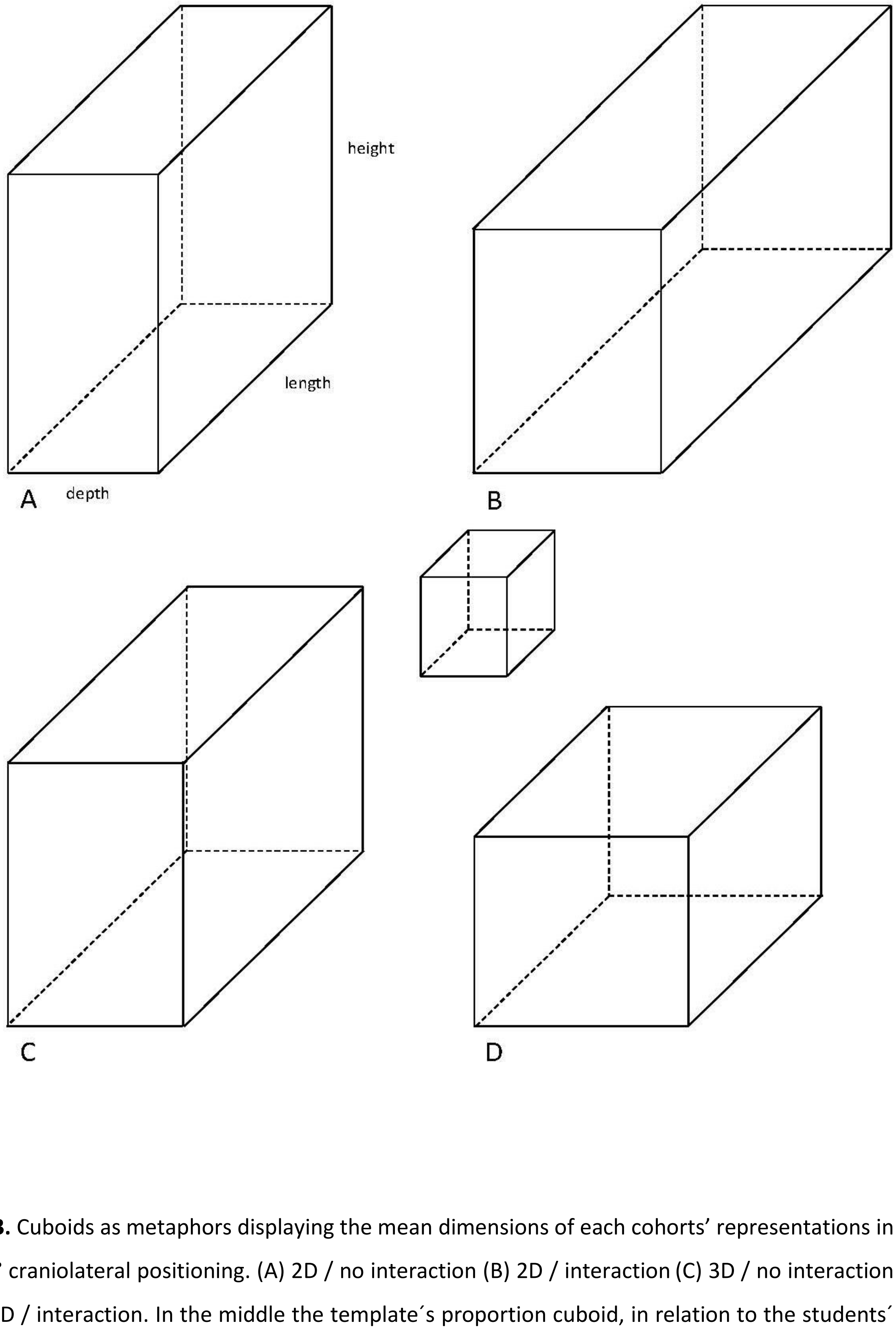

Fig. 3. Cuboids as metaphors displaying the mean dimensions of each cohorts' representations in a 45° craniolateral positioning. (A) 2D / no interaction (B) 2D / interaction (C) 3D / no interaction (D) 3D / interaction. In the middle the template´s proportion cuboid, in relation to the students´ cuboids strongly minimized.

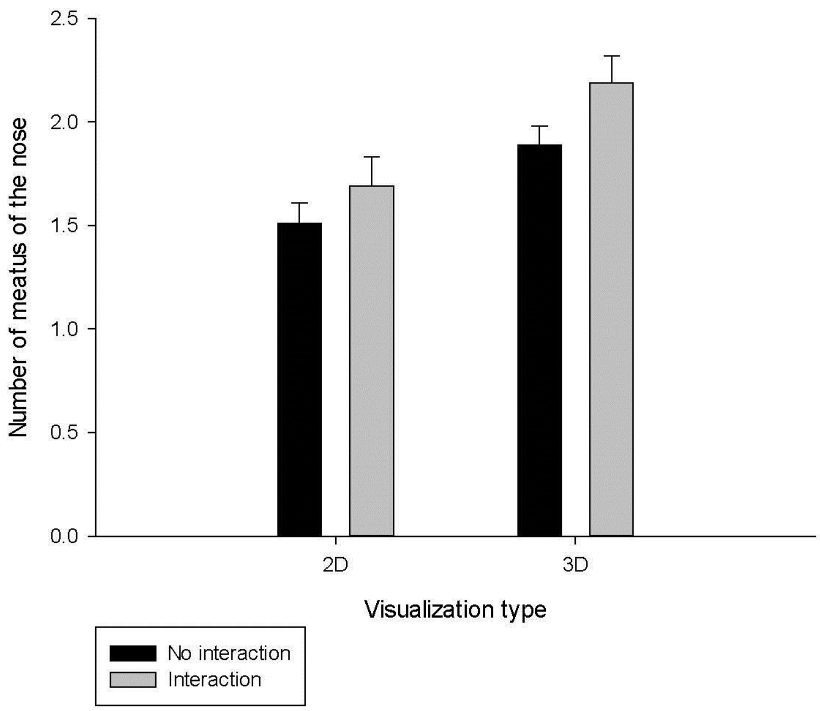

Fig. 4. Number (means and standard errors) of shaped meatus of the nose within the representations in dependency to the cohorts interaction type and visualization type (2D no interaction N = 51; 2D interaction N = 18; 3D no interaction N = 59; 3D interaction N = 16) rated on a four-point scale (raters N = 8).

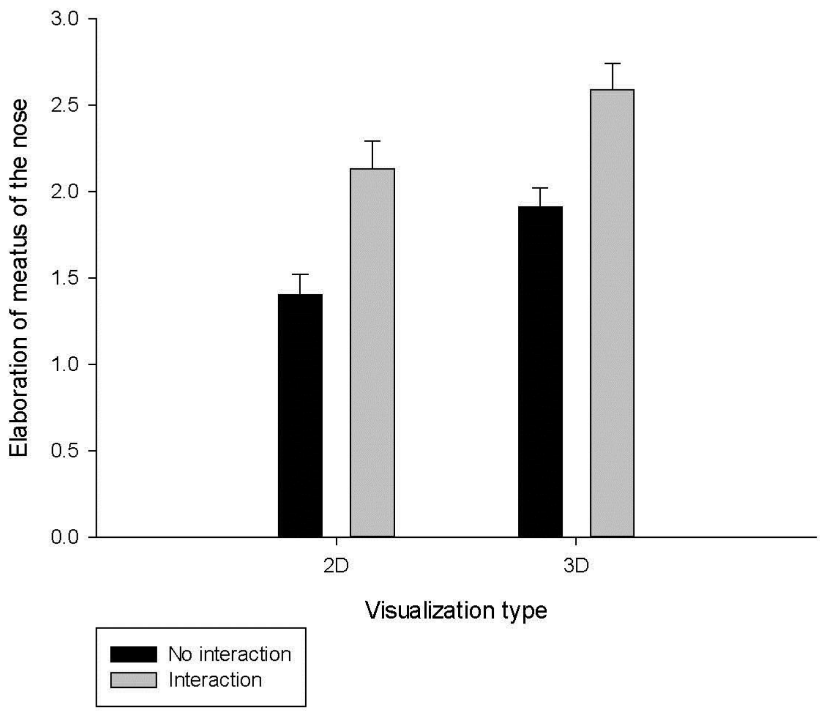

Fig. 5. Elaboration (means and standard errors) of shaped meatus of the nose within the representations in dependency to the cohorts interaction type and visualization type (2D no interaction N = 51; 2D interaction N = 18; 3D no interaction N = 59; 3D interaction N = 16) rated on a six-point scale (raters N = 8).

Studie 3

Using stereoscopic visualizations as templates to construct a spatial hands-on representation – is there a novelty effect?

Remmele, M. & Martens, A. (in preparation for Advances in Physiology Education)

Abstract

Sculpting representations of human organs out of modeling clay is an acknowledged method of teaching anatomical structures. Because of its potential to provide detailed spatial information, stereoscopic imagery can be understood to function as a suitable template for such sculpting tasks. Currently it is unknown whether the advantages of stereoscopic images for modeling structures result from enhanced depth impression alone or whether task performance is impacted by factors such as situational intrinsic motivation and perceived competence while sculpting a human organ using stereoscopic imagery as template. To clarify these queries, 35 8th grade students constructed a representation of the nasal cavity consisting of modeling clay. After the working phase, their situational intrinsic motivation and their perceived competence were assessed by a paper-and-pencil test and then analyzed, as was the elaboration of the sculpted representations. A control group with 38 students working with non-stereoscopic visualizations functioned as counterpart. Stereoscopic imagery outperformed non-stereoscopic imagery concerning the elaboration of structures within the representations. However, there was no difference between situational intrinsic motivation and perceived competence in the context of using the digital template for forming the representations. Interestingly, within the cohort working with non-stereoscopic imagery situational intrinsic motivation was correlated with task performance. In contrast, within the cohort working with stereoscopic imagery there was no relation concerning this. The findings show that depth impression due to stereoscopic imagery can be utilized to construct template-close representations independently to situational feelings. This independence from situational sensitivities enables success even for students with low situational intrinsic motivation.

Theoretical background

During the last decade, clay modelling has become a well-known tool to allow learners to represent anatomical structures in order to learn human anatomy and is acknowledged as an effective teaching method to support human anatomical topics such as the muscles, the skeletal, or the respiratory system (Motoike et al., 2009; Haspel et al., 2014). Most studies concerning this, focus either on the acquisition of knowledge about anatomical structures gained by a clay-modeling intervention or on the application of such knowledge on skills such as interpreting other representational formats such as photographs.

