Comparing 2-D and 3-D Instructional Methods for Teaching Laryngeal Anatomy Concepts

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The current study focused on the various ways undergraduate students learn laryngeal anatomy. The purpose of the study was to examine the effectiveness of three different teaching modalities: 2-D images, 3-D models, and prosected pig larynges. Freshmen and sophomore-level students majoring in communication sciences and disorders at the University of Wisconsin-Eau Claire were chosen because they have limited knowledge of laryngeal anatomy, helping to decrease prior knowledge as a confounding variable. Each participant completed a two-part pre-test including a live model and a stroboscopic image. The first portion of the pre-test required participants to identify laryngeal landmarks numbered on the neck of a live model. Students were first asked to identify the numbers through free recall, followed by cued recall, and then using a word bank. The participants then identified numbers on a stroboscopic still image through the same process.

Students were randomly placed into one of three groups: 2-D images, 3-D models, or prosected pig larynges. Two days after the pre-test, they attended a learning session in which they were taught laryngeal anatomy through the use of their assigned modality. The researcher followed a script to ensure that each group received the same instruction. Instruction lasted for fifteen minutes and the students had 30 minutes to study on their own.

The post-test was identical to the pre-test. Change scores were calculated from individuals' pre-test and post-test scores, with comparisons made using a repeated-measures ANOVA for teaching modality, type of test, and type of cuing. The students assigned to the physical models modality showed the most improvement from pre- to post-test. Overall, each group performed better on the stroboscopic still image portion of the post test. For undergraduate students learning laryngeal anatomy, 3-D physical models may be the most effective method.

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CHAPTER ONE

Introduction

It could be argued that anatomy and physiology are the foundations of all knowledge in the field of speech-language pathology. According to Carpenter and Boh (2008), anatomy and physiology are essential for understanding the biological components of normal communication and swallowing. The role of the speech-language pathologist (SLP) is to treat impaired communication and swallowing, making knowledge of normal function critical in identifying dysfunction. As defined by the American-Speech-Language-Hearing Association (ASHA) Scope of Practice, communication includes speech, fluency, language, cognition, voice, resonance, and hearing (ASHA, 2016a). Swallowing includes feeding behaviors, chewing, oral transport, the pharyngeal swallow, and esophageal function (ASHA, 2016a). All of these include function and coordination of various structures of the thorax, head, and neck. SLPs can work with individuals across the lifespan to address communication and swallowing deficits, requiring knowledge of developmental and aging processes. They are qualified to help a newborn baby in the intensive care unit breastfeed, while also being qualified to help an elderly man with Alzheimer's learn memory techniques.

Because speech-language pathologists can work in a variety of settings (public schools, birth-to-three programs, skilled nursing facilities, hospitals, university clinics, private practice, outpatient clinics, long-term care facilities, and rehab centers) with a variety of clients, it is essential that they are competent in multiple areas. The ASHA Standards of Implementation Procedures for The Certificate of Clinical Competence in Speech-Language Pathology (2016) set forth education and competency requirements

individuals must demonstrate for certification to work in the field, as well as what fits within a speech-language pathologist's scope of practice. ASHA Standard IV-B states that, "the applicant must have demonstrated knowledge of basic human communication and swallowing processes, including the appropriate biological, neurological, acoustic, psychological, developmental, and linguistic and cultural bases. The applicant must have demonstrated the ability to integrate information pertaining to normal and abnormal human development across the life span" (ASHA, 2016b). Similarly, ASHA Standard IV-C states that, "the applicant must have demonstrated knowledge of communication and swallowing disorders and differences, including the appropriate etiologies, characteristics, anatomical/physiological, acoustic, psychological, developmental, and linguistic and cultural correlates in the following areas: articulation; fluency; voice and resonance, including respiration and phonation; receptive and expressive language (phonology, morphology, syntax, semantics, pragmatics, pre-linguistic communication and paralinguistic communication) in speaking, listening, reading, writing; hearing, including the impact on speech and language; swallowing (oral, pharyngeal, esophageal, and related functions, including oral function for feeding); orofacial myology; cognitive aspects of communication (attention, memory, sequencing, problem-solving, executive functioning); social aspects of communication (including challenging behavior, ineffective social skills, and lack of communication opportunities); and augmentative and alternative communication modalities" (ASHA, 2016b). These areas of knowledge support the SLP's evaluation and treatment of individuals across the life span.

Within speech-language pathology, evaluation and treatment of disorders may draw upon different aspects of anatomical knowledge, such as the ear for hearing

disorders or the tongue for speech sound disorders. This study will focus on one specialty area – the larynx. Working with people who have voice and swallowing disorders requires knowledge of the inner workings of the larynx. This is the organ that sits on top of the trachea, or wind pipe, and acts as the "voice box." The larynx is comprised of three unpaired cartilages and three pairs of cartilages. These cartilages support the larynx and move in different ways during speech and swallowing due to muscle contractions. The larynx is surrounded by various muscles that all play a role in its overall function. The larynx contains the vocal folds (also known as the vocal cords), which vibrate when air is pushed up through the trachea from the lungs; the vocal folds close to protect the airway during swallowing. The vocal folds themselves contain multiple layers, which are essential for proper vibration and vocalization. These cartilages, muscles, and layers of vocal fold tissue must all be understood if evaluation and treatment is to be successful.

Evaluation

Voice and swallowing evaluations require the assessment of laryngeal functioning. In a typical voice evaluation, both low-tech and high-tech measures are used, such as perceptual assessment, acoustic analysis, and instrumental exams. A common evaluation technique for assessing vocal fold vibration and tissue integrity is stroboscopy, or the examination of the vocal folds and surrounding muscle and tissue through the use of a rigid camera placed in the oral cavity. This camera allows visualization of the vocal folds under a stroboscopic light source. In order to identify laryngeal pathologies during stroboscopy, an SLP must have knowledge of the vocal folds, the muscles of the larynx, and all surrounding tissue. The SLP must recognize whether structures look appropriate in color, size, and orientation. She must also be able to identify whether both movement

of structures and vibration of the folds are adequate. While stroboscopy evaluates the internal functioning of the larynx, evaluations are completed externally, as well. For example, the larynx and surrounding muscles can be palpated to assess tension in a voice assessment. Knowledge of what the larynx should look and feel like when viewed and palpated is essential for documenting atypical postures or function.

In a typical swallow evaluation, SLPs complete an oral mechanism exam to examine the integrity of the structures and functions of the larynx. SLPs use clinical assessments to identify potential signs and symptoms of dysfunction. The clinician listens to the client's voice for any wet or gurgling sounds that could indicate aspiration and the neck is palpated to assess hyolaryngeal excursion as part of a bedside clinical swallow assessment. A clinician may also utilize instrumental assessments including a modified barium swallow (MBS) and a fiberoptic endoscopic evaluation of swallowing (FEES) to visualize the larynx during swallowing. The MBS (also known as a videofluoroscopy) requires the patient to consume solids and liquids that contain barium, which allows the edible substances to be visible during fluoroscopy. This evaluation is used as a way to visualize the oral cavity, the pharynx, and the swallowing mechanism. It can then be determined if the patient is aspirating on any particular viscosity or consistency. FEES may also be completed (through using a nasendoscope) and works in much the same way as stroboscopy, as it allows the pharynx and larynx to be visualized. Through this evaluation, swallowing function can be assessed while directly visualizing the structures involved. Across all models of evaluation, the SLP is determining whether function is normal and under what conditions swallowing is safe.

Treatment

SLPs are also responsible for the treatment of laryngeal pathologies. The purpose of these treatments is to improve vocal quality, reduce tension, or improve laryngeal function. As an example of the application of anatomical and physiological knowledge, a common treatment for reducing tension of the laryngeal musculature is circumlaryngeal massage, a massage that targets the muscles of the neck (i.e., sternocleidomastoid, suprahyoid group, thyroid complex, etc.). During circumlaryngeal massage, it is imperative that the location of all external muscles of the larynx, as well as airway structures and blood vessels, are known. This knowledge allows the clinician to more effectively target these structures and avoid causing the patient any harm or discomfort. Anatomical and physiological knowledge can be applied in other treatments of voice, as well, such as muscle tension reduction exercises (MTREs), vocal function exercises (VFEs), resonant voice therapy, and vocal hygiene. Stroboscopy may also be used in treatment as a way to monitor the state of any vocal or laryngeal pathologies.

SLPs also require anatomical knowledge in the treatment of swallowing disorders. Some patients require the strengthening of various muscles of the pharynx or larynx. Exercises can be completed to assist in an effective pharyngeal swallow and laryngeal airway protection. SLPs require sufficient anatomical knowledge to effectively explain how to complete a chin tuck, a head turn and tuck, a supraglottic swallow, and the Mendelsohn Maneuver, as well as various other treatments for swallowing disorders. These techniques target compensatory airway protection maneuvers and/or strengthen hyolaryngeal elevation. The SLP needs knowledge of anatomy and physiology to monitor progress to safe, functional levels. Another treatment used for swallowing disorders is

neuromuscular electrical stimulation (NMES). This treatment requires the clinician to apply electrodes to the muscles of the head and neck to stimulate weak muscles with pulses of electricity (Langdon & Blacker, 2010). Thorough knowledge of laryngeal anatomy is required for this to be done safely, and successfully target appropriate muscles in appropriate patients.

A final example of the need for detailed anatomical and physiological knowledge is in providing patient education. When patients can understand what they are trying to accomplish and why, they are more likely to "buy-in" to the therapeutic process (Miller & Rollnick, 2013). A clinician should also possess the ability to explain anatomical and physiological processes to clients in terms that they can understand.

While it is critical to understand *why* SLPs are required to learn anatomy and physiology, it is equally critical to understand *how* SLPs learn anatomy and physiology.

Visuospatial Skills

For students just beginning to learn about anatomy, the content can be daunting. In addition to an abundance of new, unfamiliar terminology, they must also begin to develop visuospatial skills. Students studying the sciences may be accustomed to learning through rote memorization rather than through visuospatial methods (Hu et al., 2010). "Spatial intelligence allows us to encode and transform information about objects and their location and thus to find our way in the world and perform technical activities" (Terlecki, Newcombe, & Little, 2007, p. 996). Development of visuospatial skill is essential for understanding how anatomical structures exist and function within the body. How information about anatomical structures is presented may have an impact on how it is learned and applied.

Long-term practice, such as reviewing material and implementing knowledge in real-world scenarios, and repeated testing have been shown to improve mental rotation performance, regardless of gender and prior experience with spatial ability activities (Terlecki et al., 2007, p. 1011). Terlecki and colleagues (2007) demonstrated that differences in initial spatial ability do not constrain growth, although individuals with a lower starting point may take longer to demonstrate gains. Men and women differed in their growth trajectories, but repeated testing and training helped both genders improve their spatial ability. It is critical to consider visuospatial factors when students are required to manipulate 3-D tissue samples or models or examine a 2-D image of a 3-D structure.

