6-8-2017 12:00 AM

Examination and Assessment of Commercial Anatomical E-Learning Tools: Software Usability, Dual-Task Paradigms and Learning

Sonya E. Van Nuland, *The University of Western Ontario*

Supervisor: Dr. Kem Rogers, *The University of Western Ontario*
A thesis submitted in partial fulfillment of the requirements for the Doctor of Philosophy degree in Anatomy and Cell Biology

Abstract

Technological innovation is changing the landscape of higher education, and the competing interests and responsibilities of today's learners have propelled the movement of post-secondary courses into the online environment. In the anatomical sciences, commercialized e-learning tools have become a critical component for teaching the intricacies of the human body when physical classroom space and cadaveric resources are limited. This dissertation comparatively assessed the impact of two commercial anatomical e-learning tools (1) a simple 2-dimensional e-learning tool (A.D.A.M. Interactive Anatomy) and (2) a complex tool that allows for a 3-dimensional perspective (Netter's 3D Interactive Anatomy). The comparison was then extended to include a traditional visual-kinesthetic method of studying anatomy (i.e. a physical skeleton). Applying cognitive load theory and working memory limitations as guiding principles, a dual-task assessment with cross over design was used to evaluate cognitive load. Students were assessed using baseline knowledge tests, observation task reaction times (a measure of cognitive load), mental rotation test scores (a measure of spatial ability) and anatomy post-tests (a measure of knowledge recall).

Results from experiments carried out in this thesis suggest that the value of commercial anatomical e-learning tools cannot be assessed adequately on the basis of an educator's, or a software developer's, intuition alone. Despite the delivery benefits offered by e-learning tools and the positive feedback they often receive, this research demonstrates that neither commercial e-learning tool conferred any instructional advantage over textbook images. In fact, later results showed that the visual-kinesthetic experience of physically manipulating a skeleton yielded major positive impacts on knowledge recall that A.D.A.M. Interactive Anatomy, as a visual only tool, failed to deliver. The results of this dissertation also suggest that the design of e-learning tools can differentially influence students based on their spatial ability. Moreover our results suggest that learners with low spatial ability may also struggle to relate anatomical knowledge if they are examined on contralateral images.

By objectively assessing commercial anatomical e-learning tools against traditional, visual-kinesthetic modalities, educators can be confident that the learning tool they select will give their students the best chance to acquire an understanding of human anatomy.

Keywords

Gross anatomy education, cognitive load, dual-task methodology, e-learning, e-learning tools, instructional design, spatial ability, physical models, visual-kinesthetic learning

Co-Authorship Statements

The written material in this thesis is the original work of the author.

S.E. Van Nuland participated in all aspects of the work contained within this thesis including the dual-task research design and implementation, conception of the research questions, data collection, data analysis, and preparation of the manuscripts. The roles of the co-authors are detailed below.

Chapter 2: Assessing Standard Dual-Task Paradigms for the Measurement of Cognitive Load in E-Learning Tools (Study I)

S.E. Van Nuland created the concept of this research. The design of the dual-task paradigm was completed by S.E. Van Nuland with input from K.A. Rogers. Participant testing, data collection and data analysis was completed by SE. Van Nuland with input from K.A. Rogers. Funding for E-Prime® 2.0 Professional (Psychology Software Tools, Inc., Sharpsburg, PA) license was provided by K.A. Rogers. A trial license for A.D.A.M. Interactive Anatomy was provided free of charge by Ebix, Inc. (Atlanta, GA). S.E. Van Nuland carried out the composition of the manuscript with input from K.A. Rogers.

A version of this chapter has been published: Van Nuland S.E, Rogers K.A. 2016. E-Learning, Dual-task and Cognitive Load: The anatomy of a failed experiment. Anat Sci Educ 9:186-196.

Chapter 3: The Anatomy of E-Learning Tools: Does Software Usability Influence Learning Outcomes? (Study II)

The concept of this research was created by S.E. Van Nuland. Modifications to the design of the dual-task paradigm were completed by S.E. Van Nuland with input from K.A. Rogers. Participant testing, data collection and data analysis was completed by SE. Van Nuland with input from K.A. Rogers. Funding for a license to A.D.A.M. Interactive Anatomy (Ebix, Inc., Atlanta, GA) was provided by K.A. Rogers. S.E. Van Nuland carried out the composition of the manuscript with input from K.A. Rogers.

A version of this chapter has been published: Van Nuland SE, Rogers KA. 2016. The Anatomy of E-Learning Tools: Does software usability influence learning outcomes? Anat Sci Educ 9:378-390.

Chapter 4: The Skeletons in Our Closet: E-Learning tools and what happens when one side doesn’t fit all (Study III)

The concept of this research was created by S.E. Van Nuland. The design of the dual-task paradigm was completed by S.E. Van Nuland with input from K.A. Rogers. Participant testing and data collection was completed by S.E. Van Nuland and the data was analyzed by S.E. Van Nuland with input from K.A. Rogers. Funding for a license to A.D.A.M. Interactive Anatomy (Ebix, Inc., Atlanta, GA) was provided by K.A. Rogers. The articulated limb skeletons used in this study were human bones obtained from the skeletal collection of the Gross Anatomy Laboratory, Department of Anatomy and Cell Biology, University of Western Ontario. S.E. Van Nuland carried out the composition of the manuscript with input from K.A. Rogers.

A version of this chapter has been accepted for publication to Anatomical Sciences Education (May 5, 2017).

Acknowledgments

To everyone who encouraged me as I stumbled along the wild path of research, provided a distraction from the madness or bravely spoke the words that I may one day graduate, I am eternally grateful. Without your help, this would not have been possible!

First and foremost, I offer my sincere gratitude to my supervisor, Dr. Kem A. Rogers. Without your advice, guidance and most of all your support, I fear I would never have arrived where I stand now. Thank you for giving me a chance to see the world and for every single beer (and scotch) I made you buy me along the way. I am honored to have worked beside such an exceptional supervisor, educator and gentlemen and am incredibly thankful for every piece of advice and encouraging word that you offered me. From the bottom of my heart, thank you.

To my best friend Andrea, my ingenious partner in crime, where do I begin? Thank you for making me laugh every single day, and for convincing me to take breaks and eat more Reese's products. Thank you for enjoying our personal zoo as I much as I do, and for not killing the black cat when you tripped over him for the zillionth time. From our nights filled with coke and rye to the day your dog jumped out of my car in the middle of traffic, you never once stopped smiling. You have been an incredible friend, and my true soul sister, and for that I am truly grateful.

And last, but certainly not least, to my family and my sister, my tether to sanity, your tireless support of me, and my ever-changing dreams has kept me going through more than one sleepless night. Never once have you doubted my choice to become a 'student for life' (ok… maybe once…), and in the time since then you have helped me to pick up the pieces (more than once) and set me back on my path again, always a little stronger and wiser than before. Your sage advice remains my inspiration in the search for my life, myself and my soul. For everything you have given to me, and everything you sacrificed for me, I am indescribably grateful.

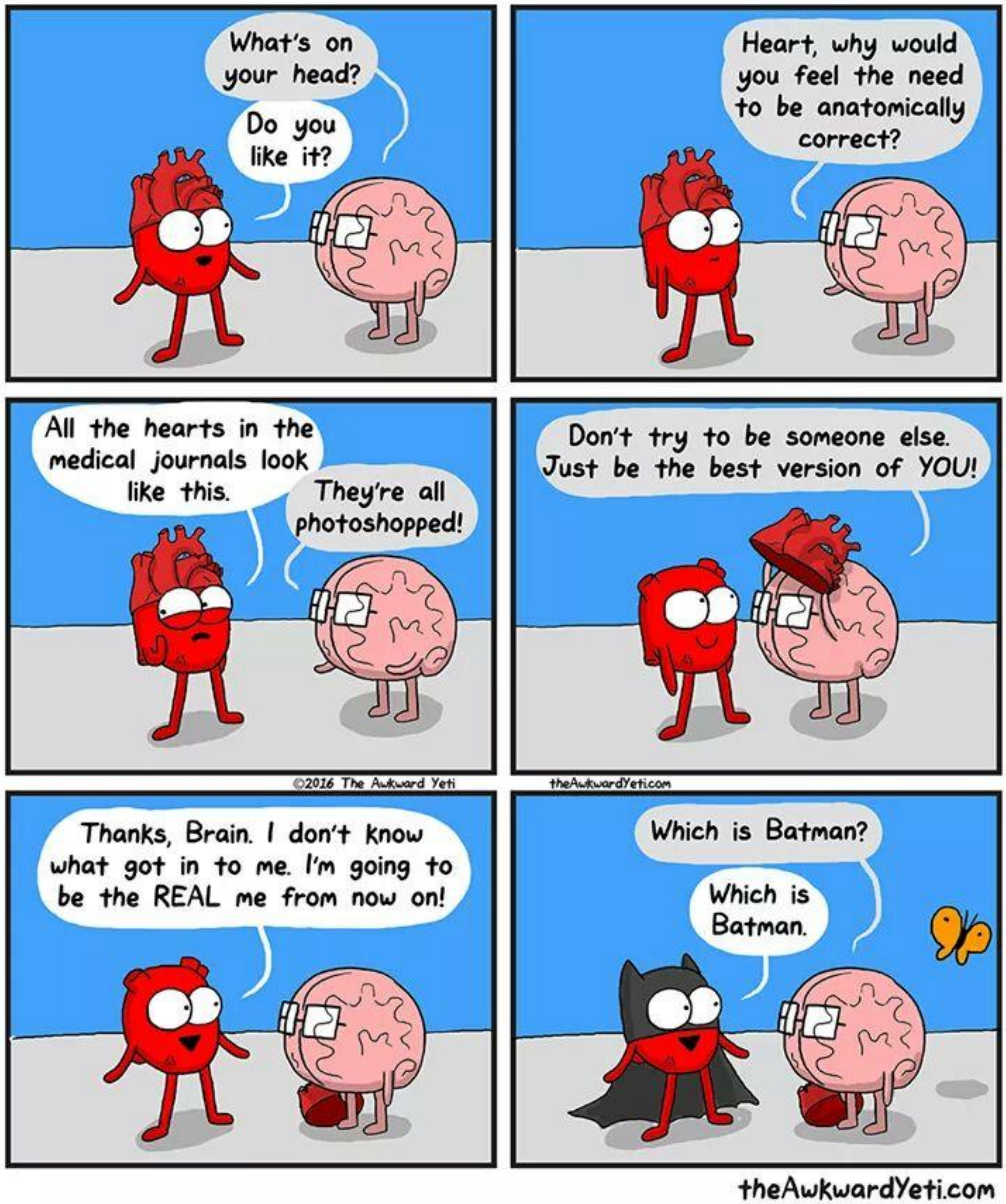
Table of Contents

List of Tables

List of Figures

List of Appendices

Preface



Creator: Nick Seluk

http://awkwardyeti.com

Chapter 1

1 Literature Review

This literature review contains text extracts from articles written by the primary author (Van Nuland and Rogers, 2016a; 2016b; Van Nuland et al., 2017)[1].

1.1 The Landscape of E-Learning in Post-Secondary Institutions

The landscape of higher education is undergoing substantial changes that have been driven by technological innovations and key economic, political, and sociocultural factors. Internationally, rising enrolment rates, calls for higher skill levels and increased student diversity, including a growing cohort of adult and returning learners, have fueled emergent demands for quality online learning opportunities that are flexible and student-centered (EU, 2014). E-learning is defined by the National Centre for Education Statistics as the process of extending learning and/or delivering instructional materials to individuals or groups that are physically separated, via any type of electronic media, such as the Internet (Waits and Lewis, 2003).

To understand the potential of e-learning on an international scale, the influence of population growth should be introduced. Estimates indicate that by 2020 more than 470 million young adults will be between the ages of 18 and 22, fuelling global demand for higher education, which is expected to surpass 250 million students by the year 2025, representing a 250% increase since the year 2000 (Bokova, 2011; Lawton et al., 2013). Global economic trends in higher education show that demand for online learning has become a driver for growth, advancing internet-based instructional delivery to the fastest

[1] These articles have been published in the journal Anatomical Sciences Education. For permission approval notices from the publisher see Appendix A, B and C.

growing sector of post-secondary education in many countries (Docebo, 2014; Allen and Seaman, 2011; Rogers et al., 2011; Pin et al., 2011; Tremblay et al., 2012).

The importance of e-learning, and its forecasted impact on post-secondary institutions, has not been lost on academic leaders. Higher educational institutions in Canada, the United States of America, Europe and China, among many others, have indicated that online learning is critical to their long-term strategy (Docebo, 2014; Allen and Seaman, 2015; EU, 2014; Rogers et al., 2011). National and state government recommendations and policies have been drafted to support the vision of accessible online education. In the European Union, a High Level Group on the Modernization of Higher Education was formed to advise the European Commission on new modes of learning and teaching through innovative technologies and open digital content (EU, 2014). In Canada, the Ontario provincial government has committed to investing 42 million dollars (CAD) between 2014-2017 to facilitate the offering of high-quality online courses (Ministry of Training, Colleges and Universities, 2014). The prevalence, global influence and sheer potential of new educational technologies has further motivated higher educational institutions to challenge their pre-existing educational paradigms; integrating new online tools and technologies to transform teaching and learning practices to meet the expanding needs and demands of 21st learners (UNESCO, 2011).

1.1.1 E-Learning Tools in the Anatomical Sciences

The change from teaching face-to-face to teaching or educating online is particularly applicable within the anatomical sciences. The rapid reforms taking place within the medical curricula have reduced the hours dedicated to the anatomical sciences in favor of teaching that is focused on clinical competencies (Irby et al., 2010; Trelease, 2016). In the effort to streamline anatomy programs and standardize learning outcomes at all undergraduate levels, post-secondary institutions consider online learning and self-directed laboratories involving e-learning tools to be vital (Skochelak, 2010; Trelease, 2016).

The demands for educational technologies that are flexible and student-centered have fueled interest in electronic learning (e-learning) tools that offer high definition graphics (Pin et al., 2011; EU, 2014). Anatomical e-learning tools have become a valuable asset considering rising enrollment rates and reductions in physical space and cadaveric resources (Irby et al., 2010; Skochelak, 2010; Trelease 2016). E-learning tools are defined as specific computer applications that mediate the learner's interaction with the educational content through an electronic interface, thereby facilitating knowledge construction (Tavangarian et al., 2004; Triacca et al., 2004). Use of e-learning tools within face-to-face anatomy courses has been detailed at numerous institutions (Sugand et al., 2010; Boyce, 2012; Gaitskell-Phillips et al., 2012; Barbeau et al., 2013; Attardi and Rogers, 2015), and their popularity has inspired many researchers and educators to create their own anatomical e-learning modules (Nicholson et al., 2006; Brenton et al., 2007; O'Bryne et al., 2008; Raynor and Iggulden, 2008: Durham et al., 2009; Hassigner et al., 2010; Sergovich et al., 2010; Adams and Wilson, 2011; Doubleday et al., 2011; Preece et al., 2013; Allen et al., 2015). The growing interest in anatomical e-learning tools has also attracted a number of companies who have developed commercial e-learning tools in an effort to capitalize on revenue possibilities (for comparison of commercial educational software programs see Attardi and Rogers, 2015; for programs specific to mobile devices see Lewis et al., 2014). The variability in the quality and usability of these commercial e-learning tools is extensive, and educators, with whom the decision of tool selection lies, often assume that they have been designed, developed and evaluated for their effectiveness on student learning (Higgins et al., 2000; Williams et al., 2004). With little guidance on how to assess these tools educators rely on the marketing materials provided by the commercial vendors and the enthusiasm for e-learning tools themselves among learners (Squires and Preece, 1999; Holden and Rada, 2011).

1.1.2 Why the Popularity Factor of Anatomical E-Learning Tools Is Not Enough

In the anatomical sciences, the evolution of technology has seen new e-learning tools supplant existing technologies and teaching methods in the classroom. E-learning tools have broadened the reach of the traditional cadaveric laboratory, enabling students to take human anatomy courses in an online format without being required to enter a cadaveric laboratory (Attardi and Rogers, 2015). Yet, even though e-learning tools have supplemented new multi-modal (models, speciments, plus prosections) laboratory activities supplanting traditional dissection-centered exercises in many medical schools (Drake, 2007; Drake et al., 2006; Drake et al., 2014). However, controversy over their adoption remains: are we headed in the right direction? Are we simply seeking/building/purchasing e-learning tools for the sake of the technology itself (Cook, 2007)? Is there an educational goal we are trying to achieve with the technology, or are the academic cultural pressures driving our pedagogical approaches (Cook, 2007; Pawlina and Drake, 2013)?

The delivery benefits of e-learning tools (e.g. increased accessibility, accountability, standardization etc.) are most often cited as their advantage over traditional teaching methods (Ruiz et al., 2006), furthermore e-learning tools often receive positive feedback from students (Glittenberg and Binder, 2006; Nicholson et al., 2006; Venail et al., 2010; Codd and Choudhury, 2011; Keedy et al., 2011; Webb and Choi, 2014; for a review see Yammine and Violato (2015)). However, research indicates that new e-learning innovations and their initial acceptance within the educational community are primarily based on perceived utility, and not immediate and objective evidence that they are equally effective as existing teaching methods (Rogers, 2003; Trelease, 2016). As a result, statistically reliable evidence comparing the efficacy of e-learning tools to each other, as well as to traditional instructional methods, is scarce (Lewis, 2003; Khalil et al., 2005; Levinson et al., 2007; Estevez et al., 2010; Preece et al., 2013; Trelease, 2016; Van Nuland and Rogers, 2016b). In today's learning environment, it is no longer sufficient to: (1) design and then neglect to test the effectiveness of learning tools, and instead provide conjecture on their effectiveness and ways they could be implemented in education (see Adams and Wilson, 2011); and (2) design learning tools and conclude they are effective based on user opinion feedback only (see O'Byrne et al., 2008; Guy et al., 2015). Without comparative studies that present statistically reliable evidence to demonstrate the effectiveness of different e-learning tools or compare those tools to more traditional methods of teaching anatomy, such as physically manipulating a skeleton, educators cannot make informed decisions about the tools they use. Without such evidence, the choice to incorporate e-learning tools into curricula will continue to be made based solely student perception, attitude and enjoyment, perpetuating the habit of blind acceptance and use of e-learning tools in education (Preece et al., 2013).

1.2 Cognitive Load and Learning

Clearly, challenging work remains to be done if educators and researchers wish to reliably characterize the comparative impact of different e-learning tools and traditional teaching methods on learning outcomes and experiences in the anatomical sciences. One method of assessing e-learning tool effectiveness is to consider the cognitive load imposed by different learning tools. Broadly, cognitive load research is designed to evaluate and model human intellectual performance and can be applied to technology use, yet its inherent complexity and use in numerous disciplines can make it difficult to define (Gwizdka, 2010). For the purposes of this dissertation, cognitive load is defined as the "total load that performing a particular task imposes on a learner's cognitive system" (Paas et al., 2004). The term 'load', as used here, refers to the working memory resources required by a task and the learner's ability to meet that resource demand, thus, cognitive load becomes a function of both the learner and the task being completed (Moray, 1979; O'Donnell and Eggemeier, 1986; Paas and van Merriënboer, 1994; Paas et al., 2003; 2004; Oviatt, 2006). For learned information to become accessible knowledge in the long-term memory, a series of subconscious processes, described in the next section, must occur.

1.2.1 Learning and Working Memory

In the learning process, information is first received through auditory, visual or tactile routes and is held in the learner's working memory, which is a temporary storage site used to process incoming information for organization into long-term memory schemas (Baddeley, 1992; Sweller et al., 1998). Over the past century, the concept of working memory has become a cornerstone of cognitive psychology, helping researchers to understand how information is temporarily processed and stored (Andrade, 2001). Historically, the limits of what the mind can accurately observe at a single point in time has been the focus of discussion in scientific journals as far back as 1871. A British economist and logician, William S. Jevons, observed that an individual is unable to correctly estimate a large number of objects without counting them successively, however, a small number of objects can be comprehended almost instantaneously (Jevons, 1871). To test his observation he blindly grabbed beans from a jar and scattered them on a table. In successive trials, he found that he made no error for sets of 3-4 beans, some small errors with sets of 5 beans and an increasing amount of errors as the number of beans on the table grew. Despite the biased nature of this study, the results that a typical adult human can keep three or four unlinked, separate items, or chunks of information, in their mind (at a single time) has been replicated many times in modern research (Miller, 1956; Daneman and Carpenter, 1980; Cowan, 2001; Baddeley, 2003).

Unfortunately, the dogma that working memory, or immediate memory as it was known at the time, is limited to 3-4 unlinked chunks of information has not always been correctly cited in educational research. In 1956, George Miller identified the 'magical number seven, plus or minus 2' as the span for immediate memory. Miller's article (1956) became a widely cited source in educational literature, and as a result the number seven garnered considerable attention in the lay public (Cowan, 2015). A later clarification by Miller (1989) however, explained that his emphasis of the number seven was a tongue in cheek attempt to connect two streams of his research that he believed to be unrelated (Cowan, 2015). He highlighted that the number seven tied together three immediate memory phenomena that he was studying: (1) that the number of items that be recalled verbatim in an immediate recall task is approximately seven; (2) that the number of items a person can apprehend or process simultaneously is approximately seven (i.e. a person at a quick glance, may know that there are 6 items on a tray); and (3), that the number of categories that can be reliably used in an absolute judgment task, where people assign numbers to the magnitudes of various aspects of a stimulus (i.e. 10 different tones varying one in pitch), is approximately seven. Modern research has demonstrated that the 'magical' number seven, it turns out, is more of a practical result that emerges when individuals use strategies like chunking (grouping together similar and familiar words or numbers) and verbal rehearsal to help them remember information (Miller, 1989; Cohen, 2015). Thus the number seven may reflect a common situation where chunks of information are formed by combining sets of two or three adjacent words or numbers (i.e. making 3 or 4 mental chunks out of 9-15 words, or 3 mental chunks out of a telephone number; Cohen, 2005). Despite being widely misquoted as the standard immediate memory limit, Miller's (1956) article served to emphasize the important message that the amount of information that can be stored and processed in the working memory depends upon how that information is grouped together.

It was not up until the 1960's that immediate memory became known as working memory (Cowan, 2014). In a book written by Miller and colleagues (1960), the term working memory was described through its association with organizing human behavior. Miller et al. used the concept of the working memory to explain how humans create and execute a hierarchy of plans and sub-plans (Miller et al., 1960). As explained by Cowan (2014), it is not possible for humans to think about all plans (cooking breakfast, driving to work, leaving on time, etc.) and sub-plans (frying the eggs, cutting fruit, depressing the toaster, finding the car keys, etc.) at once. However, with the help of the working memory it is possible to carry out one sub-plan (like watching the hot frying pan) while keeping in mind obligatory sub-plans (such as retrieving a knife) and the master plan (such as cooking breakfast) at the same moment (Cowan 2014). The idea that working memory was not only related to behavior but also to mental functions like learning, memory, attention, perception, and reasoning was highlighted by Donald Broadbent in 1958. His work with the selective attention of pilots, who could listen to a message in one ear but ignore a separate message in the other ear, helped to establish the difference between a large-capacity, short-lived sensory memory that is formed regardless of attention, and a longer-lived, smaller-capacity working memory model that requires attention to operate (Broadbent, 1958; Cowan, 2014).

From 1870 through to 1970, Jevons (1871), Miller (1956) and Broadbent (1958) as well as other academics conceptualized that the working memory as a single short-term storage system, but in 1974 Baddeley and Hitch hypothesized that the working memory was a multifaceted construct. Their working memory model included: (1) a phonological loop, for temporary auditory storage; (2) a visuospatial sketchpad, for temporary visual and spatial information storage; and, (3) a central executive, described as a supervisory system that controls and regulates the phonological loop and visuospatial sketchpad, but is not involved in temporary storage of information. In this new model Baddeley and Hitch (1974) defined working memory as a limited capacity system that allows for the temporary storage and manipulation of information necessary for such complex tasks as comprehension and learning (Baddeley, 2000). Furthermore only information processed by the working memory can be transferred to the long-term memory (Baddeley and Hitch, 1974; Baddeley, 2000). The idea of numerous working memory subsystems came from the observation that many variables appeared to effect short-term memory but that none pointed to a single storage system. For example, phonological processing interfered most with storage of that auditory information and not the storage of visuospatial information, and similarly visual-spatial processing interfered most with visual-spatial storage and not phonological storage (Baddeley and Hitch, 1974; Cowan, 2014). In 2000, Baddeley refined the multi-component working memory model to its current state, adding an episodic buffer, which accounted for the association of information that may occur across the visuospatial sketchpad and the phonological loop (e.g. spatial information about sound).

It is important to note that Baddeley's current working memory model (2000) has been criticized by experimental psychologists and functional neuroscience researchers alike (Cowan, 1988; 2001; 2005; de Jong, 2010). Despite this disagreement among researchers, Baddeley's multifaceted working memory design remains the most prominently cited model in educational literature, particularly in relation to multimedia design (Chandler and Sweller, 1996; Sweller et al., 1998; Brunken et al., 2003; Mayer and Moreno, 2003; Khalil et al., 2005; Oviatt, 2006; Moreno and Mayer, 2007; de Jong, 2010; Wong et al., 2012; Dindar et al., 2015).

To situate the concept of working memory in the larger framework of education, it is necessary to understand how learning, in the context of a multi-component working memory model, occurs. For meaningful learning to transpire, new concepts that are created by linking existing concepts with each other, must be formed. For example, an individual might know what a cat is, and separately understand what stripes are, but it is only when these concepts are joined together that they comprehend that a striped cat is a tiger (Cowan, 2014). In order for this to happen ideas must presumably exist in the working memory at the same time, that is, a learner must retain and organize relevant information into coherent representations in the working memory and make connections between these representations to form a new concept (Mayer and Moreno, 1998; Cowan, 2014). These concepts, according to Baddeley's (2000) model, are then transferred from the working memory into the long-term memory, and are remodeled overtime (Cowan, 2014; 2015). To revisit our example, children will eventually learn that not all cats with stripes are tigers, rather the concept of cat size (large vs. small) is joined with the existing concept that cats with stripes are tigers, forming a new concept that only large cats with stripes are tigers, which replaces the old concept in the long-term memory.

Though working memory may not have a unifying theory, it is the limitation of the working memory, and the practical implications it holds for learning, that most researchers can agree upon (Cowan, 2014). So while we can avoid overloading a learner's working memory capabilities by delivering only a few ideas at once, how we present those few ideas may also have significant impacts on our limited working memory resources.

1.3 Working Memory and Cognitive Load Theory

The classic adaptation to cognitive principles in post-secondary institutions has been to adjust the materials to fit the learner (Cowan, 2014). However, given that cognitive load is a function of the entire task, including the environment it is situated in, and not just the educational information itself, then working memory constraints should also be a principle consideration in the design of instructional e-learning tools. The impact of cognitive load on working memory and learning is best described by the cognitive load theory (CLT; Chandler and Sweller, 1996; Sweller et al. 1998; Sweller et al., 2011).

Using Baddeley and colleagues' working memory model (Baddeley and Hitch, 1974; Baddeley, 2000; 2003), cognitive load theory provides a basis for evaluating cognitive load fluctuations when using alternative learning interfaces (i.e. e-learning tools). It stresses that information we display to educational software users, and the way in which we display it, has tangible effects on working memory and the learning process (Mayer, 2001; 2002; Paas et al., 2003; 2004; van Merriënboer and Sweller, 2005; Oviatt, 2006)**.**

The tenets of the CLT recapitulate the limitations of working memory capacity, CLT specifically states that (1) novel information must be processed through a learner's working memory before meaningful learning (i.e., schema construction) can occur, however, (2) learners have a limited working memory capacity, it can process approximately 3-4 chunks of information at a time (Daneman and Carpenter, 1980; Cowan, 2001; Baddeley, 2003), and (3) the amount of information that must be processed during a complex learning task can exceed the processing capabilities of a learner's finite working memory resources, resulting in a situation known as cognitive overload. Importantly, under CLT, learning is defined as the increase in and transfer of knowledge from the working memory into the long-term memory; thus only concepts that are successfully processed by a learner's working memory can be integrated into the long-term memory (Figure 1.1; Sweller et al., 1998; Paas et al., 2003; Hessler and Henderson, 2013). In a learning situation where the chunks of information that must be processed overwhelm the limited working memory resources one holds, cognitive load theory suggests that learners may experience an impaired ability to transmit that information into long-term memory (Josephsen, 2015).

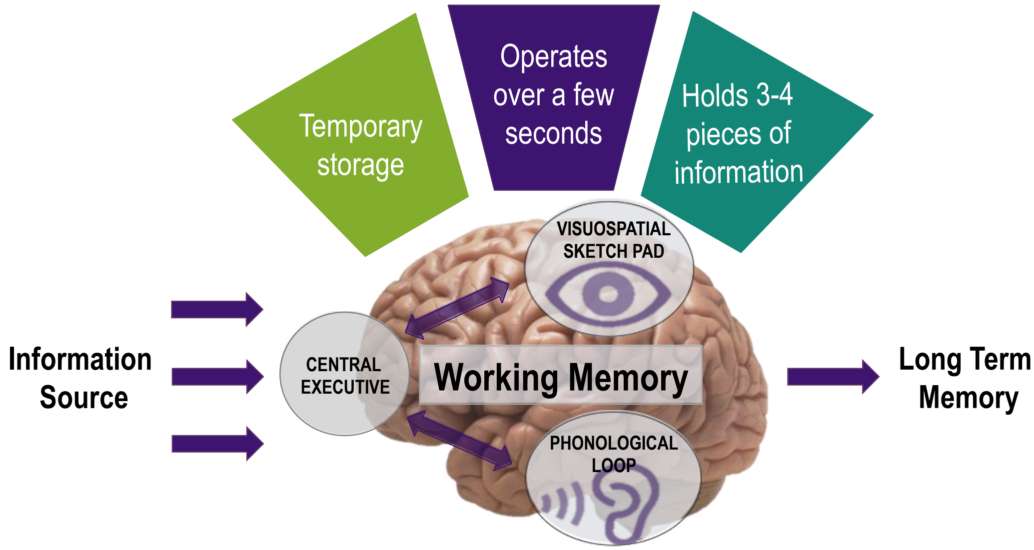


Figure 1.1: The working memory system as it relates to learning and Cognitive Load Theory

The information processing system as it relates to learning and cognitive load theory (CLT) and Baddeley's working memory model (Baddeley and Hitch, 1974; Baddeley, 2000). Under this theory, novel information must first be processed by a learner's working memory before storage in the long-term memory can occur. However the working memory has limited capacity (i.e. it only operates over a few seconds and can only process 3 to 4 unrelated chunks of information at a time) and the amount of information that must be processed during a learning task can overload the working memory resources (Miller, 1956; Brünken et al., 2004; Mayer, 2005).