Focusing on the acquisition of knowledge about anatomical structures gained by a sculpting intervention, in the field of neuroanatomy, Estevez et al. (2010) showed that sculpting representations out of modeling-clay is suitable for spatial anatomical comprehension. Utilizing comparable tasks to Estevez et al. (2010), Kooloos et al. (2014) found in one experiment some advantages of active clay-modeling compared to watching a video-tape of a clay-modeling session for anatomical knowledge gain. Accordingly, Bareither et al. (2013) showed by focusing on the muscles of the human body, the effectiveness of clay-modeling for enhancing students' ability to learn and estimate anatomical spatial relationships. The participants in the study of DeHoff et al. (2011) exhibited in one of three addressed anatomical topics a higher learning outcome on anatomical knowledge tasks in comparison to a control group dissecting a cat. However, considering all three topics the participants judged the sculpting session as more favorable than the cat dissection. Howell and Howell (2010) revealed the effectiveness of modeling stages of embryonic development out of clay to understand its relatedness to three dimensions. In addition to this, some research relates to the application of knowledge gained by a sculpting task. For instance, focusing on the application of knowledge about anatomical structures gained by a sculpting intervention, Waters et al. (2011) showed by referring to the muscular system the suitability of clay-modeling to mentally transfer the molded structures on to other kinds of representations such as photographs and diagrams. Aiming also to applicate anatomical-structural knowledge gained by a sculpting task, Oh and colleagues (2009) let students create representations of several human organs out of modeling clay and revealed the usefulness of utilizing those self-generated tools to teach students how to prepare cross-sections. The studies cited above relate to the construction of three-dimensional representations consisting of kneading mass aiming to portray structures and anatomical-spatial relationships down to the smallest detail. The main goal was to make participants familiar with those structures. That means templates for forming representations out of modeling clay ought to provide the best spatial information about anatomical structures' properties to achieve the goal of familiarization with structures in origin proportions.

Concerning this aim, digital stereoscopic representations are found to help in the estimation of anatomical structure properties and thus should be recognized as potential templates to form representations displaying human organs. For instance, Abildgaard et al. (2010) in the case of identifying blood vessels and lung nodules and Hilbelink (2009) when estimating anatomical relations within a skull specimen found advantages of stereoscopic visualizations compared to non-stereoscopic representations. This is comparable to the findings of Rosenbaum et al. (2000) in the case of identifying vascular and skeletal structures, to the findings of Nelson et al. (2000) when identifying fetal skeletal structures and to the findings of Remmele et al. (2017) for estimating anatomical-structural relationships within the middle and the inner ear. Relating directly to sculpting template-close representations of the nasal cavity consisting of modeling clay, Remmele et al. (2015) and Remmele and Martens (2016) found that stereoscopic representations as templates outperformed non-stereoscopic representations. This is true for using visualizations presented as static templates (Remmele et al., 2015; Remmele and Martens, 2016) and as well interactively moveable visualizations as templates (Remmele et al., 2015). Such advantages of stereoscopic imagery compared to non-stereoscopic imagery might be explainable by the genesis of stereoscopic depth impression: In everyday life stereoscopic spatial perception is primarily based on a human's interocular distance which inevitably leads to overlapping different retinal pictures of an observed object. These retinal pictures are automatically fused by the brain which perceives spatial information by focusing on both retinal pictures and then calculating the distance between corresponding points (Cutting & Vishton, 1995; Patterson & Martin, 1992). In addition, non-stereoscopic depth cues ('monocular depth cues') such as texture, relative size or shading support this impression of spatial depth. Watching non-stereoscopic visualizations such as 'common' images on computer, depth impression arises due to monocular depth cues alone (Hackett & Proctor, 2016; Remmele et al., 2017). Stereoscopic display technologies imitate stereoscopic vision in everyday life by using various output devices such as 3D glasses to provide the eyes with two slightly differing pictures representing the same object observed from nearly the same angle and thus provide a comparable degree of depth impression as watching an object near or around us in everyday life.

The quintessence of the research cited above is that stereoscopic imagery fosters enhanced structure recognition and as well the construction of template-close clay models. However, research shows that the application of new digital media formats can lead to a novelty effect such as the short-term increase of motivational factors (Jonassen, 1996; Liu et al., 2009; Hew & Cheung, 2010). In general, emotions aroused positively in the context of any learning settings such as situational intrinsic motivation appear suitable to increase task performance (Laukenmann et al., 2003). Situational intrinsic motivation is characterized by the dualism of interest and enjoyment (Guay et al., 2000; Deci & Ryan, 2003). Due to the novelty of stereoscopic imagery in human biological education (Remmele et al., 2015; Hackett & Proctor, 2016) the question arises whether task performance in the context of the application of stereoscopic imagery as new visualization technology is the direct result of enhanced structure recognition or whether it is additionally impacted by situational sensations such as situational intrinsic motivation in the context of working with stereoscopic imagery for the first time during a school science lesson. A special interest also lies on perceived competence. Perceived competence is said to be linked with situational intrinsic motivation (Deci & Ryan, 2003) and also to be in co-occurrence with it. Due to enhanced structure recognition participants might feel more competent while molding hands-on representations which might also impact perceived situational intrinsic motivation. In turn, increased situational intrinsic motivation due to the novel application of stereoscopic imagery perceived competence could also be impacted.

The sculpted representations made of clay are constructed not as an end in itself but to be used for the learning of anatomical facts directly (Estevez et al., 2010; Koolos et al., 2014) or to additionally be applied in some ongoing learning settings on anatomy (Waters et al., 2011; Oh et al., 2009). Because emotions aroused positively in context with any learning settings such as situational intrinsic motivation (Laukenmann et al., 2003) might also function as trigger for persisting interest to engage? with a distinct topic (Hidi and Renninger, 2006), the question is relevant whether the employment with stereoscopic imagery as a template for molding a representation is judged to be more positive when compared to non-stereoscopic imagery. However, to what extent these immediate positive emotions can be transformed into a continued interest to engage with the distinct topic is dependent on further steps of learning arrangements (Mitchell, 1993) and thus not content of the present research that focuses on a short-time intervention only.

Research aims

Outgoing from the assumptions made above, the aim of the present study was to assess the students' perceived feelings of situational intrinsic motivation in the context of using stereoscopic imagery in contrast to non-stereoscopic imagery as a template to form a human organ out of modeling clay. Furthermore, it was of interest to investigate whether there are relations between the self-reported situational intrinsic motivation and the performance during the clay-modeling task. Because it was argued that stereoscopic imagery facilitates structure recognition it should also be asked if the students working with stereoscopic imagery felt more competent while doing the modeling task, compared to students using non-stereoscopic imagery. This should also be in relation to the performance in clay-modeling and to self-reported situational intrinsic motivation.

Methods

E-learning environment

To carry out the study we utilized a virtual reality system called CyberClassroom (imsimity GmbH, St. Georgen im Schwarzwald, Germany). Hardware components were a Tarox Computer (TAROX AG, Luenen, Germany) equipped with an Intel Core i5 processor (3.20 GHz, 4 GB Ram, NVIDIA Quatro 600 graphics card) and a 47'' LCD monitor type 47LD950. The system was prepared to utilizing passive stereoscopic visualization by providing polarizer glasses. For navigation a remote was used. The software could be presented in a version with stereoscopic imagery and as well in a version utilizing non-stereoscopic imagery. The e-learning module dealt with the nasal cavity's anatomy and physiology. Physiological processes such as the warming and moistening of breath are linked with concrete anatomical structures like the meatus of the nose and their mucosa. Spatial understanding appeared to be an important factor to recognize and estimate relevant structures such as the meatus of the nose and to bring them into context with the physiological concept of breathing air's warming and moistening. To highlight those phenomena five screen page depicted parts of the nasal cavity and written text explained structures and the related physiological concepts of breath's warming and moistening (Fig. 1). To provide the best depictive information for all students working either with stereoscopic or non-stereoscopic imagery, each visualization included strong monocular depth cues, e.g. perspective imaging or shading. The students could observe the nasal cavity with dorsoventral positioning turned 20° towards the learner. The remote could be used by the research subjects to switch between the screen pages. For the stereoscopic imagery version the screen disparity was smaller than 1° to enable comfortable viewing (Lambooij et al., 2009).

Study design and outcome measures

We provided two alternative conditions. One consisted of the multimedia application utilizing stereoscopic imagery and the other the same application utilizing non-stereoscopic imagery.

Consequently, the visualization type was the independent variable. Dependent variables were (a) the self-reported perception of positive emotions, (b) the self-estimated competence during the working session, (c) the elaboration of anatomical details within the students' molded representations and (d) correlations between (a), (b) and (c).

Participants

Participants were 73 8th grade students from three schools around in the southwest of Germany. Before beginning the study, parents and students gave their approval that they would participate. All attendees belonged to a larger sample of a study aiming to investigate stereoscopic imagery's impact on sculpting representations of a human organ (Remmele et al., 2015). All students had the innate ability of stereoscopic vision, which was pre-tested by absolving a stereoscopic vision test (Fricke & Siderov, 1997). It was affirmed that they all had not had any lessons about this topic beforehand and didn't have any previous experience with stereoscopic imagery in the science classroom. The participants' mean age was 14.21(+0.71) years and the gender distribution was approximately equal.

Materials

First, a worksheet was designed to guide the students through the software application. To measure their self-reported perceptions of situational intrinsic motivation and their self-estimated competence, a paper and pencil test was adopted. This test consisted of two subscales – one for each latent construct. The subscale for situational intrinsic motivation was made up of three items which were constructed close to Guay and colleagues' (2000) scale 'intrinsic motivation' and Deci & Ryan's (2003) scale 'interest/enjoyment' in its German time-economic short-version 'Interesse/Vergnügen' (Wilde et al., 2009). To assess the amount of self-estimated competence we adopted a 3-item-subscale 'Kompetenzerleben' ('perceived competence') according to Wilde et al. (2009), too. To prepare a spatial hands-on representation (Fig. 2) as an outcome measure each research subject was provided with a 60 g kneading mass called 'Pluffy' (Eberhard Faber Vertrieb GmbH).