General Anatomy Teaching and Learning

It is clear that a detailed understanding of anatomy and physiology is essential in speech-language pathology, as well as many other healthcare fields; however, complex anatomical concepts can be challenging to teach and learn. Internal structures, such as the larynx, are often intangible and unfamiliar. Students struggle to visualize the relationships and size of internal structures, or what the actual tissue might look like. A variety of three-dimensional and two-dimensional teaching techniques have been examined in other disciplines and will be reviewed next.

Dissection. Dissection is the cutting open of a specific specimen to examine both its internal and external structures (Khot, Quinlan, Norman, & Wainman, 2013; Marquez, Patel, Rosentsveyg, Marquez, & Pagano, 2015). This process has long been the pedagogical standard for teaching anatomy concepts. Marquez and colleagues (2015) discussed that anatomy teaching is typically done through dissection, although dissection

of both animal and human specimens is a deconstructive process. Working with real tissue, in situ, can provide students an optimal environment for learning what structures look like, their locations, and how they relate to other structures (Tam, Hart, Williams, Heylings, & Leinster, 2009). McLachlan, Bligh, Bradley, and Searle (2004) describe the process of dissection as providing a three-dimensional view of human anatomy that can build upon knowledge gained in lectures and tutorials. Health care professionals must have knowledge of body structure and function and use this in the context of professional practice (McLachlan et al., 2004, p. 419). Tam and colleagues (2009) discuss that advantages of dissection commonly cited include appreciation of the ethical and moral issues related to cadavers, conceptualization of multi-dimensionality, touch-mediated perception, acquisition of practical dissection skills, and appreciation of anatomical variability.

Surgeons reported that actively completing surgeries on their patients was best learned through the dissection of cadavers. Hemmat, Wang, and Ryan (2016) sent a survey to 367 surgeons pertaining to how they learned head and neck anatomy. These surgeons revealed that they learned through both dissection and prosection. The authors found that it was important for the surgeons to actually perform the surgery/act of dissection, to observe their mentor's techniques, and to be verbally taught by a small group of surgeons (Hemmat et al., 2016).

While there are numerous benefits to dissection as a pedagogy, there are some drawbacks, mainly related to health and safety concerns, applicability to live people, and current healthcare practices. Preservation of cadaveric material could fail to eliminate potential health risks and diseases (McLachlan et al., 2004). The process of preservation

itself has the potential to be damaging to student health because of the materials used. In addition, McLachlan and colleagues (2004) claim that the process of fixation significantly changes the color of human tissue. This may not be helpful in surgical situations or when clinicians are working with live patients. Further, information gathered through dissection may not be helpful in looking at computer tomography (CT) images or magnetic resonance imaging (MRI) that use cross-sectional views (McLachlan et al., 2004), although including 2-D CT and MRI images of cross-sections of the cadaver being dissected during dissection can be helpful (Oh et al. 2009). Numerous authors related the expense of cadavers to the expertise with which they need to be preserved and space for storage, which limits the accessibility for many programs (McLachlan et al., 2004; Chan & Cheng, 2011; Khot et al., 2013). Because of the expense associated with cadavers, they may best be used in regional centers that are supported by a number of medical schools.

Prosection. Prosection is the dissection of a human or animal cadaver by an experienced individual as a means of demonstrating anatomic structure for students. In a study of occupational therapy students, Peterson (1993) found that prosection was efficient in both time and cost. Other studies have suggested that dissection and prosection are both important elements of learning anatomy and physiology (Yeager, 1996; Hemmat et al., 2016; Nnodim, Ohanaka, & Osuji, 1996; Young, 2013). Yeager (1996) studied students enrolled in a gross anatomy course in medical school. The students were split into four groups and each group did ¼ of the dissection of a cadaver. The students who completed the dissection taught the other groups using their prosected cadaveric material. An exam given at the end of the semester revealed that students who completed the dissection and those who examined the prosected materials scored

similarly. This indicates that students can learn just as well from prosection as they do from dissecting materials themselves. Nnodim and colleagues (1996) also examined students enrolled in medical school. Some of the students learned general anatomy through dissection while others learned through prosection. Written exams given to the students revealed that both groups of students scored similarly on their knowledge of anatomy and physiology (Nnodim et al., 1996).

Prosection compares similarly to dissection as a teaching method for gross anatomy in terms of student perceptions. Young, Guzman, Wimmers, Byus, and Wisco (2013) surveyed students in two different medical programs; one that was prosection-based and one that was dissection-based. Results of the survey showed that students thought prosection helped them better prepare for their board exams while dissection better prepared them for their clerkships. Both programs were regarded highly, but results show that prosection allows for the learning of dissection techniques and procedures while dissection is better suited for surgical training.

Physical Models. Physical models may be a useful substitute for dissection when resources are scarce. These models can be plastic, paper, or other moldable media and provide students with information about shape and relationships of structures. Students can manipulate the model to view a structure from different perspectives. Also, many models come in larger sizes, to make examination of small structures easier for beginning students (Chan & Cheng, 2011; Khot et al., 2013).

A specific example of 3-D physical models is a student-built clay model. Two studies (Oh et al., 2009; Marquez et al., 2015) have demonstrated positive learning outcomes with clay modeling. Marquez and colleagues (2015) used clay modeling in

teaching participants about pelvic anatomy. The participants included two former medical students, a high school teacher, anatomy faculty from two medical schools, and a third grader. This heterogenous group of participants was chosen to determine how both expert and novice learners learned from the clay modeling. While the instructors and students with previous knowledge of pelvic anatomy gained a greater appreciation for the structures through modeling, the third grader developed some preliminary knowledge of anatomy. Marquez and colleagues (2015) argue that clay modeling can be effective because it is a constructive approach to understanding spatial relations and may be a highly valuable tool across multiple educational tiers (Marquez et al., 2015); further study is required to determine whether the results of this small study are relevant to other contexts. Similarly, Oh and colleagues (2009) used clay models in teaching gross and neuroanatomy. Many students responded positively to this activity by expressing an increased interest in anatomy and by demonstrating their satisfaction of working with models through a questionnaire. Students who had difficulty creating the models and had to spend more time making them tended to respond negatively. The authors stated that models that are available for purchase are often expensive and large. The clay models made by students were small, inexpensive, and the students were allowed to keep them.

Three-dimensional clay models may be helpful beyond understanding structural relationships in situ. Cross-sectional anatomy is difficult to learn and teach because of the complex relationships among structures (Oh et al., 2009), but is important because of its application to medical imaging techniques, such as computed tomography (CT) and magnetic resonance imaging (MRI). Medical imaging techniques require interpretation of 3-D structures displayed in 2-D (Oh et al., 2009; McLachlan et al., 2004). In the study by

Oh and colleagues (2009), students in medical school made clay models of organs they were studying in their gross and neuroanatomy courses. To facilitate the necessary mental rotation, they instructed students to compare their clay models to CT and MRI. These students demonstrated better understanding of structural relationships after making the models. Students who completed the clay modeling process were then compared to students from another school who did not use clay modeling. The students performed better than the non-clay modeling group on the final exam, where they evaluated a CT image, indicating that modeling was an effective way to learn cross-sectional anatomy at the time. The two groups performed similarly on a repeat CT exam given six months after the original tests, indicating that the advantage of clay modeling may not be retained over time. The authors concluded that, "clay modeling can be a useful additional to anatomy curricula" (Oh, et al., 2009, p. 159).

Physical models, often made of plastic, can be used in teaching anatomy. Chan and Cheng (2011) examined the common features shared by anatomy models and rated their physical resemblance based on dimensionality, number of structures in the target region, relationships between the structures, absolute and relative sizes of structures, and shapes and surface details of the structures. It was determined that all models examined were low-fidelity models, meaning they often do not resemble the human body and typically represent a small number of the structures in a particular anatomical region. However, the low-fidelity physical models do have advantages; they serve as memory aids, reduce cognitive overload, facilitate problem solving, arouse students' enthusiasm and participation, and require minimal resources to produce.

Khot and colleagues (2013) found that students learning pelvic anatomy with physical models out-performed students using computer-based resources and 2-D images on a 25-item test with 15 anatomy questions and 10 physiology questions. The authors hypothesized that the students using computer-based modalities did not perform as well as the students who learned through physical models because there were more females in this group. They explain that females generally have poorer spatial ability, limiting their ability to mentally rotate 3-D images. The physical models allowed hands-on 3-D rotation. Alternate explanations were not provided; however, a more likely explanation is simply that the 3-D models were more effective.

Hiraumi, Sata, and Ito (2016) examined 110 students in speech therapy school. They used a 3-D paper model to teach temporal bone anatomy. Students demonstrated a better understanding of the anatomy following a papercraft-based lecture compared to a lecture using 3-D images and an artificial temporal bone. The authors expressed that human cadavers are the best way to teach anatomy of the temporal bone, but they are expensive and difficult to obtain. Artificial bones are adequate models, too, but are also expensive. Paper models allowed for hands-on manipulation and inspection, but did not show all of the precise anatomy. However, they gave students a solid framework for basic anatomy.

Physical models can also be constructed through the process of plastination, or the preservation of anatomical specimens through the removal of water and fat and the insertion of plastics. Latorre and colleagues (2007) completed a study on the effectiveness of plastinated resources for students studying veterinary anatomy, human anatomy, and veterinary surgery. The authors found that students highly valued the use of

plastinated resources and students using the resources scored higher than the control group in post-test results. The authors did not analyze pre-test/post-test comparisons within the group using the plastinated resources. Latorre and colleagues (2007) concluded that while plastinated specimens are a useful resource for learning anatomy, they are best used in conjunction with traditional methods of teaching.

Computer-Based 3-D Models. Computer-based 3-D models are digital images that have depth and can be manipulated on screen (Chan & Cheng, 2011). Students can visualize size, location, and relationships of structures to one another. Computer-based 3-D models are quickly becoming a viable option and have the potential to replace human cadavers as a teaching method for anatomy (Chan & Cheng, 2011; Tam et al., 2009). Digital models provide more accessibility and less expense than cadaver dissection (Chan & Cheng, 2011). The educational value of these models is dependent on how well they help students learn anatomy, such as 3-D comprehension and anatomical reasoning (Chan & Cheng, 2011).