Cognitive load theory (CLT) suggests that working memory resources can be impacted by the intellectual complexity of the task, known as intrinsic cognitive load, the load imposted by schema formation (i.e. interpreting, classifying and differentiating information), known as germane cognitive load as well as by the organization and presentation of the educational material, known as extraneous cognitive load (Sweller et al., 1998; de Jong, 2010). While intrinsic cognitive load (i.e. the difficulty of the material) and germane cognitive load (i.e. load imposed by schema construction) are considered to be relevant to the learning process, extrinsic cognitive load is not, and theoretical proposition that these three loads are additive contributes to the dogma of CLT that too much cognitive load can exhaust an individual's working memory capacity and contribute to cognitive overload. In this thesis, we are specifically focused on the extraneous cognitive load imposed by design elements including superfluous navigational functions, confusing menu bars and unclear buttons, which may cause a learner to use working memory resources to attend to and process information that is not essential to learning (Anderson, 1987; Mayer and Sims, 1994; van Merriënboer and Sweller, 2005; 2010). The central idea proposed by CLT is that e-learning tool design should keep extraneous cognitive load small enough that the working memory resources of the learner are not overly depleted by it (Cowan, 2014). In the event that the design of an e-learning tool imposes high extraneous cognitive load, fewer working memory resources may be available to devote to the educational content presented within the learning tool (Mayer, 2008; van Merriënboer and Sweller, 2010). To this end, numerous studies involving e-learning tools have shown that overloading a learner's working memory through design impairs academic performance (Sweller et al., 1998; Mayer, 2002; Lahtinen et al., 2007; DeLeeuw and Mayer, 2008).

Beyond reducing the extraneous cognitive load associated with e-learning tool design, working memory resources can also be leveraged through schema formation. Schemas are formed when individual pieces of information are combined with related elements, enabling topics and knowledge to be linked (Sweller et al., 1998; van Merriënboer and Sweller, 2005). Information elements that are incorporated into a schema can then be treated as a single element or 'chunk' by the working memory, thereby liberating capacity to process new information during learning (Paas et al., 2004; Paas and Sweller, 2012). Thus, instructional designs that promote schema development can help to unburden the working memory system, enabling more effective use of cognitive resources and efficient transfer of knowledge into long-term memory schemas, thus increasing student learning (Josephsen, 2015). However, in order to establish schemas learners must have already had previous interactions with the educational content or interface (Sweller et al., 1998). In the case of novice learners using a novel software program, schemas relating to subject information and software navigation have not yet developed. As a result, for learners in this particular population, software programs have the potential to overload a novice user's working memory processing capacity, reducing transfer of knowledge from the working memory to the long-term memory and impairing their ability to learn (Sweller, 1988; Sweller et al., 1998).

Though numerous studies have identified specific design principles and strategies that can be used to reduce extraneous cognitive load (see Sweller et al., 1998; van Merriënboer and Sweller, 2005, 2010; Mayer, 2008), many researchers argue that there is little evidence to suggest that the cognitive load of commercial anatomical e-learning tools have been measured (Chandler and Sweller, 1991a; 1991b; Park and Hannafin, 1994; Sweller et al., 1998; Grunwald and Corsbie-Massay, 2006; Moreno and Mayer, 2007). In light of technological innovation and cognitive psychology, educators and post-secondary institutions have progressed to the point where "[…] instructional designs based on visual elegance, common sense & convenience […] (p.294, Chandler et al., 1991b)" are no longer adequate. If the information displayed to educational software users, and the way in which it is presented, has tangible effects on the working memory and the learning process, there is a need for more empirical research concerning the effectiveness of commercially produced e-learning tools in order to ensure that the educational experiences in these learning environments remain effective for all students.

1.3.1 Quantification of Cognitive Load in Education

Given the potential impact a commercial e-learning tool design may have on a novice learner's working memory system, measurement of cognitive load during e-learning tool use is warranted. A common classification system of cognitive load assessment techniques describes three main categories including subjective, physiological, and task- and performance-based indices (Sweller et al., 1998; de Jong, 2010). In the fields of education and informational sciences, subjective measures as well as task- and performance-based indices are the simplest to employ in authentic learning situations (Oviatt, 2006).

Subjective techniques are based upon the assumption that people are able to examine their own cognitive processes and report the amount of mental resources expended during e-learning tool use using self-rating scales (Paas et al., 2003, 2007; Pociask and Morrison, 2008; for review see de Jong, 2010). Subjective measures in educational studies are typically collected at a single time point during the task or following its completion, and are thus a static measure of cognitive load, making them inappropriate for assessing cognitive load changes over time (Oviatt, 2006; Gwizdka, 2010).

Task- and performance-based techniques, also called dual- task paradigms, are predicated on the assumption that limited working memory resources can be allocated flexibly to different tasks when said tasks are performed simultaneously (Brünken et al., 2003). This approach involves two measurements: a primary learning task measurement, which is often a performance based metric of the task of interest, and an observational task measurement, which is an objective measure of performance, such as reaction time, when said observation task is performed in tandem with the primary learning task (Sweller et al., 1998; Brünken et al., 2003). This approach has the advantage of enabling real-time data collection in an inexpensive, highly reliable, and temporal fashion (Brünken et al., 2003; de Jong, 2010; Gwizdka, 2010). Although the dual-task method has been empirically shown to be a suitable approach for evaluating total cognitive processing loads during library system/web searches as well as multimedia learning in the subject areas of mathematics, physiology and arts and culture (Brünken et al., 2002, 2003; Kim and Rieh, 2005; Oviatt, 2006; DeLeeuw and Mayer, 2008; Gwizdka and Lopatovska, 2009); no studies to date, with the exception of the research presented in this thesis, have employed this technique to assess cognitive load during commercial anatomical learning tool use

1.3.2 Dual-Task Assessment of Cognitive Load in Education

Dual-task paradigms are grounded in CLT, which states that if two tasks require the same cognitive resources (i.e. are processed visually) and are performed simultaneously, then a learner's available working memory resources will be distributed between both tasks accordingly (Fisk et al., 1986; Brünken et al., 2002). Commonly, a learning task, performed within an e-learning tool interface, and an observation task are selected and performance measures of the latter are utilized to assess the relative amounts of mental resources consumed by the former (Kerr, 1973; Fisk et al., 1986).

To elaborate, a classic dual-task paradigm contains tasks that are organized into two distinct conditions: (1) a dual-task condition, where a learning task is performed simultaneously with an observation task; and (2) single-task conditions, which require the completion of only one task, most commonly the observation task in isolation. Theory suggests that the single task condition forms a baseline indicator of total cognitive processing loads when all working memory resources are devoted to the observation task as it is performed alone. Generally, the observation task is a simple, continuous activity that requires limited mental resources, such as responding to a visual or auditory stimulus. In the case of the observation task, performance variables such as reaction time are recorded, and compared across single-task and dual-task scenarios. Conversely, performance measures for the learning task include comparisons between knowledge acquisition scores before and after the learning task is completed.

The use of a simple observation task in a dual-task paradigm is predicated on the capacity sharing approach to explaining dual-task interference (Pashler, 1994). Under this theory, tasks that share the same working memory resources (e.g., if the tasks must be interpreted visually) and are performed concurrently can interfere with each other; that is, if two tasks are being performed simultaneously, then there is less processing capacity (i.e., fewer working memory resources) available for each individual task than there would be if each task was completed in isolation (Pashler, 1994). Cognitive load theory and dual-task procedures suggest that performance on the concurrently running tasks would be impaired in comparison with performance when said tasks are completed in isolation (Stroop, 1935; Pashler, 1994). This relative degree of this interference, called dual-task interference, can be investigated through the use of a simple observation task (Pashler, 1994). In a dual-task condition, where a learning task is completed simultaneously with a simple observation task, participants are asked to respond to the observation task as quickly as possible when they notice the task cue (e.g., a noise, a change in color, or a vibration) while also continuing to attend to the primary learning task (Posner and Boies, 1971; Pashler, 1994). The assumption inherent to the dual-task paradigm and cognitive load theory is that the speed of response to the observation task provides a relative estimate of spare working memory resources left unoccupied by the learning task (Posner and Boies, 1971).

To clarify, the dual-task condition, in theory, essentially requires learners to divide their the limited working memory resources between two tasks. As a result, fewer cognitive resources should, in theory, be available for processing each task when those tasks are performed simultaneously than would be available for processing each task if it was completed in isolation (Brünken et al., 2002). By using dual-task methodology, cognitive load theory suggests that it is possible to test different variants of a learning task or interface for the relative amount of working memory resources they require by comparing learner reaction times on the observation task when said task is completed in isolation compared to when it is performed simultaneously with a learning task (Brünken et al., 2003; de Jong, 2010). By measuring the time it takes a learner to respond to the simple visual observation task (VOT), cognitive load theory suggests it may be possible to relatively quantify the cognitive load imposed by different learning tools; that is, if a learner's reaction time on a VOT is relatively quick, compared to the time it takes that learner to respond to the VOT in isolation, it suggests that the learner's working memory resources are not overloaded by the learning tool, since they have the working memory recourses available to monitor and respond to the VOT quickly. Conversely, if learner reaction times on the VOT are significantly longer, then it suggests more working memory resources are being occupied by the learning tool and there are not enough to respond to the VOT in a timely fashion (Posner and Boies, 1971; Pashler, 1994; Brünken et al., 2003; de Jong, 2010).

1.4 Thesis Objectives and Hypotheses

The overall objective of this dissertation is to investigate the influence of commercial e-learning tool design on learner knowledge recall in the discipline of human anatomy, by applying working memory limitations, cognitive load theory and dual-task assessment as guiding principles. Three independent studies were conducted to address the unique aspects of this overall objective.

1.4.1 Study I

The objective of Study I was to measure cognitive load using standard dual-task paradigm, designed based on existing literature, when students used two commercial anatomical e-learning tools with different software designs to study anatomy (A.D.A.M. Interactive Anatomy (Ebix, Inc., Atlanta, GA) and Netter's 3D Interactive Anatomy (Elsevier Inc., Philadelphia, PA)). Study I was developed using previous studies that successfully applied dual-task paradigms to assess cognitive load across different variants of passive e-learning tools that taught dynamic concepts (i.e. heart contraction; Brünken et al., 2002; DeLeeuw and Mayer, 2008). Our *primary hypothesis* was that a similar paradigm could be applied to the assessment of cognitive load across two different commercially built e-learning tools that were fully interactive but showed static concepts (i.e. skeletal anatomy). Using the cognitive load theory and a dual-task paradigm to capitalize on the limitations of the working memory, our specific aim was to measure relative extraneous cognitive load levels induced by different e-learning software packages, using a dual-task paradigm, given that the primary learning task (i.e. the anatomy learned) and the working memory resources it required were held constant.

1.4.2 Study II

Whereas Study I utilized a standard dual-task paradigm, designed based on existing literature, as a potential tool for measuring cognitive load, Study II utilized a novel dual task methodology, corrected to address confounding variables identified in Study I, to re-examine two commercial anatomical e-learning tools. Specifically, the objective of Study II was to use a dual-task paradigm with a different visual observation task, known as a modified Stroop test (to be explained in the next Chapter) to examine cognitive load changes between two commercial anatomical e-learning tools (Netter's 3D Interactive Anatomy and A.D.A.M. Interactive Anatomy). Using simplified anatomical concepts and two single-task conditions we measured the effect of the design of these two commercial e-learning tools on learner cognitive load during two joint learning exercises (elbow and knee). Based on studies that suggested there was little evidence that commercial anatomical e-learning tools are designed with important principles such cognitive load and working memory in mind (Chandler and Sweller, 1991a; 1991b; Park and Hannafin, 1994; Sweller et al., 1998; Grunwald and Corsbie-Massay, 2006; Moreno and Mayer, 2007), we predicted that a more complex e-learning tool would impose more cognitive load on learners. More specifically, our *primary hypothesis* was that significantly longer reaction times on a visual observation task would be associated with the more complex anatomical software (Netter's 3D Interactive Anatomy), which would indicate a higher cognitive load imposed by the anatomy software and interfere with learning, thus resulting in significantly lower post-test scores.

1.4.3 Study III

The objective of Study III was to examine how the visual-kinesthetic experience of manipulating a physical skeleton impacts learning when compared to virtual manipulation of a simple 2-dimensional (2D) anatomical e-learning tool (A.D.A.M. Interactive Anatomy). Recent work has suggested that visual-kinesthetic learning experiences generate better learning outcomes than visual-only experiences because they reduce cognitive load, but interestingly researchers have not directly measured cognitive load in this context (Jones et al., 2003; 2006; Minogue and Jones, 2006; Zacharia and Olympiou, 2011). Our *primary hypothesis* was that using a physical skeleton would generate significantly better learning outcomes, due, in part, to a reduction in cognitive load, when compared to a simple, 2-dimensional commercial e-learning tool (A.D.A.M. Interactive Anatomy). Specifically, visual observation task reaction times would be significantly shorter when students interacted with a physical skeleton, indicating a lower cognitive load and resulting in significantly higher post-test scores. Furthermore, based on the results of Chapter 3, we predicted that a learner's spatial ability would not influence their knowledge recall when they studied using A.D.A.M. Interactive Anatomy, but that their spatial ability would influence knowledge recall when they studied using a physical skeleton. Given these hypotheses, Study III attempted to address three *specific* aims:

1. Investigate if a dual-task paradigm is an effective tool for measuring cognitive load changes across a visual-kinesthetic and visual-only learning modality
2. Assess the impact of knowledge recall when using a physical skeleton to study when compared to a content matched simple 2D e-learning tool (A.D.A.M. Interactive Anatomy)
3. Evaluate the effect of learner spatial ability on knowledge recall when learning from the different learning modalities mentioned above.

1.5 Literature Cited

Adams CM, Wilson TD. 2011. Virtual cerebral ventricular system: An MR-based three-dimensional computer model. Anat Sci Educ 4:340–347.

Allen IE, Seaman J. 2015. Grade Level: Tracking Online Education in the United States. Babson Survey Research Group: Babson Park, MA. URL: http://www.onlinelearningsurvey.com/reports/gradelevel.pdf [accessed 12 January 2016].

Allen LK, Bhattacharyya S, Wilson TD. 2015. Development of an interactive anatomical three-dimensional eye model. Anat Sci Educ 8:275–282.

Anderson JR. 1987. Skill acquisition: The compilation of weak-method problem solutions. Psychol Rev 94:192–210.

Andrade J. 2001. Working memory in perspective. Hove, UK: Psychology Press Ltd. 328 p.

Attardi SM, Rogers KA. 2015. Design and implementation of an online systemic human anatomy course with laboratory. Anat Sci Educ 8:53–62.

Baddeley AD. 1992. Working memory: The interface between memory and cognition. J Cognitive Neurosci 4:281-288.

Baddeley AD. 2000. The episodic buffer: a new component of working memory?. Trends Cogn Sci 4:417-423.

Baddeley AD. 2003. Working memory: Looking back and looking forward. Nat Rev Neurosci 4:829–839.

Baddeley AD, Hitch G. 1974. Working memory. Psychol Learn Motiv 8:47-89.

Barbeau ML, Johnson M, Gibson C, Rogers KA. 2013. The development and assessment of an online microscopic anatomy laboratory course. Anat Sci Educ 6:246–256.

Bokova I. 2011. Address by Irina Bokova, Director –General of UNESCO on the Occasion of the UNESCO Global Forum Rankings and Accountability in Higher Education: Uses and Misuses. 1st Ed. 6 p. Paris, France: United Nations Educational, Scientific, and Cultural Organization. URL: http://unesdoc.unesco.org/images/0019/001924/192417m.pdf [accessed 18 January 2016].

Boyce N. 2012. A new dimension for medical education. Lancet 380:1547.

Brenton H, Hernandez J, Bello F, Strutton P, Purkayastha S, Firth T, Darzi A. 2007. Using multimedia and Web3D to enhance anatomy teaching. Comput Educ 49:32–53.

Broadbent DE. 1958. Perception and communication. New York, NY: Pergamon Press.

338 p.

Brünken R, Plass JL, Leutner D. 2003. Direct measurement of cognitive load in multimedia learning. Educ Psychol 38:53–61.

Brünken R, Steinbacher S, Plass JL, Leutner D. 2002. Assessment of cognitive load in multimedia learning using dual-task methodology. Exp Psychol 49:109–119.

Chandler P, Sweller J. 1991a. Evidence for cognitive load theory. Cognit Instruct 8:351–362.

Chandler P, Sweller J. 1991b. Cognitive load theory and the format of instruction. Cognit Instruct 8:293–332.

Chandler P, Sweller J. 1996. Cognitive load while learning to use a computer program. Appl Cognit Psychol 10:151–170.

Codd AM, Choudhury B. 2011. Virtual reality anatomy: is it comparable with traditional methods in the teaching of human forearm musculoskeletal anatomy?. Anat Sci Educ 4:119-125.

Cook DA. 2007. Web-based learning: pros, cons and controversies. Clin Med 7:37-42.

Cowan N. 1988. Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system. Psychol Bull 104:163-191.

Cowan N. 2001. The magical number 4 in short-term memory: a reconsideration of mental storage capacity. Behav Brain Sci 24:87–114.

Cowan N. 2005. Working memory capacity. New York, NY: Psychology Press Ltd. 224 p.

Cowan N. 2014. Working memory underpins cognitive development, learning and education. Educ Psychol Rev 26:197-223.

Cowan N. 2015. George Miller's magical number of immediate memory in retrospect: Observations on the faltering progression of science. Psychol Rev 122:536-541.

Daneman M, Carpenter PA. 1980. Individual differences in working memory and reading. J Verb Learn Verb Be 19:450-466.

de Jong T. 2010. Cognitive load theory, educational research, and instructional design: Some food for thought. Instr Sci 38:105–134.

DeLeeuw KE, Mayer RE. 2008. A comparison of three measures of cognitive load: Evidence for separable measures of intrinsic, extraneous, and germane load. J Educ Psychol 100:223–234.

Dindar M, Kabakçı Yurdakul I, Inan Dönmez F. 2015. Measuring cognitive load in test items: Static graphics versus animated graphics. J Comput Assist Learn 31:148–

161.

Docebo. 2014. E-Learning Market Trends & Forecast 2014 – 2016 Report: A Report by Docebo | March 2014. 1st Ed. Biassono, MB, Italy: Docebo S.p.A. 48 p. URL: https://www.docebo.com/landing/contactform/elearning-market-trends-and-forecast-2014-2016-docebo-report.pdf [accessed 7 January 2016]

Doubleday EG, O'Loughlin VD, Doubleday AF. 2011. The virtual anatomy laboratory: Usability testing to improve an online learning resource for anatomy education. Anat Sci Educ 4:318–326.

Drake RL. 2007. A unique, innovative, and clinically oriented approach to anatomy education. Med Teach 82:475-478.

Drake RL, McBride JM, Lachman N, Pawlina W. 2009. Medical education in the anatomical sciences: The winds of change continue to blow. Anat Sci Educ 2:253:259.

Drake RL, McBride JM, Pawlina W. 2014. An update on the status anatomical sciences education in United States medical schools. Anat Sci Educ 7:321-325.

Durham JA, Brettell S, Summerside C, McHanwell S. 2009. Evaluation of a virtual anatomy course for clinical undergraduates. Eur J Dent Educ 13:100–109.

Estevez ME, Lindgren KA, Bergethon PR. 2010. A novel three-dimensional tool for teaching human neuroanatomy. Anat Sci Educ 3:309-317.

EU. 2014. European Union. Report to the European Commission on New Modes of Learning and Teaching in Higher Education. 1st Ed. Luxembourg: Publications Office of the European Union. 67 p. URL: http://ec.europa.eu/education/library/reports/modernisation-universities_en.pdf [accessed 25 January 2016].

Fisk AD, Derrick WL, Schneider W. 1986. A methodological assessment and evaluation of dual-task paradigms. Curr Psychol 5:315–327.

Gaitskell-Phillips G, Short N, Stanikova B. 2012. Taking veterinary anatomy online. Altern Lab Anim 40:P24–P25.

Glittenberg C, Binder S. 2006. Using 3D computer simulations to enhance ophthalmic training. Opthal Physl Opt 26:40-49.

Grunwald T, Corsbie-Massay C. 2006. Guidelines for cognitively efficient multimedia learning tools: Educational strategies, cognitive load, and interface design. Acad Med 81:213–223.

Guy R, Pisani HR, Rich P, Leahy C, Mandarano G, Molyneux T. 2015. Less is more: Development and evaluation of an interactive e-atlas to support anatomy learning. Anat Sci Educ 8:126-132.

Gwizdka J. 2010. Distribution of cognitive load in web search. J Am Soc Inform Sci Tech 61:2167-2187.

Gwizdka J, Lopatovska I. 2009. The role of subjective factors in the information search process. J Am Soc Inform Sci Tech 60:2452–2464.

Hassinger JP, Dozois EJ, Holubar SD, Camp JC, Farley DR, Fidler JL, Pawlina W, Robb RA, Larson DW. 2010. Virtual pelvic anatomy simulator: A pilot study of usability and perceived effectiveness. J Surg Res 161:23–27.

Hessler KL, Henderson AM. 2013. Interactive learning research: Application of cognitive load theory to nursing education. Int J Nurs Educ Scholarship 10:133–141.

Higgins K, Randall B, Diana LW. 2000. Evaluating educational software for special education. Technol Tr, 36:109-115.

Holden HK, Rada R. 2011. Understanding the influence of perceived usability and technology self-efficacy on teachers' technology acceptance. J Res Tech Educ 43:343–367.

Irby DM, Cooke M, O'Brien BC. 2010. Calls for reform of medical education by the Carnegie Foundation for the Advancement of Teaching: 1910 and 2010. Acad Med 85:220-227.

Jevons WS. 1871. The power of numerical discrimination. Nature 3:281-282.

Jones GM, Andre T, Superfine R, Taylor R. 2003. Learning at the nanoscale: the impact of students' use of remote microscopy on concepts of viruses, scale, and microscopy. J Res Sci Teach 40:303-322.

Jones GM, Minogue J, Tretter TR, Negishi A, Taylor R. 2006. Haptic augmentation of science instruction: does touch matter? Sci Educ 90:111-123.

Josephsen J. 2015. Cognitive load theory and nursing simulation: An integrative review. Clin Simulat Nurs 11:259–267.

Keedy AW, Durack JC, Sandhu P, Chen EM, O'Sullivan PS, Breiman RS. 2011. Comparison of traditional methods with 3D computer models in the instruction of hepatobiliary anatomy. Anat Sci Educ 4:84-91.

Kerr B. 1973. Processing demands during mental operations. Mem Cognit 1: 401–412.

Khalil MK, Paas F, Johnson TE, Payer AF. 2005. Design of interactive and dynamic anatomical visualizations: The implication of cognitive load theory. Anat Rec 286B:15–20.

Kim YM, Rieh SY. 2005. Dual-task performance as a measure for mental effort in library searching and web searching. In: Proceedings of the 68th Association for Information Science and Technology Annual Meeting (ASIS&T 2005); Sparking Synergies: Bringing Research and Practice Together; Charlotte, NC, 2005 Oct 28

- Nov 2. Volume 42. Association for Information Science and Technology, Silver Spring, MD.

Lahtinen TMM, Koskelo JP, Laitnen T, Leino TK. 2007. Heart rate and performance during combat missions in a flight simulator. Aviat Space Environ Med 78:387–391.

Lawton W, Ahmed M, Angulo T, Axel-Berg A, Burrows A, Katsomitros A. 2013. Horizon Scanning: What Will Higher Education Look Like in 2020? 1st Ed. Redhill, Surrey, UK: Observatory on Borderless Higher Education. 76 p. URL: http://www.obhe.ac.uk/documents/download?id=934 [accessed on 10 January 2016].

Levinson AJ, Weaver B, Garside S, McGinn H, Norman GR. 2007. Virtual reality and brain anatomy: A randomized trial of e-learning instructional designs. Med Educ 41:495–501.

Lewis MJ. 2003. Computer-assisted learning for teaching anatomy and histology in subjects allied to medicine. Med Teach 25:204-206.

Lewis TL, Burnett B, Tunstall RG, Abrahams PH. 2014. Completing anatomy education using three-dimensional anatomy mobile software applications on tablet computers. Clin Anat 27:313–320.

Mayer RE. 2001. Multimedia Learning. 1st Ed. Cambridge, UK: Cambridge University Press. 222 p.

Mayer RE. 2002. Multimedia learning. In: Ross BH (Editor). Psychology of Learning and Motivation. Volume 41: Advances in Research and Theory. 1st Ed. San Diego, CA: Academic Press. p 85–139.

Mayer RE. 2008. Applying the science of learning: Evidence-based principles for the design of multimedia instruction. Am Psychol 63:760–769.

Mayer RE, Moreno R. 1998. A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory. J Educ Psychol 90:312-320.

Mayer RE, Moreno R. 2003. Nine ways to reduce cognitive load in multimedia learning. J Educ Psychol 38:43-52.

Mayer RE, Sims VK. 1994. For whom is a picture worth a thousand words? Extensions of a dual-coding theory of multimedia learning. J Educ Psychol 86:389–401.

Miller GA. 1956. The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychol Rev 63:81–97.

Miller GA. 1989. George A. Miller. In: Gardner L (Editor). A history of psychology in autobiography: Volume VIII. Stanford, CA: Stanford University Press, p. 391-418.

Miller GA, Galanter E, Pribram KH. 1960. Plans and the structure of behavior. New York: Holt, Rinehart and Winston, Inc.

Ministry of Training, Colleges and Universities. 2014. Province Improving Online Learning: Ontario Giving Postsecondary Students More Flexibility. 1st Ed. Toronto. ON, Canada: Ontario Provincial Government. 1 p. URL: https://news.ontario.ca/tcu/en/2014/01/province-improving-online-learning.doc [accessed 12 January 2016].

Minogue J, Jones G. 2009. Measuring the impact of haptic feedback using the SOLO taxonomy. Int J Sci Educ 31:1359-1378.

Moray N (Editor). 1979. Mental Workload: Its Theory and Measurement. 1st Ed. New York, NY: Springer Science+Business Media. 500 p.

Moreno R, Mayer R. 2007. Interactive multimodal learning environments. Educ Psychol Rev 19:309–326.

Nicholson DT, Chalk C, Funnell WRJ, Daniel SJ. 2006. Can virtual reality improve anatomy education? A randomised controlled study of a computer-generated three-dimensional anatomical ear model. Med Educ 40:1081–1087.

O'Bryne PJ, Patry A, Carnegie JA. 2008. The development of interactive online learning tools for the study of anatomy. Med Teach 30:e260–e271.

O'Donnell RD, Eggemeier FT. 1986. Workload assessment methodology. In: Boff KR, Kaufman L, Thomas JP (Editors). Handbook of Perception and Human Performance: Volume II. Cognitive Processes and Performance. 1st Ed. New York, NY: Wiley Interscience. p 42–49.

Oviatt SL. Human-centered design meets cognitive load theory: designing interfaces that help people think. In Proceedings of the 14th annual ACM International Conference on Multimedia (MM '06); New York, NY; 2006 Oct 23-27; p 871–880. Association for Computing Machinery: New York, NY.

Paas F, Renkl A, Sweller J. 2004. Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture. Instr Sci 32:1-8.

Paas F, Sweller J. 2012. An evolutionary upgrade of cognitive load theory: Using the human motor system and collaboration to support the learning of complex cognitive tasks. Educ Psychol Rev 24:27-45.

Paas F, Tuovinen J, Tabbers H, van Gerven PWM. 2003. Cognitive load measurement as a means to advance cognitive load theory. Educ Psychol 38:63–71.

Paas F, van Gerven PWM, Wouters P. 2007. Instructional efficiency of animation: Effects of interactivity through mental reconstruction of static key frames. Appl Cognit Psychol 21:783–793.

Paas F, van Merriënboer JJG. 1994. Instructional control of cognitive load in the training of complex cognitive tasks. Educ Psychol Rev 6:51–71.

Park I, Hannafin M. 1994. Empirically-based guidelines for the design of interactive multimedia. Educ Tech Res Dev 41:63–85.

Pashler H. 1994. Dual-task interference in simple tasks: data and theory. Psychol Bull 116:220.

Pawlina W, Drake RL. 2013. Anatomical models: Don't banish them from the anatomy laboratory yet. Anat Sci Educ 6:209-210.

Pin L, Martin C, Andrey S. 2011. Rising Costs: A Look at Spending at Ontario Universities. 1st Ed. Toronto, ON, Canada: Ontario Undergraduate Student Alliance Research Contributions. 48 p.

Pociask FD, Morrison GR. 2008. Controlling split attention and redundancy in physical therapy instruction. Educ Tech Res Dev 56:379–399.

Posner MI, Boies SJ. 1971. Components of attention. Psychol Review 78:391.

Preece D, Williams SB, Lam R, Weller R. 2013. “Let's Get Physical”: Advantages of a physical model over 3D computer models and textbooks in learning imaging anatomy. Anat Sci Educ 6:216–224.

Raynor M, Iggulden H. 2008. Online anatomy and physiology: Piloting the use of an anatomy and physiology e-book-VLE hybrid in pre-registration and post-qualifying nursing programmes at the University of Salford. Health Info Libr J 25:98–105.

Rogers EM. 2003. Diffusion of Innovations. 5th Ed. New York, NY: Free Press, 576 p.

Rogers J, Usher A, Kaznowska E. 2011. The State of E-Learning in Canadian Universities, 2011: If Students Are Digital Natives, Why Don’t They Like E-Learning? 1st Ed, Toronto, Canada: Higher Education Strategy Associates. 19 p.

Ruiz JG, Mintzer MJ, Leipzig RM. 2006. The impact of e-learning in medical education. Acad Med 81:207-212.

Sergovich A, Johnson M, Wilson TD. 2010. Explorable three-dimensional digital model of the female pelvis, pelvic contents, and perineum for anatomical education. Anat Sci Educ 3:127–133.

Skochelak SE. 2010. A decade of reports calling for change in medical education: what do they say?. Acad Med 85:S26-S33.

Squires D, Preece J. 1999. Predicting quality in educational software: Evaluating for learning, usability and the synergy between them. Interact Comput 11:467–483.

Stroop JR. 1935. Studies of interference in serial verbal reactions. J Exp Psy- chol 18:643–662.

Sugand K, Abrahams P, Khurana A. 2010. The anatomy of anatomy: a review for its modernization. Anat Sci Educ 3:83-93.

Sweller J. 1988. Cognitive load during problem solving: Effects on learning. Cognit Sci 12:257–285.

Sweller J, Ayres P, Kalyuga S. 2011. Cognitive Load Theory. New York, NY: Springer Science+Business Media. 273 p.

Sweller J, van Merriënboer JJG, Paas F. 1998. Cognitive architecture and instructional design. Educ Psychol Rev 10:251–296.

Tavangarian D, Leypold ME, Nölting K, Röser M, Voigt D. 2004. Is e-Learning the solution for individual learning?. Electron J e-Learn 2:273−280.