Procedure

To assign the research subjects to a stereoscopic imagery cohort and a non-stereoscopic imagery cohort a randomized allocation procedure was utilized. Then all attendees worked with multimedia application at a single workstation. The students had 20 minutes to read the given descriptive information and to view the associated visualizations to learn about the anatomy of the nasal cavity. They were all asked to construct a representation of the nasal cavity as a solid body consisting of kneading mass during the working phase using the software visualization as a template (Remmele et al., 2015; Remmele & Martens, 2016). Afterwards the students filled in the questionnaire concerning self-reported situational intrinsic motivation and perceived competence.

Data analysis

To analyze the students' responses on the questionnaire the points on the scale were numbered from one to five, where the pole representing maximum approval scored the five. Then, means and standard deviations for both subscales were calculated. Additionally, for both the subscales the Cronbach's Alpha was calculated to prove the reliability. A factor analysis was calculated to prove the two-dimensionality of questionnaire. The presence of anatomical details was assessed by focusing on the elaboration of the meatus of the nose as they are the most obvious structure and the major cause for impacting physiological processes described in the learning module such as warming and moistening of breathing air. Therefore, we developed a six-point rating scale ranging from 0-5. Eight raters were asked to judge the elaboration of the meatus of the nose using this scale (Remmele et al., 2015; Remmele & Martens, 2016). To prove the reliability of this measuring instrument the average deviation (ADM) between the raters' judgments was determined in accordance with Burke & Dunlap (2002) and Burke, Finkelstein & Dusig (1999). For all measurements standard deviations were determined and compared by working out analyses of variances (ANOVAs). To prove relations between the elaboration of the meatus of the nose, situational intrinsic motivation and perceived competence Pearson correlation analyses were processed. All statistical calculations were proceeded by using a SPSS statistical package, version 22 for Windows (IBM Corp., Armonk, NY).

Results

Both of the questionnaire's subscales revealed sufficient reliability. For situational intrinsic motivation there was $\alpha = .75$ and for perceived competence $\alpha = .77$. A factor analyses with varimax rotation confirmed the existence of both subscales. The students of the stereoscopic imagery cohort reported a higher degree of situational intrinsic motivation (Table 1). However, the p-value ($p = .062$) missed the level of significance. Concerning perceived competence there was no difference between both groups ($p = .318$). As for elaborating the meatus of the nose, the students of the stereoscopic imagery cohort succeeded significantly better compared to the students working with non-stereoscopic imagery ($p < .01$). An average deviation <.65 showed the consistency of the raters' judgments. A significant relation between situational intrinsic motivation and task performance represented by the elaboration of the meatus of the nose was found within the non-stereoscopic imagery cohort ($r = .376$; $p = .020$; Fig. 3A) but not within the stereoscopic imagery cohort ($r = -.022$; $p = .899$; Fig. 3B). The perceived competence was for both cohorts in connection with aroused situational intrinsic motivation (stereoscopic imagery: $r = .422$; $p = .012$; non-stereoscopic imagery: $r = .580$; $p < .001$) but not with task performance (stereoscopic imagery: $r = -.049$; $p = .780$; non-stereoscopic imagery: $r = .055$; $p = .741$).

Discussion

The success of the stereoscopic imagery cohort in representing the meatus of the nose more elaborately may not be a surprise as it goes in line with Remmele et al. (2015) and Remmele & Martens (2016). This confirms that stereoscopic imagery obviously provides excellent depth cues and thus enables the research subjects to represent anatomical parts down to the smallest detail. For the reasons of anatomical knowledge gain (Estevez et al., 2010; Kooloos et al., 2014) and the application in anatomical learning settings (Waters et al., 2011; Oh et al., 2009) representations sculptured by stereoscopic templates appear to be more preferable compared to those sculptured by using non-stereoscopic templates.

Concerning subjects' self-reported situational intrinsic motivation there was no relevant difference between stereoscopic imagery and non-stereoscopic imagery. In sum, with means > 3 on a five-point scale, both perceived a moderate degree of situational intrinsic motivation while working with the e-learning environment. Nevertheless, one can suggest that the supply of high-quality non-stereoscopic imagery provoked a nearly equal level of situational intrinsic motivation, compared to the application of stereoscopic imagery and thus that there wasn't a novelty effect (Jonassen, 1996; Liu et al., 2009; Hew & Cheung, 2010). However, the large standard deviations show that this kind of perception was not true for every student and there were as well students who felt unmotivated or in contrast enjoyed the intervention very much. Similarly to situational intrinsic motivation, even though the participants of the stereoscopic imagery cohort succeeded better in portraying anatomical structures, this didn't lead to a higher level of perceived competence compared to non-stereoscopic imagery. Both cohorts reached means > 3. Comparable to the sensation of situational intrinsic motivation, this shows that in sum the participants were moderately satisfied with their performance during the working process. Hence, for the present study the assumption that enhanced task performance is in line with increased perceived competence due to enhanced structure recognition can no longer be supported. Given that the students working with stereoscopic imagery had enhanced perception of anatomical structures, this perception can expected to be the level to reach with their own representations. Vice versa, participants working with non-stereoscopic imagery had decreased perception of anatomical structures and maybe had a lower level to reach with their molded representations. Both consequently resulted in a comparable perception of competence. Thus, without a comparison of the student's own representation with the original there cannot be a difference in the perception of competence between both cohorts. Interestingly, a correlation between task performance and perceived competence wasn't found. This might be explainable as follows: For the participants in the present study sculpting was a rather new task in their biology lessons. Thus, all students were unexperienced and because of that failed to estimate their competence realistically. However, for both cohorts the relation between situational intrinsic motivation and perceived competence was rather high. This circumstance doesn't appear surprising as the connection between both factors was suggested and empirically documented by research (Deci & Ryan, 2003; Wilde et al, 2009).

Relations between situational intrinsic motivation and task performance reveal quite different results within both visualization types. Interestingly within the cohort working with non-stereoscopic imagery there was a significant relation between the arousal of situational intrinsic motivation and the success of representing anatomical details within the hands-on representations. In contrast even though the research participants of the stereoscopic imagery cohort succeeded significantly better in representing the meatus of the nose, within the stereoscopic imagery cohort there was no relation between situational intrinsic motivation and task performance. However, there was a relation between perceived competence and situational intrinsic motivation, but no relation between task performance and perceived competence. Because of this missing connection, it can be assumed that the success of the stereoscopic imagery cohort couldn't function as a motor of increased situational intrinsic motivation during the working phase. Vice versa, situational intrinsic motivation couldn't function as motor of task performance. That means the positive impact of stereoscopic imagery for representing anatomical details appears to be independent from humans' situational feelings of motivation whereas the performance on constructing hands-on representations while working with non-stereoscopic visualizations is actually in connection with humans' situational intrinsic motivation. For science education these findings provide strong arguments for the application of stereoscopic imagery instead of non-stereoscopic visualizations. First, the task performance in the case of representing anatomical structure within spatial hands-on representations is better compared to non-stereoscopic imagery. Because of the relevance of the construction of own external representations in learning science (Prain & Tytler, 2013; Prain & Tytler, 2012; Yore & Hand, 2010; diSessa, 2004) it can be assumed that a more elaborate representation provides enhanced opportunities for learning concepts relating to this. These might be physiological concepts which are related to distinct anatomical structures (Nguyen et al., 2012; Ferdig et al., 2015; Remmele et al., 2017). Concerning this, further research should be carried out. Second, science lessons as all other lessons have to deal with heterogeneous degrees of students' motivation and thus must also deal with students with low situational intrinsic motivation. Thus it appears reasonable to apply an instructional setting which acts regardless of situational sensitivities and allows enhanced task performance. For the application of stereoscopic imagery in human biological learning contexts and the construction of anatomical hands-on representations this appears to be the case.

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Tab. 1. The table shows students' situational intrinsic motivation and perceived competence in the context of constructing a hands-on representation using stereoscopic vs non-stereoscopic imagery as template. In relation to that, the performance on elaborating meatus of the nose is reported.

		Visualization type (mean ± SD)				
	dF	non-stereo (N=38)	stereo (N=35)	F	p	Partial Eta^2
Situational intrinsic motivation	1	3.40±0.79	3.72±0.64	3.586	0.062	0.048
Perceived competence	1	3.34±0.71	3.17±0.74	1.010	0.318	0.014
Elaboration of meatus*	1	1.33±0.84	1.92±0.83	8.987	0.004	0.112

* Rated by 8 raters on a six-point scale.