Computer-assisted learning (CAL) can provide some of the same benefits of dissection, with the added advantages that CAL can be modified to meet the needs of individuals, can follow the individual's pace, and is always available (Tam et al., 2009). Tam and colleagues (2009) completed a systematic search of the literature surrounding the use of CAL in teaching anatomy to undergraduate medical students. Results of their review showed that overall, CAL improved knowledge of anatomy and physiology on various types of tests. In a study completed by Nicholson, Chalk, Funnell, and Daniel (2006), students who had access to a computer model of the inner ear performed significantly higher on a 15-question quiz than the control group who did not have access

to the computer model. A retrospective study comparing performance between a group of students who learned from traditional anatomy teachings and a group of students who had traditional anatomy instruction in addition to two hours per week of multi-media laboratory showed that the group with computer learning had higher final grades in the course (Elizondo-Omana et al., 2004). Unfortunately, the authors did not account for the differences in time of instruction between the two groups, so the improvement could be the result of extra instructional time as opposed to the multi-media resources. Some studies (McNulty, Halama, & Espiritu, 2004; Inwood & Ahmad, 2005) analyzed the use of computer resources to support dissection; results indicated that they are helpful to learn and prepare for class. Nieder, Scott, and Anderson (2000) evaluated a computer-based model used for learning skull anatomy. Students reported it was easy to use and promoted learning, but that it was best used in conjunction with a real skull.

Peterson (2014) examined whether 3-D methods are more effective in teaching gross anatomy to undergraduate and graduate students than 2-D images. Peterson (2014) found that students preferred 3-D images, but used 2-D materials more when studying. They utilized the 3-D images more often when not cramming (Peterson, 2014). Student scores increased with the use of either of the study materials, but students scored better after studying the 3-D material.

Khot and colleagues (2013) explain that even with virtual reality digital enhancements to computer-based resources (CBR), it is still a two-dimensional projection of a three-dimensional object. Computer-based learning relies heavily on visual spatial ability (.In their comparison of medical students, Khot and colleagues (2013) found no difference existed between groups using two-dimensional pictures and groups using

CBRs. They concluded that anatomical models serve as a more effective learning tool for anatomy than computer-based resources. Because visual spatial abilities vary across learners, CBR is difficult to make effective for all. Computer-based models still have a place in learning, but may not be as effective for students with lower visual spatial abilities.

Multi-Modality Instruction. Each of these methods of learning anatomy and physiology appear to be effective, as reported by Day, Goldberg, Molloy, Moran, and Rocco (2013). They completed a literature review of the most effective ways for physical therapy students to learn anatomy and physiology. It was found that while dissection is effective, it is not as effective alone as it is when paired with other modalities, including prosection, plastination, and computer-aided technology. Similarly, Chen, Glicksman, Haase, Johnson, Wilson, and Fung (2010) used 2-D images, 3-D computer models, plastic models, and cadaveric specimen to teach gross anatomy to first-year medical students. Through a student perception survey, it was found that while computer models allow for increased control and individualized engagement, students still enjoy and value traditional lectures. Students also reported that the most valued component of the mixed modalities was being taught by a surgeon during their dissection labs.

Teaching Anatomy in Speech-Language Pathology

In teaching anatomy concepts in speech-language pathology, it can be challenging to help students understand the complex, three-dimensional relationships among structures. Most instructors in this content area utilize a combination of images, verbal descriptions, and models to assist students in developing an understanding of the

mechanisms of speech and hearing (Adler, 2005). Hmelo-Silver and Pfeffer (2003) examined a group of seventh grade students (novice learners), preservice teachers from a large public university (semi-experts), and experts to determine how novice learners learn best compared to expert learners. They determined that novice learners find structures to be the most understandable. In contrast, expert learners find that more complex concepts create the basis for their understanding. For students studying speech language pathology, this could indicate that structures should be mastered and understood before they are expected to demonstrate knowledge of the functions/physiology of these structures. However, the best practice for teaching these structures and anatomical concepts has not been determined. Similar to other fields, several teaching methods and tools have been examined, including dissection and computer-based models.

Dissection. Information about general and speech anatomy has been obtained through the practice of dissection for years (Kuehn, 2016), although published studies are limited. Kuehn (2016) stated that, "dissection studies have been very important in generating information not only of whole body anatomy but also in relation to a greater understanding of speech and hearing mechanisms." Hu, Wilson, Ladak, Haase, Doyle, and Fung (2010) state that dissection gives students a 3-D view of human anatomy and allows them to develop an appreciation for anatomical variation.

However, dissection is time consuming, and may not be sufficient for surface anatomy, skeletal systems, nervous systems, or for delicate structures, like the larynx (Hu et al., 2010). Within the larynx, some structures and muscles are too small for novice dissectors to see and isolate, and dissecting the larynx requires advanced skill and practice that students may not possess (Hu et al., 2010). In a survey of current teaching

practice, Adler (2005) found that for both anatomy and physiology and neuroanatomy and neurophysiology, human specimens are expensive and not easy to attain. Most programs are not housed within a medical program, limiting their access to human cadavers (Adler, 2005). As a result, many SLP programs rely upon physical and/or computer models or 2-D images.

Prosection. Because anatomy and physiology courses often have a large number of students, it isn't practical when working with human specimens to have numerous students completing, or even observing, the sequences of dissection (Kuehn, 2016). As such, students often get an opportunity to see prosected sections/structures that have been preserved. No studies have presented the outcomes of prosection as a teaching method in speech-language pathology.

Computer-Based 3-D Models. Computer-based models may be an effective alternative to dissection, as they are inexpensive, don't rely on the availability of human cadavers, are not associated with any ethical concerns, and can be used by students on their own time (Hu et al., 2010). Hu et al. (2010) state that small, delicate structures (e.g., the larynx) can be magnified for closer examination and deeper understanding. They found, through a student opinion questionnaire, that the 3-D computer-based model of the larynx was not more beneficial to student learning than standard written instruction, but the students showed a preference for the 3-D model, describing it as effective, user-friendly, and preferred over standard written instruction. In the original study, 50 students were randomly placed in either a 3-D computer-based group or a standard written instruction group. The students were then tested with a 20-question laryngeal exam, with the students who completed the 3-D computer-based learning performing equally as well

as the students receiving written instruction. Fritz, Hu, Wilson, Ladak, Haase, and Fung (2011) conducted a six-month follow-up to the previous study and examined the long-term retention of laryngeal anatomy when taught via a 3-D computer-based model compared to standard written instruction. The follow-up study asked the same students to take the exam again, six months later. They found that standard written instruction was just as effective as computer-based 3-D models in the learning of laryngeal anatomy, and that learning from either method may last up to six months.

The Current Study

Dissection, models, 3-D images, and even 2-D images and written instruction are used in teaching anatomy, but it is not clear whether one method is better than the others for SLP students. While high achieving students may learn the content regardless of how the information is presented (i.e., pictures, models, or dissection), many students may require teaching that incorporates more tangible aspects, especially during early stages. Incorporating a real-life structure, with various levels of dissection, may provide students with a concrete method of understanding the complexity and relationships of human head and neck anatomy. Students who have the opportunity to visualize a three-dimensional structure may be more likely to grasp the complexities of mechanisms like the larynx.

While dissection could be a useful tool for all anatomy related to the speech and hearing mechanisms, the current study focuses on the larynx and its structures. The larynx can be an abstract concept to teach. Because the larynx is an internal structure, it may be difficult for students to grasp its orientation and size. It is challenging to view the larynx from various perspectives and understand its relationship to other structures.

While difficult to teach and hard to understand, the larynx is critical for clinical voice applications, such as circumlaryngeal massage or laryngoscopy. It also plays an essential role in videofluoroscopy, FEES, and swallowing dysfunction. The jump from learning anatomy to applying it in clinical contexts is perhaps the most critical aspect of teaching in this content area. By employing a variety of teaching methods within this study, we aim to gain a preliminary understanding of which visual representation helps students begin to move to that level of clinical application more effectively.

The purpose of the current study is to complete an analysis of the effectiveness of different teaching methods for anatomy in the field of speech-language pathology. The question this study aims to answer is: in the examination of 2-D images, 3-D physical models, and prosected pig larynges, which modality is a more effective way for undergraduate students to learn both internal and external laryngeal anatomy? Two-dimensional images and 3-D physical models are the current teaching modalities in the UW-Eau Claire CSD Department. In this study, the prosected pig larynges are the experimental teaching modality.

CHAPTER 2

Methods

Participants

The participants were 31 undergraduate students in the Communication Sciences and Disorders major at the University of Wisconsin – Eau Claire who have not yet taken or were currently enrolled in CSD 256: Anatomy and Physiology of Speech and Hearing (Table 1). For the students currently enrolled in CSD 256, the study was completed before the instructor of the course taught the phonation unit.

Table 1.

Participant demographic data

Demographic characteristic	Number
Age	19.4 years (SD = 1 year)
Gender	
Male	0
Female	31
Year in School	
Freshman	6
Sophomore	14
Junior	10
Senior	1

Procedures

Comparisons of student learning from 2-D images, 3-D models, and real tissue (prosected pig larynges) were made to identify the most effective method for teaching anatomy. A between groups design was used, with participants randomly assigned into three different groups. Group 1 (n=12) was taught laryngeal anatomy using 2-D pictures.

Group 2 (n=9) was taught laryngeal anatomy using plastic 3-D models. Group 3 (n=10) was taught through a series of prosected pig larynges.

To establish a baseline of knowledge of laryngeal anatomy, a pre-test/post-test was used. The 20-item pre-test included two parts; a 3-D section (10 items) and a 2-D section (10 items) which were further broken down into free recall, cued recall, and a word bank. For the 3-D section, students were asked to identify 10 superficial (or surface) laryngeal structures/landmarks on a live model (Figure 1). This live model had numbered markers on his anatomy (e.g., hyoid bone, thyroid notch, cricothyroid membrane) and the participants were asked to label the structure or muscle indicated by the number. They were first asked to do this through free recall. They then received a cued recall sheet that indicated what type of anatomical element each structure was (i.e.; cartilage, muscle, bone, etc.) and repeated the 10 items. Finally, they completed this section with a word bank, again with the same 10 items. The 2-D portion of the pre-test included a laryngoscopic still capture of a superior view of typical vocal folds (Figure 2). As with the live model, participants were instructed to label 10 numbered structures on this still capture (e.g., true vocal folds, false vocal folds, arytenoids) through free recall, cued recall, and then using a word bank. The live model and laryngoscopic image were chosen to represent common clinical applications of laryngeal anatomy knowledge. The structures/landmarks included in the pre- and post-tests are included in Table 2. The pre-test occurred at least two days prior to the learning activity and two weeks before the post-test, to avoid testing bias.

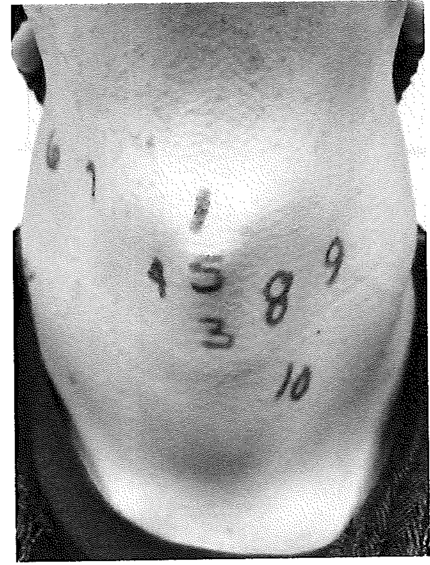

Figure 1. Live model for pre-test and post-test.