Trelease RB. 2016. From chalkboard, slides, and paper to e-learning: How computing technologies have transformed anatomical sciences education. Anat Sci Educ 9:583-602.

Tremblay K, Lalancette D, Roseveare D. 2012. Assessment of Higher Education Learning Outcomes (AHELO): Feasibility Study Report. Volume 1: Design and Implementation. 1st Ed. Paris, France: Organization for Economic Cooperation and Development. 169 p. URL: http://www.oecd.org/education/skills-beyond-school/AHELOFSReportVolume1.pdf [accessed 24 January 2016].

Triacca L, Bolchini D, Botturi L, Inversini A. 2004. MiLE: Systematic Usability Evaluation for E-learning Web Applications. In: Proceedings of EdMedia- World Conference on Educational Multimedia, Hypermedia and Telecommunciations; Lugano Switzerland; 2004 June 21-26; p. 4398-4405. Association for the Advancement of Computing in Education: Waynesville, NC.

UNESCO. 2011. United Nations Educational, Scientific and Cultural Organization. ICT for Higher Education: Case studies from Asia and the Pacific. 1st Ed. Bangkok, Thailand: UNESCO Bangkok, Asia and Pacific Regional Bureau for Education. 171 p. URL: http://unesdoc.unesco.org/images/0021/002141/214143E.pdf [accessed 14 January 2016].

van Merriënboer JJG, Sweller J. 2005. Cognitive load theory and complex learning: Recent developments and future directions. Educ Psychol Rev 17:147–177.

van Merriënboer JJG, Sweller J. 2010. Cognitive load theory in health professional education: Design principles and strategies. Med Educ 44:85–93.

Van Nuland SE, Rogers KA. 2016a. E-Learning, Dual-task and Cognitive Load: The anatomy of a failed experiment. Anat Sci Educ 9:186-196.

Van Nuland SE, Rogers KA. 2016b. The Anatomy of E-Learning Tools: Does software usability influence learning outcomes?. Anat Sci Educ 9:378-390.

Van Nuland SE, Eagleson R, Rogers KA. 2017. Educational Software Interface Usability: Artifact or Design?. Anat Sci Educ 10:190-199.

Venail F, Deveze A, Lallemant B, Guevara N, Mondain M. 2010. Enhancement of temporal bone anatomy learning with computer 3D rendered imaging softwares. Med Teach 32:e282-e288.

Waits T, Lewis L. 2003. Distance Education at Degree-Granting Postsecondary Institutions: 2000–2001. E.D. Tabs. (NCES 2003-017). 1st Ed. Washington, DC: National Center for Education Statistics, U.S. Department of Education. 95 p.

Webb AL, Choi S. 2014. Interactive radiological anatomy eLearning solution for first year medical students: Development, integration, and impact on learning. Anat Sci Educ 7:350-360.

Williams DL, Boone R, Kingsley KV. 2004. Teacher beliefs about educational software. J Res Technol Educ 36:213-229.

Wong A, Leahy W, Marcus N, Sweller J. 2012. Cognitive load theory, the transient information effect and e-learning. Learn Instr 22:449-457.

Yammine K, Violato C. 2015. A meta-analysis of the educational effectiveness of three-dimensional visualization technologies in teaching anatomy. Anat Sci Educ 8:525-538.

Zacharia ZC, Olympiou G. 2011. Physical versus virtual manipulative experimentation in physics learning. Learn Instr 21:317-331.

Chapter 2

2 Assessing Standard Dual-Task Paradigms for the Measurement of Cognitive Load in E-Learning Tools

This chapter describes the development and testing of a dual-task paradigm that could be used to assess the impact of different anatomical e-learning tool designs on learner cognitive load and knowledge recall.[2]

2.1 Literature Review

Post-secondary institutional investment in commercial anatomical e-learning tools is often a product of the assumption that the use of new technologies with greater interactivity invariably produces better learning (Tam et al., 2009). In the business of education, the drive to satisfy millennial learners on a technological level, specifically in anatomy, has led to the rapid adoption of commercial e-learning tools into anatomy curricula. Yet, despite their popularity among students, evidence regarding the impact of these commercial tools on student learning remains scarce. Furthermore, the methodologies used to evaluate how different interfaces and interactive features impact the learning process are imprecise (Khalil et al., 2005). Given the investment in and popularity of commercial anatomical e-learning tools it is necessary to understand how different functionalities can influence a novice user's learning process.

The design of e-learning tool interfaces can liberate or occupy learner working memory resources as described by the cognitive load theory (CLT; Chandler and Sweller, 1996; Sweller et al. 1998; Sweller et al., 2011). If the design of an e-learning tool is overly complicated by superfluous software navigational functions, confusing menu bars and unclear buttons, it may occupy more of the limited working memory resources than a

[2] A version of this chapter has been published in the journal Anatomical Sciences Education. For the permission approval notice from the publisher see Appendix A.

simple e-learning tool (Sweller et al., 2011). In a learning environment where the educational information, and the way in which it is presented, overwhelms the limited amount of working memory resources one holds, learners may experience an impaired ability to transmit that information into long-term memory (Baddeley, 2000; 2003; Lahtinen et al., 2007; DeLeeuw and Mayer, 2008; Josephsen, 2015).

A learner's working memory resources can be affected by the intellectual complexity of the educational task or information, known as intrinsic cognitive load, and the organization and presentation of that information, known as extraneous cognitive load (Chandler and Sweller, 1996; Sweller et al., 1998; Oviatt, 2006). In the context of education, intrinsic cognitive load is considered to be relevant to the learning process (i.e. schema construction), however extraneous cognitive load is not and can actually interfere with learning (Sweller et al., 1998; Paas et al., 2004). Design choices made during educational e-learning software development can impact extraneous cognitive load levels in users and affect the overall software usability. In this context, software usability is "the extent to which a product can be used by specific users to achieve certain goals (i.e. learning) with effectiveness, efficiency and satisfaction in a specific context (i.e. the anatomy curriculum)" (ISO, 1998). Thus, interfaces that require a learner to arbitrarily test possibilities without proper guidance, or search for information that is needed to complete a learning task, can increase extraneous cognitive load levels (Anderson, 1987; van Merriënboer and Sweller, 2010). Extraneous navigational functions, confusing menu bars and unclear buttons can contribute to high user cognitive load and poor software usability (Eva et al., 2000). Since cognitive load theory suggests that only information that is successfully processed by the working memory is integrated into the learner's long-term memory, the absence of well-designed, cognitively efficient e-learning interfaces may result in students spending so much time learning how to navigate the interface that their learning of the educational material is compromised (Sweller et al., 1998; Wong et al., 2003; Ardito et al., 2006; Grunwald and Corsbie-Massay, 2006)

Sweller et al.'s cognitive load theory, described in Section 1.3, specifically addresses multimedia interfaces and working memory limitations using Baddeley's multi-component working memory model (Chandler and Sweller, 1996; Sweller et al. 1998;

Baddeley, 2000; Sweller et al., 2011). Using CLT, Sweller et al. (1998) have suggested strategies for e-learning tool interface design that theoretically minimize extraneous cognitive load, which have been utilized by academics when developing individual learning tools (Stull and Mayer, 2007; O'Bryne et al., 2009; Rich and Guy, 2013; Allen et al., 2015; 2016). However, there is little evidence to suggest that commercially developed tools and the common design strategies they use (i.e. enhanced graphics, extensive navigational controls, and multiple viewing angles) have been successful in reducing cognitive load, because cognitive load has never been formally quantified whens students use these tools.

To assess the influence of commercial anatomical e-learning design on learner cognitive load and knowledge recall, a dual-task paradigm was selected to assess cognitive load across two commercial anatomical e-learning tools. Previous studies have demonstrated that dual-task experimental designs are a suitable instruments for evaluating cognitive processing loads in the designs of educational and computer sciences learning software (Brünken et al., 2002, 2003; Kim and Rieh, 2005; Oviatt, 2006; DeLeeuw and Mayer, 2008; Gwizdka and Lopatovska, 2009). Based on these results, the dual-task designs used by Brünken et al. (2002) and DeLeeuw and Mayer (2008) were used to guide our own. In these studies, the classic dual-task design utilizes three separate testing conditions, a single-task involving the completion of an observation task in isolation and two dual-task conditions involving the use of different interfaces or presentations of information simultaneously with an observation task (Chandler and Sweller, 1996; Brünken et al., 2002; Brünken et al., 2004; Kim and Rieh, 2005; Lahtinen et al., 2007; DeLeeuw and Mayer, 2008).

In a dual-task paradigm, observation tasks are often selected so that the mode of delivery (i.e. auditory or visual stimuli) overlaps with the primary learning task modality. In the case where the primary learning task contains only visual information, a visual observation task such a color changing box, background or letter is often selected as a sensitive measure of the load placed on the visual working memory subsystem (i.e. visuospatial sketchpad; Brünken et al., 2002; Kim and Rieh, 2005; DeLeeuw and Mayer, 2008; Knox et al., 2014). Literature involving dual-task paradigms, also indicates that observation tasks should be simple enough in nature to enable participants to easily learn and perform the task, thus reducing the risk that the observation task will interfere overtly with primary task performance (Brünken et al., 2003; Kerr, 1973). To prevent participants from developing familiarity with the observation task and reducing the total cognitive processing loads while completing the task, participants are often not permitted to practice the observation task in isolation prior to testing (Brünken et al., 2002; Kim and Rieh, 2005; DeLeeuw and Mayer, 2008).

While literature exists regarding the usage of observation tasks in dual-task paradigms, there is little guidance to be found in the literature about restrictions surrounding selecting a primary learning task. The total time commonly allotted to complete the primary learning task varies widely between studies, however, on average participants are given between 12-15 minutes per dual-task condition (Brünken et al., 2002; Brünken et al., 2004; Kim and Rieh, 2005).

As previously discussed in Section 1.3.2, single task conditions form a baseline indicator of cognitive processing load when all working memory resources are devoted to the observation task. The use of a simple observation task in a dual-task paradigm is predicated on the capacity sharing approach to explaining dual-task interference, a concept acknowledged in cognitive load theory (Pashler, 1994). Dual-task interference and cognitive load theory posit that tasks, which share the same working memory resources (e.g. are interpreted visually), and are performed concurrently can interfere with each other. That is, if two tasks are being performed simultaneously, then there is less processing capacity (i.e., fewer working memory resources) available for each individual task than there would be if each task was completed in isolation (Pashler, 1994). The dual-task condition essentially requires a learner to divide their limited working memory resources, with the assumption being that the speed of response to the observation task will provide a relative estimate of spare working memory resources left unoccupied by the learning task (Brünken et al., 2002; Posner and Boies, 1971). If more working memory resources are consumed by a particular learning task, less cognitive capacity is available to devote to the monitoring task and reactions will be slower (Brünken et al., 2003; de Jong, 2010). Thus, if performance on an observation task fluctuates based on the working memory load imposed by a learning interface, it should be possible to assess relative extraneous cognitive load levels induced by different e-learning software packages, if the primary learning task, and the total cognitive processing load it requires, are held constant.

2.1.1 Objective

The aim of this study was to measure cognitive load using standard dual-task paradigm, designed based on existing literature, when students used two commercial anatomical e-learning tools with different software designs to study anatomy (A.D.A.M. Interactive Anatomy (Ebix, Inc., Atlanta, GA) and Netter's 3D Interactive Anatomy (Elsevier Inc., Philadelphia, PA)). We hypothesized that previously successful dual-task paradigms used to assess cognitive load across different variants of passive e-learning tools that taught dynamic concepts (i.e. heart contraction; Brünken et al., 2002; DeLeeuw and Mayer, 2008) could be applied to study cognitive load across two different commercially built e-learning tools that were fully interactive but showed static concepts (i.e. skeletal anatomy). Our hypothesis was that the complex design of Netter's 3D Interactive Anatomy would impose a higher level of extraneous cognitive load compared to the simplistic design of A.D.A.M. Interactive Anatomy, given that the primary learning task (i.e. the anatomy learned) and the working memory resources it required were held constant.

2.2 Methodology

The research protocol was approved by the Office of Research Ethics at The University of Western Ontario, Canada (Appendix D).

2.2.1 Participants and Recruitment

Participants were recruited from the Allied Health Sciences at The University of Western Ontario. A total of 20 students, recruited by emails from the first author, participated in the study.

2.2.2 Experimental Design Overview

Each participant was scheduled for two separate testing sessions that were held on different days. Prior to the first testing session participants were asked to complete two pre-test measures inclusive of a demographic questionnaire and an anatomy knowledge baseline test. The demographic questionnaire asked participants to declare if they had used anatomy e-learning tools in the past, and if so, which products. The anatomy knowledge baseline test assessed participant’s familiarity with the knee and elbow joint and consisted of 20 short answers (50:50, knee:elbow). Students were asked to identify the ligaments, blood vessels and muscles that crossed each joint as well as important bony landmarks immediately surrounding the joint. Fourteen out of 20 questions had an associated static cadaveric image, with a structure marked by an arrow. Participants were given 20 minutes to answer all questions, and each question required a typed response with accurate spelling.

To assess the cognitive load that each e-learning tool’s design placed on the learner, participants were involved in two single-task conditions, each involving the completion of the visual observation task (VOT) in isolation, and two dual-task conditions involving a VOT and joint learning exercise completed simultaneously. During both the first and second testing sessions, each participant took part in one single-task condition and one dual-task condition (Table 2.1).

Table 2.1: E-Learning Tool and Joint Learning Exercise Assignments

	Day 1		Day 2	
Participant	VOT in isolation	E-learning tool and joint learning exercise	VOT in isolation	E-learning tool and joint learning exercise
1	✓	Elbow in A.D.A.M. Interactive Anatomy	✓	Knee in Netter's 3D Interactive Anatomy
2	✓	Knee in A.D.A.M. Interactive Anatomy	✓	Elbow in Netter's 3D Interactive Anatomy
3	✓	Elbow in Netter's 3D Interactive Anatomy	✓	Knee in A.D.A.M. Interactive Anatomy
4	✓	Knee in Netter's 3D Interactive Anatomy	✓	Elbow in A.D.A.M. Interactive Anatomy

In both e-learning tool and joint learning exercises (dual-task conditions) participants are randomly assigned to explore the anatomy of two joints (elbow and knee) using two different learning methods (A.D.A.M. Interactive Anatomy and Netter's 3D Interactive Anatomy). Due to this cross over design the e-learning tools and joints studied on Day 1 and Day 2 vary depending on the participant.

VOT, visual observation task.

2.2.3 Commercial Anatomical E-Learning Tools Examined

In an effort to understand how significantly different commercial anatomical software interfaces affect a learner's cognitive load, A.D.A.M. Interactive Anatomy (Ebix, Inc., Atlanta, GA) and Netter's 3D Interactive Anatomy (Elsevier Inc., Philadelphia, PA) were selected. These tools were chosen because 1) they contained the relevant structures, anatomical landmarks and labels required for a participant to meet the objectives outlined for each joint learning exercise (see below) and 2) their interface designs were significantly dissimilar (Fig. 2.1).

A.D.A.M. Interactive Anatomy is a 2-dimensional tool that presents static anatomical images in a textbook-like fashion using a navigational tool set containing 9 buttons that can be used to manipulate the image, including extracting, highlighting and changing the magnification of a selected structure. Within A.D.A.M. Interactive Anatomy, users have the ability to access four key anatomical views including anterior, posterior, lateral and medial. Rollover labels are used to identify structures and users manipulate a sliding depth bar to examine different image layers. However, A.D.A.M. Interactive Anatomy does not enable body systems, such as the skeletal and digestive systems, to be viewed independent from the rest of the body (Fig. 2.1A).

Conversely, Netter's 3D Interactive Anatomy has a 3-dimensional usability that is generated through the compilation of static images whose three-dimensional coordinates are stored on a server. These coordinates are used to generate animations, where depth cues are conveyed to the learner by the differing speeds of near and far structures when the objects are rotated (Cohen and Hegarty, 2007). This gives the illusion of depth to a two-dimensional structure, even though no stereopsis is required. In addition, users are able to rotate a structure along any axis point, enabling viewing from all angles (Attardi and Rogers, 2015). Netter's 3D Interactive Anatomy has 20 buttons contained within its navigational tool set that can be used to execute a wide range of functions including, but not limited to, magnifying and peeling away individual structures, as well as translating and rotating images. Rollover labels are only visible for larger structures, such as individual bones like the femur, however, in order to access more specific labeling (e.g. bony landmarks), users must choose two different buttons in succession. Within Netter's 3D Interactive Anatomy students can dissect the cadaveric images by removing individual structures, a function that is not possible within A.D.A.M. Interactive Anatomy. Furthermore, Netter's 3D Interactive Anatomy enables users to toggle on and off different categories of structures (e.g. skeletal, circulatory and muscular systems; Fig. 2.1B).

Previous research suggests that e-learning tools that enable high navigational control through extensive tool sets and multiple viewing angles can disorient novice users and increase extraneous cognitive load (Dias et al., 1999; Garg et al., 1999; Khalil et al., 2005; Levinson et al., 2007; Dindar et al., 2015). The extensive tool set of Netter's 3D Interactive Anatomy may result in elevated extraneous cognitive load levels, as learners are forced to spend more time arbitrarily testing possibilities when learning to navigate the program (Sweller et al., 1998; Wong et al., 2003; Ardito et al., 2006; Grunwald and Corsbie-Massay, 2006; van Merriënboer and Sweller, 2010). These features in conjunction with each other were used to classify this tool as complex. To further support this classification, previous research involving Netter's 3D has demonstrated that students often find the software difficult to install and use, which may further contribute to extraneous cognitive load and learner frustration (Attardi, 2015). A.D.A.M. Interactive Anatomy, which has significantly fewer tools available in the menu bar, limits how a user can interact with the anatomical structures, which may reduce confusion when using the program, and for the purposes of this research has been called simple. In terms of viewing angles, Netter's 3D Interactive Anatomy is a highly interactive system, as it allows structures to be rotated on any axis and studied from multiple views, where as A.D.A.M. Interactive Anatomy only allows anatomical structures to be studied from four key views (e.g. anterior, posterior, lateral, medial; Luursema et al., 2006).

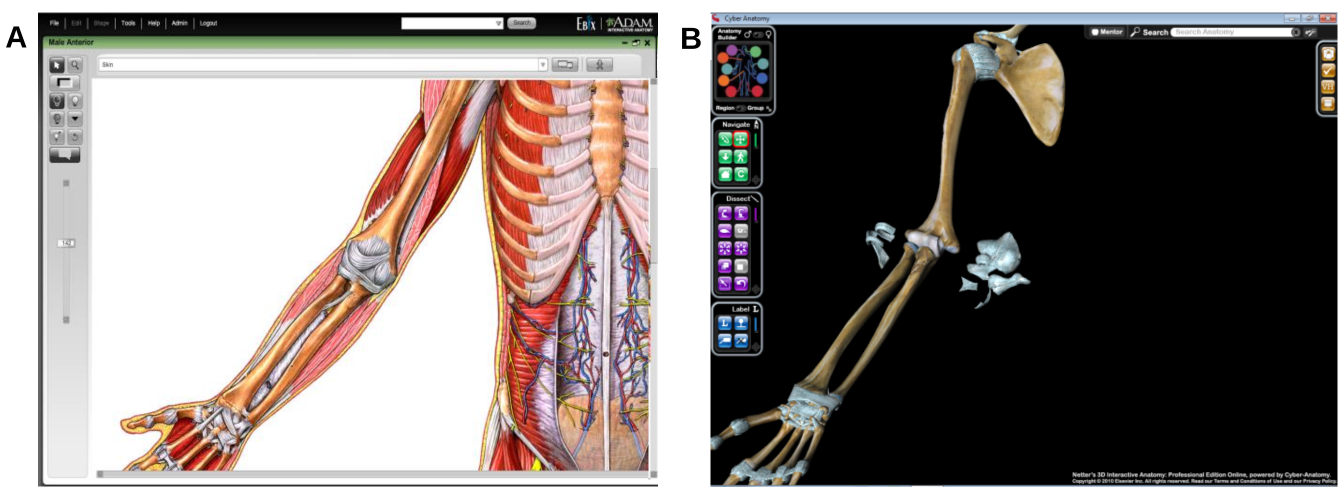


Figure 2.1: Screen captures of commercial anatomical e-learning tools assessed.

A.D.A.M. Interactive Anatomy (A) displays anatomical content in a textbook-like fashion with limited buttons for student interaction. Conversely, Netter's 3D Interactive Anatomy (B) has a 3-dimensional appearance and 20 buttons through which users can interact with the program.

2.2.4 Visual Observation Task in Isolation

The research station used in this study to present each e-learning tool consisted of a LG PC with Intel dual-core processor running Windows 7 (Microsoft Corp., Redmond, WA) connected to a 26-inch LG Flatron Wide monitor (LG Electronics Inc., Seoul, Korea). A second 26-inch LG Flatron Wide monitor was placed directly behind the first on a raised platform and was connected to a 15-inch Lenovo laptop (ThinkPad E531, Lenovo, Morrisville, NC) running Windows 7. This laptop, with an external keyboard, was used to run the VOT (Fig. 2.2).

The single-task condition involved responding to the VOT and was conducted twice for each participant (once during each testing session). Two single-task sessions were performed in order to control for testing taking place on separate days and to account for factors that may affect reaction times (i.e. caffeine intake, time of day, etc.). Participants were asked to press the space bar on an external keyboard as soon as they perceived a color change in a small window displayed on the upper right area of a computer screen (Fig. 2.2).

A VOT, instead of an auditory task, was chosen for this study because its optical nature makes it ideal to measure the resources of the working memory's visual subsystem occupied during the use of a visual only e-learning tool (Fisk et al., 1986; Brünken et al., 2002; Kim and Rieh, 2005; DeLeeuw and Mayer, 2008). Furthermore, the VOT involved the detection of a color-change, which is most commonly utilized in other dual-task studies comparing computer interface designs (Brünken et al., 2002; Kim and Rieh, 2005; DeLeeuw and Mayer, 2008; Knox et al., 2014). The VOT in this study involved a small computer window programmed to change colors semi-randomly every 15-60 seconds from grey to red or red to grey. The researchers ensured that identical colors were not presented consecutively. A simple VOT, as used in this study, should enable participants to easily learn and perform the VOT while reducing the risk that it will interfere directly with e-learning task performance (Kerr, 1973; Brünken et al., 2003).

E-Prime® 2.0 Professional (Psychology Software Tools, Inc., Sharpsburg, PA) was utilized to program color changes and record time lapses between each color change and participant response. Each VOT was 15-minutes in duration and included a total of 23 color changes. The length of the joint learning session, discussed below, predetermined the total VOT duration described here. The color-change intervals (15-60 seconds) were selected based on previous research that indicated that such a range would be short enough to affect performance on the VOT but still allow for close to normal performance during the learning task (Wastlund et al., 2008; Gwizdka, 2010). In order to estimate participants' average response times on the VOT when 100% of their visual working memory resources were devoted to the visual observation task, they were asked to complete a VOT in isolation. In accordance with previous dual-task research, participants were not exposed to the VOT prior to this task being completed in isolation, in an effort to prevent the development of task familiarity, which may impact the total cognitive processing load over time (Brünken et al., 2002; Kim and Rieh, 2005; DeLeeuw and Mayer, 2008). It should also be noted that color-change intervals were scrambled for each VOT displayed to a participant in an effort to prevent prediction and automation of responses.

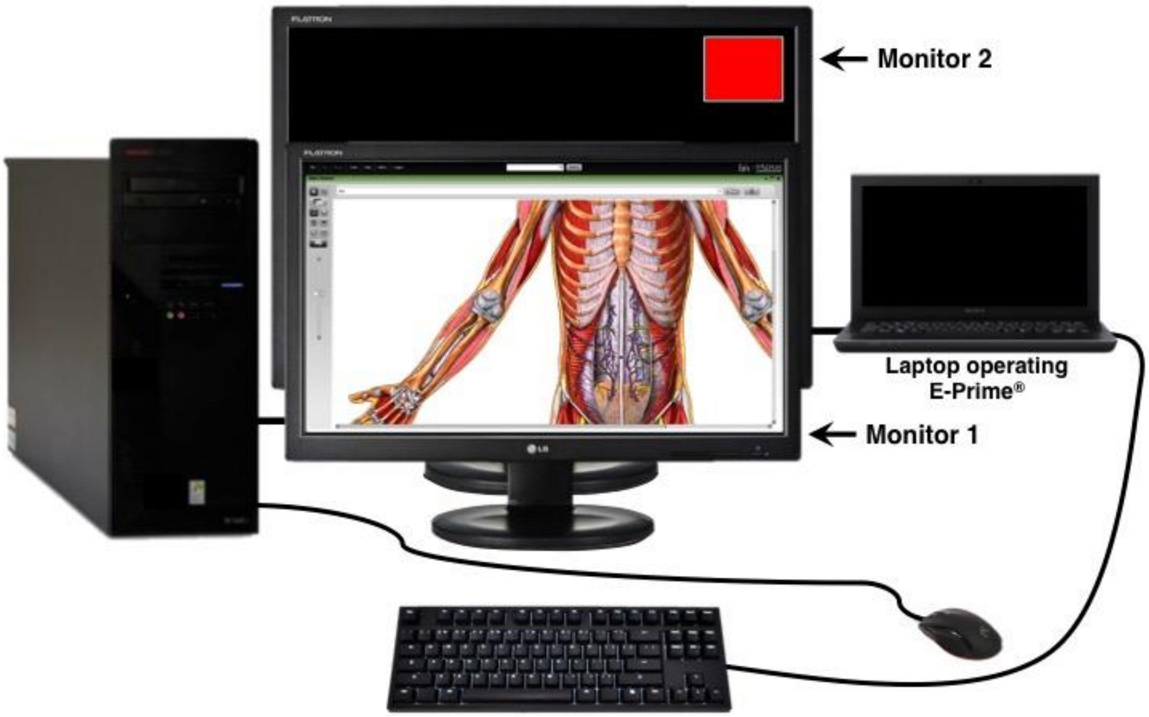


Figure 2.2: Initial design of dual-task experimental design station.

During the visual observation task in isolation, participants responded to a modified Stroop test that appeared on Monitor 2, no images were shown on Monitor 1 during this time. In the dual-task testing conditions where participants completed both a visual observation task and joint learning exercise in tandem, the visual observation task was displayed on Monitor 2, while, at the same time, the assigned e-learning tool was displayed on Monitor 1.

2.2.5 Visual Observation Task and Joint Learning Exercise Combined (Dual-task Condition)

The dual-task testing conditions involved completing a joint learning exercise as well as a VOT (described above) simultaneously (Fig. 2.2). Participants were randomly assigned at the start of the study to explore both the elbow and knee joints, using different commercial e-learning software packages (Netter's 3D Interactive Anatomy and A.D.A.M. Interactive Anatomy; Table 2.1). Participants studied one joint using one e-learning tool on the first day of testing and the second joint and e-learning tool on the following day of testing. The elbow and knee joints were chosen because they are both complex hinge joints with unique ligaments. The knee is arguably the more complex hinge joint, however, it is more commonly understood by students prior to their exposure to a formal anatomy course. Prior to beginning a combined VOT and joint learning exercise, participants were provided an instruction page that detailed how to use the e-learning tool and included four objectives to help guide the student: (1) Identify the different ligaments that cross the joint; (2) Identify the blood vessels that cross the joint; (3) Identify the muscles that cross the joint; and (4) Identify the bony landmarks on the bones that immediately surround the joint.

Using previous dual-task parameters as a guide, participants were given 15 minutes to explore a joint (elbow or knee) using a pre-assigned e-learning tool (Brünken et al., 2002; Brünken et al., 2004; Kim and Rieh, 2005). Participants were free to use their allotted study time as they wished; however, they were not given access to other resources (online or otherwise) during the session. Furthermore, neither e-learning tool enabled students to type in structure names during the learning session. At the same time participants were learning using a specific e-learning tool, they were also asked to respond to the VOT described above (Fig. 2.2). Upon completion of each combined dual-task exercise, participants were asked to write a scrambled version of the same pretest questions relevant to the joint just learned (10 of 20 questions). It should be noted that the two combined testing conditions took place on separate testing days to avoid mental exhaustion caused by the extended duration of the testing session.

Under the theories of cognitive load and dual-task research, if an e-learning tool imposes a higher extraneous cognitive load on a learner (i.e. if it has a confusing menu bar and/or unclear buttons like Netter's 3D Interactive Anatomy), said learner will have fewer working memory resources to devote to: (1) the content within the learning tool; and, (2) the VOT task in the background. Thus, learners who are exposed to an e-learning tool that imposes high cognitive load will have low performance scores and slower reaction times, that when the same learner used a simple e-learning tool that did imposed a low cognitive load (such as A.D.A.M. Interactive Anatomy; Fig. 2.3).

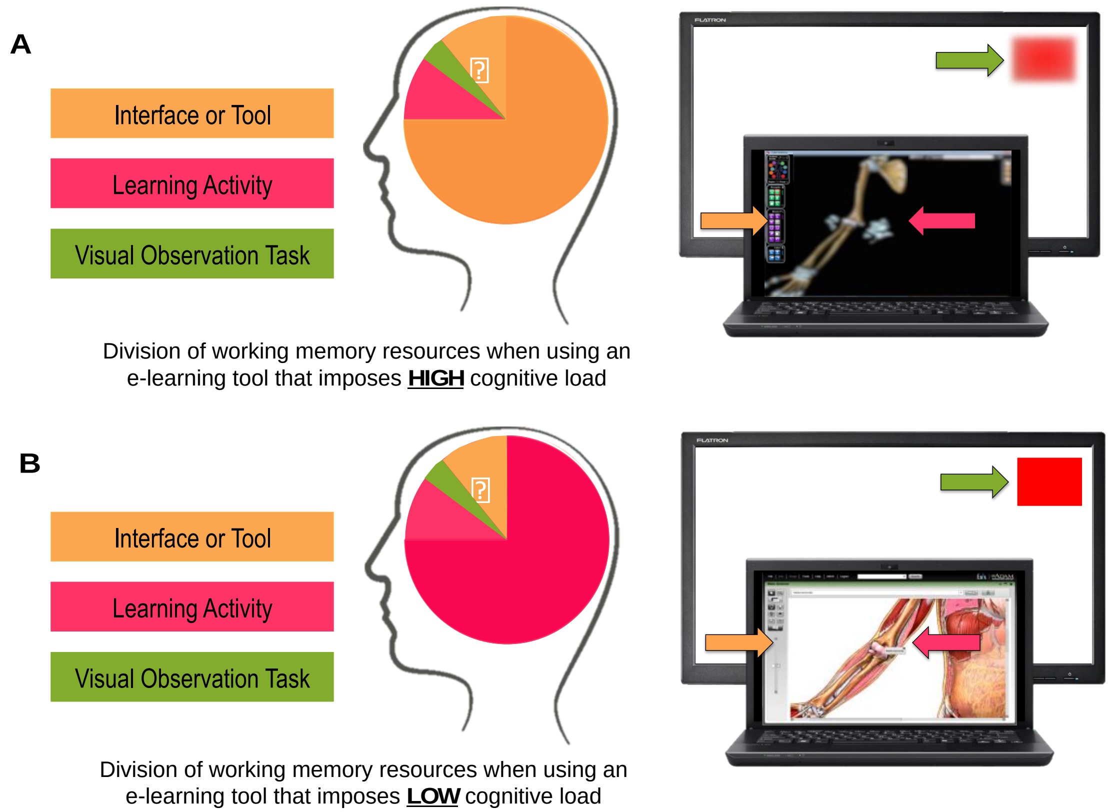


Figure 2.3: How a commercial e-learning tool that imposes high or low cognitive load may impact a learner during a dual-task condition.