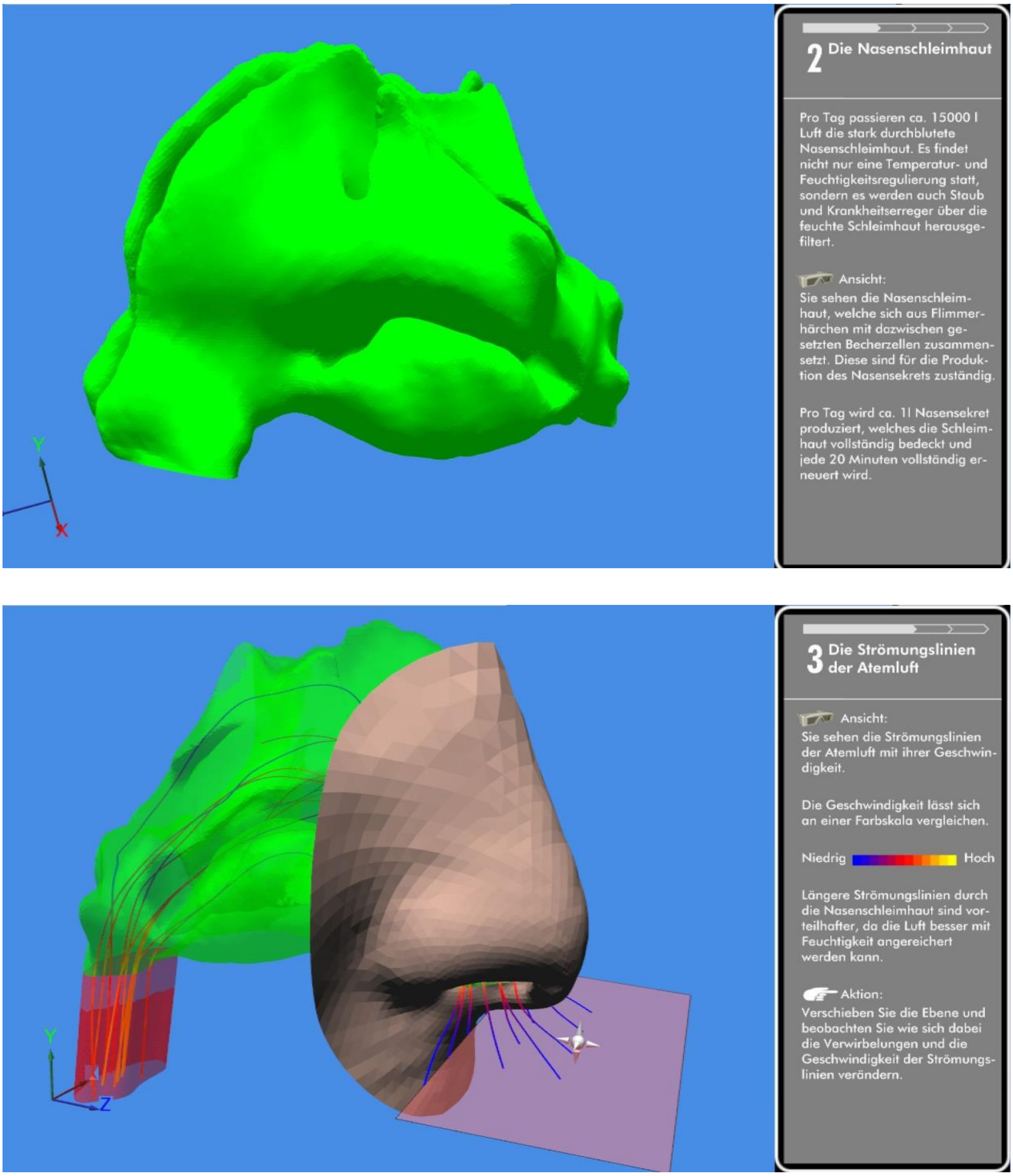

Fig. 1. Screen pages of the e-learning module included depictive and descriptive information concerning the nasal cavity’s anatomical structures and the related physiological concepts of breathing air’s warming and moistening (Remmele et al., 2015).

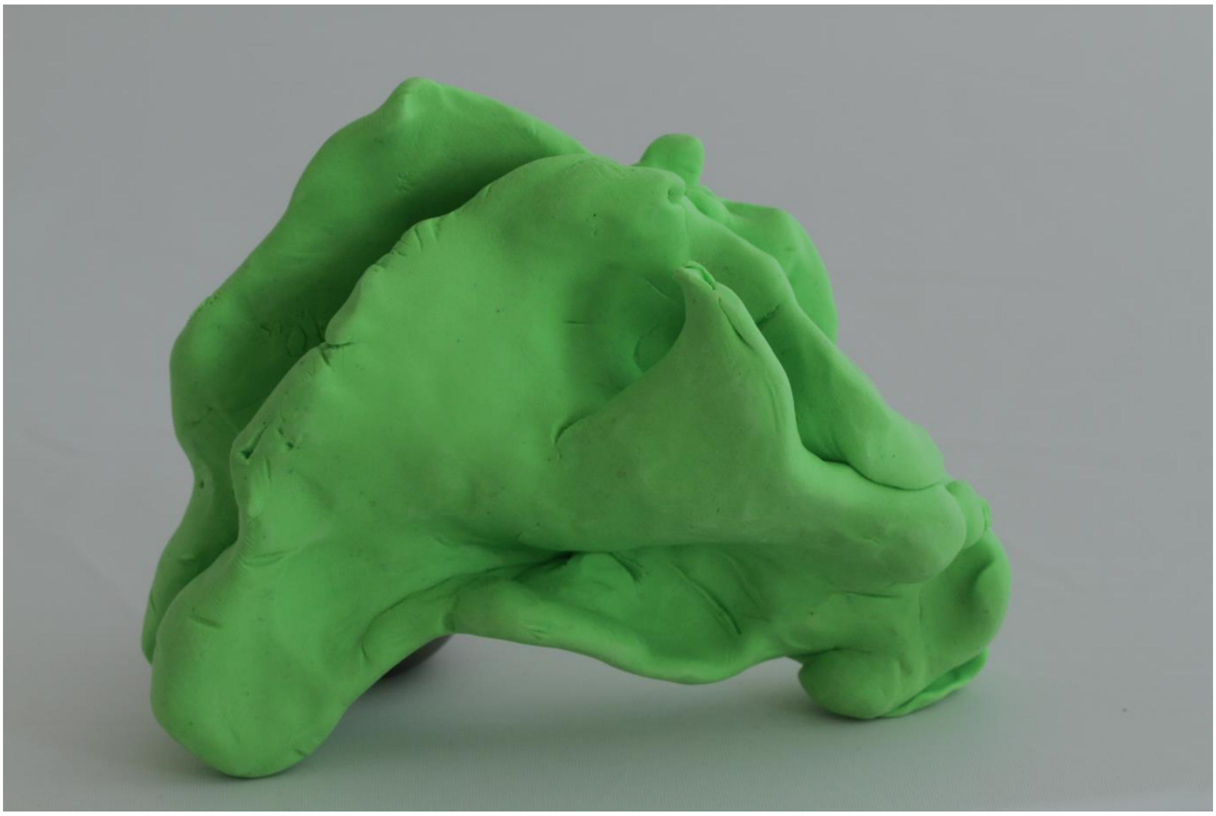

Fig. 2. A hands-on representation consisting of kneading mass was formed by a student to display the anatomy of the nasal cavity (Remmele et al., 2015).

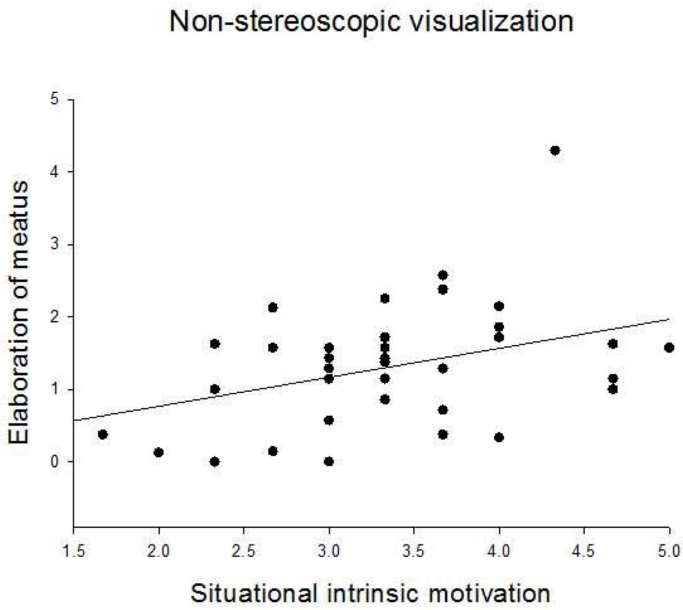

Fig. 3A. Relation between situational intrinsic motivation and elaboration of meatus of the nose within the cohort working with non-stereoscopic visualizations.

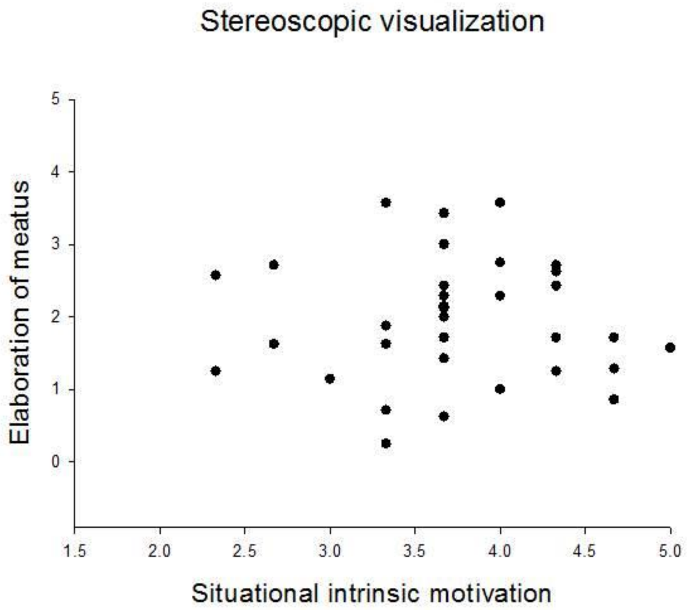

Fig. 3B. Relation between situational intrinsic motivation and elaboration of meatus of the nose within the cohort working with stereoscopic visualizations.

Studie 4

The impact of stereoscopic imagery and motion on anatomical structure recognition and visual attention performance.

Remmele, M., Schmidt, E., Lingenfelder, M. & Martens, A. (Published online 31.5.2017). *Anatomical Sciences Education*, doi: 10.1002/ase.1704

ABSTRACT

Gross anatomy is located in a three-dimensional space. Visualizing aspects of structures in gross anatomy education should aim to provide information that best resembles their original spatial proportions. Stereoscopic three-dimensional imagery might offer possibilities to implement this aim, though some research has revealed potential impairments that may result from observing stereoscopic visualizations, such as discomfort. However, possible impairments of working memory such as decreased visual attention performance due to applying this technology in gross anatomy education have not yet been investigated. Similarly, in gross anatomy education the impact of stereoscopic imagery on learners' recognition of anatomical-spatial relationships and the impact of different presentation formats have only been investigated in a small number of studies. In the present study the performance of 171 teacher trainees working on the anatomy of hearing was examined, either with non-stereoscopic or stereoscopic imagery. Static and dynamic picture presentations were applied. Overall, benefits for stereoscopic imagery on estimating anatomical-spatial relations were found. The performance on a visual attention test indicates that the impact of stereoscopic visualizations on the human cognitive system varies more from person to person compared to non-stereoscopic visualizations. In addition, combinations of temporarily moving pictures and stereoscopic imagery lead to decreased visual attention performance compared to combinations of moving pictures and non-stereoscopic imagery.