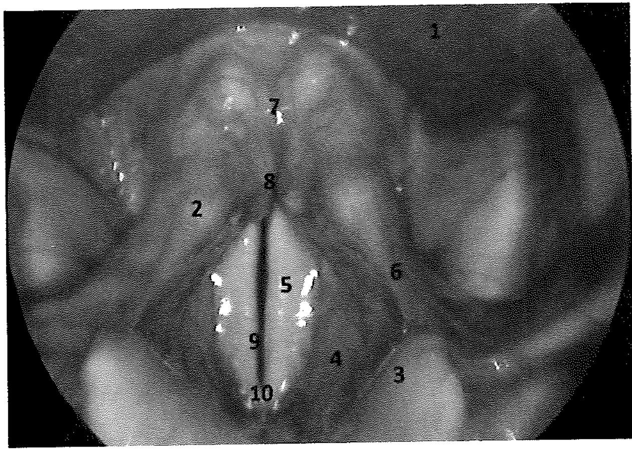

Figure 2. Stroboscopic image for pre-test and post-test.

Table 2

Structures/Landmarks included in the pre- and post-tests

Live Model	Stroboscopic Still Image
1. Thyroid notch	1. Pyriform sinus
2. Sternocleidomastoid	2. Arytenoid
3. Cricoid	3. Epiglottis
4. Thyroid lamina	4. False vocal folds
5. Thyroid angle	5. True vocal folds
6. Greater horn of the hyoid bone	6. Aryepiglottic fold
7. Hyoid bone	7. Interarytenoid muscle
8. Cricothyroid membrane	8. Vocal processes
9. Thyrohyoid membrane	9. Glottis
10. Sternothyroid	10. Anterior commissure

After taking the pre-test, each participant was randomized into one of the three groups: Group 1 (2-D images), Group 2 (3-D plastic models), and Group 3 (prosected pig larynges). Two days after taking the pre-test, each participant completed a learning session where they were taught laryngeal anatomy using their assigned modality.

The teaching portion lasted approximately 15 minutes and occurred separately for each modality. The researcher followed a script and participants were not allowed to ask content-specific questions so as to ensure that each participant and group received the same instruction. Following instruction, participants were given 30 minutes to study on their own. They were told they did not need to stay for the full 30 minutes if they felt they did not need it. Participants studied for an average of 24 minutes (see table 3 for details of each group's studying). Because of scheduling challenges, the participants attended the learning sessions in small groups (1-4 people). The participants took the post-test (identical to the pre-test) between 12-14 days following their learning session. The pre- and post-tests can be found in the Appendices A and B, respectively.

Table 3

Group demographic and timing data

Group	Average age (SD)	Average days pre- to post-test (SD)	Average study time used (SD)
1	19.3 years (0.75)	13.5 days (0.9)	21.42 minutes (7.8)
2	19.2 years (1.2)	13.4 days (0.8)	24.44 minutes (7.3)
3	19.6 years (1.1)	13.1 days (0.6)	27 minutes (6.3)

Materials

Because the University of Wisconsin-Eau Claire is not associated with a medical school, cadaveric material is not readily accessible. Prior research has shown that animal specimens are a quality alternative. Jiang, Raviv, and Hanson (2001) examined the similarities between four different larynx types: human, dog, pig, and deer. Results showed that the thickness of pig vocal fold mucosa was similar to the thickness of human vocal folds. The fundamental frequency and phonation range of the pig larynx was also most closely related to that of the human larynx. These results indicate that pig laryngeal anatomy is the superior model when working with animal specimen (Jiang et al., 2001) as a substitute for the human larynx.

Pig larynges were donated to the study by a local slaughter house. These larynges were frozen and then thawed two days prior to dissection. The author and supervising mentor dissected the larynges prior to the study and then froze them until they were needed for teaching Group 3. One larynx remained completely intact and showed the extrinsic muscles and nearby structures like the esophagus (Figure 3a). The second larynx had extrinsic tissue removed to expose intrinsic muscles and cartilages (Figure 3b). A third larynx was cut vertically down the posterior side (Figure 3c) to allow students to see

the full length of both the true and false vocal folds. The fourth larynx had half of the thyroid cartilage removed to reveal intrinsic muscles (Figure 3d). The fifth larynx was cut completely in half vertically (Figure 3e). Students could view both halves of the larynx and examine the layers of the vocal folds as well as determine the location of the arytenoids and other medial structures.

The 3-D models (Figure 4) and 2-D pictures (Figure 5) were obtained from the UW-Eau Claire Communication Sciences and Disorders Department. The models were those used for courses within the department; they were labelled with the same structures and views as the pig larynges. Two-D images were created from the 3-D models to ensure the images had sufficient detail and matched the structures labelled on the 3-D models and pig larynges. The live model was a graduate student volunteer and the laryngoscopic still was chosen from a pool of stroboscopy videos used for student learning.

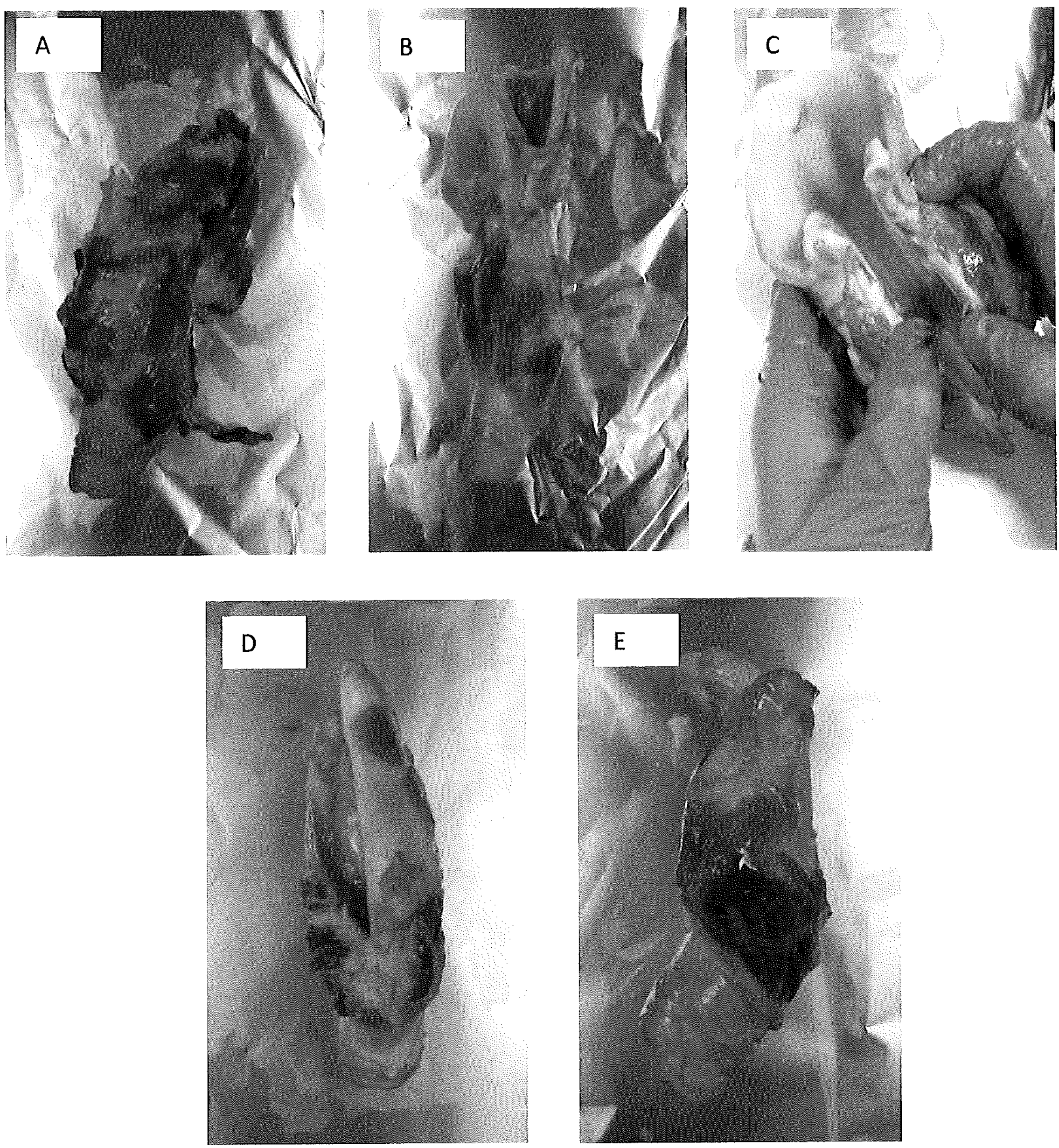

Figure 3. Pig larynges in stages of prosection. A) full larynx; B) extrinsic tissue removed; C) posterior cut; D) half of thyroid removed; E) half of larynx.

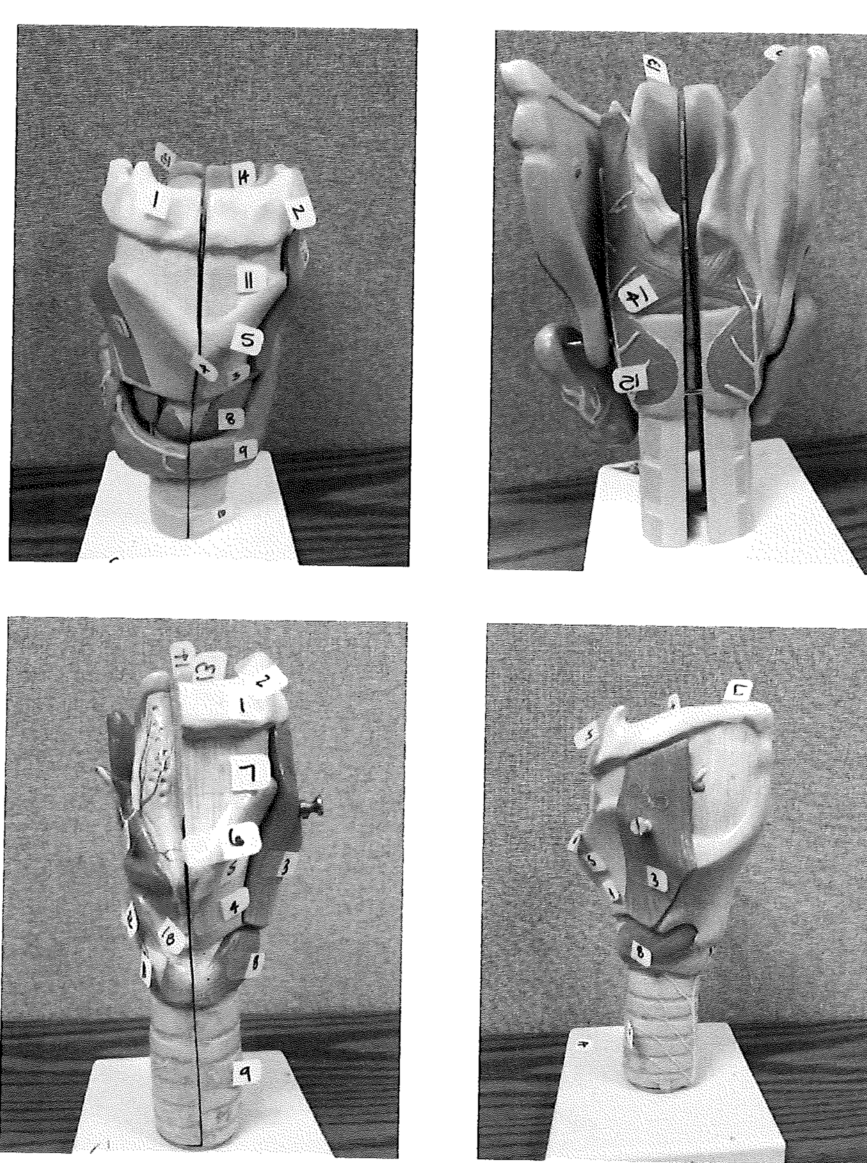

Figure 4. 3-D models of the larynx.