Figure A depicts how a dual-task condition, that involves an e-learning tool that imposes high cognitive load, may appear to learner. In the event that an e-learning tool has an extensive and confusing tool set as seen in Netter's 3D Interactive Anatomy (A: orange arrow), students are more likely to spend their working memory resources and time learning how to navigate the program, that they will be less likely to learn the educational material or notice the visual observation ask (VOT; A: blurred images marked by the green and pink arrows).

Conversely, Figure B depicts how a dual-task condition, that involves an e-learning tool that imposes low cognitive load, may appear to learner. In this situation, a simplified e-learning tool that presents a limited tool set marked with clear labels, such as that seen in A.D.A.M. Interactive Anatomy (B: orange arrow), will not burden student working memory resources. Instead, easy navigation will allow a learner to devote their remaining working memory resources to the educational material with the tool and monitoring the VOT (B: sharp images marked by green and pink arrows).

2.2.6 Analysis

Participant VOT reaction times in the isolated condition were averaged across Day 1 and Day 2 and compared to the averaged reaction times when the VOT was paired with a joint learning exercise (dual-task condition). The reaction times gathered during the dual-task condition were compared by e-learning tool (A.D.A.M. Interactive Anatomy or Netter's 3D Interactive Anatomy), by joint learning exercise (knee or elbow) and by day of use (Day 1 or Day 2) using paired samples t-tests. Reaction times were further compared by e-learning tool and day of use as well as by joint and day of use using independent samples t-tests.

Participant pre-test and post-test scores, as well as gain scores, were compared by e-learning tool, joint learning exercise, and by day of use using paired samples t-tests. Further to this, the relationship between reaction time and post-test score or gain score was explored using a Pearson correlation.

2.2.7 Exclusion Criteria

Participants were excluded from analysis if: 1) they scored perfect on one or more sections of the anatomy knowledge baseline pretest, 2) they failed to take all tests or 3) if their performance on the visual observation task was more than two standard deviations away from the mean.

2.3 Results

2.3.1 Demographics

Of the 20 Allied Health Sciences students who participated in the study, 13 individuals had complete, usable data sets (n = 13, M to F 6:7, mean age = 23.4 years). Of the 13 participants, 11 were enrolled in a Clinical Anatomy Master's program and 2 were enrolled in undergraduate programs at the time of the study. It should be noted that those participants enrolled in the Clinical Anatomy Masters program were tested prior to receiving formal anatomy instruction through their program. Six participants reported they had used anatomical e-learning programs in the past, and 4 of these individuals identified that e-learning tool as Netter's 3D Interactive Anatomy, while only 1 individual had used A.D.A.M. Interactive Anatomy.

2.3.2 Visual Observation Task Reaction Times Assessed by E-Learning Tool

When the visual observation task was completed in isolation, the mean reaction time (mean ± SD) across all participants (*n* = 13) was 431 ± 86 milliseconds. This baseline value was compared to reaction times on the VOT when said task was completed in tandem with a joint learning exercise. Participants mean reaction times in this dual-task condition, when grouped by e-learning tool use and regardless of the day of use, were 927 ± 468 and 1054 ± 576 milliseconds for Netter's 3D Interactive Anatomy and A.D.A.M. Interactive Anatomy respectively. A paired samples t-test performed between VOT reaction times in the baseline and dual-task conditions demonstrated significantly longer reaction times in the dual-task conditions when participants used Netter's 3D Interactive Anatomy ($t(12) = -3.72$, $p = 0.003$) or A.D.A.M. Interactive Anatomy ($t(12) = -4.06$, $p = 0.002$). However, no significant difference was found between VOT reaction times when participants used Netter's 3D Interactive Anatomy when compared to A.D.A.M. Interactive Anatomy in the dual-task condition.

Visual observation task reaction times in conditions where said tasks were performed simultaneously with a joint learning exercise were further broken down by e-learning tool and day of use (Table 2.2). No significant difference was found using an independent t-test between VOT reaction times in A.D.A.M. Interactive Anatomy and Netter's 3D Interactive Anatomy on Day 1 or Day 2. Similarly, no significant difference was found between reaction times in Netter's 3D Interactive Anatomy on Day 1 and Day 2 or A.D.A.M. Interactive Anatomy on Day 1 and Day 2.

Table 2.2: Visual Observation Task Reaction Times Assessed by E-Learning Tools and Day of Use

Condition	VOT Reaction Time (ms) (mean ± SD) Day 1	Day 2
Netter's 3D Interactive + VOT	1049 ± 588 n = 6	822 ± 349 n = 7
A.D.A.M. Interactive Anatomy + VOT	1293 ± 680 n = 7	775 ± 260 n = 6

Independent t-tests were used to analyze the dual-task reaction times measured on Day 1 and 2.

No significant differences were found.

VOT, visual observation task.

2.3.3 Visual Observation Task Reaction Times Assessed by Joint Learning Exercise

Visual observation task reaction times during the joint learning exercises were also analyzed by joint task (i.e. elbow and knee), regardless of e-learning tool, and compared to the baseline reaction time. The mean reaction time (mean ± SD) on the VOT while learning the knee joint was 919 ± 534 milliseconds, compared to the elbow joint, which was recorded as 1062 ± 513 milliseconds. A paired samples t-test between VOT reaction times during the baseline condition as well as during the knee and elbow joint learning exercises reveal significantly longer reaction times when participants were learning about the knee joint ($t(12) = -3.37$, $p = 0.006$) and elbow joint ($t(12) = -4.44$, $p = 0.001$) when compared to baseline. However, no significant difference was detected between VOT reaction times when participants learned about the knee joint compared to elbow joint.

Reaction times for the VOTs that were completed in tandem with a joint learning exercise were further broken down by day of use and joint (Table 2.3). An independent samples t-test did not reveal any significant difference between elbow and knee visual observation task reaction times on Day 1, however, knee visual observation task reaction times were significantly shorter than the elbow reaction times on Day 2 ($t(11) = 2.21$, $p = 0.049$). When VOT reaction times were compared across days for a single joint, independent samples t-tests did not reveal any significant differences between elbow reaction times on Day 1 and Day 2 or knee reaction times on Day 1 or Day 2.

Table 2.3: Visual Observation Task and Reaction Times Assessed by Joint Learning Exercise and Day of Use

	VOT Reaction Time (ms) (mean ± SD)	
Condition	Day 1	Day 2
Elbow + VOT	1094 ± 625 n = 8	1002 ± 335[a] n = 5
Knee + VOT	1319 ± 672 n = 5	674 ± 206[a] n = 8

Independent t-tests were used to analyze the dual-task reaction times measured on Day 1 and 2.

[a]Reaction times were significantly faster when studying the knee than when studying the elbow joint on Day 2 ($p<0.05$).

Note that identical superscripts are significantly different.

VOT, visual observation task.

2.3.4 Pre-Test, Post-Test, and Gain Scores Assessed by E-Learning Tool

Mean anatomy pre-test scores, post-test scores and overall gain scores (mean ± SD) in the dual-task conditions, using Netter's 3D Interactive Anatomy and A.D.A.M. Interactive Anatomy, irrespective of day were calculated (Table 2.4). A paired samples t-test revealed that post-test scores were significantly higher than pre-test scores after students used either of the e-learning tools (Netter's 3D Interactive Anatomy: $t(12) = -2.94$, $p = 0.012$ and A.D.A.M. Interactive Anatomy: $t(12) = -6.23$, $p < 0.001$). However, no significant difference was found between Netter's 3D Interactive Anatomy and A.D.A.M. Interactive Anatomy pre-test scores, post-test scores or gain scores.

Table 2.4: Pre-Test, Post-Test and Gain Scores Assessed by E-Learning Tool in Dual-Task Conditions (+Visual Observation Task)

Condition	Pre-Test Score	Post-Test Score	Gain Score
Netter's 3D Interactive Anatomy + VOT	5.77 ± 3.32^a	7.38 ± 2.40^a	1.62 ± 1.98
A.D.A.M. Interactive Anatomy + VOT	6.15 ± 2.30^b	8.00 ± 2.3^b	1.85 ± 1.07

Paired samples t-tests were used to analyze the performance data.

[a,b] Significant improvement on post-test scores was found when compared to respective pre-test scores ($p < 0.05$).

All pre-tests and post-tests were out of 10 marks total; $n = 13$. Note that identical superscripts are significantly different.

VOT, visual observation task.

2.3.5 Assessing the Relationship Between Visual Observation Task Reaction Times and Post-Test Scores or Gain Scores

The average VOT reaction time when performed in tandem with a joint learning exercise (mean ± SD), and regardless of e-learning tool, joint learning exercise or day of use, was 990 ± 518 milliseconds. The average post-test scores and gain scores (mean ± SD), regardless of e-learning tool or joint learning exercise, were 7.69 ±2.33 and 1.73 ±1.56, respectively. When the average VOT reaction times of all participants were compared to their post-test scores, no relationship, by way of Pearson correlation, was detected. Similarly, when participant’s gain scores were compared with their average VOT reaction times, no relationship, by way of Pearson correlation, was detected.

2.4 Discussion

Dual-task paradigms have been suggested as a direct and objective tool to measure cognitive load differences between e-learning platforms (Brünken et al., 2003). To date no studies have employed this technique to assess cognitive load during commercial anatomical e-learning tool use (Kim and Rieh, 2005; Gwizdka, 2010). The aim of this study was to assess the effect of two commercial anatomical e-learning software designs (Netter’s 3D Interactive Anatomy and A.D.A.M. Interactive Anatomy) on learner cognitive load using a dual task paradigm. Using previous dual-task literature to guide design, we employed a simple color-change visual observation task (VOT) as a relative measure of the extraneous cognitive load induced by each e-learning tool (Brünken et al., 2002; Kim and Rieh, 2005; DeLeeuw and Mayer, 2008; Knox et al., 2014).

When software packages were compared, irrespective of joint, our dual-task paradigm (VOT reaction times and post-test scores) did not detect any significant difference in terms of cognitive load across e-learning tools. These results could indicate one of two possibilities, (1) A.D.A.M. Interactive Anatomy and Netter’s 3D Interactive Anatomy impose the same cognitive load on users, or (2) the dual task paradigm, as designed, is insensitive to the cognitive load differences across different e-learning tool interfaces. Previous research suggests that e-learning tools which enable structures to be studied from multiple views, such as Netter's 3D Interactive Anatomy, should produce an increase in extraneous cognitive load, particularly if a learner has a poor ability to mentally rotate structures in space (Garg et al., 1999; Levinson et al., 2007). Furthermore, e-learning tools that allow high navigational control (i.e. the ability to control a computer program independently) via extensive tool sets, as is the case with Netter's 3D Interactive Anatomy, can confuse and disorient a learner (Dias et al., 1999; Khalil et al., 2005). High navigational control can produce high extraneous cognitive load caused by the additional time investment required to learn how to use the software, hampering user learning (Wong et al., 2003; Ardito et al., 2006; Levinson et al., 2007). Consequently, e-learning software packages that present key views of anatomical structures, instead of multiple views, and limit navigational control, as is the case with A.D.A.M. Interactive Anatomy, should theoretically impose a lower load on working memory resources, than tools such as Netter's 3D Interactive Anatomy. Thus, VOT reaction times, when participants were using Netter's 3D Interactive Anatomy, were expected to be longer than VOT reaction times when the same student used A.D.A.M. Interactive Anatomy. As an extension of this prediction, post-test scores, as well as gain scores should have been significantly lower when a joint was studied using Netter's 3D Interactive Anatomy, compared to A.D.A.M. Interactive Anatomy. Given this, our results strongly suggest that the dual-task paradigm and the VOT used in the study were insensitive to the cognitive load differences across commercial anatomical e-learning tools.

The unexpected results of this study revealed three key inconsistencies in the design parameters of a standard dual-task experiment, when applied to the study of cognitive load during anatomical e-learning tool use. Visual observation task suitability, performance task tradeoff and the nature of the primary learning task were identified as major drawbacks to the standard dual-task design. Interestingly, difficulties applying standard dual task designs have also been encountered in other areas of medical education (Knox et al., 2014).

As mentioned above, VOT suitability in this study was brought into question when data analysis revealed that reaction times were notably, although not significantly, faster on Day 2 when compared to Day 1. This finding suggests that the VOT, as designed, did not require consistent or effortful visual working memory processing throughout the experiment. Instead, participant responses became automatized, that is, as exposure to the VOT progressed, negligible amounts of working memory resources were required for efficient performance on the VOT, even though it demanded significant resources initially (Fisk et al., 1986). Utilizing an inadequate VOT, as designed here, would most likely result in erroneous conclusions about the participant’s cognitive load during e-learning tool use (Fisk et al., 1986; Goh et al., 2014). To prevent automization, observation tasks that require effortful processing in the working memory throughout the experiment should be utilized. We propose using a modified Stroop test (Stroop, 1935) in future experiments; this task requires participants to indicate, in either a verbal or in a tactile fashion, if a displayed word (red, blue green or yellow) is the same as the ink color (red, blue green or yellow) it is presented in, or different. Modified Stroop tests require more visual working memory resources than a simple color change because of the semantic processing involved in incongruent stimuli (i.e. when the word and color do not match). Moreover, this task offers 16 different stimuli (12 incongruent stimuli and 4 congruent stimuli), instead of 2 (two different colored boxes) as was used previously. Increasing the number of novel stimuli and the inconsistency of congruent stimuli are key features that should be considered when developing a VOT where the cognitive load remains constant throughout the experiment (Fisk et al., 1986; MacLeod, 2005). An additional advantage of the modified Stroop test, unlike the color change task, is that participant practice does not impact performance over time (MacLeod, 1998). These factors make a modified Stroop test an ideal choice for an observational task within the dual-task paradigm (Gwizdka, 2010). Interestingly, in educational studies that used a dual-task paradigm to assess cognitive load levels, automization and practice effects were not discussed or referenced (Brünken et al., 2002; Kim and Rieh, 2005; DeLeeuw and Mayer, 2008).

Beyond automization, subjects who participate in dual-task testing may also employ trade-off strategies while completing simultaneous tasks (Fisk et al., 1986; Abernathy, 1988). This process, known as task performance tradeoff, increases the risk that participants will sacrifice primary learning task performance to improve performance on the VOTs, and ultimately deprives the primary learning task of the maximum working memory resources required for task performance (Fisk et al., 1986). While faster VOT reaction times on Day 2 indicate that trade-off may have been transpiring, the standard dual-task methodological design as outlined in the literature prevented the researchers from determining the extent of the tradeoff. Under the logic of the dual-task paradigm, it is imperative that participants maintain maximum usage of working memory resources during the primary learning task performance, in order to correctly interpret VOT reaction times as sensitive measures of cognitive load (Fisk et al., 1986; Hegarty et al., 2000). In order to detect task-performance tradeoff, primary learning task measures should be recorded while the primary learning task (or some similar form of the task) is completed in isolation, much like how VOTs are completed in isolation and used a baseline (Fisk et al., 1986; Brumby et al., 2007; Goh et al., 2014). This baseline performance measure of the primary learning task can then be compared to learning task performance in the dual task coonditions, enabling researchers to ensure equivalency of primary task performance during both single and dual-task conditions (Fisk et al., 1986). Furthermore, current educational and information sciences studies that use dual task neglect the importance of explicit participant instructions during testing sessions. Precise instructions on task priority should be given to participants in an effort to convey task precedence and avoid performance tradeoff (Levy and Pashler, 2001; Brumby et al., 2007).

The nature of the primary task, that is the inherent cognitive load of the primary task itself, is a topic that is often taken for granted during dual-task studies and is rarely discussed. Instead the focus lies mainly on the load imposed by the observation task (Brünken et al., 2003; Paas et al., 2003). Yet, poor gain scores in this study suggest that the anatomical learning objectives were too extensive and detailed, overloading the learner’s working memory resources in the absence of the VOT. This highlights an important consideration that should be taken into account during dual-task design. It is possible that by recording the learning measures of the primary joint task in isolation, such overload may be detected at the outset of the study, enabling researchers to modify their paradigm by reducing learning content.

2.4.1 Study Limitations

As demonstrated throughout the discussion, the dual-task paradigm utilized in this study was not suitable for the author's intended purposes. Beyond the paradigm itself, only a small number of subjects participated in this study and the majority were pursuing Masters of Sciences degrees. Further studies using a large number of naïve, undergraduate anatomy students may better elucidate the validity and generalizability of the proposed novel dual-task paradigm in anatomical education.

2.5 Conclusions

The results of this study suggest that the standard dual-task design, as described in literature, does not eliminate confounding variables, such as response automization, performance-task tradeoff or difficulty of the primary learning task, from influencing participants. Based on these results, the researchers propose the use of a novel dual-task paradigm to address these shortcomings. The authors suggest that future dual-task paradigms utilized to study the cognitive load of e-learning tools in anatomy should meet the following criteria: (1) the observation task should use enough working memory resources to affect performance on the learning task but still allow for close to normal performance, such as a modified Stroop test; (2) performance task measures should be studied while the task is performed in isolation as well as in tandem with an observation task, furthermore, explicit identical instructions regarding task priority should be given to every participant; 3) cognitive load requirements of the primary learning task should be investigated closely to ensure they do surpass the working memory resources of a novice learner. These modifications to the dual-task paradigm will be critical in ensuring the validity of this methodology in future educational studies investigating the cognitive load impact of anatomical e-learning software on students.

2.6 Literature Cited

Abernethy B. 1988. Dual-task methodology and motor skills research: Some applications and methodological constraints. J Hum Mov Stud 14:101–132.

Allen LK, Bhattacharyya S, Wilson TD. 2015. Development of an Interactive Anatomical Three-Dimensional Eye Model. Anat Sci Educ 8:275-282.

Allen LK, Eagleson R, de Ribaupierre S. 2016. Evaluation of an online three-dimensional interactive resource for undergraduate neuroanatomy education. Anat Sci Educ 9:431-439.

Anderson JR. 1987. Skill acquisition: The compilation of weak-method problem solutions. Psychol Rev 94:192–210.

Ardito C, Costabile MF, De Marsico M, Lanzilotti R, Levildi S, Roselli T, Rossano V. 2006. An approach to usability evaluation of e-learning applications. Univ Access Inf Soc 4:270–283.

Attardi SM. 2015. Design, Implementation and Evaluation of an Online Systemic Human Anatomy Course with Laboratory. The University of Western Ontario: London, Canada. Doctorate of Philosophy Dissertation. 210 p.

Attardi SM, Rogers KA. 2015. Design and implementation of an online systemic human anatomy course with laboratory. Anat Sci Educ 8:53–62.

Baddeley AD. 2000. The episodic buffer: a new component of working memory?. Trends Cogn Sci 4:417-423.

Baddeley AD. 2003. Working memory: Looking back and looking forward. Nat Rev Neurosci 4:829–839.

Brumby DP, Salvucci, DD, Howes A. 2007. An empirical investigation into dual-task trade-offs while driving and dialing. In: Proceedings of the 21st British HCI Group Annual Conference on People and Computers: HCI...but not as we know it -Volume 2; Lancaster, UK; 2007 Sept 3-7. p 11–14. British Computer Society: Swinton, UK.

Brünken R, Plass JL, Leutner D. 2003. Direct measurement of cognitive load in multimedia learning. Educ Psychol 38:53–61.

Brünken R, Plass JL, Leutner D. 2004. Assessment of cognitive load in multimedia learning with dual-task methodology: Auditory load and modality effects. Instr Sci 32:115–132.

Brünken R, Steinbacher S, Plass JL, Leutner D. 2002. Assessment of cognitive load in multimedia learning using dual-task methodology. Exp Psychol 49:109–119.

Chandler P, Sweller J. 1996. Cognitive load while learning to use a computer program. Appl Cognit Psychol 10:151–170.

Cohen CA, Hegarty M. 2007. Individual differences in use of external visualisations to perform an internal visualisation task. Appl Cognit Psychol 21:701–711.

de Jong T. 2010. Cognitive load theory, educational research, and instructional design: Some food for thought. Instr Sci 38:105–134.

DeLeeuw KE, Mayer RE. 2008. A comparison of three measures of cognitive load: Evidence for separable measures of intrinsic, extraneous, and germane load. J Educ Psychol 100:223–234.

Dias P, Gomes MJ, Correia AP. 1999. Disorientation in hypermedia environments: Mechanisms to support navigation. J Educ Comput Res 20:93–117.

Dindar M, Kabakçı Yurdakul I, İnan Dönmez F. 2015. Measuring cognitive load in test items: static graphics versus animated graphics. J Comput Assist Learn 31:148–161.

Eva KW, MacDonald RD, Rodenburg D, Regehr G. 2000. Maintaining characteristics of effective clinical teachers in computer assisted learning environments. Adv Health Sci Educ Theory Pract 5:233–246.

Fisk AD, Derrick WL, Schneider W. 1986. A methodological assessment and evaluation of dual-task paradigms. Curr Psychol Res Rev 5:315–327.

Garg A, Norman GR, Spero L, Maheshwari P. 1999. Do virtual computer models hinder anatomy learning. Acad Med 74:S87–S89.

Goh HT, Gordon J, Sullivan KJ, Winstein CJ. 2014. Evaluation of attentional demands during motor learning: Validity of a dual-task probe paradigm. J Mot Behav 46:95–105.

Grunwald T, Corsbie-Massay C. 2006. Guidelines for cognitively efficient multimedia learning tools: Educational strategies, cognitive load, and interface design. Acad Med 81:213–223.

Gwizdka J. 2010. Distribution of cognitive load in web search. J Am Soc Inform Sci Tech 61:2167–2187.

Gwizdka J, Lopatovska I. 2009. The role of subjective factors in the information search process. J Am Soc Inform Sci Tech 60:2452–2464.

Hegarty M, Shah P, Miyake A. 2000. Constraints on using the dual-task methodology to specify the degree of central executive involvement in cognitive tasks. Mem Cognit 28:376–385.

ISO 9241-11. 1998. Ergonomics Requirements for Office with Visual Display Terminals (VDTs) – Part 11: Guidance on Usability. 1998 Ed. Geneva, Switzer- land: International Organization for Standardization. 22 p.

Josephsen J. 2015. Cognitive load theory and nursing simulation: An integrative review.

Clin Simulat Nurs 11:259–267.

Kerr B. 1973. Processing demands during mental operations. Mem Cognit 1:401–412.

Khalil MK, Paas F, Johnson TE, Payer AF. 2005. Design of interactive and dynamic anatomical visualizations: The implication of cognitive load theory. Anat Rec 286B:15–20.

Kim YM, Rieh SY. 2005. Dual-task performance as a measure for mental effort in library searching and web searching. In: Proceedings of the 68th Association for Information Science and Technology Annual Meeting (ASIS&T 2005); Sparking Synergies: Bringing Research and Practice Together; Charlotte, NC, 2005 Oct 28 - Nov 2. Volume 42. Association for Information Science and Technology, Silver Spring, MD.

Knox A, Eliasz K, Lineberry M, Tekian A, Anastakis D, Brydges R. 2014. If a picture is worth a thousand words, is a video worth two thousand pictures? Novices experience similar cognitive load when using dynamic or static multimedia to learn surgical skills. In: Abstract book of the Association for Medical Educators in Europe (AMEE 2014) Conference; Milan, Italy, 2014 Aug 30 - Sept 3; Abstract 2I2 (23039). Association for Medical Education in Europe: Dundee, Scotland, UK.

Lahtinen TMM, Koskelo JP, Laitnen T, Leino TK. 2007. Heart rate and performance during combat missions in a flight simulator. Aviat Space Environ Med 78:387–391.

Levinson AJ, Weaver B, Garside S, McGinn H, Norman GR. 2007. Virtual reality and brain anatomy: A randomized trial of e-learning instructional designs. Med Educ 41:495–501.

Levy J, Pashler H. 2001. Is dual-task slowing instruction dependent? J Exp Psychol Hum Percept Perform 27:862–869.

Luursema J-M, Verwey WB, Kommers PAM, Geelkerken RH, Vos HJ. 2006. Optimizing conditions for computer-assisted anatomical learning. Interact Comput 18:1123–1138.

MacLeod CM. 1998. Training on integrated versus separated Stroop tasks: The progression of interference and facilitation. Mem Cognit 26:201–211.

MacLeod CM. 2005. The Stroop task in cognitive research. In: Wenzel A, Rubin DC (Editors). Cognitive Methods and Their Application to Clinical Research. 1st Ed. Washington DC: American Psychological Association. p 17–40.

O'Byrne PJ, Patry A, Carnegie JA. 2008. The development of interactive online learning tools for the study of anatomy. Med Teach 30:260-271.

Oviatt SL. Human-centered design meets cognitive load theory: designing interfaces that help people think. In Proceedings of the 14th annual ACM International

Conference on Multimedia (MM ’06); New York, NY; 2006 Oct 23-27; p 871–880. Association for Computing Machinery: New York, NY.

Paas F, Renkl A, Sweller J. 2004. Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture. Instr Sci 32:1-8.

Paas F, Tuovinen J, Tabbers H, van Gerven PWM. 2003. Cognitive load measurement as a means to advance cognitive load theory. Educ Psychol 38:63–71.

Pashler H. 1994. Dual-task interference in simple tasks: data and theory. Psychol Bull 116:220.

Posner MI, Boies SJ. 1971. Components of attention. Psychol Review 78:391.

Rich P, Guy R. 2013. A “Do-It-Yourself” interactive bone structure module: Development and evaluation of an online teaching resource. Anat Sci Educ 6:107-113.

Stroop JR. 1935. Studies of interference in serial verbal reactions. J Exp Psychol 18:643-662.

Stull AT, Mayer RE. 2007. Learning by doing versus learning by viewing: Three experimental comparisons of learner-generated versus author-provided graphic organizers. J Educ Psychol 99:808-820.

Sweller J, Ayres P, Kalyuga S. 2011. Cognitive Load Theory. New York, NY: Springer Science+Business Media. 273 p.

Sweller J, van Merriënboer JJG, Paas F. 1998. Cogntive architecture and instructional design. Educ Psychol Rev 10:251–296.

Tam MD, Hart AR, Williams S, Heylings D, Leinster S. 2009. Is learning anatomy facilitated by computer-aided learning? A review of the literature. Med Teach 31:e393–e396.

van Merriënboer JJG, Sweller J. 2005. Cognitive load theory and complex learning: Recent developments and future directions. Educ Psychol Rev 17:147–177.

van Merriënboer JJG, Sweller J. 2010. Cognitive load theory in health professional education: Design principles and strategies. Med Educ 44:85–93.

Wastlund E, Norlander T, Archer T. 2008. The effect of page layout on mental workload: A dual-task experiment. Comput Hum Behav 24:1229–1245.

Wong SK, Nguyen TT, Chang E, Jayaratna N. 2003. Usability metrics for e-learning. In: Meersman R, Tari A (Editors). On the Move to Meaningful Internet Systems 2003: OTM 2003 workshops. OTM Confederated International Workshops HCI-SWWA, IPW, JTRES, WORM, WMS and WRSM 2003 Catania, Sicily, Italy, November 3–7, 2003, Proceedings. 1st Ed. Heidelberg, Germany: Springer-Verlag. p 235–252.

Chapter 3

3 The Anatomy of E-Learning Tools: Does software usability influence learning outcomes?

This chapter describes the development and testing of a novel dual-task paradigm, which was designed, in part, using the solutions identified in Chapter 2, to assess the effect of two commercial anatomical e-learning tools (Netter's 3D Interactive Anatomy and A.D.A.M. Interactive Anatomy) on learner cognitive load and spatial ability.[3]

3.1 Literature Review

Competing interests and responsibilities of today's learners have propelled the movement of post-secondary courses into the online environment, and in the anatomical sciences, e-learning tools have become a critical component of teaching the intricacies of the human body when classroom space and cadaveric resources are limited (Toynton, 2005; Burguillo, 2010; Dahlstrom, 2012). Yet, as e-learning tools gain popularity, questions remain: Does the design of an e-learning tool influence learning? For example, does a complex interface, which has high interactivity, benefit a learner more so than if they were to use a simplistic e-learning tool?

In the sciences, and specifically anatomy, commercial e-learning tools feature interactive interfaces (2- or 3-dimensional) that offer numerous buttons and functions to virtually dissect a computer generated human. Given these highly variable interfaces, an important characteristic to consider when assessing the impact of e-learning tool design is a learner's visuo-spatial ability. Visuo-spatial ability is defined as the ability to mentally manipulate an object and its spatial relationships and perform a mental transformation of that representation (Carpenter and Just, 1986; Mayer and Sims, 1994; Luursema et al.,

[3] A version of this chapter has been published in the journal Anatomical Sciences Education. For the permission approval notice from the publisher see Appendix B.

2006). In anatomy, visuo-spatial ability can be further classified as the ability to mentally manipulate the three-dimensional properties of different anatomical structures and their spatial relationships in the human body. Previous studies have demonstrated a significant, positive correlation between anatomy learning and visuo-spatial ability (Rochford, 1985; Garg et al., 1999a; 1999b). However, what is unknown is the extent to which learning from an e-learning tool is impacted by a student's spatial ability and if that learning is differentially influenced by spatial ability based on the e-learning tool interface (e.g. complex versus simplistic).

To understand how the different designs of e-learning interfaces impact learning, it is necessary to address the theory of cognitive load. Cognitive load theory (CLT) is used by educational researchers to inform instructional design with the goal of modulating the cognitive load placed on a student's working memory during e-learning software use. Since humans have limited working memory resources, which can simultaneously process 3-4 chunks of information at a time, learning situations that present more information than the working memory resources can process have been shown to disrupt learning (Miller 1956; Sweller et al., 1998; Cowan, 2001; Mayer, 2002; Baddeley, 2003; Lahtinen et al., 2007; DeLeeuw and Mayer, 2008). Under the CLT definition of learning, only information that is successfully processed by the working memory is integrated into schemas in the learner's long-term memory. Thus if e-learning interfaces require a learner to search for information or press numerous buttons to uncover information required for task completion, the learner uses their limited working memory-resources to process material that is not essential (Anderson, 1987; van Merriënboer and Sweller, 2010). As a result, fewer cognitive resources will be available to attend to and process the domain-specific knowledge being learned (Anderson, 1987; Mayer and Sims, 1994; Mayer, 2008; van Merriënboer and Sweller, 2010).