Keywords: gross anatomy education; stereoscopic 3D representations; static and dynamic imagery; estimating anatomical-spatial relationships; visual attention performance

INTRODUCTION

Human anatomy and physiology deal with structures in a three-dimensional space. As such, learning gross anatomy is related to gaining knowledge about structures and spatial relationships of structures within this space (Hilbelink, 2009; Yammine and Violato, 2015). Thus, visualizations of human gross anatomy should contain spatial information about human anatomy that is authentic as possible. One common way to do so is through direct observation by dissection. However, certain degree programs obligated to teach human gross anatomy, e.g. to become a biology teacher have no access to human cadaver material. Moreover, it appears that even medical schools have little resources for providing learning experiences in gross anatomy with original material such as cadaver dissections (Drake et al., 2009; Gregory et al., 2009; Drake, 2014). Some researchers have therefore identified the usage of three-dimensional digital formats as common alternatives (Aziz et al., 2002; McLachlan and Patten, 2006; Tam et al., 2009; Rizzolo et al., 2010; Nguyen et al., 2012; Hackett and Proctor, 2016). Applying computer-based digital imagery, non-stereoscopic and stereoscopic representation formats are used to display anatomical properties (Nguyen et al., 2012; Remmele et al., 2015; Hackett and Proctor, 2016). Currently, computer-aided stereoscopic learning programs are still less commonly applied to portray human anatomy (Sergovich et al., 2010; Remmele et al., 2015; Hackett and Proctor, 2016; Remmele and Martens, 2016; Cui et al., 2017), however, meta-analyses across several disciplines reveal the basic suitability of stereoscopic three-dimensional imagery to convey information about spatial structures (McIntire et al., 2012, 2014). Based on this basic suitability, the focus in the present study was on the question of what kind of picture presentation predicts the successful application of stereoscopic imagery to enhance perception of anatomical structures. Hereby, the research desideratum was deduced by focusing on the mechanism of stereoscopic and non-stereoscopic depth perception.

Stereoscopic imagery and motion as depth cues

Stereoscopic spatial perception emerges due to humans eyes' distance from one another. When looking at an object, two overlapping pictures project the observed object from different viewing angles onto the retina. These images are then are processed by the human cognitive system as one internal spatial image (Patterson and Martin, 1992). Similarly to this, stereoscopic e-learning environments imitate stereoscopic vision in everyday life by presenting two similar pictures of an object imitating slightly different viewing angles to the eyes. This happens by utilizing certain hardware technologies such as polarizer glasses or shutter glasses (Urey et al., 2011). In contrast, when looking at non-stereoscopic pictures such as software applications, depth impression arises due to monocular depth cues such as relative size, texture or object motion parallax (‘motion’) solely (van Beurden et al., 2012; Hackett and Proctor, 2016). Especially the monocular depth cue motion was found to provide enhanced information on spatiality comparable to stereoscopy (Rogers and Graham, 1982; Sollenberger and Milgram, 1993; Ware and Mitchell, 2005). Accordingly, recent research reveals both stereoscopic imagery and dynamic picture presentations as established techniques aiming to convey spatial relationships in gross anatomy (Nguyen and Wilson, 2009; Nguyen et al. 2012; Cui et al., 2015; Remmele et al., 2015; Cui et al., 2017). Learning gross anatomy within an e-learning environment, participants can observe moving images in two ways: firstly by passively watching self-moving images or secondly, by moving images themselves via an interaction device (Nguyen et al., 2012; Remmele et al., 2015). Hence, to investigate the impact of stereoscopic representations in gross anatomy education, it appears to be fruitful to distinguish between the impact of stereoscopic representations on anatomical structure-related tasks in both the presence and absence of the depth cue motion. Consequently, to review the state of research of stereoscopic visualizations in gross anatomy education the following kinds of studies were considered:

First, studies varying only the stereoscopic or non-stereoscopic imagery factor and leaving other factors constant. Those studies compared stereoscopic static imagery versus non-stereoscopic static imagery or stereoscopic dynamic imagery versus non-stereoscopic dynamic imagery.

Second, studies varying the stereoscopic or non-stereoscopic imagery factor and also varying the motion with static imagery in contrast to dynamic imagery factor. Those studies had a two-factor mixed design.

Studies varying the stereoscopic versus non-stereoscopic imagery factor

Using static stereoscopic imagery participant performance was better in identifying lung nodules and marked blood vessels compared to non-stereoscopic imagery (Abildgaard et al. 2010). Hilbelink (2009) created a learning setting on the human skull applying a non-stereoscopic video and additionally either computer-based stereoscopic or non-stereoscopic visualizations. The cohort working on stereoscopic representations succeeded in better identifying structures as well as estimating spatial relationships while examining a skull specimen. Luursema et al. (2008) had different groups of participants learn organs of the human body in stereoscopic or non-stereoscopic vision. Both cohorts had the possibility to observe the images as they were moving. Subsequently, the participants of the stereoscopic imagery cohort succeeded in better localizing the organs within given non-stereoscopic representations of cross-sections. In line with these results, in the study of Rosenbaum et al. (2000) physicians were more likely to identify structures of the vascular system as well as of skeletal structures using imaging techniques such as digital subtraction angiography (DSA), magnetic resonance tomography (MRT) and computed tomography (CT) presented in dynamic stereoscopic imagery compared to using dynamic non-stereoscopic representations. The study of Ferdig et al. (2015) offers also relevant impulse. Their study on learning various anatomical structures using interactive stereo and as well interactive non-stereo representations suggests that the success of the participants might depend on the particular topic that is visualized.

Studies varying both the stereoscopic versus non-stereoscopic imagery and static versus dynamic imagery factors

In contrast, for identifying fetal bone structures within stereoscopic and non-stereoscopic ultrasound representations Nelson et al. (2008) found advantages of stereoscopic imaging only in a condition without motion but not in a condition with motion. Remmele et al. (2015) focused on representing displayed structures of the nose by utilizing both static and dynamic picture presentations. Stereoscopic imagery presented statically was found to facilitate the representation of anatomical structures of the nasal cavity within clay models compared to non-stereoscopic imagery. Stereoscopic imagery also enhanced learners' success on molding spatial hands-on representations of the nasal cavity for both 'static presentation' and 'dynamic presentation' conditions. Notably, the combination of object motion parallax realized with stereoscopic vision led to the best performances. This means that there is a contrast to the findings of Nelson et al. (2008). However, the gap between two-dimensional imagery and stereoscopic imagery diminished due to object motion parallax. Limiting a direct comparison of both studies is the fact that Nelson et al. (2008) focused on an identification task while Remmele et al. (2015) focused on representing spatial relationships; in addition both teams focused on different organic structures.

Models of multimedia learning (Mayer, 2003; Schnotz and Bannert, 2003) in the tradition of dual coding theory (Paivio, 1986) describe working memory as a capacity-limited system that includes not only a phonological but also a visuospatial pathway. Both interact with one another and also with long-term memory. That means, post-perceptive performance measures refer not only to the visualization quality's impact but also, for instance, to the quality of descriptive information, which is given in almost every learning situation and which interacts with the visuospatial pathway during information processing in working memory (Wilson, 2015). Thus, an excellent descriptive instruction might overlay the effect of the visualization modus in contrast to an average one. In contrast, measuring anatomical-spatial perception within given representations provides information about the visualization's informational content directly.

The studies cited above reveal heterogeneous orientation. Some address the perception of anatomical-spatial properties within given computer-generated representations (Rosenbaum et al., 2000; Nelson et al., 2008; Abildgaard et al., 2010). In contrast, others assess primarily students' learning outcome by referring the content, which was presented beforehand by some computer-aided working phase and then stored in their long-term memory, to other kinds of representations such as skull specimen (Hilbelink, 2009), images of cross-sections (Luuresma et al., 2008), or anatomical content knowledge tasks (Ferdig et al., 2015).

In addition to the heterogeneous levels of performance measurements, the presence or absence of motion also varied from study to study. Hence, the number of studies that are directly comparable to one another is rather small. Concerning measuring anatomical-structural perception directly without referring to other representations and simultaneously varying both stereoscopic versus non-stereoscopic imagery or static versus dynamic imagery, only two studies were found (Nelson et al., 2008; Remmele et al., 2015). Furthermore, irrespective of the measured content, the findings on the impact of combinations of stereoscopic imagery and motion reveal quite heterogeneous results (Nelson et al., 2008; Remmele et al., 2015). Hence, there is a need for further research, especially concerning possible interactions of both stereoscopic imagery and motion depth cues.

Negative consequences caused by stereoscopic 3D visualizations

Assuming that the quality of perception mediates information processing in working memory, it is worthy not only to ask to what extent stereoscopic imagery and motion impact anatomical-structure perception positively, but to what extent negative aftereffects on information processing in working memory due to this kind of imagery could be expected.

Some authors have reported on impairments that have resulted from using stereoscopic imagery. For instance, Hoffman et al. (2008) and Kooi and Toet (2004) reveal stereoscopic 3D visualizations' potential to increase visual discomfort. Visual discomfort is a subjective sensation of impairments (Lambooij et al., 2009). The most common reason for visual discomfort appears to be a mismatch between vergence and accommodation (Inoue and Ohzu, 1997; Lambooiij et al., 2009; Hackett and Proctor, 2016). When observing objects close to us, vergence and accommodation are related to one another, in that each alignment of one eye to the other has a corresponding accommodation grade. While watching stereoscopic visualizations, this mechanism might be disturbed due to the diverging information of a flat display and the stereoscopic depth information of the image (Inoue and Okano, 1997; Eadie et al., 2000). This might happen especially when watching stereoscopic representations presented by a screen disparity of both slightly different pictures bigger than one degree (Lambooij et al., 2009) or when watching moving stereoscopic images that portray motions in depth. Hence, combinations of stereoscopic imagery and motion appear quite critical in this respect. In line with these findings, studies from the field of surgical training confirm that impacts from stereoscopic imagery can result in physical discomfort such as headache (Hanna et al., 1998; Alaraimi et al., 2014). In sum, the studies cited above focus on discomfort but not on impacts of working memory, although for the case of gross anatomy education the focus on working memory appears to be relevant. It is not clear to what extent feelings of discomfort are comparable with impaired information processing in working memory. Across all areas of research on stereoscopic imagery there was only one study dealing with aftereffects in the context of stereoscopic imagery (Bombeke et al., 2013). To assess aftereffects, Bombeke et al. (2013) proposed measuring visual attention performance. Visual attention is said to be linked with working memory (de Fockert et al., 2001). Research postulates that visual attention and visual working memory probably relate to one system for selecting pertinent visual information (Luck and Vogel, 2013; Tas et al., 2016). Related to this, decreased visual attention performance can be interpreted as impaired information processing in visual working memory. Arguing with Mayer's cognitive theory of multimedia learning, these impairments of visual working memory can be interpreted as poor conditions for effective learning. From the viewpoint of cognitive load theory (Chandler and Sweller, 1991) such impairments can be understood to be critical to provoke extraneous load.