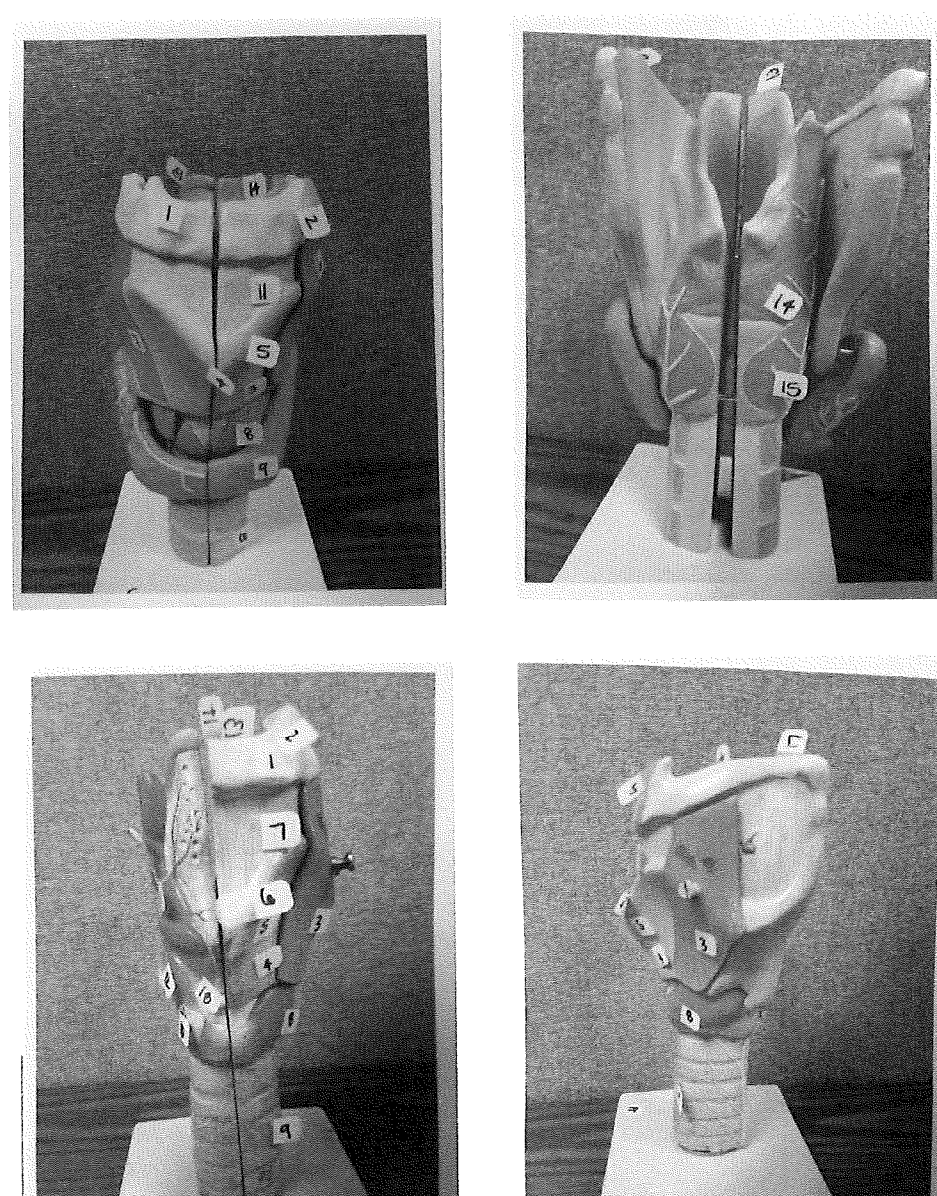

Figure 5. 2-D pictures of the larynx.

Data Analysis

Change scores (post-test – pre-test) were calculated for each participant. A repeated measures ANOVA was used to determine statistical significance between the 2-D picture, 3-D model, and prosected pig larynx conditions. Between subjects variables included the teaching modality and type of test; the within subjects variable was the type

of cuing. Main effects considered included teaching modality, type of test (live model or stroboscopic image), and type of cuing.

It was hypothesized that different learning modalities may help students with different portions of the post-test. For example, if a student was assigned to the 3-D model group or to the prosected pig larynx group, they may score higher on the "live model" portion of the post-test. Because the laryngoscopic still image is 2-D, students who worked with 2-D pictures may excel at this portion of the test. Therefore, two-way and three-way interaction effects were also examined.

CHAPTER THREE

Results

The question this study aimed to answer was: in the examination of 2-D images, 3-D physical models, and prosected pig larynges, which modality is a more effective way for undergraduate students to learn both internal and external laryngeal anatomy?

Participants were randomly assigned to the three different modalities. Group equivalency at the outset was established by completing a one-way ANOVA of the pre-test scores. The pre-test scores were not significantly different across groups ($F=0.233$, $p=0.794$). Other demographic variables were equal across groups as well (see Table 3 above). The pre-test, post-test, and change scores by test-type and level of cuing for each group can be found below in Table 4.

Table 4

Pre-test, post-test, and change scores by test-type and level of cuing for each group.

		Images Mean (standard deviation)	Models Mean (standard deviation)	Pigs Mean (standard deviation)
Pre-test	Live model			
	Free recall	0.25 (0.45)	0.22 (0.44)	0.30 (0.48)
	Cued recall	0.50 (0.67)	0.78 (0.83)	0.30 (0.48)
	Word bank	1.67 (1.30)	1.00 (1.00)	2.00 (1.94)
	Stroboscopy			
	Free recall	0.75 (0.87)	0.67 (0.50)	0.90 (0.74)
	Cued recall	0.83 (0.83)	0.67 (0.50)	0.90 (0.99)
	Word bank	2.25 (1.82)	2.56 (1.74)	2.30 (1.95)
Post-test	Live model			
	Free recall	0.58 (0.75)	1.67 (1.12)	1.00 (1.05)
	Cued recall	1.25 (1.14)	2.11 (1.76)	1.50 (1.08)
	Word bank	2.58 (1.73)	4.22 (1.99)	2.20 (1.55)
	Stroboscopy			
	Free recall	1.17 (1.11)	3.44 (0.88)	2.50 (1.58)
	Cued recall	1.25 (1.14)	3.22 (1.30)	2.30 (1.42)
	Word bank	2.58 (1.51)	5.00 (1.73)	3.60 (1.43)
Change scores	Live model			
	Free recall	0.33 (0.78)	1.44 (1.13)	0.70 (1.06)
	Cued recall	0.75 (1.36)	1.33 (1.22)	1.20 (0.92)
	Word bank	0.92 (1.93)	3.22 (1.64)	0.20 (1.82)
	Stroboscopy			
	Free recall	0.42 (1.08)	2.78 (0.97)	1.60 (1.58)
	Cued recall	0.42 (0.67)	2.56 (1.59)	1.40 (1.07)
	Word bank	0.33 (1.23)	2.44 (1.01)	1.30 (1.25)

A repeated measures ANOVA was completed to examine main effects and interactions between variables. The primary comparison of interest was between groups on the basis of modality. A second comparison of interest was the interaction between modality and the type of test (internal/strobe image vs. external/live model). All analyses were completed using change scores and are reported in Table 5.

Table 5

Repeated measures ANOVA results for main effects and interactions.

Test	df	F	p	Partial η^2	Power
Main effect – group	2	20.36	<0.001	0.421	>0.999
Main effect – test type	1	2.315	0.134	0.040	0.321
Main effect – cuing	1.44*	.458	0.571	0.008	0.112
Interaction effect – group x test type	2	2.064	0.137	0.069	0.407
Interaction effect – group x cuing	2.88*	2.22	0.095	0.073	0.532
Interaction effect – test type x cuing	1.44*	2.24	0.127	0.039	0.377
Interaction effect – group x test type x cuing	2.88*	2.24	0.093	.0074	0.536

*Mauchly's Test of Sphericity was violated, therefore an adjusted df was utilized following the Greenhouse-Geisser correction.

Differences in change scores for the three teaching modalities were examined as a main effect of the repeated measures ANOVA. The main effect for group was statistically significant ($F=20.36$, $p=<0.001$, $\eta^2=0.421$, power=>0.999); a follow-up Tukey test identified the 3-D models group as performing significantly better than the 2-D images or prosected larynges groups. No significant differences were noted between the group learning from pictures and the group learning from the prosected pig larynges. The participants in the 3-D model group showed the most improvement from pre- to post-test, followed by the prosected pig larynx group, and finally the images group (Figure 6); each group showed improvement in their scores following the instruction, as illustrated by positive average change scores.