The benefits and challenges of using dual-task paradigms in order to objectively and quantifiably assess cognitive load have been discussed in Chapters 1 and 2. In summary, tasks that share the same working memory resources (e.g., if the tasks must be interpreted visually) and are performed concurrently can interfere with each other; that is, if two tasks are being performed simultaneously, then there is less processing capacity (i.e., fewer working memory resources) available for each individual task than there would be if each task was completed in isolation (Pashler, 1994). Theory would predict that performance on the concurrently running tasks would be impaired in comparison with performance when said tasks are completed in isolation (Stroop, 1935; Pashler, 1994). If the primary learning task (i.e. learning the anatomy of a specific joint) and the cognitive resources it requires are held constant, dual-task conditions that use *dissimilar* e-learning tools (i.e. tools with different interfaces) should, in theory, provide a measure of the cognitive load associated with the design of each software package. To examine this theoretical dogma, learning and observation task performance variables (e.g., knowledge acquisition scores, observation task reaction time and error rate, etc.) are compared across single-task and dual-task conditions. Through the extension of Kerr's (1973) reasoning and in consideration of the capacity sharing model of dual-task interference, reaction times should theoretically be slower or more inaccurate when the observation task is performed simultaneously with the cognitively demanding e-learning tool interface than compared with when the observation task is performed in isolation, or in combination with a less cognitively demanding e-learning tool (Posner and Boies, 1971; Pashler, 1994; Brünken et al., 2003; de Jong, 2010).

Dual-task has been empirically shown to be a suitable approach for evaluating cognitive load during library system/Web searches and multimedia learning in the subject areas of mathematics, physiology, and arts and culture (Brünken et al., 2002, 2003; Kim and Rieh, 2005; Oviatt, 2006; DeLeeuw and Mayer, 2008; Gwizdka and Lopatovska, 2009). However, no studies to date, with the exception of our previous work (Chapter 2), have attempted to use this technique to assess cognitive load during educational, commercial anatomical e-learning tool use.

3.1.1 Objectives

Based on our findings outlined in Chapter 2, the study presented here utilized a novel dual task methodology, corrected to address confounding variables identified in Study I, to re-examine two commercial anatomical e-learning tools. Specifically, the objective of Study II was to use a dual-task paradigm with a modified Stroop test, simplified anatomical concepts and two single-task conditions to examine two commercial anatomical e-learning tools (Netter's 3D Interactive Anatomy and A.D.A.M. Interactive Anatomy) to determine the effect of their design on learner cognitive load during two joint learning exercises (elbow and knee). We hypothesized that longer reaction times on a visual observation task would be associated with the more complex anatomical software (Netter's 3D Interactive Anatomy), which would indicate a higher cognitive load imposed by the anatomy software and interfere with learning, thus resulting in lower post-test scores.

3.2 Methodology

The research protocol was approved by the Office of Research Ethics at The University of Western Ontario, Canada (Appendix E).

3.2.1 Participants and Recruitment

All students in the Fall 2014 undergraduate anatomy course Systemic Human Anatomy (ANATCELL3319) at The University of Western Ontario were eligible to participate in the study. Of those students in the course 25.49% consented to participate (n = 78). Students were recruited through an in-class announcements and e-mails from the first author. In accord with The University of Western Ontario Research Ethics Board, the first author had no relationship with the students and was not associated with the course.

3.2.2 Systemic Human Anatomy Course Description

The course from which participants were recruited in this study, Systemic Human Anatomy, is a full credit, third year undergraduate course offered by the Department of Anatomy and Cell Biology at The University of Western Ontario, Canada. It is comprised of biweekly, 50-minute didactic lectures (50 hours total) in conjunction with a weekly one-hour laboratory demonstration (23 hours total) over a 26-week period. The first 13 weeks of the course covers the central and peripheral nervous systems, special senses and the musculoskeletal system of the head and thorax. The second 13 weeks covers the musculoskeletal system of the upper and lower limbs as well as the circulatory, respiratory, digestive, urinary and reproductive systems. This course is offered in a face-to-face (F2F) and online format. Every didactic lecture is streamed live and then archived using Blackboard Collaborate 12 for use by both the online and F2F students (Blackboard Inc., Washington, DC). The audio/video equipment required for simultaneous delivery of F2F lectures using BBC has been previously described by Barbeau et al. (2013). Additionally, a description of the development and delivery of the online anatomy laboratories has been detailed by Attardi and Rogers (2015).

Students who participated in the study did so in the final week of the first half of the course. At the time of testing, participants had not yet received a formal lecture on the joints (wrist, elbow, and knee) used in this study, however, participants had received a formal lecture on anatomical terminology (e.g. anterior, posterior, supination, pronation etc.). Participants can be considered to have a low-level of experience in anatomy, and thus possess a small amount of domain-specific knowledge (Mayer and Sims, 1994).

3.2.3 Experimental Design Overview

Participants were asked to complete two pre-test measures, inclusive of a demographic questionnaire and a mental rotations test (MRT). The demographic questionnaire asked participants to declare if they had used anatomy e-learning tools in the past, and if so, which products. The revised Vandenberg & Kuse Mental Rotations Test-A (MRT) was administered to participants as a measure of spatial ability prior to the study (Peters et al., 1995; Fig. 3.1).

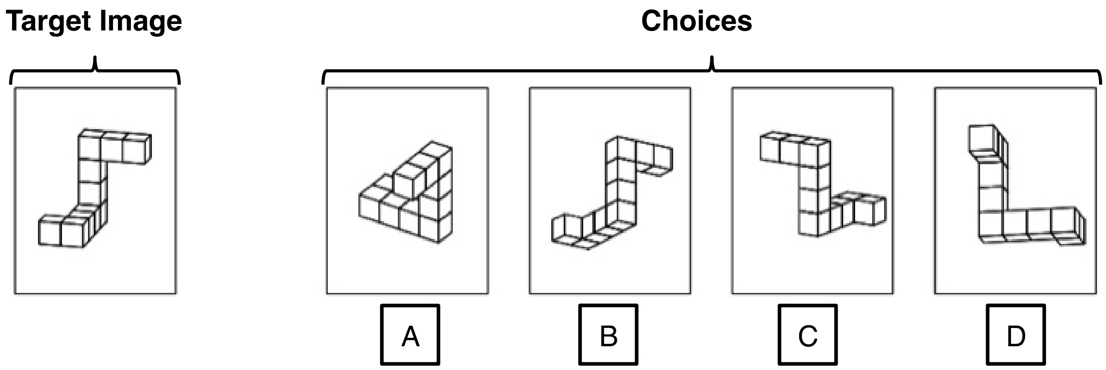


Figure 3.1: An example from the Mental Rotations Test.

Each of the 24 MRT items redesigned by Peters et al. (1995) were presented individually on a computer screen and participants were given 6 minutes to answer as many questions as possible. One point was awarded per question if both choice figures that matched the target image were identified correctly, thus the maximum score obtainable on the MRT was 24.

To assess the cognitive load that each e-learning tool's design (A.D.A.M. Interactive Anatomy and Netter's 3D Interactive Anatomy; Figure 2.1) placed on the learner, participants were involved in four separate testing conditions, including two single-task conditions, where a visual observation task (VOT) and then a joint learning task were completed in isolation, followed by two dual-task conditions, where a VOT and a joint learning task were completed simultaneously (Table 3.1). In both dual task conditions participants were randomly assigned to explore the anatomy of two joints, the elbow and the knee, using two dissimilar e-learning tools.

Table 3.1: E-Learning Tool and Joint Learning Exercise

Participant	Condition 1: VOT in isolation	Condition 2: Wrist learning task in isolation	Condition 3: E-learning tool and joint learning exercise	Condition 4: E-learning tool and joint learning exercise
1	✓	✓	Elbow in A.D.A.M. Interactive Anatomy	Knee in Netter's 3D Interactive Anatomy
2	✓	✓	Knee in A.D.A.M. Interactive Anatomy	Elbow in Netter's 3D Interactive Anatomy
3	✓	✓	Elbow in Netter's 3D Interactive Anatomy	Knee in A.D.A.M. Interactive Anatomy
4	✓	✓	Knee in Netter's 3D Interactive Anatomy	Elbow in A.D.A.M. Interactive Anatomy

Each participant in this study completes Conditions 1 through 4. In both dual task conditions participants are randomly assigned to explore the anatomy of two joints (elbow and knee) using two different learning methods (A.D.A.M. Interactive Anatomy and Netter's 3D Interactive Anatomy). Due to this cross over design Conditions 3 and 4 vary depending on the participant.

VOT, visual observation task.

3.2.4 Experimental Station Design

The research station used in this study consisted of a 15.6-inch Lenovo laptop (ThinkPad E531, Lenovo, Morrisville, NC; Monitor 1) with Intel dual-core processor running Windows 7 (Microsoft Corp., Redmond, WA) connected to an external mouse. The laptop was used to display all pre-tests and post-tests in addition to the e-learning tools. A 26-inch LG Flatron Wide monitor (LG Electronics Inc., Seoul, Korea; Monitor 2) was placed directly behind the 15.6-inch Lenovo laptop and was connected to a second Lenovo laptop which was used to run E-Prime® 2.0 Professional (Psychology Software Tools, Inc., Sharpsburg, PA) in the background while the external monitor (e.g. Monitor 2) was used to display the VOT to participants (Fig. 3.2).

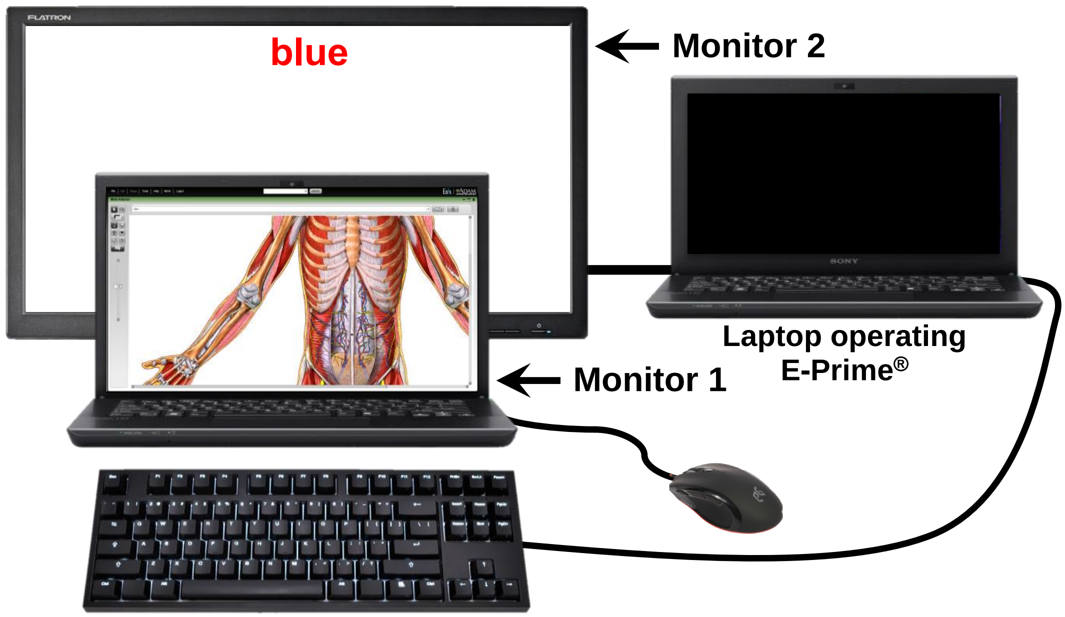


Figure 3.2: Revised design of dual-task experimental station.

During the visual observation task (VOT) in isolation (Condition 1), participants responded to a modified Stroop test that appeared on Monitor 2, no images were shown on Monitor 1 during this time. In the single-task condition where the a learning task about the wrist was completed in isolation (Condition 2), an image was displayed on the Monitor 1 and no images were shown on Monitor 2 positioned behind. In the dual-task testing (Conditions 3 and 4), where participants completed both a visual observation task and joint learning exercise in tandem, the visual observation task was displayed on Monitor 2, while, at the same time, the assigned e-learning tool was displayed on Monitor 1.

3.2.5 Condition 1: Visual Observational Task in Isolation (Single-Task Condition)

The VOT single-task condition was used to estimate participants' average response times when 100% of their visual working memory resources were available. The VOT used in this study was a modified Stroop test. Based on the classic color-naming test (Stroop, 1935), a modified Stroop test is a simplified paradigm that makes the test less cognitively demanding and a better fit as a 'probe' task (i.e. observation task) under the dual-task paradigm (Chapter 2; Van Nuland and Rogers, 2016). In this study, the Stroop test was modified to its simplest form, in which participants were asked to respond to color word (red, blue, green or yellow) that appeared on Monitor 2 (Fig. 3.2). The color word appeared in lower case and was shown in one of four ink colors (red, blue, green or yellow; Fig. 3.3). E-Prime® 2.0 Professional was used to program the image changes and record the time lapse between each image change and participant response.

Participants were introduced to the VOT during a practice round to ensure that they were acclimatized to the display set-up and response characteristics of the task (MacLeod, 1998; 2005). The relative robusticity of Stroop test in the face of practice indicates that familiarity with the task is less likely to impact the total cognitive processing load invested in the VOT over time (Brünken et al., 2002; Kim and Rieh, 2005; MacLeod, 1998; 2005; DeLeeuw and Mayer, 2008). Following the practice round, which consisted of 8 modified Stroop stimuli, participants were exposed to 10 additional modified Stroop stimuli (50% congruent stimuli and 50% incongruent stimuli), which were used to establish a stable recording of participant's baseline reaction times on the VOT. Equal proportions of congruent and incongruent stimuli were utilized for all VOTs, as is common in cognitive research (MacLeod, 2005). Each participant's average baseline reaction time was then compared to their reaction time on the VOT during the dual-task testing conditions (Conditions 3 and 4). Since participants must then divide working memory resources between these two tasks, cognitive load theory predicts that reaction times on the VOT should be slower when cognitive load imposed by the learning tool is higher (Posner and Boies, 1971; Kerr, 1973).

A visual stimulus, instead of an auditory stimulus, was chosen for this study because its optical nature makes it ideal to estimate the impact of a visually based e-learning tool on the resources of the visual subsystem of the working memory (Fisk et al., 1986; Brünken et al., 2002; Kim and Rieh, 2005; DeLeeuw and Mayer, 2008). In regards to the VOT, the use of a modified, rather than a classic Stroop test was intentional as research indicates that the modified version requires fewer cognitive resources than its classical counterpart, therefore reducing the risk that it will impact learning task performance artificially (Kerr, 1973; Brünken et al., 2003; for further discussion on VOT design see Section 2.4).

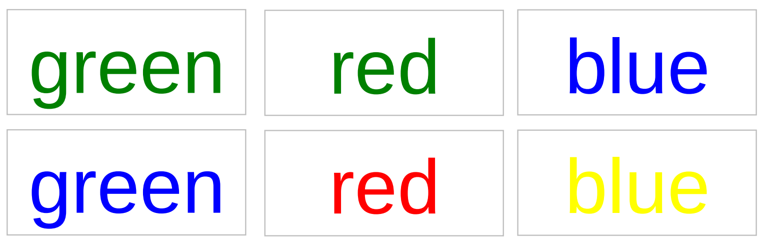


Figure 3.3: Examples of modified Stroop test stimuli.

Participants were asked to press the up arrow if the ink color was the same as the word, known as a congruent stimulus, or the down arrow if the ink color is different from the word, known as an incongruent stimulus. Each image was presented for 5-9 seconds and was followed by a blank interval of 15-29 seconds. Research has suggested that such a range would be short enough for a primary (learning) task to affect performance on the VOT but still allow for close to normal performance during the learning task (Wastlund et al., 2008; Gwizdka, 2010).

3.2.6 Condition 2: Joint Learning Task in Isolation (Single-Task Condition)

Following completion of the VOT in isolation (Condition 1), participants were asked to complete a second single-task condition involving learning the anatomical structure of the bony wrist joint. Prior to the start of this learning task, participants were given 10-minutes to complete 10 multiple-choice questions, each with its own cadaveric image, to assess their baseline level of anatomical knowledge of the wrist joint. Questions were related to identification of the carpal bones and whether it was an anterior or posterior view of the wrist joint. To ensure the quality and scope of the questions utilized in this study, a qualified anatomist, unrelated to the study, validated the questions used to assess participant knowledge of the bony wrist.

Once the baseline was established, participants were given the opportunity to learn the anatomy of the bony wrist joint and were provided with an instruction page that detailed the two objectives of the wrist exercise: (1) Identify bones of the wrist, known as the carpal bones (of which there are 8), in both the anterior and posterior view; and (2) Distinguish between an anterior versus a posterior view of the joint (Appendix F). Participants were presented with a labeled, static 2-dimensional textbook image of the bony wrist joint on Monitor 1 (Fig. 3.2), which they were permitted to study for 12-minutes. The textbook image showed a palmar and dorsal view the bony hand with all carpal bones labeled accordingly.

Upon completion of the wrist learning exercise, participants were asked to complete a one-minute math worksheet containing addition/subtraction problems consistent with a Grade 5 math level. The math sheet was designed to erase memorized information held in the learner's short-term memory (working memory) (Fisk et al., 1986). Participants then completed a post-knowledge test to assess how studying from a static 2-dimensional image impacted their anatomical knowledge of the bony wrist. The 10-minute post-knowledge quiz was based on the same questions as the anatomical knowledge baseline quiz, however, the questions were presented in a scrambled format.

3.2.7 Conditions 3 and 4: Visual Observation Task and Joint Learning Exercise Combined (Dual-Task Condition)

The final testing conditions involved the completion of a joint learning task and a visual observation task simultaneously using a dual task paradigm (Fig. 3.2). Participants were randomly assigned to explore both the elbow and knee joints, using different commercial e-learning software packages (Table 3.1). Participants studied the first joint using one e-learning tool during the first dual-task condition and the second joint and e-learning tool during the following dual-task condition. The elbow and knee joints were chosen because they are both complex hinge joints with unique ligaments. The knee is arguably the more complex hinge joint, however, it is more commonly understood by students prior to their exposure to a formal anatomy course.

Prior to the beginning of each dual task condition, participants were asked to complete a multiple choice baseline anatomy knowledge test based on the respective joint they were to learn about. Each baseline test consisted of 10 questions, each associated with a cadaveric picture, and was designed to assess their level of anatomical knowledge of the elbow or knee joint prior to e-learning tool exposure. Questions related to the identification of articulating bones at each joint, associated bony landmarks and whether the joint originated from the left or right side of the body (Appendix G and H). Again, to ensure the quality and scope of the questions utilized in this study, a qualified anatomist, unrelated to the study, validated the questions used to assess the bony elbow and knee.

Following each baseline knowledge test, participants were given the opportunity to learn about a joint from a pre-assigned e-learning tool (Table 3.1). Participants were provided with an instruction page that briefly outlined how to manipulate the basic functions of the e-learning tool and included three guiding objectives: (1) Identify the bones that articulate at the (elbow or knee) joint; (2) Identify which side (left or right) a joint originates from; and (3) Identify the bony landmarks on the bones immediately surrounding the (elbow or knee) joint. Using dual-task parameters proposed in our previous study (Chapter 2; Van Nuland and Rogers, 2016), participants were given 12 minutes to explore their pre-assigned joint (elbow or knee) using the e-learning tool. At the same time, participants were also asked to respond to the VOT described above (Fig. 3.2).

Upon completion of each combined dual-task exercise, participants were asked to complete another 1-minute math worksheet followed by a scrambled version of knowledge questions administered during the baseline test, however, only questions relevant to the joint the participant just learned were displayed. Again, participants were given 10 minutes to complete the post-test questions in order to assess how studying from a different e-learning tool impacted a user's anatomical knowledge of the knee and elbow joint. This sequence was repeated for the second dual task condition, which involved the remaining joint and the second e-learning tool (e.g. if, during the first dual-task condition, a student studied the elbow joint using A.D.A.M. Interactive Anatomy, then they would study the knee joint using Netter's 3D Interactive Anatomy; Table 3.1).

Under the theories of cognitive load and dual-task research, if an e-learning tool imposes a higher extraneous cognitive load on a learner (i.e. if it has a confusing menu bar and/or unclear buttons), said learner will have fewer working memory resources to devote to: (1) the content within the learning tool; and, (2) the VOT task in the background. Thus, learners who are exposed to an e-learning tool that imposes high cognitive load will have low performance scores and slower reaction times, than when the same learner used a simple e-learning tool that imposed a low cognitive load (Fig. 2.3).

3.2.8 Analysis

Participant VOT reaction times in the single-task condition were averaged and compared to reaction times when the VOT was paired with a joint learning task in the dual-task condition. The reaction times gather during the single-task and dual-task conditions were compared by e-learning tool (A.D.A.M. Interactive Anatomy or Netter's 3D Interactive Anatomy), joint learning exercise (knee or elbow) and by dual-task condition (first dual-task or second dual-task condition) using one-way repeated measures ANOVAs. Reaction times were also compared by joint learning task and e-learning tool using independent t-tests.

Participant pre-test and post-test scores, as well as gain scores, were also compared by e-learning tool, joint learning exercise, and by dual-task condition using one-way repeated measures ANOVAs. Performance scores were also compared to participant's spatial ability scores using linear regression analysis.

3.2.9 Exclusion Criteria

Participants were excluded from analysis if: 1) they failed to complete all tests, 2) they self-identified as color blind or 3) if their performance on the visual observation task was more than two standard deviations away from the mean.

3.3 Results

3.3.1 Demographics

Of the 78 Systemic Human Anatomy students who participated in the study, 70 individuals had usable data sets that passed the exclusion criteria (n = 70, M to F 30:40, mean age = 21.5 years). Of those who participated, 64.3% were third year undergraduate students, 32.9% were fourth year undergraduate students while 2 participants chose not to declare their standing. Approximately 55.7% of the participants were registered in the online portion of the Systemic Human Anatomy course, while the remaining students were registered in the face-to-face section. No participant involved in the study had received formal anatomy lectures on the joints tested in this study. Sample sizes were determined

When participants were asked about past e-learning tool use, 48.6% indicated they had not used e-learning tools in the past, however, 45.7% indicated they had (4 students either could not remember or did not answer). Of those participants that had utilized e-learning tools in the past, 71.9% reported having used Netter's 3D Interactive Anatomy to study anatomy. This was not surprising, as those students enrolled in the online section of the course had been using Netter's 3D Interactive Anatomy as part of their online laboratory experience. Approximately 19 % of participants reported having used other anatomy e-learning tools including Anatomy TV (Primal Pictures), Anatomy One and Visible Body. The remaining 9.3% of those participants that had used e-learning tool in the past could not remember which anatomical e-learning tools they had used. When participants were questioned about their comfort level with computer technology, 47.1% indicated they were somewhat comfortable while the majority (52.9%) indicated that they were extremely comfortable.

3.3.2 Visual Observation Task Reaction Times Assessed by E-Learning Tool

In the visual observation single-task condition, where the VOT was completed in isolation (VOT baseline; Condition 1), the mean reaction time (mean ±SD) across all participants (*n* = 70) was 875 ±210 milliseconds. Mean VOT reaction times in the dual-task condition were virtually identical when participants used Netter's 3D Interactive Anatomy (1518 ±356 milliseconds) or A.D.A.M. Interactive Anatomy (1530 ±414 milliseconds). A one-way repeated measures ANOVA with a Greenhouse-Geisser correction determined that VOT reactions times were significantly slower for each e-learning tool compared to baseline values ($F(1.83, 126.53) = 163.37$, $p < 0.001$).

3.3.3 Visual Observation Task Reaction Times Assessed by Joint Learning Task

Using a one-way repeated measures ANOVA, VOT baseline values were also compared to dual-task VOT reaction times (mean ±SD) when participants learned the elbow joint (1540 ±424 milliseconds) and knee joint (1507 ±343 milliseconds). Again, while reaction times for each joint were significantly slower than baseline values ($F(2, 138) = 164.32$, $p < 0.001$), there was no significant difference between elbow and knee VOT reaction times. When reaction times were compared by dual-task condition (Conditions 3 and 4), similar results were found. Baseline reaction times were significantly faster than reaction times in both dual-task conditions, however, when the dual-task conditions were compared to each other, no significant difference was found (data not shown).

3.3.4 Visual Observation Reaction Times Assessed by Joint Learning Task and E-Learning Tool

Dual-task VOT reaction times were further broken down by joint learning task and e-learning tool (Table 3.2). No significant differences were found between VOT reaction times when the elbow and knee was studied within Netter's 3D Interactive Anatomy or A.D.A.M. Interactive Anatomy.

Table 3.2: Visual Observation Task Reaction Times Assessed by Joint Learning Exercise and E-Learning Tool

Joint Learning Task	Condition	Number of Participants	VOT Reaction Time (ms) (mean ±SD)
Elbow	Netter's 3D Interactive Anatomy	38	1533 ± 382
	A.D.A.M. Interactive Anatomy	32	1550 ± 475
Knee	Netter's 3D Interactive Anatomy	32	1500 ± 328
	A.D.A.M. Interactive Anatomy	38	1513 ± 360

Independent t-tests were used to analyze the dual-task reaction times in Conditions 3 and 4.

No significant differences were found.

VOT, visual observation task.

3.3.5 Baseline, Post-Test, and Gain Scores Assessed by E-Learning Tool

Baseline, post-test and overall gain scores (mean ±SD) were compared when students used a 2-dimensional textbook image, Netter's 3D Interactive Anatomy and A.D.A.M. Interactive Anatomy to study and no significant differences were found (Table 3.3).

When baseline, post-test and gain scores were compared by single and dual-task conditions (i.e. Conditions 2, 3 and 4), again no significant differences were found between related anatomical assessment scores (data not shown).

Table 3.3: Pre-Test, Post-Test and Gain Scores Assessed by E-Learning Tool (+ Visual Observation Task)

Condition	Baseline Score (mean ±SD)	Post-Test Score (mean ±SD)	Gain Scores (mean ±SD)
2-D Textbook Image	3.10 ± 2.21	7.67 ± 2.14	4.57 ± 2.86
Netter's 3D Interactive Anatomy + VOT	3.19 ± 2.33	7.80 ± 1.81	4.61 ± 2.89
A.D.A.M. Interactive Anatomy + VOT	3.20 ± 2.24	7.86 ± 1.86	4.66 ± 2.51

A one-way repeated measures ANOVAs with a Greenhouse-Geisser was used to analyze performance data.

No significant differences were found; *n* = 70. All pre-tests and post-tests were out of 10 marks total.

VOT, visual observation task.

3.3.6 Baseline, Post-Test, and Gain Scores Assessed by Joint Learning Exercise

Baseline, post-test and gain scores were also analyzed by joint learning task (e.g. wrist, elbow and knee), regardless of e-learning tool (Table 3.4). A one-way repeated measures ANOVA with a Greenhouse-Geisser correction indicated a significant difference between joint learning exercise pre-test scores ($F(1.79, 123.49) = 16.15$, $p < 0.001$), with knee pre-test scores significantly higher than the wrist and elbow ($p \leq 0.001$; post hoc test with Bonferroni correction). No significant difference was found between wrist, knee and elbow post-test scores, however, there was a significant difference between joint learning exercise gain scores ($F(1.57, 108.42) = 14.05$, $p < 0.001$), with higher differences seen with the wrist and elbow than the knee (post hoc with Bonferroni corrections; $p = 0.011$ and $p < 0.001$, respectively). However, no significant difference was found between wrist and elbow gain scores.

Table 3.4: Pre-Test, Post-Test, and Gain Score Assessed by Joint Learning Task (+ Visual Observation Task)

Condition	Baseline Score (mean ±SD)	Post-Test Score (mean ±SD)	Gain Scores (mean ±SD)
Wrist	3.10 ± 2.21[a]	7.67 ± 2.14	4.57 ± 2.86[c]
Elbow + VOT	2.43 ± 1.70[b]	8.23 ± 1.93	5.80 ± 2.70[d]
Knee + VOT	3.96 ± 2.53[a,b]	7.43 ± 1.63	3.47 ± 2.15[c,d]

One-way repeated measures ANOVAs with Greenhouse-Geisser and Bonferroni corrections were used to analyze performance data.

[a,b]Baseline Test Scores: Knee baseline scores were found to be significantly higher than wrist and elbow baseline scores (*a:* $p = 0.001$; *b:* $p < 0.001$).

[c,d] Gain Scores: Knee gain scores were found to be significantly lower than wrist and elbow gain scores (*c:* $p = 0.011$; *d:* $p < 0.001$).

All pre-tests and post-tests were out of 10 marks total. Note that identical superscripts are significantly different; $n = 70$.

VOT, visual observation task.

3.3.7 Baseline, Post-Test and Gain Scores Assessed by Joint Learning Task and E-Learning Tool

Post-test scores were found to be significantly higher when students used Netter's 3D Interactive Anatomy to study the elbow joint than when they used the same tool to study the knee joint ($t(64.71) = -2.35$, $p = 0.022$; Table 3.5). However, no such difference was found when looking at the joints studied using A.D.A.M. Interactive Anatomy. Gain scores were also significantly higher when students studied the elbow joint using Netter's

3D Interactive Anatomy than when they studied the knee using the same tool ($t(66.65) = -4.22$, $p < 0.001$; Table 3.5). A similar pattern was also observed for A.D.A.M Interactive Anatomy gain scores, with elbow gain scores being significantly higher than knee gain scores ($t(68) = -3.88$, $p < 0.001$; Table 3.5). However, no significant difference, by way of independent samples t-tests, was found between e-learning tools.

Table 3.5: Baseline, Post-Test and Gain Scores Assessed by Joint Learning Task and E-Learning Tool.

Joint Learning Task	Condition	Number of Participants	Baseline Test Score (mean ±SD)	Post-Test Score (mean ±SD)	Gain Score (mean ±SD)
Elbow	Netter's 3D Interactive Anatomy	38	2.44 ± 1.97	8.24 ± 2.03[a]	5.79 ± 2.94[b]
	A.D.A.M. Interactive Anatomy	32	2.41 ± 1.34	8.22 ± 1.84	5.81 ± 2.41[c]
Knee	Netter's 3D Interactive Anatomy	32	4.06 ± 2.45	7.28 ± 1.35[a]	3.22 ± 2.14[b]
	A.D.A.M. Interactive Anatomy	38	3.87 ± 2.62	7.55 ± 1.84	3.68 ± 2.17[c]

Independent samples t-tests were used to analyze performance data.

[a]Post-Test Scores: Values with identical superscripts were significantly different ($p = 0.022$).