Visual attention can be measured by identifying some visual information from some surrounding distractors. Bombeke et al. (2013) measured visual attention performance after watching a film with non-stereoscopic and stereoscopic visualization. They didn't find any aftereffects on the cognitive system due to stereoscopic imagery, however, because no tasks were completed while watching the film it is not sure to what extent this can be compared to the demands of a working phase on gross anatomy. It can be assumed that observing and distinguishing anatomical structures are in line with deep visual information processing and possible impairments can appear in this context sooner than while watching a film.

Research aims

Since learning human biology is characterized by a connection of complex anatomical structures with distinct related functions (Nguyen et al., 2012; Ferdig et al., 2015), an accurate perception of anatomical-spatial properties can be understood as a prerequisite of the successful learning of human biological concepts. Although estimating anatomical-spatial properties is one main objective of gross anatomy education and three-dimensional imagery appears to be a useful tool in this endeavor, only a small number of studies focus on static and dynamic stereoscopic imagery and students' related performances on estimating anatomical-spatial properties. Moreover, the few studies on dynamic picture presentation in combination with stereoscopy reveal heterogeneous results (Nelson et al., 2008; Remmele et al., 2015). This means that there is currently only little evidence that combinations of stereoscopy and a dynamic picture presentation bring benefits compared to either stereoscopy or motion alone. Despite there being only little research until now on this subject, combinations of stereoscopic imagery and motion appear to have the potential to impact human visual working memory rather than just stereoscopic imagery alone. Hence, our research questions are: (1) What is the impact of stereoscopic vision in the presence and absence of motion on estimating anatomical-structural properties? (2) What is the impact of stereoscopic vision in the presence and absence of motion on learners' visual attention performance?
As human biological content for carrying out the study, a software module on the anatomy of the middle and the inner ear was chosen because of their complicated spatial structures. Moreover, this topic is addressed rather rarely in gross anatomy education. Nicholson et al (2006) conducted a study on ear anatomy using a computerized non-stereoscopic anatomical model and explicitly called for more research however we were unable to find any further studies conducted on this topic since then.

MATERIALS AND METHODS

Multimedia system

In the present study the CyberClassroom (imsimity GmbH, St. Georgen im Schwarzwald, Germany) was used, which is comprised of a biology software package and several hardware components such as a Tarox Computer (TAROX AG, Luenen, Germany) (Intel Core i5 processor, 3.20 GHz, 4 GB Ram) and a stereoscopic 3D Sanyo projector (Sanyo Electric Co., Ltd., Moriguchi-shi, Japan) with active 3D by shutter technology.

Software module

The software module consisted of seven screen pages. It dealt with the middle inner ear and featured their anatomical structures (Fig. 1). Every page depicted particular structures and provided related text for explanation about those structures and their functions. Using a remote, one could navigate between the screen pages. In addition, motion was inducible by moving and rotating the displayed content. This could be realized by pressing a button on the remote for 'rotation' and for 'zoom / zoom out'. This kind of user-controlled presentation was referred to as 'dynamic'. A presentation without moving and rotating the images was called 'static'. Both the stereoscopic and the non-stereoscopic software version could be presented by a 'static' or a 'dynamic' condition. Pictures presented by stereoscopic imagery had a screen disparity smaller than one degree to allow for comfortable viewing (Lambooij et al., 2009).

Design

The study was carried out utilizing a two-factor mixed design. Therefore, the non-stereoscopic / stereoscopic vision modus was chosen as an independent variable as well the degree of dynamism with the levels 'static' and 'dynamic' as a between-groups-measure. This resulted in four settings which differed in the way of picture presentation: the middle ear and the inner ear were presented statically by non-stereoscopic imagery, statically by stereoscopic imagery, dynamically by non-stereoscopic imagery and dynamically by stereoscopic imagery. In order to assess the perception of anatomical-spatial properties, the focus on the estimation of anatomical-spatial relations appeared to be an appropriate choice. Thus, the following dependent variables were chosen: (1) The precision of estimating anatomical-spatial relations by working with the application; (2) The performance on a visual attention test.

Participants

The ethical board of the University of Education Karlsruhe gave the approval for the present study. Research subjects were 171 teacher trainees at this German university representing a cross-section of almost all semesters. 119 of them were students of biological education. In order to have a bigger sample 52 non-biology education students were also included. 148 teacher trainees were female and only 23 male. This corresponds with the gender distribution at this university. The data collection was not part of any lecture. All students participated voluntarily and they were recruited from the undergraduate courses at the university. Because it was not planned to determine any age effect, participant age was not assessed. However, the undergraduate teacher trainee mean age at this university is approximately 23±3 years. A criterion for participating in the study was having stereoscopic vision, which was tested beforehand by applying the titmus test to participants' ability to perceive spatial depth by binocular vision (Fricke and Siderov, 1997; Stereo Optical Co., S/N F1113965899, Chicago, Illinois, USA).

Materials

A worksheet was developed for the use during the working phase with the e-learning environment in order to draw learners' attention to relevant information in the images and the text on the screen. It also contained four items assessing the students' performance on estimating anatomical-spatial relationships such as judging the positioning of the visualized ear's various organic structures towards to another or towards the learner (Tab. 1). These questions were formulated in a closed answer format. Each question referred to another screen page. Each screen page depicted the content from a different perspective by varying the viewing angle, the highlighted detail, and the size. All questions could therefore be answered independently. To assess students' visual attention performance the d2-R test attention test (Brickenkamp et al., 2010) was chosen. The test consists of 14 rows, each with 57 characters. These characters display the letter d or p, each shown one, two, three or four lines under, above or under and above the character. The research subjects were asked to identify all ds with two stripes and to cross them out. To process one row 20 seconds were available. In sum the participants had four minutes and 40 seconds to complete the test. Test performance is determined as a result of the sum of the correctly and incorrectly crossed out characters. According to Brickenkamp et al. (2010, p. 67) the standard value for visual attention performance of the age group of 20-39 years is 158.6 ± 29.4 (N=708). This reference group included participants of all educational levels.

Procedure

First, research subjects were arranged in groups of 4-8 participants. Then the groups were randomly assigned to work with one of four settings: static presentation by non-stereoscopic imagery, static presentation by stereoscopic imagery, dynamic presentation by non-stereoscopic imagery and dynamic presentation by stereoscopic imagery. In sum, 17 of 36 students in the cohort with stereoscopic imagery and static presentation were biology education students, as were 25 of 41 in the cohort with non-stereoscopic imagery and static presentation. For the dynamic presentations, 33 of 46 participants with stereoscopic imagery were students of biological education, as well as 34 of 48 in the non-stereo cohort. Because there are gender differences in spatial abilities (Linn and Petersen, 1985; Cooke-Simpson and Voyer, 2007; Peters et al., 2007; Lufler et al., 2011) and spatial abilities may influence an individual's performance on anatomical tasks (Wilson, 2015), it was taken care to distribute female teacher trainees and male teacher trainees evenly. Before starting the participants were instructed as how to complete the d2-R attention test according to the test manual (Brickenkamp et al., 2010). For the working phase with the e-learning environment, each participant received the worksheet. 14 minutes (2 minutes for each screen page) were spent learning with the e-learning environment and thereby also filling in the worksheet. An instructor handled a remote to switch from one screen page to the next. The function of the instructor was not to explain the displayed subject matter but to guarantee standardized procedures. Thus he did not give responses to content-related questions. For the dynamic condition the instructor additionally rotated the organs and zoomed them towards the learners and back into the starting position several times for each screen page. Hence, any learner in the dynamic condition could see the same quantity and quality of dynamism. In contrast, participants of both static conditions saw a picture presentation without any motion. After completing the last screen page the software module was switched off and the students filled out the d2-R test.

Data analysis

In order to compare the performance on estimating anatomical-spatial relationships the correctly performed items were coded with 1 and the rest with 0. For each participant a test score was then counted. To judge whether the subjects' choices had an impact on the results or not, biology education as a major was assessed as a covariate, even though biology education students at this university did not receive any instruction utilizing digital visualizations concerning this topic beforehand.

For each cohort means as well as the standard deviations were calculated. Outcome measures were compared by (2 x 2) mixed analyses of variances (ANOVAs), each with two levels of between-subjects conditions: static or dynamic presentation and non-stereoscopic or stereoscopic imagery. These calculations were made with SPSS , version 22 for Windows (IBM Corp., Armonk, NY). To determine each student's attention performance the amount of characters processed for each row was counted. The number of confusion errors and missing errors were then subtracted. The sum of each rows' results was taken as the value for the student's attention performance. Finally, analyses were calculated as described above for estimating anatomical-spatial relationships. Because there were few male participants, no gender effects were determined.

RESULTS

Findings for estimating anatomical-spatial relationships (Table 2) reveal differences between the four tested working settings. There was a significant effect for the vision modus (F (1,170) = 24.67, $P < 0.001$, ${}_{p}\eta^2 = 0.129$). For the degree of dynamism there was no effect (F (1,170) = 0.03, $P = 0.862$, ${}_{p}\eta^2 = 0.000$). Analysis of an effect of the interaction of the vision modus and the degree of dynamism revealed a significant result (F (1,170) = 5.44, $P = 0.021$, ${}_{p}\eta^2 = 0.032$). The influence of the biology education major covariate had no statistical relevant impact (F (1,170) = 0.84, $P = .360$, ${}_{p}\eta^2 = 0.005$).

Focusing on the visual attention performance (Table 2), neither a relevant effect for the vision modus (F (1,170) = 0.06, $P = 0.804$, ${}_{p}\eta^2 = 0.000$) nor for the degree of dynamism can be reported (F (1,170) = 0.61, $P = 0.437$, ${}_{p}\eta^2 = 0.004$). However, a significant effect of an interaction between the vision modus and the degree of dynamism could be detected (F (1,170) = 5.42, $P = 0.021$, ${}_{p}\eta^2 = 0.032$). There was no effect with regard to the biology education covariate (F (1,170) = 0.10, $P = 0.758$, ${}_{p}\eta^2 = 0.001$).