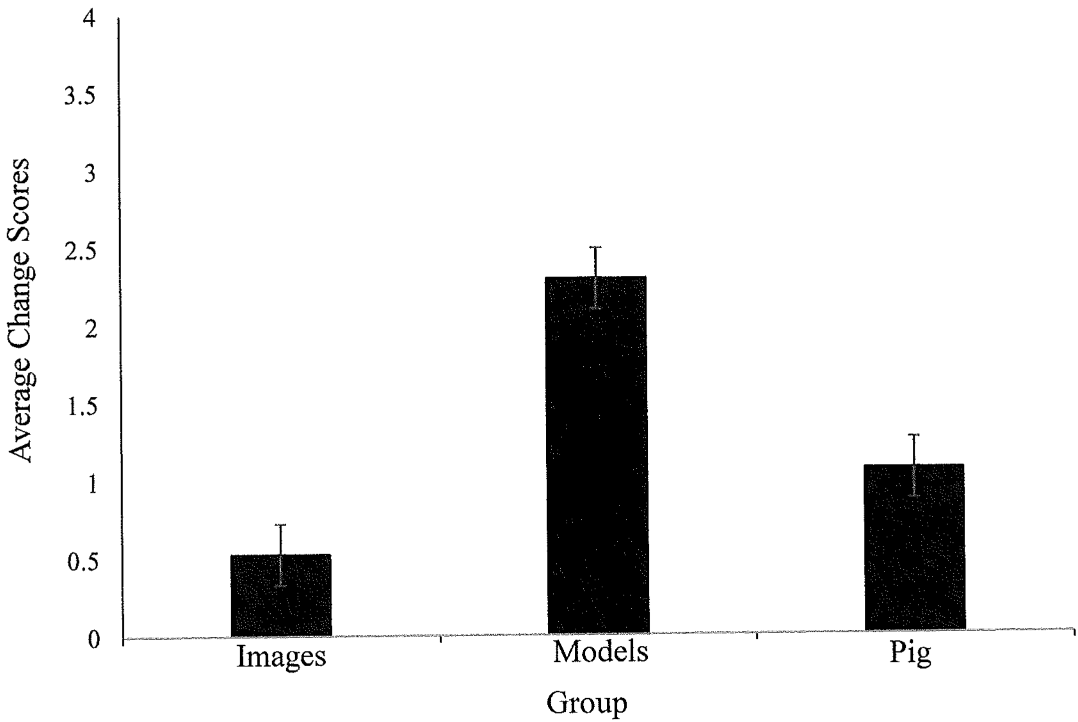

Figure 6. Average change scores by group.

The main effect for type of test, internal and external, was not statistically significant ($F=2.315$, $p=0.134$, $\eta^2=0.040$, power=0.321). Students performed slightly better on the stroboscopic still image portion of the tests than on the live model portion (Figure 7).

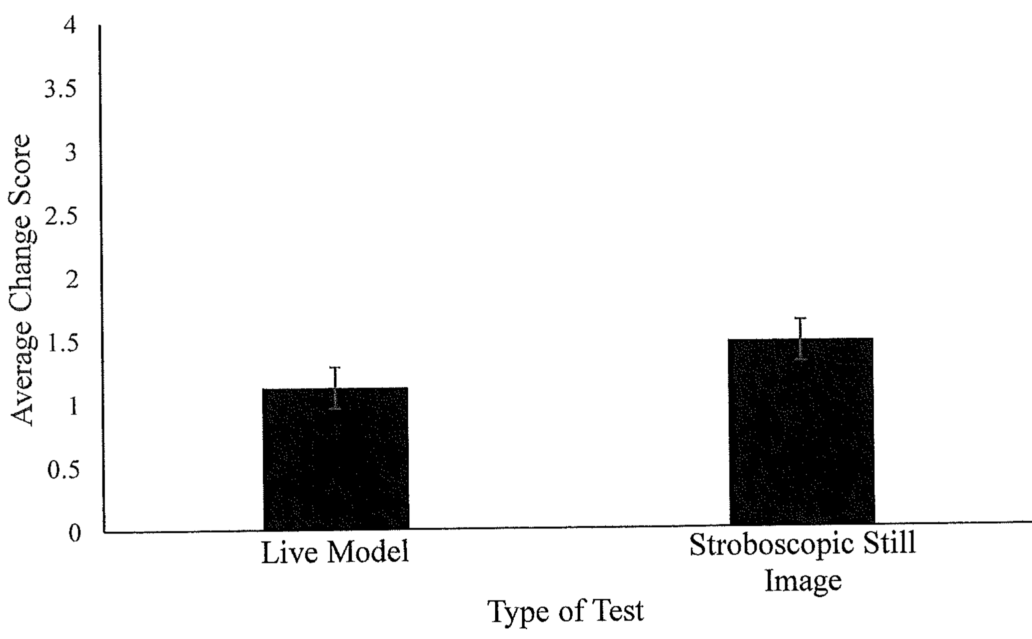

Figure 7. Average change scores by test type.

The main effect for level of cuing (free recall, cued recall, word bank) was not statistically significant ($F=0.458$, $p=0.571$, $\eta^2=0.008$, power=0.112). Across the different levels of cuing, students showed slightly better performance on the word bank, followed by cued recall, followed by free recall (Figure 8).

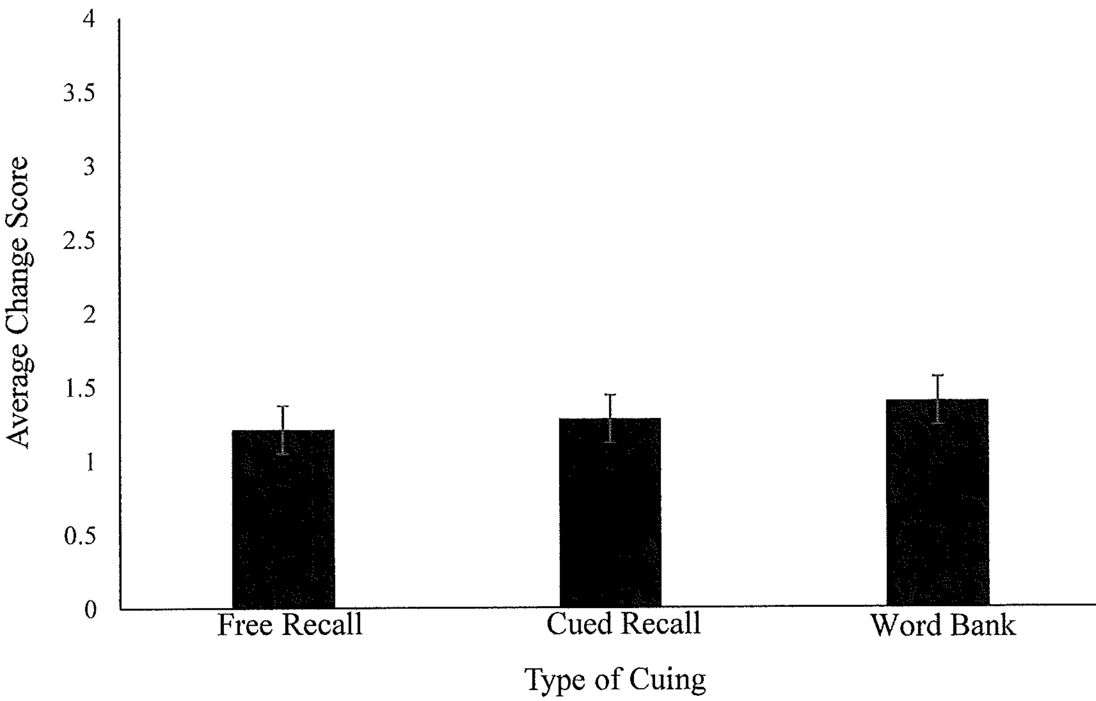

Figure 8. Average change scores by type of cuing.

Interaction effects between the variables were also examined. The interaction of interest, between group and test type (collapsed across cuing as an average), was not significant ($F=2.064$, $p=0.137$, $\eta^2=0.069$, power=0.407; Figure 9). The group learning with 2-D images had greater change scores in the live model condition as compared to the stroboscopic image, while the groups learning with 3-D models and pig larynges had greater change scores in the stroboscopic image condition as compared to the live model.

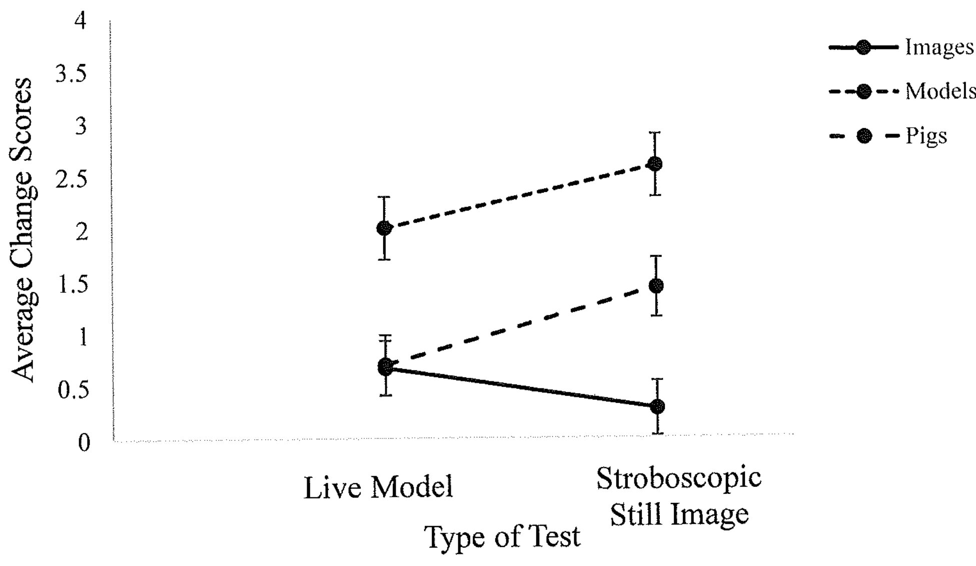

Figure 9. Interaction effects between group and type of test.

The interaction between group and cuing type was not significant (F=2.22, p=0.095, η^2=0.073, power=0.532; Figure 10). The group learning from 2-D images showed slightly higher change scores at each successive stage of recall. The group learning from the pig larynges showed equivalent change scores in free and cued recall, and worse change scores for the word bank condition. The group learning from 3-D models showed roughly equivalent change scores in free and cued recall, but higher scores in the word bank condition.

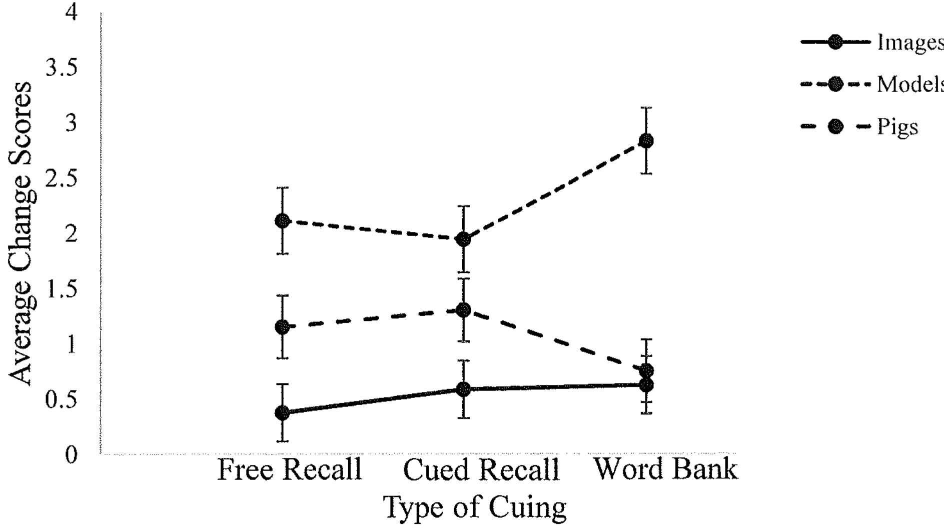

Figure 10. Interaction effects between group and type of cuing.