[b,c]Gain Scores: Values with identical superscripts were found to be significantly different ($p < 0.001$)

3.3.8 Mental Rotations Test Scores versus Post-Test Scores Assessed by E-Learning Tool and Joint

The mean mental rotations test (MRT) score (±SD) across all participants was 9.84 ±4.17. No significant difference between genders was detected by means of a student t-test (female MRT score: 10.30 ±4.08, male MRT score: 9.23 ±4.27). When mental rotations test scores were plotted against A.D.A.M. Interactive Anatomy and Netter's 3D

Interactive Anatomy post-test scores, linear regression analysis established that, while MRT scores did not significantly predict A.D.A.M. Interactive Anatomy post-test scores (Fig. 3.4A), they did predict Netter's 3D Interactive Anatomy post-test scores ($F(1,68) = 7.81$, $p = 0.007$), with an R^2 of 0.103 (Fig. 3.4B). When Netter's 3D Interactive Anatomy post-test scores were separated by joint and assessed using linear regression, the correlational significance was isolated to the elbow joint only, ($F(1,35) = 4.90$, $p = 0.034$), with an R^2 of 0.123. No such correlation was found when Netter's 3D Interactive Anatomy knee post-test scores were compared to participant spatial ability. When A.D.A.M. Interactive Anatomy post-test scores were separated by joint, linear regression established that MRT scores did not significantly predict specific joint post-test outcomes.

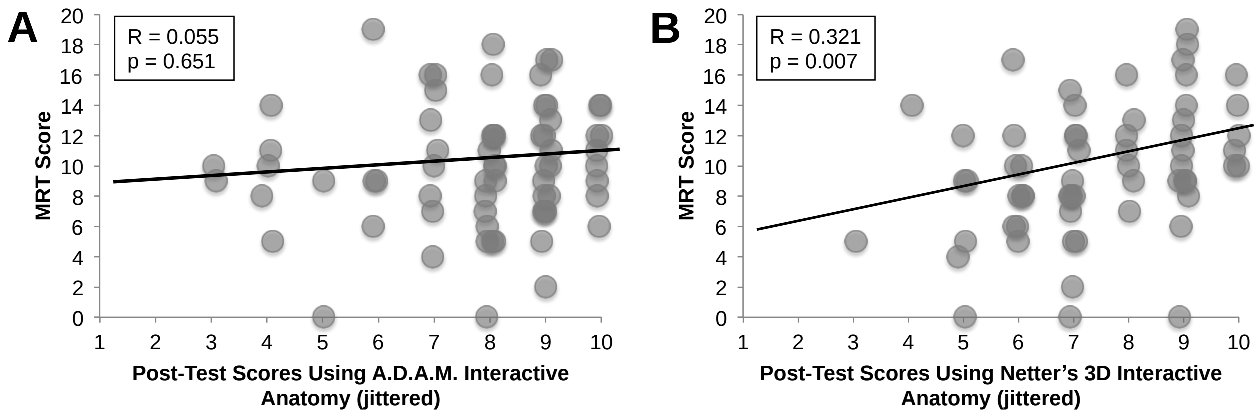


Figure 3.4: Correlation between participant mental rotation test scores and post-test scores according to e-learning tool.

Participant mental rotation test (MRT) scores were compared with their post-test performance scores when they learned using A.D.A.M. Interactive Anatomy (A) and Netter's 3D Interactive Anatomy (B). Post-test scores following Netter's 3D Interactive Anatomy utilization were significantly and positively correlated with a student's spatial ability, as determined by the MRT ($p = 0.007$). All pre-tests and post-tests were out of 10 marks total; $n = 70$.

3.4 Discussion

Dual-task paradigms have been used in previous studies to evaluate cognitive load differences between learning interfaces in web searches as well as physiology and cultural learning platforms (Brünken et al., 2002; 2003; Kim and Rieh, 2005). The aim of this study was to examine two commercial anatomical e-learning tools (Netter's 3D Interactive Anatomy and A.D.A.M. Interactive Anatomy) to determine the effect of their design on learner cognitive load during two joint learning exercises (elbow and knee), using a novel dual-task paradigm design, described by Van Nuland and Rogers (2016; Chapter 2). We hypothesized that the design of the Netter's 3D Interactive Anatomy interface would impose higher cognitive load than the A.D.A.M. Interactive Anatomy interface, thus resulting in longer VOT reaction times and lower post-test scores.

The methodology utilized in this study was designed to limit three important confounding variables including response automation of the visual observation task, task performance tradeoff during the dual-task conditions and the inherent cognitive load of the learning task itself. The assessment of the reaction times on the visual observation task (VOT) demonstrated no significant difference between first or second dual-task conditions. This suggests that the VOT required consistent and effortful processing in the working memory throughout the experiment, reducing response automation to negligible levels and improving the quality of the dual-task paradigm (Fisk et al., 1986; MacLeod, 2005). Furthermore, this novel paradigm was designed to detect task performance trade-off, a process through which participants sacrifice learning task performance in order to improve their performance on the VOT (Fisk et al., 1986). The pre-test, post-test and gain scores of the single-task learning condition involving the wrist were not significantly different from the pre-test, post-test or gain scores of the dual-task conditions, suggesting that the cognitive processing load invested for learning during both the single and dual-task conditions was equivalent (Fisk et al., 1986). In other words, participants maintained a consistent usage of working memory resources during each learning task across all conditions, suggesting that no performance trade-off occurred enabling VOT reaction times to be interpreted as a sensitive measure of cognitive load (Fisk et al., 1986; Hegarty et al., 2000).

Using this novel dual-task design, we investigated cognitive load during learner interactions with two commercial anatomical e-learning tools, Netter's 3D Interactive Anatomy and A.D.A.M. Interactive Anatomy, through the usage of a VOT. Not surprisingly, when learners performed the VOT simultaneously with a learning task, reaction times were significantly slower than when the VOT was completed in isolation. These results, which are consistent with previous dual-task studies using visual observation tasks, suggest that the learning task and VOT use the same working memory resources and that the VOT is a sensitive measure of cognitive load during processing of the joint learning task (Brünken et al., 2002).

Confirming the sensitivity of the VOT, reactions times during Netter's 3D Interactive Anatomy and A.D.A.M. Interactive Anatomy usage were then compared. Cognitive load theory indicates that e-learning tools which contain animations may impose extraneous cognitive load on the student since animations only provide transient information, meaning that once the animation has advanced beyond a specific frame, that frame is no longer available to the viewer and must be mentally reconstructed (Chandler and Sweller, 1991; Hegarty, 2004). Numerous studies have shown that multiple views of an animated structure in a 2-dimensional environment do not provide an instructional or performance advantage over that of key views represented by static images (Garg et al., 1999a; 1999b; Jain and Getis, 2003; Levinson, 2007; Vogel-Walcutt et al., 2010). Furthermore, research suggests systems with high interactivity may increase extraneous cognitive load levels in novice users, particularly if a learner has a poor ability to mentally rotate structures in space (Garg et al., 1999a; Levinson et al., 2007). Our initial hypothesis, based on e-learning tool usability studies, predicted that the Netter's 3D Interactive Anatomy interface would be associated with longer VOT reaction times than A.D.A.M. Interactive Anatomy due to its high navigational control and multiple viewing angles, which require more working memory resources. However, our dual-task paradigm did not detect any significant difference in terms of cognitive when using Netter's 3D Interactive Anatomy compared to A.D.A.M. Interactive Anatomy to study.

While these results may lead some readers to suggest that the cognitive load imposed by these two e-learning tools is similar, e-learning tool usability studies and studies comparing static to animated images do not support such a conclusion (Dias et al., 1999; Garg et al., 1999a; 1999b; Mayer, 2001; Wong et al., 2003; Khalil et al., 2005; Ardito et al., 2006; Grunwald and Corsbie-Massay, 2006; Levinson et al., 2007; van Merriënboer and Sweller, 2010; Dindar et al., 2014). It is the opinion of the authors that this result may be attributable to our study population. The reality is that today's university students generally have more exposure to technological interfaces during their education than their predecessors (Brown, 2000; Oblinger and Oblinger, 2005; Oblinger et al., 2005; Skiba and Barton, 2006). This daily exposure to different interfaces can increase user comfort navigating within and 'reading' from starkly different yet novel multimedia interfaces (Brown, 2000; Skiba and Barton, 2006). Learner experience and breadth of use with the Internet in almost every aspect of their everyday lives may explain why no differences in VOT reaction times were seen between the dissimilar e-learning tools used in this study (Helsper and Eynon, 2009). While current students may possess skills that enable them to navigate across different learning interfaces, the anatomy e-learning tools used in this study did not confer any instructional advantage over the static 2-dimensional image of this wrist. This finding is consistent with earlier studies that demonstrate similar learning outcomes between students who use static images and those who use dynamic ones (Garg et al., 1999a; 1999b; Levinson et al., 2007; Vogel-Walcutt et al., 2010; Dindar et al., 2015).

In terms of basic anatomy knowledge, the joint pre-test scores of this study demonstrate that naïve anatomy students are more familiar with the general anatomy of the knee joint than either the wrist or elbow joint. This may be due, in part, to the increased athletic activity in pivoting sports (e.g. soccer, football, basketball) among the pediatric population and the resultant incidence of knee injuries (Soprano, 2005; Micheli and Purccell, 2007). Approximately 25% of primary care office visits by adolescents are sports related, with the knee being among the most common injury and the most frequent complaint when seeking medical attention (Ziv et al., 1999; Rice, 2000; Hambidge et al., 2002). These incidences of knee injury and the consequent discussion with medical professionals may explain why naïve anatomy students are more familiar with knee anatomy than other joints. Interestingly, joint post-test scores demonstrate that the higher pre-test scores in the knee did not result in higher post-test scores. This suggests that higher pre-test knowledge of the knee did not impact the post-test knowledge results of the study.

The effect of user visuo-spatial ability on post-test outcomes is perhaps one of the more critical results in this study. To understand the role spatial ability plays in acquiring knowledge from two dissimilar e-learning tools, a mental rotations test (MRT) was utilized to quantify students' spatial ability (Shepard and Metzler, 1978; Vandenberg and Kuse, 1978; Peters et al., 1995). When MRT scores were plotted against e-learning tool-specific post-test scores, our results suggested that visuo-spatial ability was positively correlated with performance outcomes in Netter's 3D Interactive Anatomy (specifically with the elbow), but when the same students used A.D.A.M. Interactive Anatomy, visuo-spatial ability did not confer an academic advantage. These results may be attributable to the design of each e-learning tool. Previous research has shown that highly interactive e-learning software such as Netter's 3D Interactive Anatomy, which enables the rotation, transformation and manipulation of unfamiliar virtual objects, is guided by mental rotation and as such, is a spatially demanding task related to a user's spatial ability (Wohlschläger and Wohlschläger, 1998; Ruddle and Jones, 2001; Stull, 2009). While some studies have found that external animations and high interactivity tools benefit students, they often depict systems that contain an element of dynamism (e.g. mechanical systems, computer algorithms or geological and astronomical phenomena; see, for example, Narayanan and Hegarty (2002) and Rebetez et al. (2004); see Höffler and Leutner (2007) for review). Numerous studies have indicated that not only do animations fail to confer an academic advantage over static images, but they may also hinder the learning processes of those users with lower spatial abilities. (Large et al., 1996; Garg et al., 1999a; 1999b; 2001; 2002; Narayanan and Hegarty, 2002; Jain and Getis, 2003; Yang et al., 2003; Cohen and Hegarty, 2007; Levinson, 2007; Keehner et al., 2008; Stull et al., 2009; Vogel-Walcutt et al., 2010; see also Tversky et al., 2002 for review). It has been suggested that low-spatial individuals may have difficulty manipulating and interpreting virtual models and as a result achieve lower knowledge acquisition scores compared their highly spatial colleagues (Narayanan and Hegarty, 2002; Levinson, 2007, Stull et al., 2009). Consistent with the studies mentioned above, our results suggest that virtual anatomical animations within a high interactivity software package may be more cognitively and perceptually demanding for lower spatial ability users than for those with high spatial ability.

3.4.1 Study Limitations

While the research presented is an important step in understanding the impact of commercial anatomical e-learning tools on student's working memory systems, it is imperative that the limitations of this study also be discussed. As described in the methodology, post-tests were administered the same day students utilized the e-learning tools, meaning that immediate learning and recall were assessed, however, long-term retention and learning were not. Beyond the methodological design, this study should be repeated with the wrist and ankle joint substituted for the knee and elbow joint to eliminate pre-test knowledge as a confounding variable.

3.5 Conclusion

In an educational era where the rapid adoption of e-learning tools to facilitate online learning has been propelled, in part, by rising annual enrollments and an influx of new learners from a digital generation, the findings of our study are noteworthy. The body of research suggests that as highly interactive software products intrinsically favor higher spatial ability learners over lower spatial ability learners, we may be unintentionally placing students with low spatial ability at an academic disadvantage. Nevertheless, the results of our study leave a number of questions unanswered. As Hegarty (2004) highlighted, too often investigators assume that while learners may use dissimilar interactive displays differently, they nonetheless use each display in an efficient, productive and effective manner. Yet, research on user interactions with interactive displays contradicts this assumption, suggesting that not all individuals have the metacognitive skills to manipulate said software and animations to learn effectively (Morrison, 2000; Hegarty et al., 2002; Hegarty, 2004; Lowe, 2004; Rieber et al., 2004; Cohen and Hegarty, 2007; Hegarty et al., 2008). Future research involving cursor and gazing tracking as well as fixation patterns may provide valuable insights about how learners with different visuo-spatial abilities use various interactive functions and allow us to elucidate strategy differences between successful and unsuccessful learners in a virtual environment.

3.6 Literature Cited

Anderson JR. 1987. Skill acquisition: The compilation of weak-method problem solutions. Psychol Rev 94:192–210.

Attardi SM, Rogers KA. 2015. Design and implementation of an online systemic human anatomy course with laboratory. Anat Sci Educ 8:53–62.

Ardito C, Costabile MF, De Marsico M, Lanzilotti R, Levildi S, Roselli T, Rossano V. 2006. An approach to usability evaluation of e-learning applications. Univ Access Inf Soc 4:270–283.

Baddeley AD. 2003. Working memory: Looking back and looking forward. Nat Rev Neurosci 4:829–839.

Barbeau ML, Johnson M, Gibson C, Rogers KA. 2013. The development and assessment of an online microscopic anatomy laboratory course. Anat Sci Educ 6:246–256.

Brown JS. 2000. Growing up digital: How the web changes work, education and the ways people learn. Change 32:10–20.

Brünken R, Plass JL, Leutner D. 2003. Direct measurement of cognitive load in multimedia learning. Educ Psychol 38:53–61.

Brünken R, Steinbacher S, Plass JL, Leutner D. 2002. Assessment of cognitive load in multimedia learning using dual-task methodology. Exp Psychol 49:109–119.

Burguillo JC. 2010. Using game theory and competition-based learning to stimulate student motivation and performance. Comput Educ 55:566–575.

Carpenter PA, Just MA. 1986. Spatial ability: An information processing approach to psychometrics. Adv Psychol Hum Intell 3:221–253.

Chandler P, Sweller J. 1991. Cognitive load theory and the format of instruction. Cognit Instruct 8:293–332.

Cohen CA, Hegarty M. 2007. Individual differences in use of external visualisations to perform an internal visualisation task. Appl Cognit Psychol 21:701–711.

Cowan N. 2001. The magical number 4 in short-term memory: a reconsideration of mental storage capacity. Behav Brain Sci 24:87–114.

Dahlstrom E. 2012. ECAR Study of Undergraduate Students and Information Technology, 2012. 2012 Ed. Louisville, CO: EDUCAUSE Centre for Applied Research. 38 p. URL: http://net.educause.edu/ir/library/pdf/ERS1208/ERS1208.pdf [accessed 25 Apr. 2017].

DeLeeuw KE, Mayer RE. 2008. A comparison of three measures of cognitive load: Evidence for separable measures of intrinsic, extraneous, and germane load. J Educ Psychol 100:223–234.

de Jong T. 2010. Cognitive load theory, educational research, and instructional design: Some food for thought. Instr Sci 38:105–134.

Dindar M, Kabakçı Yurdakul I, İnan Dönmez F. 2015. Measuring cognitive load in test items: static graphics versus animated graphics. J Comput Assist Learn 31:148–161.

Dias P, Gomes MJ, Correia AP. 1999. Disorientation in hypermedia environments: Mechanisms to support navigation. J Educ Comput Res 20:93–117.

Fisk AD, Derrick WL, Schneider W. 1986. A methodological assessment and evaluation of dual-task paradigms. Curr Psychol 5:315–327.

Garg A, Norman GR, Spero L, Maheshwari P. 1999a. Do virtual computer models hinder anatomy learning. Acad Med 74:S87–S89.

Garg A, Norman GR, Spero L, Taylor I. 1999b. Learning anatomy: Do new computer models improve spatial understanding? Med Teach 21:519–522.

Garg AX, Norman G, Sperotable L. 2001. How medical students learn spatial anatomy. Lancet 357:363–364.

Garg AX, Norman GR, Eva KW, Spero L, Sharan S. 2002. Is there any real virtue of virtual reality?: The minor role of multiple orientations in learning anatomy from computers. Acad Med 77:S97–S99.

Grunwald T, Corsbie-Massay C. 2006. Guidelines for cognitively efficient multimedia learning tools: Educational strategies, cognitive load, and interface design. Acad Med 81:213–223.

Gwizdka J. 2010. Distribution of cognitive load in web search. J Am Soc Inform Sci tech 61:2167-2187.

Gwizdka J, Lopatovska I. 2009. The role of subjective factors in the information search process. J Am Soc Inform Sci Tech 60:2452–2464.

Hambidge SJ, Davidson AJ, Gonzales R, Steiner JF. 2002. Epidemiology of pediatric injury-related primary care office visits in the United States. Pediatrics 109:559–565.

Hegarty M. 2004. Dynamic visualizations and learning: Getting to the difficult questions. Learn Instr 14:343–351.

Hegarty M, Narayanan NH, Freitas P. 2002. Understanding machine from multimedia and hypermedia presentations. In: Otero J, León JA, Graesser AC, (Editors). The Psychology of Science Text Comprehension. 1st Ed. Mahwah, NJ: Lawrence Erlbaum Associates. p 357–384.

Hegarty M, Shah P, Miyake A. 2000. Constraints on using the dual-task methodology to specify the degree of central executive involvement in cognitive tasks. Mem Cognit 28:376–385.

Hegarty M, Smallman HS, Stull AT. 2008. Decoupling of intuitions and performance in the use of complex visual displays. In: Proceedings of the 30th Annual Conference of the Cognitive Science Society (CogSci 2008); Washington, DC, 2008 July 23-26. p 881–886. Cognitive Science Society, Wheat Ridge, CO.

Helsper EJ, Eynon R. 2010. Digital natives: where is the evidence?. Brit Ed Res J 36:503-520.

Höffler TN, Leutner D. 2007. Instructional animation versus static pictures: A meta-analysis. Learn Instr 17:722–738.

Howe N, Strauss W. 2000. Millenials Rising: The Next Great Generation. 1st Ed. Toronto, Canada: Random House, Inc. 415 p.

Jain C, Getis A. 2003. The effectiveness of internet-based instruction: An experiment in physical geography. J Geogr High Educ 27:153–167.

Keehner M, Hegarty M, Cohen C, Khooshabeh P, Montello DR. 2008. Spatial reasoning with external visualizations: What matters is what you see, not whether you interact. Cognit Sci 32:1099–1132.

Kerr B. 1973. Processing demands during mental operations. Mem Cognit 1:401–412.

Khalil MK, Paas F, Johnson TE, Payer AF. 2005. Design of interactive and dynamic anatomical visualizations: The implication of cognitive load theory. Anat Rec 286B:15–20.

Kim YM, Rieh SY. 2005. Dual-task performance as a measure for mental effort in searching a library system and the Web. In: Proceedings of the 68th Annual Meeting of the American Society for Information Science and Technology (ASIS&T 2005). Sparking Synergies: Bringing Research and Practice Together; Charlotte, NC, 2005 Oct 28-Nov 2. Volume 42. American Society for Information Science and Technology, Silver Spring, MD.

Lahtinen TMM, Koskelo JP, Laitnen T, Leino TK. 2007. Heart rate and performance during combat missions in a flight simulator. Aviat Space Environ Med 78:387–391.

Large A, Beheshti J, Breuleux A, Renaud A. 1996. Effect of animation in enhancing descriptive and procedural texts in a multimedia learning environment. J Am Soc Inform Sci 47:437–448.

Levinson AJ, Weaver B, Garside S, McGinn H, Norman GR. 2007. Virtual reality and brain anatomy: A randomized trial of e-learning instructional designs. Med Educ 41:495–501.

Lowe R. 2004. Interrogation of a dynamic visualization during learning. Learn Instr 14:257–274.

Luursema J-M, Verwey WB, Kommers PAM, Geelkerken RH, Vos HJ. 2006. Optimizing conditions for computer-assisted anatomical learning. Interact Comput 18:1123–1138.

MacLeod CM. 1998. Training on integrated versus separated Stroop tasks: The progression of interference and facilitation. Mem Cognit 26:201–211.

MacLeod CM. 2005. The Stroop task in cognitive research. In: Wenzel A, Rubin DC, (Editors). Cognitive Methods and Their Application to Clinical Research. 1st Ed. Washington, DC: American Psychological Association. p 17–40.

Mayer RE. 2001. Multimedia Learning. 1st Ed. Cambridge, UK: Cambridge University Press. 222 p.

Mayer RE. 2002. Multimedia learning. In: Ross BH (Editor). Psychology of Learning and Motivation. Volume 41: Advances in Research and Theory. 1st Ed. San Diego, CA: Academic Press. p 85–139.

Mayer RE. 2008. Applying the science of learning: Evidence-based principles for the design of multimedia instruction. Am Psychol 63:760–769.

Mayer RE, Sims VK. 1994. For whom is a picture worth a thousand words? Extensions of a dual-coding theory of multimedia learning. J Educ Psychol 86:389–401.

Micheli LJ, Purccell L (Editors). 2007. The Adolescent Athlete: A Practical Approach. 1st Ed. New York, NY: Spinger Science+Business Media, LLC. p 441.

Miller GA. 1956. The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychol Rev 63:81–97.

Morrison JB, Tversky B, Betrancourt M. 2000. Animation: Does it facilitate learning? In: Butz A, Kruger A, Oliver P (Editors). Smart Graphics: Papers from the 2000 AAAI Spring Symposium (Technical Reports, Vol. SS-00-04). 1st Ed. Menlo Park, CA: Association for the Advancement of Artificial Intelligence Press. p 53–59.

Narayanan NH, Hegarty M. 2002. Multimedia design for communication of dynamic information. J Educ Psychol 57:279–315.

Oblinger DG, Oblinger JL. 2005. Is it age or IT: First steps toward understanding the Net Generation. In: Oblinger DG, Oblinger JL (Editors). Educating the Net Generation. Boulder, CO: EDUCAUSE. p 2.1–2.20.

Oblinger DG, Oblinger JL, Lippincott JK (Editors). 2005. Educating the Net Generation. 1st Ed. Boulder, CO: EDUCAUSE. 264 p.

Oviatt SL. Human-centered design meets cognitive load theory: designing interfaces that help people think. In Proceedings of the 14th annual ACM International Conference on Multimedia (MM ’06); New York, NY; 2006 Oct 23-27; p 871–880. Association for Computing Machinery: New York, NY.

Pashler H. 1994. Dual-task interference in simple tasks: data and theory. Psychol Bull 116:220.

Peters M, Laeng B, Latham K, Jackson M, Zaiyouna R, Richardson C. 1995. A redrawn Vandenberg & Kuse mental rotations test: Different versions and factors that affect performance. Brain Cognit 28:39–58.

Posner MI, Boies SJ. 1971. Components of attention. Psychol Rev 78:391.

Rebetz C, Sangin M, Bétrancourt M, Dillenbourg P. 2004. Effects of collaboration in the context of learning from animations. In: Proceedings of the European Association for Research on Learning and Instruction Special Interest Group (EARLI Sig) Conference on Comprehension of Text and Graphics: Basic and Applied Issues; Valencia, Spain, 2004 Sept 9 – 11. European Association for Research on Learning and Instruction, Leuven Belgium.

Rice SG. 2000. Risks of injury during sports participation. In: Sullivan JA, Anderson SJ (Editors). Care of the Young Athlete. 1st Ed. Rosemont, IL: American Academy of Orthopaedic Surgeons and American Academy of Pediatrics. p 9–18.

Rieber LP, Tzeng SC, Tribble K. 2004. Discovery learning, representation, and explanation within a computer-based simulation: Finding the right mix. Learn Instr 14:307–323.

Rochford K. 1985. Spatial learning disabilities and underachievement among university anatomy students. Med Educ 19:13–26.

Ruddle RA, Jones DM. 2001. Manual and virtual rotations of a three-dimensional object. J Exp Psychol Appl 7:286–296.

Shepard S, Metzler D. 1978. Mental rotation: Effects of dimensionality of objects and types of tasks. J Exp Psychol Hum Percept Perform 14:3–11.

Skiba DJ, Barton AJ. 2006. Adapting your teaching to accommodate the net generation of learners. Online J Issues Nurs 11:15.

Soprano JV. 2005. Musculoskeletal injuries in the pediatric and adolescent athlete. Curr Sports Med Rep 4:329–334.

Stroop JR. 1935. Studies of interference in serial verbal reactions. J Exp Psychol 18: 643.

Stull AT. 2009. Anatomy learning in virtual reality: A cognitive investigation. University of California: Santa Barbara, CA. Doctorate of Philosophy Dissertation. 184 p.

Sweller J, van Merriënboer JJG, Paas F. 1998. Cognitive architecture and instructional design. Educ Psychol Rev 10:251–296.

Toynton R. 2005. Degrees of disciplinarity in equipping mature students in higher education for engagement and success in lifelong learning. Active Learn High Educ 6:106–117.

Tversky B, Morrison JB, Betrancourt, M. 2002. Animation: Can it facilitate?. Int J Hum-Comput Int 57:247–262.

Vandenberg SG, Kuse AR. 1978. Mental rotations, a group test of three-dimensional spatial visualization. Percept Motor Skill 47:599–604.

van Merriënboer JJG, Sweller J. 2010. Cognitive load theory in health professional education: Design principles and strategies. Med Educ 44:85–93.

Van Nuland SE, Rogers KA. 2016. E-Learning, Dual-task and Cognitive Load: The anatomy of a failed experiment. Anat Sci Educ 9:186-196.

Vogel-Walcutt JJ, Gebrim JB, Nicholson D. 2010. Animated versus static images of team processes to affect knowledge acquisition and learning efficiency. J Online Teach Learn 6:1.

Wastlund E, Norlander T, Archer T. 2008. The effect of page layout on mental workload: A dual-task experiment. Comp Human Behav 24:1229–1245.

Wohlschläger A, Wohlschläger A. 1998. Mental and manual rotation. J Exp Psychol Hum Percept Perform 24:397–412.

Wong SK, Nguyen TT, Chang E, Jayaratna N. 2003. Usability metrics for e-learning. In: Meersman R, Tari A (Editors). On the Move to Meaningful Internet Systems 2003: OTM 2003 workshops. OTM Confederated International Workshops HCI-SWWA, IPW, JTRES, WORM, WMS and WRSM 2003 Catania, Sicily, Italy, November 3–7, 2003, Proceedings. 1st Ed. Heidelberg, Germany: Springer-Verlag. p 235–252.

Yang EM, Andre T, Greenbowe TJ, Tibell L. 2003. Spatial ability and the impact of visualization/animation on learning electrochemistry. Int J Sci Educ 25:329–349.

Ziv A, Boulet JR, Slap GB. 1999. Utilization of physician offices by adolescents in the United States. Pediatrics 104:35–41.

Chapter 4

4 The Skeletons in Our Closet: E-Learning tools and what happens when one side doesn't fit all

This chapter investigates if a dual-task paradigm is an effective tool for measuring cognitive load changes across different learning modalities in regards to a visual-kinesthetic learning. It also describes the impact of visual-kinesthetic learning on knowledge recall and how spatial ability may influence said anatomical knowledge recall.[4]

4.1 Literature Review

While e-learning tools often receive positive feedback from students (Glittenberg and Binder, 2006; Nicholson et al., 2006; Venail et al., 2010; Codd and Choudhury, 2011; Keedy et al., 2011; Webb and Choi, 2014; for a review see Yammine and Violato (2015)), controversy over e-learning tool adoption and questions regarding their efficacy remain. Recent publications have examined the impact of e-learning tools on student knowledge, and while some have demonstrated that e-learning tools created by individual institutions are more effective than traditional study methods (e.g. cadaveric dissection, textbook learning; Elizondo-Omaña et al., 2004; Qayumi et al., 2004; Glittenberg and Binder, 2006; Nicholson et al., 2006; Hisley et al., 2008; Venail et al., 2010; Codd and Choudhury, 2011), most have demonstrated that e-learning tools developed by individual researchers either do not offer an advantage or actually disadvantage students when compared to traditional instructional methods (Garg, 1998; Garg et al., 1999a; 1999b; 2002; Kurihara et al., 2004; Levinson et al., 2007; Keedy et al., 2011; Khot e tal., 2013; Preece et al., 2013; Saltarelli et al., 2014; Webb and Choi, 2014; Mathiowetz et al., 2016). While e-learning tools may be more stimulating and enjoyable, research has

---

[4] A version of this chapter has been submitted to the journal Anatomical Sciences Education for publication.

suggested that they rely heavily on the spatial ability of the learner, defined as the innate ability to mentally manipulate an object, and can disadvantage those who struggle with mental manipulation (Carpenter and Just, 1986; Mayer and Sims, 1994; Luursema et al., 2006; Levinson et al., 2007; Estevez et al., 2010; Preece et al., 2013; Van Nuland and Rogers, 2016). While there is no shortage of the development and implementation of commercial e-learning tools within curricula, empirical evidence relating the comparative efficacy of these commercial tools to traditional instructional methods is scarce (Lewis, 2003; Khalil et al., 2005; Trelease, 2016). In the absence of this evidence, incorporation of these tools into curricula has relied solely on validations based on student perception, attitude and enjoyment, leading to blind acceptance and use of commercial e-learning tools in education (Preece et al., 2013). Comparative studies in anatomy education have shown that naïve students who use e-learning tools to study anatomical concepts face distinct educational disadvantages compared to those who study using more traditional, tactile methods (Khot et al., 2013; Preece et al., 2013). Results, such as these, emphasize that the purchase, implementation and acceptance of e-learning tools should not be made based on instinct or because such tools represent a “more modern” approach to education, but should be supported by statistically reliable scientific evidence (Khot et al., 2013; Preece et al., 2013). As computer and mobile interfaces become synonymous with post-secondary institutions, there is an increasing concern that the wide use of e-learning technologies is not achieving the intended impact on learning (Cook et al., 2008).