DISCUSSION

Results suggest that estimating anatomical-spatial relations from stereoscopic templates was significantly more successful than using non-stereoscopic templates. This is in line with findings about enhanced structure recognition in gross anatomy education applying static stereoscopic imagery (Hilbelink, 2009; Abildgaard et al. 2010; Remmele et al., 2015; Hackett and Proctor, 2016). With ${}_{p}\eta^2 = 0.129$ this effect can be interpreted as almost strong. Interestingly, the difference between the means of both cohorts working with static imagery is rather large. In the dynamic condition the contrast between both visual representation types diminished. Still, for comparing static imagery versus dynamic imagery the cohorts working with stereoscopic imagery reached higher means than those who were working with non-stereoscopic imagery. However, the effect of the degree of dynamism wasn't statistically significant at all. For the interaction of stereoscopic imagery with dynamism there was statistical evidence of an effect. However, with ${}_{p}\eta^2 = .032$ this effect is rather small. In particular, combinations of non-stereoscopic imagery and static presentation reached a considerably lower performance score compared to other combinations of the vision modus and degrees of dynamism.

The findings of the present study indicate that the combination of stereoscopic imagery and motion is better suited to convey one's perception of human anatomical structures than using

non-stereoscopic moving images alone (Rosenbaum et al., 2000; Luursema et al., 2008; Remmele et al., 2015). On the other hand, there is also a contrast to the findings of Nelson et al. (2008), who found benefits of stereoscopic imagery only in combination with static imagery and not in combination with dynamism. This contract depends perhaps on the anatomical content addressed. Nelson and colleagues (2008) focused on identifying fetal boney structures instead of estimating spatial relationships of the middle and inner ear. Perhaps the task of identifying fetal bony structures in their research was much easier compared to estimating proportions of the ear, and therefore motion alone was sufficient to succeed and the application of motion in combination with stereoscopic imagery could not bring a benefit. Another contrast is found when comparing the findings of Remmele et al. (2015), which indicate that the combination of stereoscopic vision and motion led to the best performance. In the present study, this combination did not lead to enhanced performance on interacting with anatomic structures compared to static stereoscopic vision. This may be due to the middle and inner ear's complex structure. It's possible that the judgment of the ear's anatomical relations was so difficult that the combination of both depth cue stereoscopy and motion couldn't bring any advantage compared to stereoscopy or motion alone. Another explanation may be that in the present study the students could not interact with the e-learning module but they could do so in the study of Remmele et al. (2015). Perhaps participants work more successfully when controlling and moving the e-learning module themselves rather than passively watching moving images. A starting point for further investigations into these questions may be the suggestion of Nguyen et al. (2012) to distinguish between non-interactive dynamic and interactive dynamic conditions.
With regard to the depth cues, stereoscopic imagery and dynamism, the findings of the present study suggest that only stereoscopic imagery can be described as powerful depth cue. When compared to research that highlights dynamism as important depth cue (Rogers and Graham, 1982; Sollenberger and Milgram, 1993; Ware and Mitchell, 2005), this result appears rather surprising. It suggests that stereoscopic presentation formats should be privileged compared to non-stereoscopic dynamic presentation formats in teaching novices about anatomical-structural properties.

There was no significant difference between the four cohorts' visual attention performance, which is in line with Bombeke et al. (2013). Compared to the standard value for the age group of 20-39 years old all four research cohorts obtained higher means and thus reached a higher level of visual attention performance. In the reference group all educational levels were included

(Brickenkamp et al., 2010), in the present research however participated absolvents of Germany's school system's highest stratification level.

Concerning effects of the vision modus and dynamism there was no significance. However, there was a lower effect of an interaction between the vision modus and the degree of dynamism. In this context it is remarkable that stereoscopic imagery in combination with static presentation led to the best results. In contrast, the combination of stereoscopic imagery with dynamism led to the lowest performance. In the present study the critical combinations of stereoscopic imagery and motion (Lambooij et al., 2009) led to increased impairments of participants' visual attention (Tab. 2). Interestingly, it was found that the visual attention performance for both stereoscopic imagery cohorts is characterized by notably larger standard deviations compared to the non-stereo cohorts. In particular, the standard deviation of the cohort working with stereoscopic imagery and dynamic presentation was nearly double that of the cohort working with non-stereoscopic imagery and dynamic presentation. It can be assumed that students react individually and differently on stereoscopic visualizations: some are aided by the visualizations and experience enhanced visual attention performance while other students are hindered and result in decreased visual attention performance. On the contrary, the performance of the students within the non-stereo cohort was more homogeneous. Recent research (Roach et al., 2017) indicates that a high spatial visualization ability drives participants' visual attention immediately to prominent structures within given images and thus reduces task completion time. In the present study, participants of the stereoscopic visualization cohorts had to interpret both stereoscopic and monocular depth cues, as they are both inherent within any stereoscopic representations of organic structure. In contrast, participants of the non-stereoscopic visualization cohort had to interpret monocular depth cues solely. It could be that participants with a high spatial visualization ability switched easily between interpreting both stereoscopic and monocular depth cues. On the contrary, participants with a low spatial visualization ability also might have succeeded in estimating anatomical-spatial relationships but were more challenged in correlating both kinds of depth cues and thus resulted in decreased visual attention performance. In the dynamic condition there was no difference between cohorts in visual attention performance. Coming from the assumption of a connection between visual attention and working memory (de Fockert et al., 2001; Luck and Vogel, 2013; Tas et al., 2016) one can reason that individuals' working memory was impacted differently by stereoscopic imagery. Arguing with the cognitive load theory (Candler and Sweller, 1991), enhanced visual attention performance might be interpretable as a good prerequisite of germaine load while learning anatomical content. In contrast, low visual attention performance appears to go in hand with extraneous load. However, what the reasons are for such heterogeneous impacts on working memory remains unknown.

LIMITATIONS

The present study makes general statements on the impact of combinations of stereoscopic and moving imagery on estimating anatomical-structural relationships and doesn't refer to learners' spatial abilities. However, it is well known that individuals' spatial visualization ability impacts performance on spatiality-related tasks and thus is a predictor for gaining anatomical knowledge (Lufler et al., 2012; Nguyen et al., 2012; Roach et al., 2017). For interacting with stereoscopic representations in the context of laparoscopic skills, Roach et al. (2014) have shown that participants with low spatial visualization ability can especially benefit from working with stereoscopic visualizations. In this respect, it would be of interest to clarify how participants' spatial visualization ability affects their performance in estimating anatomical-structural relationships when working with combinations of stereoscopic and static in contrast to stereoscopic and moving images. Taking dynamism into account within the context of visualization ability, research shows mixed results regarding the extent to which the level of visualization ability and the degree of dynamism interact (for an overview see Nguyen et al., 2012). However, some studies revealing mixed results didn't refer to stereoscopic but rather to non-stereoscopic imagery (Huk, 2006; Höffler and Leutner, 2011). Hence, for the case of combinations of stereoscopy and dynamism, the influence of visualization ability remains rather underexplored.

One aim of the present study was to investigate stereoscopic visualizations' suitability in enhancing students' estimations of anatomical-structural relationships. The participants were all novices to the presented content. This means that the significance of the findings is not related to experts. It arises however the question if experts on these subjects could also benefit from stereoscopic imagery. Perhaps stereoscopic visualizations are only suitable for novice levels. In contrast stereoscopic visualizations might be unimportant for expert anatomists who know the human body very well and learnt to interpret non-stereoscopic representations during their professional activities before.

The findings of the present study are related to anatomical structure estimations but not to learning physiological concepts. Theories for multimedia learning (Mayer, 2003; Schnotz and Bannert, 2003) underline a linkage of the computation of descriptive and depictive information in working memory. According to these theories, one can assume that a better visual recognition of structures and their relationships can facilitate the understanding of related descriptive information and thus could foster the understanding of structural and functional concepts (Nguyen et al., 2012; Ferdig et al., 2015) such as the anatomy and physiology of hearing. To what extent the four tested combinations of stereoscopic imagery, non-stereoscopic imagery, static and dynamic picture presentation impact the learning of such concepts was not evaluated in the present study and needs further investigation. One way to do so might be to assess participants' concepts of structure and function by using concept mapping techniques and to parallel assess their perception of structures by the construction of spatial-hands-on representations of this organ (Remmele et al., 2015; Remmele & Martens, 2016). Subsequently, the relationship between the elaboration of formed structures and the quality of written concepts should also be studied.

CONCLUSION

In regards to the usage of stereoscopic imagery in gross anatomy education, our findings show that stereoscopy is quite valuable in conveying representations of anatomical spatial properties. Hence, especially when working with static imagery, the application of stereoscopic imagery is advisable. Moreover, combinations of stereoscopy and motion result in better performance of estimating anatomical spatial relations than motion alone. This finding is quite important for gross anatomy education because the application of self-moving or interactive non-stereoscopic representations is currently very common (Hackett and Proctor, 2016). With the findings of the present and other studies (Rosenbaum et al., 2000; Luursema et al., 2008; Remmele et al., 2015), stereoscopic visualizations appear to be more preferable in helping novice learners estimate anatomical-spatial relations. However, like any other interactive visualization, the usage of interactive stereoscopic visualizations might be only meaningful when enough single work stations are available so that everyone can work on his or her own. In contrast, non-interactive moving stereoscopic representations and static stereoscopic representations could be applied much more easily when equipped with fewer resources. For example, only one piece of hardware equipment such as a 3D projector would be necessary. In gross anatomy education this means that those techniques could be implemented even in courses of universities with more modest financial means.

Stereoscopic vision appears to impact students' information processing in working memory differently. Although the standard deviations between stereoscopic imagery and non-stereoscopic imagery differed significantly, the differences between all cohorts' visual attention performance score in any condition appears to be inconsiderable. The consequences for learning settings seem to be minimal. Despite this, the significantly larger standard deviations in the groups working with stereoscopic imagery should be considered. When put into practice, participants who could be impaired by stereoscopic imagery should be identified. Non-stereoscopic imagery is perhaps an adequate alternative for such persons as it allows working without increased impairments on visual working memory. Subsequently teachers in gross anatomy education utilizing stereoscopic imagery should be aware of how each student gets along with this kind of imagery, especially when working with combinations of stereoscopy and motion. This insight is quite new with regards to working memory. Which personal properties contribute to increased or decreased attention performance due to stereoscopic imagery remains unknown and should be investigated further. Moreover, the question is raised of how long potential negative impacts o working memory continue after the working phase. It is worth noting that the visual attention performance measures of the present study were taken immediately after the working phase with the e-learning environment. It could be useful to judge the impacts longer after the working phase in order to study the impacts and impairments due to this technology on following working sessions. It also seems to be useful to assess the impact of prolonged working sessions with stereoscopic imagery in gross anatomy education on students' attention performance. In the present study, the duration of the working phase was 14 minutes only. However, many learning sessions might last longer. All things considered, when original cadaver material in gross anatomy education is missing, stereoscopic representations could be a better alternative compared to non-stereoscopic representations. For gross anatomy education in the medical domain (Drake et al., 2009; Gregory et al., 2009; Drake, 2014) this might be true particularly for those organ systems that are rarely presented by direct observation. This might be also true for gross anatomy education in biology teacher education in which human cadaver material isn't normally used.