The interaction between type of cuing and type of test was also not significant (F=2.24, p=0.127, η^2=0.039, power=0.377; Figure 11). On the live model portion of the test, participants showed greater change scores with greater levels of cuing. In contrast, on the stroboscopic image, participants showed greater change scores with reduced levels of cuing. Note change scores were very small in this comparison.

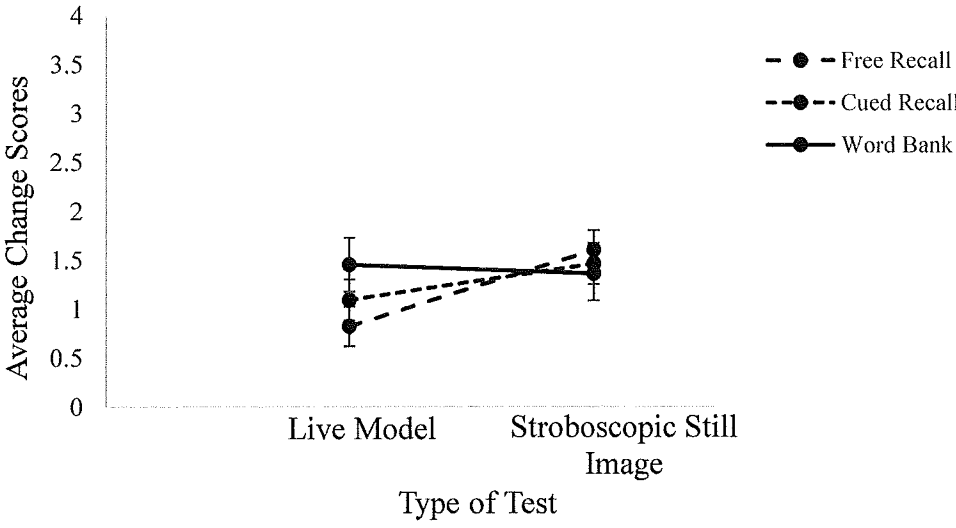

Figure 11. Interaction effects between type of test and type of cuing.

The three-way interaction was not significant ($F=2.24$, $p=0.093$, $\eta^2=0.074$, power=0.536; Figure 12). In general, most groups showed similar change scores across the various test and cuing conditions. The exception was the 3-D models group, who had higher change scores in the word bank portion of the live model test.

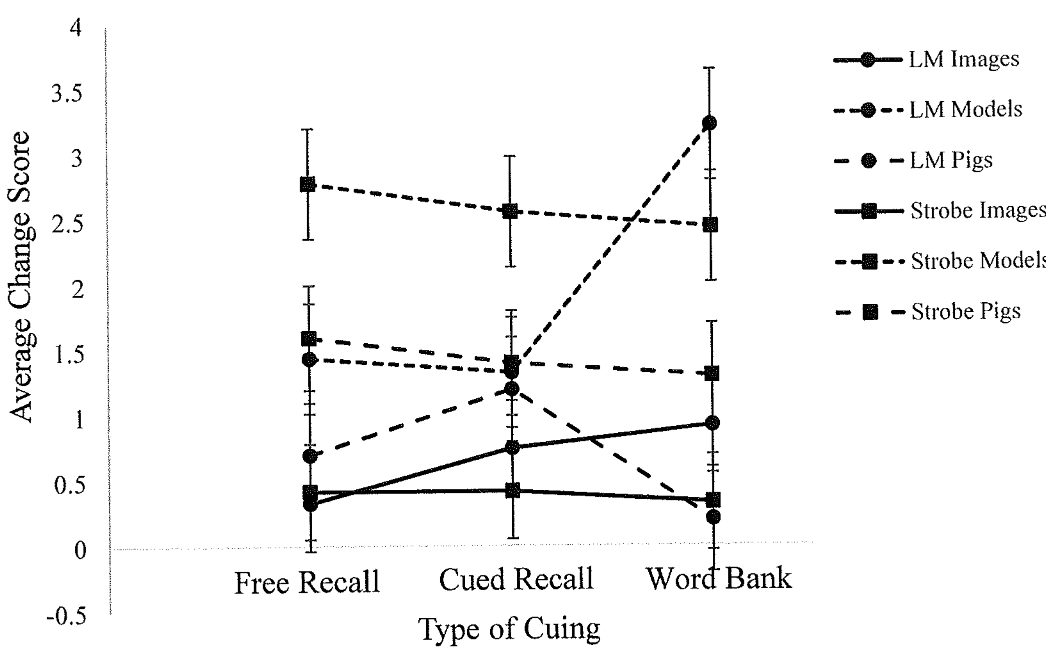

Figure 12. Three-way interaction effects.

Of the three main effects in this study (group/modality, type of test, and cuing type), the modality used in the learning session was the only significant effect. No interactions were significant.

CHAPTER FOUR

Discussion

The purpose of the current study was to determine if 2-D images, 3-D physical models, or prosected pig larynges were a more effective tool for undergraduate students to learn both internal and external laryngeal anatomy. Overall, the participants in the 3-D physical models group outperformed the participants in the other two groups, showing greater change scores from pre- to post-test. The models group was followed in performance by the prosected pig larynges group and the 2-D images group, respectively; however, these groups were not significantly different in their performance. In general, participants performed better on the stroboscopic still image portion of the pre- and post-tests with the exception of the participants in the 2-D images group who tended to perform better on the live model portion.

It was hypothesized that the prosected pig larynges group would outperform the other groups because the participants were handling real tissue, manipulating the larynges in 3-D, and could view multiple larynges at various stages of dissection. The tactile stimulation of the smell and feel of the tissue were also expected to aid in learning. These factors did not seem to facilitate learning in the students assigned to that group. Instead, the 3-D model group showed greater change scores from pre- to post-test. One possible explanation is that the participants may have been overwhelmed by both the new concept of laryngeal anatomy and the unfamiliarity of prosected tissue. Previous research has indicated that 3-D models may be a positive learning tool due to larger size, ease of viewing small structures, and simplification of complex anatomy (Chan & Cheng, 2011;

Khot, et al., 2013). Comments by the study participants indicated that the prosected tissue was interesting, but intimidating.

Another explanation for why the 3-D model group was the superior modality could be that the models are clear and color-coded. For example, all of the cartilages on the model were light blue, all of the muscles were red, and the membranes were white. The structures were clear and easily identifiable. In contrast, the cartilages, muscles, and membranes on the prosected pig larynges were roughly all the same color. It could have been difficult to distinguish one structure from another.

A further explanation of the 3-D model group outperforming the other two groups may relate to developmental level. Undergraduate students in CSD may not learn in quite the same way as medical students learn, as they are generally four years younger and lacking the extensive academic experience that medical students may have. Because the undergraduate student participants were novice learners, the prosected tissue may have been overwhelming. This is similar to previous studies, which indicate that simplified structures are an appropriate place to start instruction with novice learners (Hmelo-Silver & Pfeffer, 2003). The delicate structures and surface anatomy did not seem to be easier to see in the prosected pig larynges, similar to previous findings (Hu, et al., 2010). Beyond comparing the groups learning through 3-D models and the pig larynges, the 2-D images showed even smaller change scores across the board. The 2-D images may have been underwhelming for these students. The 3-D physical models appeared to have been the perfect "in-between" modality. They were in 3-D, they were manipulatable, and they were adequately realistic (Chan & Cheng, 2011).

It was also hypothesized that the prosected pig larynges group and the 3-D models group would perform better on the live model portion of the pre- and post-tests, as both the learning modalities and the assessment were in 3-D. Similarly, it was hypothesized that the 2-D images group would perform better on the stroboscopic still image portion, as both the learning modality and the assessment were in 2-D. This did not hold true; in fact, the results were the opposite of this hypothesis. Several potential reasons exist for this finding: relationship between the pig larynges and the stroboscopic image, overall experience with stroboscopic images as compared to surface structures, and distinct color differences in the stroboscopic image.

For students in the pig larynx group, what they saw on the stroboscopic still image was similar to what they saw when studying the pig larynges. They could see the vocal folds and internal structures on the pig larynges. This could have prepared them well for the structures presented in the stroboscopic still image, even though the larynges were 3-D and the image was 2-D.

Students in the CSD program have more exposure early in their program (even before they take anatomy) to stroboscopic still images than opportunities to examine external laryngeal anatomy. Students rarely examine external anatomy, until they reach clinical coursework or experiences in voice and dysphagia, often at the graduate level. While students were either not enrolled in a CSD anatomy course, or, if they were enrolled, had not yet learned laryngeal anatomy, it is possible that a number of students had seen stroboscopic images in their Introduction to CSD course. Any previous exposure to laryngeal anatomy and physiology the participants may have had was likely to be from a stroboscopic still image or video.

As an alternative explanation, the stroboscopic still image portion may have been easier for students to label, despite the modality used to study (2-D or 3-D), because structures were more discernable from each other. The internal anatomy of the larynx is comprised of different colors and shapes (i.e., the vocal folds are white, while the surrounding mucosa is pink). With the exception of a few structures (i.e., the thyroid angle, the thyroid notch), many of the external laryngeal structures look similar to each other. They are also all the same color. These aspects may have helped the participants distinguish the structures from each other on the stroboscopic image but not on the live model.

Within the field of speech-language pathology, minimal literature exists on how best to teach laryngeal anatomy and physiology. Within the broader context of teaching anatomy and physiology, the literature leans heavily towards the importance of dissection (Khot, et al., 2013; Marquez et al., 2015; Tam et al., 2009; McLachlan et al., 2004; Hemmat et al., 2016; Koba et al., 2012; Oh et al., 2009). Computer-based programs are beginning to replace or supplement dissection (Chang & Cheng, 2011; Tam et al., 2009; Nicholson et al., 2006; Elizondo-Omana et al., 2004; McNulty et al., 2005; Nieder et al., 2000; Peterson, 2014; Khot et al., 2013). Physical models (Chang & Cheng, 2011; Khot et al., 2013; Oh et al., 2009; Marquez et al., 2015) and prosection (Yeager, 1996; Hemmet et al., 2016; Nnodim et al., 1996) are also used in anatomy and physiology teaching. Results of this study suggest that for students who are early in their academic career in CSD, 3-D models may be the best teaching tool for anatomy.

Implications

The results of the current study indicate that 3-D modalities are a more appropriate way to teach laryngeal anatomy and physiology than 2-D modalities for early college-aged students. The students learning from 2-D images showed the least amount of improvement and the least amount of engagement. Students spent less time studying the 2-D images than the students in the other two groups spent studying their respective modalities.