4.1.1 Physicality and Traditional Anatomical Models: The missing sense

Although some anatomical e-learning tools allow learners to manipulate virtual objects, they ultimately lack the element of physicality. Defined as actual, active touching of a concrete object, physicality involves the element of discovery through intentional tactile actions on the part of the learner (Stankov et al., 2001; Jones et al., 2006; Wiebe et al., 2009; Zacharia and Olympiou, 2011). Kinesthetic learning is not only an active process, but when combined with visual perception is thought to allow for mental representations to be encoded in a multisensory format involving a larger neural network which, in turn, may induce more effective recall of that information from the learner's memory (Reiner, 1999; Stankov et al., 2001; Jones et al., 2003; 2006; Seitz et al., 2006; Seitz and Dinse, 2007; Shams and Seitz, 2008; Wiebe et al., 2009; Richardson, 2011). Contour following, where a learner's hands maintain contact with an object, can provide important information about the shape and volume of an object, and is particularly applicable in anatomical sciences where students have the opportunity to physically handle specimens (Lederman and Klatzky, 1987; Minogue and Jones, 2009). Within STEM education research, many studies continue to support teachers' proclivities toward incorporating physical hands-on models alongside instruction, in a multisensory format, to generate a more meaningful learning experience (Reiner, 1999; Jones et al., 2003; 2006; Krontiris-Litowitz, 2003; Shams and Seitz, 2008; Minogue and Jones, 2009; Khot et al., 2013; Preece et al., 2013). In anatomy, cadaveric dissection and other kinesthetic visual activities continue to promote better understanding and recall of anatomical concepts and their spatial relationships than visual-only e-learning tools (Rizzolo and Stewart, 2006; Motoike et al., 2009; Oh et al., 2009; DeHoff et al., 2011; Khot et al., 2013; Preece et al., 2013).

While consideration of the relative impact of visual-kinesthetic learning modalities compared to visual-only e-learning tools is undoubtedly significant, understanding why visual-kinesthetic learning promotes better learning than content matched e-learning tools is equally important. It is interesting to note here that the majority of studies have not answered why visual-kinesthetic experiences generate better learning outcomes, only showing that they do (Khot et al., 2013; Preece et al., 2013). The few studies that have attempted to explain their results, have attributed better performance measures involving visual-kinesthetic learning to cognitive load reductions, but have not measured cognitive load in their studies to support this argument (Jones et al., 2003; 2006; Minogue and Jones, 2006; Zacharia and Olympiou, 2011).

4.1.2 Objectives

In this study we set out to examine how the visual-kinesthetic experience of manipulating a physical skeleton impacts learning when compared to virtual manipulation of a simple 2-dimensional (2D) anatomical e-learning tool, A.D.A.M. Interactive Anatomy in terms of cognitive load and visuo-spatial ability. We hypothesized that a physical skeleton would generate significantly better learning outcomes, due, in part, to a reduction in cognitive load, when compared to a simple, 2-dimensional commercial e-learning tool (A.D.A.M. Interactive Anatomy). More specifically, we predicted that visual observation task reaction times would be significantly shorter when students studied using a physical skeleton, indicating a lower cognitive load and resulting in significantly higher post-test scores. Furthermore, based on the results of Chapter 3, we predicted that a learner's spatial ability would not influence their knowledge recall when they studied using A.D.A.M. Interactive Anatomy, but that it would influence knowledge recall when they studied using a physical skeleton. Given these hypotheses, three objectives for this study were identified: (1) to investigate if a dual-task paradigm is an effective tool for measuring cognitive load changes across a visual-kinesthetic and visual-only learning modality; (2) to assess the impact of knowledge recall when using a physical skeleton to study when compared to a content matched simple 2D e-learning tool (A.D.A.M. Interactive Anatomy); and (3) to evaluate the effect of learner spatial ability on knowledge recall when learning from the different learning modalities mentioned above.

4.2 Methodology

The research protocol was approved by the Office of Research Ethics at The University of Western Ontario, Canada (Appendix I).

4.2.1 Participants and Recruitment

All students in the Fall 2015 undergraduate anatomy course Systemic Human Anatomy (ANATCELL3319) at The University of Western Ontario were eligible to participate in the study. The description of this course appears in Section 3.2.2. Of those students in the course 25.39% (*n* = 81) consented to participate. Students were recruited through in-class announcements and e-mails from the first author. In accord with The University of Western Ontario Research Ethics Board, the authors had no relationship with the students and were not associated with the course. Furthermore, the authors had no significant ties with the e-learning tools used in this study, or the company that created it.

4.2.2 Experimental Design Overview

Participants were asked to complete two pre-test measures, including a demographic questionnaire and a mental rotations test. A virtual version of the revised Vandenberg & Kuse Mental Rotations Test-A (MRT) was administered, as described in Section 3.2.3, to participants as a measure of spatial ability prior to the study (Peters et al., 1995; Fig. 3.1).

To determine if a dual-task paradigm (described in Section 3.2) was an effective tool for measuring cognitive load across a visual-kinesthetic (physical skeleton) and a visual only learning modality (A.D.A.M. Interactive Anatomy (Ebix, Atlanta, GA); described in Section 2.2.1), participants were involved in four separate testing conditions, including two single-task conditions (Conditions 1 and 2; Table 4.1), where a visual observation task (VOT) and then a joint learning task were completed in isolation, followed by two dual-task conditions, where a VOT and a joint learning task were completed simultaneously (Conditions 3 and 4; Table 4.1). A.D.A.M. Interactive Anatomy was selected based on the results of Chapter 3, demonstrating that its interface design did not disadvantage students based on spatial ability.

In both dual-task conditions participants were randomly assigned to explore the bony anatomy of two joints, the wrist and the ankle, using two different learning methods. To ensure the quality and scope of the anatomical questions used in this study, a qualified anatomist, unrelated to the study, validated the question.

Table 4.1: Learning Tool and Joint Learning Task Assignments.

Participant	Condition 1: Visual Observation Task in Isolation	Condition 2: Elbow Learning Task in Isolation	Condition 3: Learning Tool and Joint Learning Task	Condition 4: Learning Tool and Joint Learning Task
1	✓	✓	Wrist in A.D.A.M. Interactive Anatomy	Ankle using a physical skeleton
2	✓	✓	Ankle in A.D.A.M. Interactive Anatomy	Wrist using a physical skeleton
3	✓	✓	Wrist using a physical skeleton	Ankle in A.D.A.M. Interactive Anatomy
4	✓	✓	Ankle using a physical skeleton	Wrist in A.D.A.M. Interactive Anatomy

Each participant in this study completed Conditions 1 through 4. In both dual task conditions participants are randomly assigned to explore the anatomy of two joints (wrist and ankle) using two different learning methods (A.D.A.M. Interactive Anatomy and physical skeleton). Due to this cross over design Conditions 3 and 4 vary depending on the participant.

4.2.3 Physical Skeleton Utilized

The articulated limb skeletons used in this study were human bones obtained from the skeletal collection of the Gross Anatomy Laboratory, Department of Anatomy and Cell Biology, University of Western Ontario. The articulated lower limb used included the patella, tibia, fibula, tarsal bones (calcaneus, cuboid, navicular, talus, medial, intermediate and lateral cuneiforms) and all metatarsals and phalanges. Similarly, the articulated upper limb included the humerus, ulna, radius and the carpal bones (scaphoid, lunate, triquetrum, pisiform, hamate, capitate, trapezoid and trapezium) as well as all the metacarpals and phalanges. Each of the tarsal and carpal bones was labeled with a number, which corresponded to a printed list of bone names that accompanied the skeleton. A 2D compiled atlas image of an articulated limb was also provided. In each image the carpal and tarsal bones were labeled and provided an anterior/posterior (wrist) or dorsal/plantar (ankle) view of the respective joint. The atlas images were provided to recreate how a student would typically study skeletal anatomy in a self-study fashion using a bone box and anatomical atlas.

4.2.4 Experiment Station Design

The research station (Fig. 4.1) used in this study consisted of a 15.6-inch Lenovo laptop (ThinkPad E531, Lenovo, Morrisville, NC; Monitor 1) with Intel dual-core processor running Windows 7 (Microsoft Corp., Redmond, WA) connected to an external mouse. This laptop was used to display all pre-tests and post-tests in addition to the e-learning tool. A 26-inch LG Flatron Wide monitor (LG Electronics Inc., Seoul, Korea; Monitor 2) was placed directly behind Monitor 1 and was connected to a second Lenovo laptop which was used to run E-Prime® 2.0 Professional (Psychology Software Tools, Inc., Sharpsburg, PA) in the background while the external monitor (e.g. Monitor 2) was used to display the visual observation task (VOT) to participants (Fig. 4.1A).

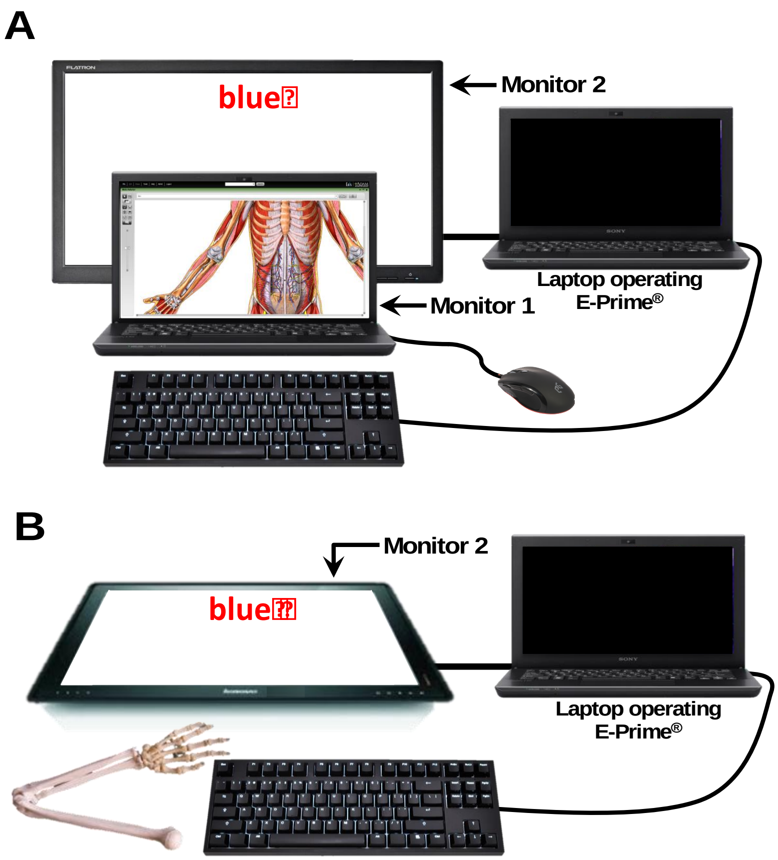


Figure 4.1: Experimental station design.

During Condition 1, where the visual observation task (VOT) was completed in isolation, participants used setup A to respond to a modified Stroop test that appeared on Monitor 2; no images were shown on Monitor 1, as this monitor is turned off during this time. Set up A was also used in Condition 2, where a learning task (elbow) was completed in isolation. Again, an image was displayed on Monitor 1, and no images were shown on Monitor 2 positioned behind. For the dual-task conditions, where participants completed both a VOT and joint learning exercise simultaneously (Conditions 3 and 4), two different experimental setups were used. When participants studied using A.D.A.M. Interactive Anatomy setup A was used. However, when participants studied using the physical skeleton, setup B was used. In both dual-task conditions (Conditions 3 and 4), Monitor 2 was used to display the VOT.

4.2.5 Condition 1- Visual Observational Task in Isolation (Single-task Condition)

This condition was executed in the same manner as described in Section 3.2.5.

4.2.6 Condition 2- Joint Learning Task in Isolation (Single-task Condition)

Following completion of the VOT in isolation (Condition 1), participants were asked to complete a second single-task condition involving learning the anatomical structure of the bony elbow joint (Condition 2). Prior to the start of this learning task, participants were given 10-minutes to complete 10 multiple-choice questions, each with its own cadaveric image, to assess their baseline level of anatomical knowledge of the elbow joint. Questions were related to identification of articulating bones at the elbow joint, associated bony landmarks and whether the joint originated from the left or right side of the body (Appendix G).

Once a baseline knowledge level was established, participants were given the opportunity to learn the anatomy of the bony elbow joint for 12 minutes using a labeled, static 2-dimensional image on Monitor 1 (Fig. 4.1A). Students were provided with an instruction page that detailed the three objectives of the elbow exercise: (1) Identify the bones that articulate at the elbow joint; (2) Identify which side (left or right) the joint originates from; and (3) Identify the bony landmarks on the bones immediately surrounding the elbow joint. The anatomy of the bony elbow joint was chosen because our previous study showed it did not to overload the working memory of participants, and students could acquire the required depth of knowledge to answer the knowledge acquisition questions in the restricted time limit given (Chapter 3).

Upon completion of the elbow learning exercise, participants completed a one-minute math worksheet containing addition/subtraction problems consistent with a Grade 5 math level, which was designed to erase information held in the learner’s short-term working memory (Fisk et al., 1986; Van Nuland and Rogers, 2016). Participants then completed a scrambled version of the knowledge questions administered during the baseline test (10 multiple-choice questions/10-minutes) to assess how studying from a static 2-dimensional image impacted their anatomical knowledge of the bony elbow.

4.2.7 Conditions 3 and 4- Visual Observation Task and Joint Learning Task Combined (Dual-task Condition)

The final testing conditions involved the completion of a joint learning task and a visual observation task (VOT) simultaneously, known as a dual-task experiment (Fig. 4.1; Table 4.1). Participants were randomly assigned to explore both the bony wrist and ankle joints, using different learning tools: (1) a simple 2D e-learning tool, A.D.A.M. Interactive Anatomy, and (2) a physical skeleton, using a crossover design with order reversal (Table 4.1). Participants studied the first joint using one learning tool during the first dual-task condition (Condition 3) and the second joint and learning tool during the second dual-task condition (Condition 4). The wrist and ankle joints were chosen because they are distal limb joints that have a similar number of bones involved, and participants for the most part were naïve to their anatomy.

Prior to the beginning of each dual-task condition, participants were asked to complete 10 multiple-choice questions to establish their baseline anatomy knowledge of the assigned joint. Each question was associated with a cadaveric picture, and was related to the identification of articulating bones at each joint or which view of a joint was being shown (wrist: anterior/posterior; ankle: dorsal/plantar; Appendix J and K).

Following each baseline knowledge test, participants were given the opportunity to learn about a joint from a pre-assigned learning tool (Condition 3; Table 4.1). When participants interacted with A.D.A.M. Interactive Anatomy, they were provided an instruction page that briefly outlined how to manipulate the basic functions of the e-learning tool. All students were also given two guiding objectives: (1) Identify the (carpal or tarsal) bones that articulate at the (wrist or ankle) joint; and (2) Identify the (anterior/posterior) or (dorsal/plantar) aspect of the (wrist or ankle) joint. Using dual-task parameters outlined in our previous study (see Section 3.2.6), participants were given 12-minutes to explore their pre-assigned joint using the assigned learning tool. At the same time, participants were also asked to respond to a similar VOT described in Condition 1. Three modifications to the VOT were implemented in the dual-task conditions: (1) No practice round was administered; (2) The modified Stroop test was extended to 12-minutes in length (the same length of the concurrent learning task), displaying a total of 25 color-words; and (3) The presentation of the stimuli was reversed for the second dual-task condition to preclude improvement in response times due to participant memorization.

Two distinct dual-task set-ups were used based on the learning tool being assessed. When participants interacted with A.D.A.M. interactive Anatomy, the arrangement depicted in Figure 5A was used. However, when participants used the physical skeleton to study, Monitor 2 was laid flat and angled 20° toward the user to enable users to respond to the VOT when looking down at the skeleton (Fig. 4.1B).

Upon completion of the dual-task exercise, participants were asked to complete a 1-minute math worksheet followed by a scrambled version of the knowledge questions administered during the baseline test (10 multiple choice questions/10 minutes) This sequence was repeated for second dual-task condition (Condition 4), which involved the remaining joint and the second learning tool (e.g. if, during the first dual-task condition, a student studied the ankle joint using A.D.A.M. Interactive Anatomy, then they would study the wrist joint using the physical skeletal model; Table 4.1).

4.2.8 Analysis

Participant VOT reaction times in the single-task condition (Condition 1) were averaged and compared to reaction times when the VOT was paired with a joint learning task in the dual-task condition (Conditions 3 and 4). Reaction times and performance scores gathered during the single-task and dual-task conditions were compared by learning tool (A.D.A.M. Interactive Anatomy or physical skeleton), joint learning task (wrist or ankle) and by dual-task condition (first dual-task, Condition 3; or second dual-task, Condition 4) using a Friedman test, with a Wilcoxon signed-rank test and Bonferroni correction. Reaction times and performance scores were further compared by joint learning task and learning tool using independent t-tests or Mann-Whitney U tests. Friedman and Mann-Whitney U tests (non-parametric tests) were selected for statistical analysis when the corresponding data failed to meet parametric assumptions, such as normality. Finally, performance scores were compared to participant's spatial ability scores using linear regression analysis. All Cohen's r effect size calculations were interpreted using literature from Cohen (1988), Coes (2002), Coolican (2009) and Fritz et al. (2012).

4.2.9 Exclusion Criteria

Participants were excluded from analysis if: 1) they failed to complete all tests or 2) if there was a technical error with E-Prime that resulted in lost data.

4.3 Results

4.3.1 Demographics

Of the 81 Systemic Human Anatomy students who participated in the study, 77 were included in the study data set (M:F 39:38, mean age = 20.2 years). Of those who participated, 77.9% were third year undergraduate students and the remaining were in their fourth year. Approximately 79.2% of participants were registered in the F2F portion of the Systemic Human Anatomy course, while the remaining students were registered in the online section. As noted in the course description, at the time of testing, participants had not received formal anatomy lectures on the joints tested in this study.

The majority of participants in this study reported they were comfortable when using computer technology (94.8%), while the remaining students reported feeling neither comfortable nor uncomfortable or somewhat uncomfortable. Despite reported comfort with technology, only 20.7% of participants had used non-anatomical e-learning tools in past undergraduate courses. When studying anatomy, only 26.0% had used an e-learning tool to review material prior to the study (including Netters 3D Interactive Anatomy and Anatomy One (Elsevier, Philadelphia, GA), Visible Body (Argosy Publishing Inc, Newton Upper Falls, MA), Anatomy TV (Primal Pictures, London, UK), or Essential Anatomy 5 (3D4Medical, Del Mar, CA)).

4.3.2 Visual Observation Task (VOT) Reaction Times Assessed by Learning Tool

When the VOT was completed in isolation (VOT baseline; Condition 1), the mean reaction time (mean ±SD) across all participants (n = 77) was 977 ±428 milliseconds. A Friedman test with a Wilcoxon signed-rank test and a Bonferroni correction determined that VOT reactions times were significantly slower when students used each learning tool compared to when they completed the VOT in isolation (X^2 (2) = 123.97, $p < 0.001$; A.D.A.M: 1631 ±396 msec; Z = -7.28, $p < 0.001$; Skeleton: 2327 ±699 msec; Z = -7.59, $p < 0.001$). Mean VOT reaction times in the dual-task conditions were also significantly slower when participants studied using the skeletal model compared to A.D.A.M. Interactive Anatomy (Z = -7.24, $p < 0.001$).

4.3.3 Visual Observation Task (VOT) Reaction Times Assessed by Joint Learning Task

Using a Friedman test with a Wilcoxon signed-rank test and Bonferroni correction, VOT baselines (Condition 1; 977 ±428 msec) were compared to dual-task VOT reaction times (Condition 3 and 4; mean ±SD) when participants studied the wrist joint (2034 ±765 msec) and ankle joint (1925 ±546 msec). Again, reaction times associated with each joint were significantly longer than baseline values (X^2 (2) = 98.36, $p < 0.001$; Wrist: Z = -7.50, $p < 0.001$; Ankle: Z = -7.42, $p < 0.001$), however, there was no significant difference between wrist and ankle VOT reaction times.

To verify that the VOT required consistent and effortful processing, reaction times were compared by dual-task conditions. Baseline VOT reaction times were found to be significantly faster than reaction times in both dual-task conditions (Conditions 3 and 4), however, when the dual-task conditions were compared to each other, no significant difference was found, demonstrating that participants applied a consistent effort to the VOT overtime (data not shown; Fisk et al., 1986; MacLeod, 2005).

4.3.4 Visual Observation Task (VOT) Reaction Times Assessed by Joint Learning Task and Learning Tool

Dual-task VOT reaction times (Conditions 3 and 4) were further broken down by joint learning task and learning tool (Table 4.2). Independent t-tests revealed that VOT reaction times were significantly slower when participants used the physical skeleton to study when compared to A.D.A.M. Interactive Anatomy for both the wrist ($t(57.41) = -7.72$, $p < 0.001$) and ankle joint ($t(62.47) = -3.23$, $p = 0.002$). Participants also had significantly slower reaction times when studying the ankle joint using A.D.A.M. Interactive Anatomy compared to the wrist ($t(75) = -2.44$, $p= 0.017$). Conversely, participants had significantly slower reaction times when studying the wrist using the skeleton than compared to the ankle ($t(75) = 2.70$, $p = 0.009$).

Table 4.2: Dual-Task Visual Observation Task Reaction Times Assessed by Joint Learning Task and Learning Tool

Joint Learning Task	Condition	Number of Participants	VOT Reaction Time (msec) (mean ± SD)
Wrist	A.D.A.M. Interactive Anatomy	38	1524 ± 374[a,c]
	Physical skeleton	39	2531 ± 721[a,d]
Ankle	A.D.A.M. Interactive Anatomy	39	1737 ± 392[b,c]
	Physical skeleton	38	2118 ± 616[b,d]

Independent t-tests were used to analyze the dual-task reaction times measured in Conditions 3 and 4.

[a,b]Significant differences were found between the physical skeleton and A.D.A.M. Interactive Anatomy, for the wrist joint ($p < 0.001$) and ankle joint ($p < 0.002$).

[c,d]Significant differences were found between the ankle joint and wrist joint when studying using A.D.A.M. Interactive Anatomy ($p = 0.017$) as well as when the joints were studied using a physical skeleton ($p = 0.009$).

Note that identical superscripts are significantly different. The significance level was set at 0.05.

VOT, visual observation task.

4.3.5 Post-Test and Gain Scores Assessed by Learning Tool

Anatomical knowledge performance scores (mean ±SD) when studying using a 2D textbook image (single-task condition, Condition 2; involving the bony elbow joint), a physical skeleton and a simple e-learning tool (dual-task conditions, Conditions 3 and 4; involving the bony ankle and wrist joints) were compared using Friedman tests with

Wilcoxon signed-rank tests and Bonferroni corrections (Table 4.3). Interestingly, participants had significantly higher post-test scores when they studied using the physical skeleton compared to a 2D textbook image (X^2 (2) = 43.46, $p < 0.001$; $Z = -5.60$, $p < 0.001$, large effect according to Cohen's r) or A.D.A.M. Interactive Anatomy ($Z = -5.63$, $p < 0.001$, large effect according to Cohen's r; Table 4.3). However, no such significant difference was found between post-test scores when students studied using a textbook image and A.D.A.M. Interactive Anatomy. When gain scores were assessed a similar pattern to that of the post-test scores was seen (X^2 (2) = 67.12, $p < 0.001$). When students studied using a physical skeleton their gain scores were again significantly higher than when they studied using (1) a 2D textbook image ($Z = -7.05$, $p < 0.001$, large effect according to Cohen's r) or (2) A.D.A.M. Interactive Anatomy ($Z = -4.94$, $p < 0.001$, large effect according to Cohen's r; Table 4.3). A.D.A.M. Interactive Anatomy gain scores were also significantly higher than those associated with learning from a 2D textbook image ($Z = -2.82$, $p = 0.005$; medium effect according to Cohen's r; Table 4.3).

Table 4.3: Baseline Test, Post-Test and Gain Scores Assessed by Learning Tool (+ Visual Observation Task)

Condition	Baseline Test Score (mean ±SD)	Post-Test Score (mean ±SD)	Gain Scores (mean ±SD)
2-D Textbook Image	2.71 ± 1.78[a,b]	7.60 ± 1.88[c]	4.88 ± 1.88[e,g]
A.D.A.M. Interactive Anatomy + VOT	1.56 ± 1.34[a]	7.30 ± 2.43[d]	5.75 ± 2.50[f,g]
Physical skeleton + VOT	1.45 ± 1.18[b]	9.26 ± 1.23[c,d]	7.79 ± 1.45[e,f]

Friedman tests with Wilcoxon signed-rank tests and a Bonferroni correction were used to analyze performance data.

[a,b]Baseline Test Scores: Values with identical superscripts were significantly different ($p < 0.001$).

[c,d]Post-Test Scores: Values with identical superscripts were significantly different and there were two large effect sizes found ($p < 0.001$; *c:* Cohen's $r = 0.638$; and, *d:* Cohen's $r = 0.642$)

[e,f,g]Gain Scores: Values with identical superscripts were significantly different, and there were two large and one medium effect sizes found (*e, f:* $p < 0.001$; Cohen's $r = 0.803$ and 0.563, respectively; and, *g:* $p = 0.005$, Cohen's $r = 0.321$).

All pre-tests and post-tests were out of 10 marks total; $n = 77$. The Bonferroni correction set the significance level at 0.017.

VOT, visual observation task.

4.3.6 Baseline Test, Post-Test, and Gain Scores Assessed by Joint Learning Task

Performance scores were analyzed by joint learning task (e.g. elbow (Condition 2), wrist and ankle (Conditions 3 and 4)), regardless of e-learning tool, using a Friedman test with a Wilcoxon signed-rank test and Bonferroni correction (Table 4.4). Baseline knowledge scores were found to be significantly higher for the elbow (X^2 (2) = 40.41, $p < 0.001$) compared to the wrist ($Z = -5.15$, $p < 0.001$) or ankle joint ($Z = -5.21$, $p <0.001$). However, there was no difference in baseline knowledge scores between the wrist and ankle joint.

Participants achieved significantly higher scores on the wrist post-test than when compared to elbow post-test scores (X^2 (2) = 10.56, $p = 0.005$; $Z = -3.38$, $p = 0.001$; Table 4.4). However, no such difference was found between ankle and elbow post-test scores or ankle and wrist post-test scores. In regard to overall gain scores, elbow gain scores were significantly lower than wrist (X^2 (2) = 43.15, $p < 0.001$; $Z = -5.76$, $p < 0.001$) and ankle gain scores ($Z = -4.50$, $p < 0.001$; Table 4.4), however, no significant difference was found between wrist and ankle gain scores. While statistically significant, the importance of these findings is mitigated by the fact that the initial elbow baseline scores were higher (i.e. it is likely you would have smaller gain scores when baseline scores are higher).

Table 4.4: Baseline Test, Post-Test and Gain Scores Assessed by Joint Learning Task (+ Visual Observation Task)

Condition	Baseline Test Score (mean ±SD)	Post-Test Score (mean ±SD)	Gain Scores (mean ±SD)
Elbow	2.71 ± 1.78[a,b]	7.60 ± 1.88[c]	4.88 ± 1.88[d,e]
Wrist + VOT	1.44 ± 1.21[a]	8.45 ± 2.06[c]	7.01 ± 2.07[d]
Ankle + VOT	1.57 ± 1.31[b]	8.10 ± 2.24	6.53 ± 2.47[e]

Friedman tests with Wilcoxon signed-rank tests and a Bonferroni correction were used to analyze performance data.

[a,b]Baseline Test Scores: Values with identical superscripts were significantly different ($p < 0.001$).

[c]Post-Test Scores: Values with identical superscripts were significantly different ($p = 0.001$).

[d,e]Gain Scores: Values with identical superscripts were significantly different ($p < 0.001$).

All pre-tests and post-tests were out of 10 marks total; $n = 77$. The Bonferroni correction set the significance level at 0.017.

VOT; visual observation task.

4.3.7 Post-Test and Gain Scores Assessed by Joint Learning Task and Learning Tool

Post-test scores were found to be significantly higher when students used a physical skeleton to learn than when they studied using A.D.A.M. Interactive Anatomy (wrist: $U = 371.50$, $p < 0.001$, large effect according to Cohen’s r; ankle: $U = 353.50$, $p < 0.001$, large effect according to Cohen’s r; Table 4.5). Gain scores were also significantly higher when students studied using the physical skeleton, than when they studied using

A.D.A.M. Interactive Anatomy, regardless of joint (wrist: $U = 417.50$, $p = 0.001$, medium effect according to Cohen's r; ankle: $U = 308.50$, $p < 0.001$, large effect according to Cohen's r; Table 4.5).

Table 4.5: Baseline Test, Post-Test and Gain Scores Assessed by Joint Learning Task and Learning Tool

Joint Learning Task	Condition	Number of Participants	Baseline Test Score (mean ±SD)	Post-Test Score (mean ±SD)	Gain Score (mean ±SD)
Wrist	A.D.A.M. Interactive Anatomy	38	1.37 ± 1.30	7.61 ± 2.27^{a}	6.24 ± 2.28^{c}
	Physical skeleton	39	1.51 ± 1.12	9.28 ± 1.43^{a}	7.77 ± 1.51^{c}
Ankle	A.D.A.M. Interactive Anatomy	39	1.74 ± 1.37	7.03 ± 2.59^{b}	5.28 ± 2.65^{d}
	Physical Skeleton	38	1.39 ± 1.24	9.21 ± 0.99^{b}	7.82 ± 1.41^{d}

Mann-Whitney U tests were used to analyze performance data.

[a,b]Post-Test Scores: Values with identical superscripts were significantly different and two large effect sizes were ascribed to these difference ($p < 0.001$, Cohen's $r = 0.457$; $p < 0.001$, Cohen's $r = 0.464$).

[c,d] Gain Scores: Values with identical superscripts were found to be significantly different, medium and large effect sizes were ascribed to these difference (*c:* $p = 0.001$, Cohen's $r = 0.384$; and, *d:* $p < 0.001$, Cohen's $r = 0.511$).

All pre-tests and post-tests were out of 10 marks total. The significance level was set at 0.05.

4.3.8 Mental Rotations Test Scores versus Post-Test and Gain Scores Assessed by Learning Tool and Joint Learning Task

The mean mental rotations test (MRT; Fig. 3.1) score (± SD) across all participants was 9.18 ± 3.74. Consistent with previous literature, no significant gender difference was detected, by way of a Mann-Whitney U test, as the MRT was administered virtually (Parsons et al., 2004; female MRT score: 9.38 ± 3.47, male MRT score: 8.97 ±4.04). When MRT scores were plotted against learning tool post-test scores, there was no significant relationship (not shown). However, when MRT scores were plotted against learning tool gain scores, spatial ability was significantly correlated to gain scores, but only when students studied using a physical skeleton ($F(1,75) = 6.27$, $p = 0.014$, $R^2 = 0.077$, 95% CI (0.022, 0.194)) and not when they studied using A.D.A.M. Interactive Anatomy (Fig. 4.2). Physical skeleton gain scores were further separated by joint and assessed using linear regression and the positive correlational was isolated to the ankle joint only ($F(1,36) = 4.27$, $p = 0.046$, $R^2 = 0.106$, 95% CI (0.002, 0.217); Fig. 4.3). Here, it is important to note that when participants studied the wrist joint, they did so using a right physical skeleton and were tested on ipsilateral images (right wrist), however, when students studied the ankle joint, they used a left physical skeleton but were tested on contralateral images (right ankle; Fig. 4.3).