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Table 1.

Content of the tasks on estimating anatomical-spatial relationships in dependency to working with a non-stereoscopic imagery / stereoscopic imagery e-learning module dealing with the anatomy of the middle and the inner ear.

1	Determining an order between visualized ossicles, cochlea and semicircular canals concerning their estimated distances toward the pinna.
2	Determining an order between visualized ossicles, cochlea, semicircular canals and auditory canal concerning their estimated distances toward the learner.
3	Determining an order between visualized malleus, incus and stapes concerning their estimated distances toward the learner.
4	Identifying the number of nerve fibers visualized overlapping.

Table 2.

Students' performances on estimating anatomical-spatial relationships and on the d2-R visual attention test.

Degree of dynamism	Assessment tasks	Vision modus **non-stereoscopic** (mean ± SD)	Vision modus **stereoscopic** (mean ± SD)
Static			
	Estimating anatomical-spatial relationships (max. score =4)	0.85±0.88	1.94±1.09
	Visual attention performance (max. score unlimited)	165.80±33.15	182.53±44.48
		N=41	N=36
Dynamic			
	Estimating anatomical-spatial relationships (max. score =4)	1.25±0.93	1.65±1.04
	Visual attention performance (max. score unlimited)	175.42±30.34	162.13±53.23
		N=48	N=46

The data were assessed in dependency to working with an e-learning module dealing with the anatomy of the middle and the inner ear utilizing combinations of non-stereoscopic / stereoscopic imagery and static / dynamic picture presentations. The maximum possible score for estimating anatomical-spatial relationships was 4. For visual attention performance the score was unlimited.

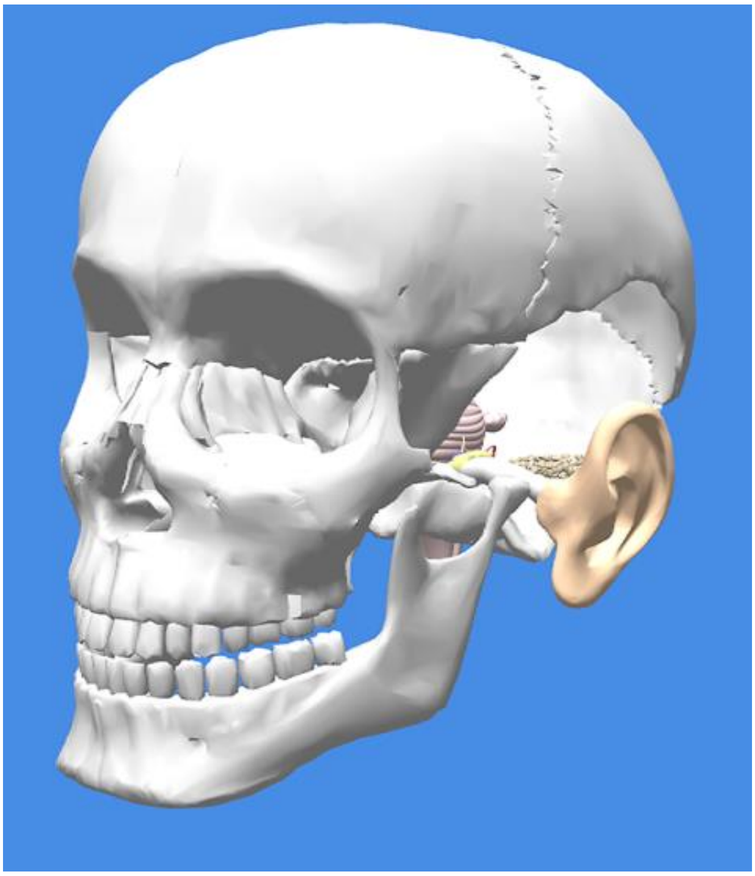

Figure 1.

Screenshot of the e-learning module providing a view of the virtual skull model from outside.

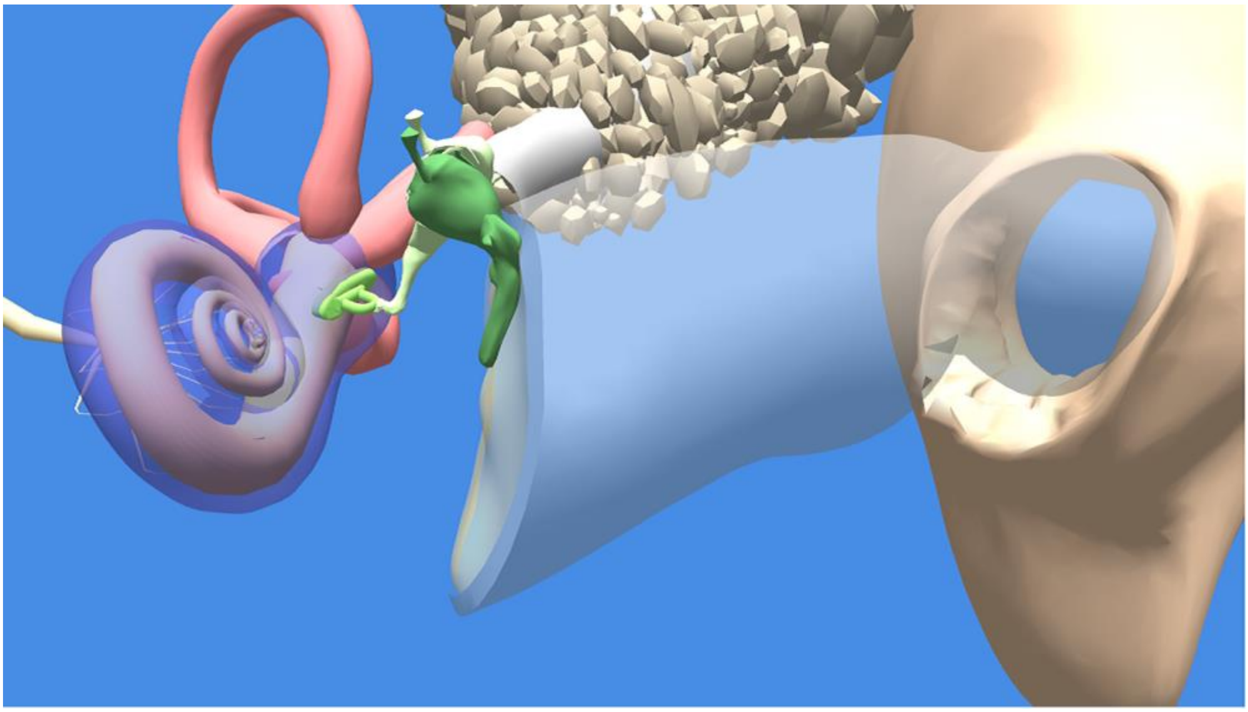

Figure 2.

This screenshot shows a view into the virtual skull model depicting the middle ear and the inner ear. Depth impression arises due to depth cues such as shading and masking.

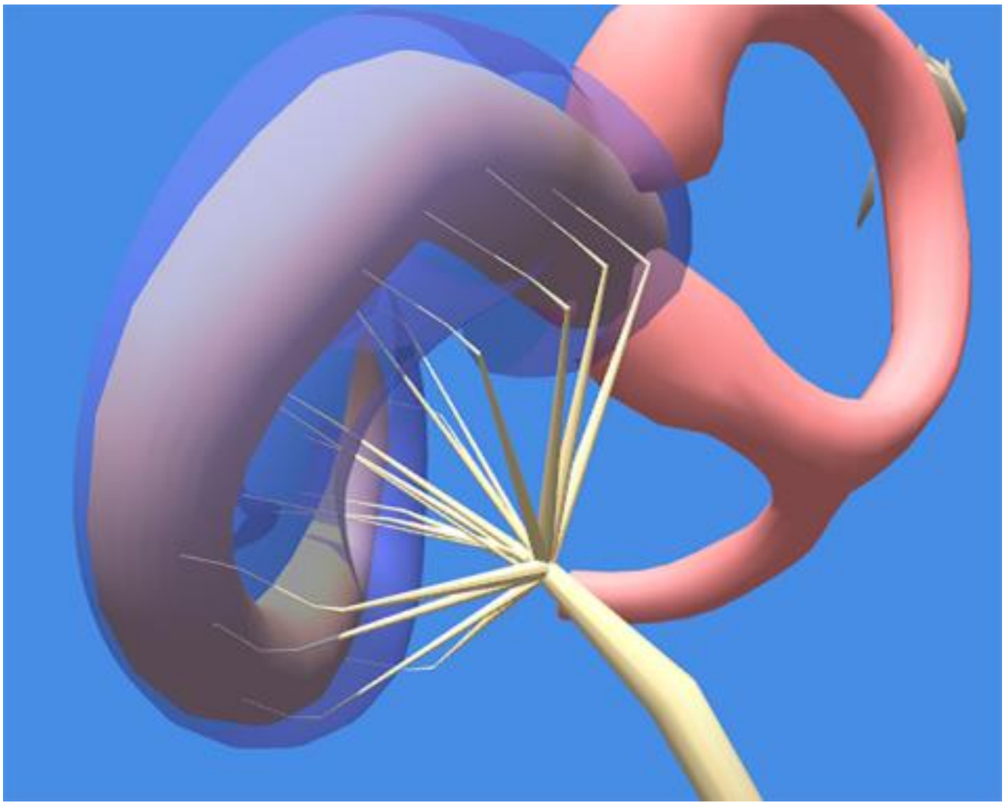

Figure 3.

This screenshot highlights the anatomy of the inner ear. From this perspective, parts of the cochlea and one semicircular canal are hidden. That means, anatomical-spatial properties are difficult to estimate.