It is possible that the developmental level of the participants plays a large role. The participants in this study were underclassmen in the CSD program at the University of Wisconsin – Eau Claire. They were either currently enrolled in an anatomy and physiology of speech and hearing course or had not yet taken it. The study was completed before the students received instruction on phonation and laryngeal anatomy. Therefore, the participants had limited prior exposure to laryngeal anatomy and physiology. The 3-D physical models group may have performed with the most success because the 3-D models were well matched to their developmental level. The real prosected tissue may have been too complex and unfamiliar, whereas the 2-D images were too simple.

Individuals teaching anatomy and physiology within speech-language pathology should give special consideration to the modalities they are using in their courses. Three-dimensional physical models may be the most effective modality for undergraduate students in their first exposure. Two-dimensional images may not be detailed, manipulable, or engaging enough alone to foster big gains in learning; it is important to note that the group learning from 2-D images did show improvements in anatomical

understanding. Prosection may be an effective option for graduate-level students, although this would warrant further research. As novice learners, undergraduates may benefit from learning the anatomical structures first through the 3-D physical models and then move towards learning through prosection. If they have a thorough understanding of the structures first, prosection may be an effective next step, but again, this will require further research.

Instructors should also consider the type of test they will administer (2-D vs. 3-D, internal vs. external) and the type of cuing they will provide their students with (free recall, cued recall, word bank). If an instructor wishes to assess students' understanding of anatomical structures, an exam using 2-D images may be a good fit. If the instructor hopes to see if students can apply their knowledge of anatomical structures clinically, a 3-D exam may be more appropriate. If students will be working clinically with voice disorders and will have access to stroboscopy, it is essential that they understand the internal anatomy and can interpret a strobscopic video or still image. Clinically, students will be working primarily with external laryngeal anatomy in completing circumlaryngeal massage, assessing tension, palpating, and assessing hyolaryngeal excursion.

The results of this study indicate that students perform best with a word bank when assessing their knowledge of laryngeal anatomy. Instructors should consider how much they value free recall on their exams (essay questions, short answer, etc.) and determine if free recall is necessary to show growth and learning.

While this study examined each modality separately, comments from participants indicate that they may best be used in a multi-modality approach. For example, a participant mentioned that they thought they would have "gotten more out of" the

prosected pig larynges if they had learned the basic anatomy from the physical model first. As previously cited, Day and colleagues (2013) found that dissection was not as effective alone as it was when paired with other modalities (prosection, plastination, computer-aided technology). Chen and colleagues (2010) had similar findings when students reported that they learned from computer models but still enjoyed and valued traditional lectures. Students may show the most growth and improvement if exposed to various modalities when learning laryngeal anatomy.

Limitations

A main limitation of this study was the small sample size. Because of attrition, the groups also ended up being slightly uneven in terms of number of participants in each group. It would have been ideal to have a larger number of participants with an equal number of participants in each group. The participants were also all female. The population of CSD students at UW-Eau Claire did not contain enough male participants for them to be equally distributed to each group. Ideally, this study would be repeated with large numbers of both male and female participants.

The participants may have also varied in background. While their ages only varied slightly, they may have had different life and educational experiences. A 21-year-old transfer student may have had life experiences and educational experiences that increased their success compared to an 18-year-old first-semester freshman. Despite these age differences, the participants were well-matched within each group and performed similarly on the pre-test.

The author could not control for some extraneous variables. The participants were asked not to study laryngeal anatomy between the learning session and the post-test, but

the author cannot guarantee that they did not study or learn pertinent information in some of their other courses during the intervening two weeks. Because of scheduling, some students attended the learning sessions in small groups while others attended alone. While the author instructed them not to talk to each other or discuss content, the students were left alone to study and this was not controlled. If some groups talked and worked together, they may have gained a deeper understanding of the content than students who studied alone. The time the students spent studying was also not controlled. Each group was given 30 minutes to study, but they were not required to stay for the full time. Therefore, they stayed for varying amounts of time.

Further Research

Future research should repeat this study with different levels of students. For example, graduate students may perform differently than undergraduate students, and they may have more success with the prosected tissues than the undergraduate students did, based on their experience as learners. Similarly, this study could be carried out at the doctoral level with individuals pursuing a Ph.D. in the areas of voice or swallowing disorders. Most graduate programs, at either the master's or doctoral level, do not include coursework in anatomy and physiology. It is possible that these groups of learners could benefit from instruction to build upon prior knowledge.

If the resources are attainable, human larynges should be used instead of pig larynges. While pig larynges are most closely related to human larynges, it would be best to use prosected human tissue. There should also be fewer levels of dissection used with the larynges. Students appeared to be overwhelmed by the five different larynges and

may have performed better if given only one or two. The various stages of dissection may be effective for more expert learners (i.e., graduate students and practicing clinicians).

In this study, participants were not allowed to touch the live model or palpate his laryngeal anatomy. It is possible that participants would be more successful in labeling external anatomy if given the opportunity to palpate the structures rather than just visualize them. Similarly, the structures in the stroboscopic still image may have been easier to identify if it was a video, rather than a still image. If participants could visualize the structures moving and working together, they may have showed more success. These aspects of the pre- and post-tests should be examined further.

Results of this study indicated that the 3-D physical models were the most effective method for learning laryngeal anatomy. The participants completed the post-test an average of two weeks after the learning session. However, most students are required to retain anatomical content knowledge for years as they move into clinical practice. Therefore, it is important to determine which method is the most effective in long-term retention. While the 3-D physical models proved to be effective for short-term retention, they may not be the most effective method for long-term retention.

These teaching modalities should also be examined not as individual entities but as an approach to multi-modality teaching. Students may show more success if they are given the opportunity to establish a foundation of knowledge and terminology by examining 2-D images first. Once they have a solid understanding of the anatomy, they can examine the 3-D physical models. Finally, they can examine the prosected larynges and experience exposure to real tissues and structures. The order in which the modalities are presented should also be studied further. It is unknown whether presenting the

modalities in order of complexity (images, models, prosected tissue) is more effective than exposing students to the most complex modality (prosected tissue) first.

Finally, future research should also address both anatomy and physiology. If students understand and know the anatomical structures, that does not mean that they also have a deep understanding of the physiology. Both anatomical and physiological knowledge of laryngeal structures are essential for the proper treatment of patients. The field of speech-language pathology requires more research into how students are learning anatomy and physiology so undergraduate and graduate programs can continue to train well-rounded and knowledgeable future clinicians.

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Appendix A: Pre-Test

Comparing 2-D and 3-D Instructional Methods for Teaching Laryngeal Anatomy Concepts

Pre-Test

Katie Beck
Dr. Abby Hemmerich

Name:

Age:

Race/Ethnicity:

Biological Sex:

Gender:

Year in School:

Overall GPA:

CSD GPA:

Part 1: Live Model

Free Recall:

1. ________________________________

2. ________________________________

3. ________________________________

4. ________________________________

5. ________________________________

6. ________________________________

7. ________________________________

8. ________________________________

9. ________________________________

10. ________________________________

Cued Recall:

1. ________________________________ (landmark)
2. ________________________________ (muscle)
3. ________________________________ (cartilage)
4. ________________________________ (connective tissue)
5. ________________________________ (landmark)
6. ________________________________ (bone)
7. ________________________________ (bone)
8. ________________________________ (connective tissue)
9. ________________________________ (connective tissue)
10. ________________________________ (muscle)

Word Bank:

1. ______________________________	A. Sternothyroid
2. ______________________________	B. Hyoid bone
3. ______________________________	C. Sternocleidomastoid
4. ______________________________	D. Cricoid
5. ______________________________	E. Thyroid angle
6. ______________________________	F. Thyroid notch
7. ______________________________	G. Thyrohyoid membrane
8. ______________________________	H. Greater horn of hyoid
9. ______________________________	I. Thyroid lamina
10. ______________________________	J. Cricothyroid membrane

Part 2: Videostroboscopy Still

Free Recall:

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________
8. ______________________________
9. ______________________________
10. ______________________________

Cued Recall:

1. ________________________________ (landmark)
2. ________________________________ (cartilage)
3. ________________________________ (cartilage)
4. ________________________________ (landmark)
5. ________________________________ (muscle/connective tissue)
6. ________________________________ (connective Tissue)
7. ________________________________ (muscle)
8. ________________________________ (landmark)
9. ________________________________ (space)
10. ________________________________ (landmark)

Word Bank:

1. ______________________	A. Epiglottis
2. ______________________	B. Interarytenoids
3. ______________________	C. Anterior commissure
4. ______________________	D. Arytenoid
5. ______________________	E. Pyriform sinus
6. ______________________	F. False vocal fold
7. ______________________	G. Aryepiglottic fold
8. ______________________	H. True vocal fold
9. ______________________	I. Glottis
10. ______________________	J. Vocal processes

Appendix B: Post-Test

Comparing 2-D and 3-D Instructional Methods for Teaching Laryngeal Anatomy Concepts

Post-Test

Katie Beck
Dr. Abby Hemmerich

Name:

Part 1: Live Model

Free Recall:

1. ____________________________

2. ____________________________

3. ____________________________

4. ____________________________

5. ____________________________

6. ____________________________

7. ____________________________

8. ____________________________

9. ____________________________

10. ____________________________

Cued Recall:

1. ________________________________ (landmark)

2. ________________________________ (muscle)

3. ________________________________ (cartilage)

4. ________________________________ (connective tissue)

5. ________________________________ (landmark)

6. ________________________________ (bone)

7. ________________________________ (bone)

8. ________________________________ (connective tissue)

9. ________________________________ (connective tissue)

10. ________________________________ (muscle)

Word Bank:

1. ______________________	A. Sternothyroid
2. ______________________	B. Hyoid bone
3. ______________________	C. Sternocleidomastoid
4. ______________________	D. Cricoid
5. ______________________	E. Thyroid angle
6. ______________________	F. Thyroid notch
7. ______________________	G. Thyrohyoid membrane
8. ______________________	H. Greater horn of hyoid
9. ______________________	I. Thyroid lamina
10. ______________________	J. Cricothyroid membrane

Part 2: Videostroboscopy Still

Free Recall:

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________
8. ______________________________
9. ______________________________
10. ______________________________

Cued Recall:

1. ________________________________ (landmark)

2. ________________________________ (cartilage)

3. ________________________________ (cartilage)

4. ________________________________ (landmark)

5. ________________________________ (muscle/connective tissue)

6. ________________________________ (connective Tissue)

7. ________________________________ (muscle)

8. ________________________________ (landmark)

9. ________________________________ (space)

10. ________________________________ (landmark)

Word Bank:

1. ______________________________	A. Epiglottis
2. ______________________________	B. Interarytenoids
3. ______________________________	C. Anterior commissure
4. ______________________________	D. Arytenoid
5. ______________________________	E. Pyriform sinus
6. ______________________________	F. False vocal fold
7. ______________________________	G. Aryepiglottic fold
8. ______________________________	H. True vocal fold
9. ______________________________	I. Glottis
10. ______________________________	J. Vocal processes