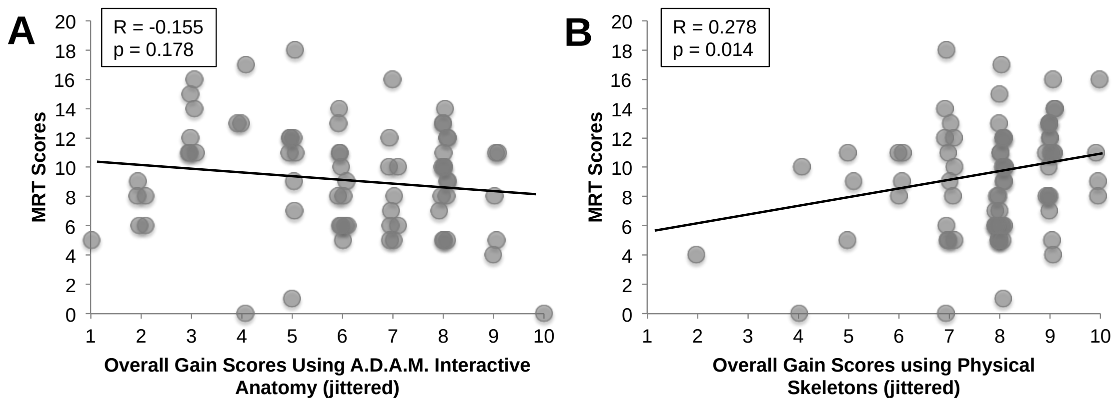


Figure 4.2: Correlation between participant mental rotation test scores and overall performance (gain score) according to learning tool.

Student spatial ability, as determined by MRT (mental rotation test) scores, was not correlated to A.D.A.M Interactive gain scores (A), however, spatial ability was significantly correlated with gain scores when learning from a physical skeleton (B; $p < 0.014$). Gain scores have been jittered in these graphs to break up plotting locations. All pre-tests and post-tests were out of 10 marks total ($n = 77$) with the significance level set at $p \leq 0.05$.

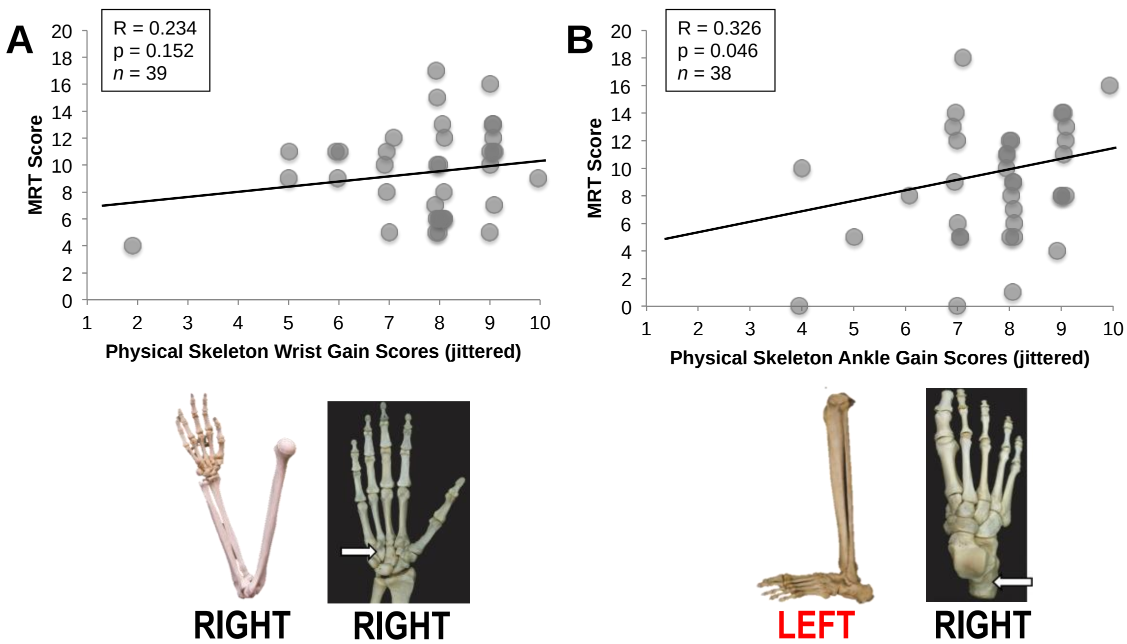


Figure 4.3: Correlation between participant mental rotation test scores and overall performance (gain scores) associated with learning the wrist and ankle from a physical skeleton.

Participant MRT scores were compared with gain scores when they learned about (A) the wrist joint using a right physical skeleton and were tested on ipsilateral images and (B) the ankle joint using a left physical skeleton and were tested on contralateral images. Ankle gain scores were significantly and positively correlated with student spatial ability, as determined by the MRT ($p = 0.046$). Gain scores have been jittered in these graphs to break up plotting locations. All pre-tests and post-tests were out of 10 marks total.

4.4 Discussion

Although e-learning tools remain popular among students, studies that compare them to more traditional, kinesthetic learning modalities are of paramount importance as we seek to understand if e-learning tools are effective replacements for traditional tactile study methods. Yet, studies often validate e-learning tools based on student perception, attitude and enjoyment, and those that compare these different learning modalities using performance measures are uncommonly rare. This is particularly concerning within anatomical sciences education considering the role visual-kinesthetic learning has played historically, and the importance it continues to have on teaching human anatomy.

The fundamental difference between visual-kinesthetic learning modalities (i.e. physical skeletons) and visual-only anatomical e-learning tools is the element of physicality. To understand how physicality, or the absence of it, impacts learner knowledge acquisition we examined students while they learned anatomy of bony joints by physically manipulating a skeleton in comparison to a simple 2D e-learning tool, A.D.A.M. Interactive Anatomy. Using a cognitive load model, known as a dual-task paradigm, and a measurement of learner spatial ability, we identified three objectives: (1) to investigate if a dual-task paradigm is an effective tool for measuring cognitive load changes across both a visual-kinesthetic (physical skeleton) and a visual-only (A.D.A.M. Interactive Anatomy) learning modality; (2) to assess the impact of knowledge recall when using a physical skeleton to study compared to that of a content matched simple, 2D e-learning tool (A.D.A.M. Interactive Anatomy); and (3) to evaluate the effect of learner spatial ability on knowledge recall when learning from these two modalities.

The results of the dual-task study suggested that the learner’s experienced increased cognitive load when physically manipulating a skeleton. However, cognitive load theory indicates that if a learning tool imposes a higher cognitive load, then fewer working memory resources would be available to process the educational content of that tool. Thus, when students studied by physically manipulating a skeleton, we would expect to see lower post-test and gain scores when compared to a non-cognitively demanding tool (Anderson, 1987; Mayer and Sims, 1994; Mayer, 2008; van Merriënboer and Sweller, 2010). Yet, performance scores associated with learning from a physical skeleton were significantly higher than those associated with A.D.A.M. Interactive Anatomy, moreover that the estimated magnitude of this effect (Cohen's r) indicated a large practical significance. These latter results indicate that it is unlikely that learning from physical skeletons imposes high cognitive load, rather they suggest that the dual-task paradigm described in this study is not an effective tool for measuring cognitive load across different learning modalities. Recalling our first objective, the results presented here may lead others to the conclusion that it is not possible to compare cognitive loads across a learning modality that relies on vision only and one that uses both kinesthetic and visual cues. However, such conclusions should be reserved until further studies can verify if other modified dual-task designs can quantify cognitive load under these circumstances.

Curiously, educational research that compares visual-kinesthetic learning tools to visual-only e-learning tools has consistently attributed the positive outcomes of kinesthetic learning to its ability to reduce cognitive load (Jones et al., 2003; 2006; Minogue and Jones, 2006; Zacharia and Olympiou, 2011; Khot et al., 2013; Preece et al., 2013). Yet, cognitive load research, including that within the anatomical sciences, has been limited to e-learning tools that involve the visual and auditory streams, with no attempts to include learning modalities that involve visual-kinesthetic perception (Zacharia and Olympiou, 2011). Furthermore, none of the aforementioned studies have attempted to measure the cognitive load to which they ascribe their results (Jones et al., 2003; 2006; Minogue and Jones, 2006; Zacharia and Olympiou, 2011; Khot et al., 2013; Preece et al., 2013). So herein lies the importance of attempting cognitive load quantification; to fully understand if the effects of multisensory learning that involve visual and touch modalities are, in fact, due to reduced cognitive load, it is necessary to measure cognitive load changes across these different learning modalities. Prior to assuming that dual-task paradigms are not an effective tool in this pursuit, we must first make attempts to redesign the dual-task paradigm presented here.

This study represents the first time a dual-task paradigm was investigated as a tool for measuring cognitive load changes across a visual-kinesthetic and a visual-only learning modality. To understand if dual-task studies can be effectively applied to the study of cognitive load across different learning modalities, future studies should seek to correct the limitations identified in our paradigm. The reaction time data presented in Table 4.2 suggests that participants struggled to respond to the VOT when physically manipulating the skeletons. The delay caused by having to stop manipulation of the physical skeleton to respond to the VOT is known as structural interference, and can produce erroneous interpretations of response times and thus cognitive load (Kahneman, 1973; Kerr, 1973; Olive, 2004). To mitigate structural interference in future dual-task studies, researchers should consider having participants respond to the VOT using a foot pedal, thereby reducing the need for the hands to be used in both activities. To prevent confounding variables, it will be important that: (1) participants are allowed ample practice to ensure they were comfortable with the response system; and (2) that a foot pedal is used for responding to the VOT across all learning modalities. Overall, given the success of dual-task paradigms in comparing different e-learning tools (Van Nuland and Rogers, 2016), further development of these paradigms across different learning modalities is warranted as educational researchers continue to look for ways to objectively and quantifiably compare e-learning tools to traditional teaching methods.

Unlike prior comparative studies in the anatomical sciences, which used independent testing groups and inherently complex anatomy to assess the impact of physical and computer models on knowledge recall, this study implemented a cross over design with an alternating order and tested simplistic anatomical concepts (Khot et al., 2013; Preece et al., 2013). Furthermore, and perhaps more importantly, our study is the only one we are aware of that makes a direct comparison of physical models to a commercial anatomical e-learning tool. The performance outcomes of this study suggest that handling physical specimens enables significantly better anatomy knowledge recall than commercial e-learning tool use. It further supports the body of literature that highlights the importance of tactile feedback and multi-sensory learning offered by anatomical models during learning (Rizzolo and Stewart, 2006; Shams and Seitz, 2008; Estevez et al., 2010; DeHoff et al., 2011; Khot et al., 2013; Preece et al., 2013). However it also represents the only study we are aware of to-date that assesses a commercial e-learning tool, rather an institutionally built one (Khot et al., 2013; Preece et al., 2013).

To understand what it means when a large effect size was observed when learners studied using a physical skeleton, it is necessary to interpret these effect sizes in a more practical manner. Using Frtiz et al.'s Associated Values Table (2012), we can translate our Cohen's r value of 0.642, associated with post-test scores in Table 4.3, to an equivalent Cohen's d value of 1.6, which can be further interpreted using Coes (2002) explanation of estimated effect sizes. Using both these resources (Coes, 2002; Fritz et al., 2012) we can conceptualize that our Cohen's d effect size of 1.6 means that 95% of participants using a physical skeleton to study scored higher on post-test measures than 95% of people in the A.D.A.M. Interactive Anatomy group, who were initially equivalent. This is the same as saying that if we had two groups of 25 students, one group that studied using a physical skeleton to study and one that used A.D.A.M Interactive Anatomy to study, the average person who studied using the physical skeleton (i.e. ranked 13th out 25 in his/her skeleton use group), would have a similar post-test score as the person ranked first in the A.D.A.M. Interactive Anatomy study group. Using these interpretations, it is easier to understand the practical significance that learning with a physical specimen had on the students in this study. The results presented here indicate that handling physical specimens yields major, positive impacts on anatomy knowledge recall, which, a content matched, simple commercial e-learning tool fails to deliver.

In the anatomical sciences, new technologies have superseded, and will continue to supersede, existing visual-kinesthetic teaching methods, due, in part, to today's technological culture and assumptions about what millennial students will expect. These factors have contributed to the mentality within higher educational institutions of 'build it (or invest in it) and they will come'. Yet, in the business of education, assumptions that sleek anatomical e-learning tools will: (1) entice millennial learners (Chumley-Jones et al., 2002; Azer and Eizenberg, 2007; Smith and Mathias, 2010; Davis et al., 2014; Smith et al., 2014); and, (2) be effective alternatives to simpler e-learning tools or more traditional physical specimens, are based on perceptions rather than objective scientific evidence (Holden and Rada, 2011; Trelease, 2016). The results of our study show the magnitude of the effect and moreover, the practical significance that a visual-kinesthetic experience, like physical manipulation of a skeleton, has on anatomy knowledge recall. While the development of innovative teaching and learning resources should be encouraged, the responsibility of educators is to continually and critically assess these new learning methods against existing standards on a multitude of variables; while anatomy e-learning tools may elicit excitement and feelings of satisfaction among users, the results of this study demonstrate they simply do not deliver the same results as traditional, visual-kinesthetic learning methods.

A learner's innate spatial ability can also impact performance on anatomical knowledge tests and has been well documented in the literature (Rochford, 1985; Garg et al., 2002; Gulliot et al., 2007; Preece et al., 2013; Berney et al., 2015; Langlois et al., 2015). The visuospatial results of our study expand on this body of research and suggest that students with low spatial ability are handicapped when they study a joint from one side of the body, but are presented with an image of the contralateral joint on a test. Conversely, those who have high spatial ability can apply their acquired anatomical knowledge from one joint equally well regardless of what image they are tested on (Fig 4.). This novel result can be explained by mental rotation literature, which suggests that objects are remembered in the familiar orientation they were learned in, and that unfamiliar orientations are recognized by mentally rotating structures from this familiar view (Garg et al., 1999b; 2001; 2002). Performing these spatial rotations and mental transformations, however, depends on a learner's innate spatial ability (Rochford, 1985; Garg et al., 2001, 2002; Guillot et al., 2007; Langlois et al., 2015). When students attempt to translate their visual representations, they must mentally represent the target figure (i.e. the ipsilateral image) and then transform this internal representation to compare it to the image in the question (i.e. the contralateral image; Miyake et al., 2001). Research has demonstrated that matching a mirror-image back to the initial visual representation (i.e. the familiar orientation in which the object was learned) not only requires a mental rotation of the mirror-image within the image plane but also an additional mental rotation to flip the image (Hamm et al., 2004; Kung and Hamm, 2010). To complicate matters further, the mirror–image shares the same features of that object, as when it is presented in its familiar orientation (i.e. the orientation it was initially learned in; Cooper and Shepard, 1973; Corballis and McMaster, 1996). Due to this, individuals must rely on the transformed internal representation, discussed above, to identify features of the object when it is presented in an orientation other than the one it was learned in (Cooper and

Shepard, 1973; Corballis and McMaster, 1996; Kung and Hamm, 2010). It is not a surprise then that low spatial ability learners find it difficult to extract pertinent information from objects and mentally transform those objects that they generally take longer to complete tests, and make more errors while doing so (Yang et al., 2003; Hegarty and Waller, 2005; Nguyen et al., 2012; Wilson, 2015).

The effect of visuospatial ability on performance outcomes is perhaps one of the more critical results of this study, and its implications for the medical training field are considerable. In the context of anatomy, our novel results imply that students with low spatial ability may need to study both sides of the human body to apply their anatomical knowledge effectively. However, if you review any anatomy textbook it is most likely that limb, head, and neck anatomy are pictured either on the left or the right side but anatomical structures are never shown in an identical format on both sides (for example, Gray's Anatomy for Students, 3rd Ed.; Clinically Oriented Anatomy, 7th Ed.). Understandably, authors and editors have likely seen illustrations or cadaveric pictures of both limbs or both sides of the neck, showing identical information, as redundant in nature, adding extraneous information to an already difficult topic and extending the number of pages in textbooks unnecessarily; besides, the opposite limb or side of the neck is just the mirror image of what appears in the textbook, right? Yet, the results of this study demonstrate that learners with low spatial ability have difficulty mentally transforming their knowledge of an ankle joint to the contralateral side, something that would be difficult to rectify using current anatomy textbooks.

It is of particular interest to note that anatomical simulators used for training various clinical skills are also designed with the notion that "one side fits all". This inherent bias to sidedness is present in simulators designed by institutions (Scerbo et al., 2006; McClusky III and Smith, 2008; Cz et al., 2012; Escoto et al., 2013), as well as those designed by commercial entities (for example, the I.V. (P50) and Intramuscular Injection Arm (P55/1) Simulators from 3B Scientific (left side only; Tucker, GA), the Multipurpose Injection Training Arm LM-074 from Koken Co., Ltd, (right side only; Tokyo, Japan) or the ARTHRO Mentor Simulator from 3D Systems (Airport City; Israel; formerly known as Simbionix Corp.) which offers a left shoulder, a left hip and a right knee, with no other options). Advances in modern medicine have made simulators a critical tool for training those in medicine because of their capacity to allow instructors to determine if the learner can execute the skills of a procedure without endangering patients (Wayne et al., 2005; Savoldelli et al., 2006; Michelson and Manning, 2008). Nonetheless, how effective is such a system in real world skill execution if a student can only proficiently execute said skill on one side of the body and not the other? If achievement of excellence in patient care is dependent upon providing professional trainees with all the tools they require to become competent in all technical skills in their field, we must be critical of the assumption that 'one side fits all' (Langlois et al., 2015). So while many studies ultimately suggest that low spatial learners may need to be given supplementary practice, feedback, and additional course modules to understand spatial concepts and be proficient in skill execution (Wanzel et al., 2002, Nilsson et al., 2007; Buckley et al., 2013; Shafqat et al., 2015), we argue that institutions must first look at the resources being provided, to make sure that trainees are given the tools they need to take their knowledge and skills into the clinic and apply them successfully.

4.4.1 Study Limitations

The research presented here challenges basic assumptions about the learning tools provided in anatomical education and sheds light on the learners who may struggle in understanding anatomical concepts. However, there are key limitations of this study that must be discussed. The results of our study suggest that participants in our crossover design had a reduction in attention over the dual-task testing conditions (Conditions 3 and 4). Inattention may have been due to the duration of the study or the timing of the testing (in December prior to exams). Future studies should consider scheduled breaks in between each testing condition that incorporate a short entertaining activity to refresh participant attention. In regards to the methodological design, this study specifically tested anatomy recall but did not assess long-term retention or learning. Furthermore, it should be noted that the physical skeleton and corresponding contralateral test images used in this study involved the leg skeleton only. To verify the generalizability of the findings presented here, more studies should be conducted involving other anatomical structures and other learning tools to chart the effect spatial ability may have on applying anatomical knowledge to the contralateral side. Lastly, while our study shows that the ability of a subject to mentally transform an anatomical image to the contralateral view can be predicted, in part based on their MRT score, the fact remains that a relatively small portion of the variance in performance scores was attributed to mental rotations ability. A possible explanation of these small variances is that students are offered tactile feedback by physically manipulating a skeleton. Münzer (2015) found that the ability to mentally rotate structures is less important if the structures and its spatial attributes studied could be physically rotated during learning; suggesting that the 'true' performance variability that is predicted by MRT scores may have mitigated by the ability to physically rotate the skeleton during learning.

4.5 Conclusion

Current post-secondary education is intricately entwined with technology, and understanding what learners want to learn with, what the administration assumes learners want to learn with and how each tool may, or may not, differentially impact knowledge acquisition is a daunting task. This study is the only one of which we are aware of to date that makes a direct comparison of physical models to a *commercial* anatomical e-learning tool. Broadly, our study sought to examine how the visual-kinesthetic experience of manipulating a physical skeleton impacts the learning of simple bony joint anatomy, when compared to virtual manipulation of a simple 2-dimensional (2D) anatomical e-learning tool, A.D.A.M. Interactive Anatomy using a cross-over design with order reversal. The results of this study demonstrated that the dual-task paradigm, described in this study, is not an effective tool for measuring cognitive load across different learning modalities. However, further studies that involve a different method of response (i.e. foot pedals) are strongly encouraged and may better elucidate if dual-task paradigms can be used to quantify cognitive load in these situations. Our second study objective, involving performance scores, suggested that visual-kinesthetic learning modalities deliver superior learning experiences compared to content-matched, simple, 2D e-learning tools. As discovered in our third study objective, the importance of learning tool selection and provision during anatomy education is further complicated by the innate spatial abilities of the learner. Recognizing how those with low spatial ability perform in anatomy and which instruction, or lack thereof, may impede their success in applying anatomical concepts in the clinic is critical if indeed one side does not fit all. As new medical technologies and imaging techniques become mainstream in the health care system, future educational research should explore the relationship between spatial ability and contralateral image performance when other anatomical structures are involved. Research that extrapolates these anatomical education results to medical simulation training may provide valuable insight into how best to support learners with different spatial abilities in a variety of educational environments.

4.6 Literature Cited

Anderson JR. 1987. Skill acquisition: The compilation of weak-method problem solutions. Psychol Rev 94:192–210.

Azer SA, Eizenberg N. 2007. Do we need dissection in an integrated problem-based learning medical course? Perceptions of first-and second-year students. Surg Radiol Anat 29:173-180.

Berney S, Bétrancourt M, Molinari G, Hoyek N. 2015. How spatial abilities and dynamic visualizations interplay when learning functional anatomy with 3D anatomical models. Anat Sci Educ 8:452-462.

Buckley CE, Kavanagh DO, Gallagher TK, Conroy RM, Traynor OJ, Neary PC. 2013. Does aptitude influence the rate at which proficiency is achieved for laparoscopic appendectomy?. J Am Coll Surgeons 217:1020-1027.

Carpenter PA, Just MA. 1986. Spatial ability: An information processing approach to psychometrics. Adv Psychol Hum Intell 3:221–253.

Chumley-Jones HS, Dobbie A, Alford CL. 2002. Web-based learning: sound educational method or hype? A review of the evaluation literature. Acad Med 77:S86- S93.

Codd AM, Choudhury B. 2011. Virtual reality anatomy: is it comparable with traditional methods in the teaching of human forearm musculoskeletal anatomy?. Anat Sci Educ 4:119-125.

Coes R. 2002. It's the effect size, stupid: What effect size is and why it is important. In: Annual Conference of the British Educational Research Association; University of Exeter, England; 2002 September 12-14. British Educational Research Association: London, UK.

Cohen J. 1988. Statistical power analysis for the behavioral sciences. 2nd Edition. Hillsdale, NJ: Lawrence Erlbaum Associates, 567 p.

Corballis MC, McMaster H. 1996. The roles of stimulus-response compatibility and mental rotation in mirror-image and left-right decisions. Can J Exp Psychol 50:397-401.

Coolican H. 2009. Research methods and statistics in psychology. 5th Edition. New York, NY: Routledge, 689 p.

Cooper LA, Shepard, RN. 1973. Chronometric studies of the rotation of mental images. In: Chase WG (Editor). Visual Information Processing. New York, NY: Academic Press. P 75–176.

Cz NA, Komeda T, Low CY. 2012. Design of upper limb patient simulator. Procedia Eng, 41:1374-1378.

Davis CR, Bates AS, Ellis H, Roberts AM. 2014. Human anatomy: Let the students tell us how to teach. Anat Sci Educ 7:262-272.

DeHoff ME, Clark KL, Meganathan K. 2011. Learning outcomes and student-perceived value of clay modeling and cat dissection in undergraduate human anatomy and physiology. Adv Physiol Educ 35:68-75.

Elizondo-Omaña RE, Morales-Gómez JA, Guzmán SL, Hernández IL, Ibarra, RP, Vilchez FC. 2004. Traditional teaching supported by computer-assisted learning for macroscopic anatomy. Anat Rec Part B: The New Anatomist 278:18-22.

Escoto A, Le Ber F, Trejos AL, Naish MD, Patel RV, LeBel ME. 2013. A knee arthroscopy simulator: design and validation. In: 35th Annual International Conference of the IEEE; Osaka, Japan; 2013 July 3-7; pp. 5715-5718. Engineering in Medicine and Biology Society: Piscataway, NJ.

Estevez ME, Lindgren KA, Bergethon PR. 2010. A novel three-dimensional tool for teaching human neuroanatomy. Anat Sci Educ 3:309-317.

Fisk AD, Derrick WL, Schneider W. 1986-1987. A methodological assessment and evaluation of dual-task paradigms. Curr Psychol 5:315–327.

Fritz CO, Morris PE, Richler JJ. 2012. Effect size estimates: current use, calculations, and interpretation. J Exp Psychol Gen 141:2-18.

Garg AX. 1998. Learning anatomy from rotating three dimensional virtual models. University of Toronto: Toronto, Ontario, Canada. Master of Science Dissertation. 51 p.

Garg A, Norman GR, Spero L, Maheshwari P. 1999a. Do virtual computer models hinder anatomy learning. Acad Med 74:S87–S89.

Garg A, Norman GR, Spero L, Taylor I. 1999b. Learning anatomy: Do new computer models improve spatial understanding? Med Teach 21:519–522.

Garg AX, Norman G, Sperotable L. 2001. How medical students learn spatial anatomy. Lancet 357:363–364.

Garg AX, Norman GR, Eva KW, Spero L, Sharan S. 2002. Is there any real virtue of virtual reality?: The minor role of multiple orientations in learning anatomy from computers. Acad Med 77:S97–S99.

Glittenberg C, Binder S. 2006. Using 3D computer simulations to enhance ophthalmic training. Opthalamic Physiol Opt 26:40-49.

Guillot A, Champely S, Batier C, Thiriet P, Collet C. 2007. Relationship between spatial abilities, mental rotation and functional anatomy learning. Adv Health Sci Educ Theory Pract 12:491–507.

Hamm JP, Johnson BW, Corballis MC. 2004. One Good Turn Deserves Another: An event-related brain potential study of rotated mirror-normal letter discriminations. Neuropsychologia 42:810-820.

Hegarty M, Waller DA. 2005. Individual differences in spatial abilities. In: Shah P, Miyake A (Editors). The Cambridge Handbook of Visuospatial Thinking. 1st Ed. New York, NY: Cambridge University Press, p 121–169.

Hisley KC, Anderson LD, Smith SE, Kavic SM, Tracy JK. 2008. Coupled physical and digital cadaver dissection followed by a visual test protocol provides insights into the nature of anatomical knowledge and its evaluation. Anat Sci Educ 1:27-40.

Holden HK, Rada R. 2011. Understanding the influence of perceived usability and technology self-efficacy on teachers' technology acceptance. J Res Tech Educ 43:343–367.

Jones GM, Andre T, Superfine R, Taylor R. 2003. Learning at the nanoscale: the impact of students' use of remote microscopy on concepts of viruses, scale, and microscopy. J Res Sci Teach 40:303-322.

Jones GM, Minogue J, Tretter TR, Negishi A, Taylor R. 2006. Haptic augmentation of science instruction: does touch matter? Sci Educ 90:111-123.

Kahneman, D. 1973. Attention and effort. Englewood Cliffs, NJ: Prentice-Hall, p. 246

Keedy AW, Durack JC, Sandhu P, Chen EM, O'Sullivan PS, Breiman RS. 2011. Comparison of traditional methods with 3D computer models in the instruction of hepatobiliary anatomy. Anat Sci Educ 4:84-91.

Kerr B. 1973. Processing demands during mental operations. Mem Cognit 1:401–412.

Khalil MK, Paas F, Johnson TE, Payer AF. 2005. Design of interactive and dynamic anatomical visualizations: The implication of cognitive load theory. Anat Rec 286B:15–20.

Khot K, Quinlan K, Norman GR, Wainman B. 2013. The relative effectiveness of computer-based and traditional resources for education in anatomy. Anat Sci Educ 6:211-215.

Krontiris-Litowitz J. 2003. Using manipulatives to improve learning in the undergraduate neurophysiology curriculum. Adv Phys Educ 27:109-119.

Kung E, Hamm JP. 2010. A model of rotated mirror/normal letter discriminations. Mem Cognition 38:206-220.

Kurihara Y, Kuramoto S, Matsuura K, Miki Y, Oda K, Seo H, Watabe T, Qayumi AK. 2004. Academic performance and comparative effectiveness of computer- and textbook-based self-instruction. St Heal T 107:894–897.

Langlois J, Bellemare C, Toulouse J, Wells GA. 2015. Spatial abilities and technical skills performance in health care: a systematic review. Med Educ 49:1065-1085.

Lederman SJ, Klatzky RL. 1987. Hand movements: A window into haptic object recognition. Cognitive Psychol 19:342–368

Levinson AJ, Weaver B, Garside S, McGinn H, Norman GR. 2007. Virtual reality and brain anatomy: A randomized trial of e-learning instructional designs. Med Educ 41:495–501.

Lewis MJ. 2003. Computer-assisted learning for teaching anatomy and histology in subjects allied to medicine. Med Teach 25:204-206.

Luursema J-M, Verwey WB, Kommers PAM, Geelkerken RH, Vos HJ. 2006. Optimizing conditions for computer-assisted anatomical learning. Interact Comput 18:1123–1138.

MacLeod CM. 2005. The Stroop task in cognitive research. In: Wenzel A, Rubin DC, (Editors). Cognitive Methods and Their Application to Clinical Research. 1st Ed. Washington, DC: American Psychological Association. p 17–40.

Mathiowetz V, Yu CH, Quake-Rapp C. 2016. Comparison of a gross anatomy laboratory to online anatomy software for teaching anatomy. Anat Sci Educ 9:52-59.

Mayer RE. 2008. Applying the science of learning: Evidence-based principles for the design of multimedia instruction. Am Psychol 63:760–769.

Mayer RE, Sims VK. 1994. For whom is a picture worth a thousand words? Extensions of a dual-coding theory of multimedia learning. J Educ Psychol 86:389–401.

McClusky III DA, Smith CD. 2008. Design and development of a surgical skills simulation curriculum. World J Surg 32:171-181.

Michelson JD, Manning L. 2008. Competency assessment in simulation-based procedural education. Am J Surg 196:609-615.

Minogue J, Jones G. 2009. Measuring the impact of haptic feedback using the SOLO taxonomy. Int J Sci Educ 31:1359-1378.

Miyake A, Friedman NP, Rettinger DA, Shah P, Hegarty M. 2001. How are visuospatial working memory, executive functioning, and spatial abilities related? A latent-variable analysis. J Exp Psychol 130:621-640.

Motoike HK, O'Kan RL, Lenchner E, Haspel C. 2009. Clay modeling as a method to learn human muscles: A community college study. Anat Sci Educ 2:19-23.

Münzer S. 2015. Facilitating recognition of spatial structures through animation and the role of mental rotation ability. Learn Individ Differ 38:76-82.

Nicholson DT, Chalk C, Funnell WR, Daniel SJ. 2006. Can virtual reality improve anatomy education? A randomised controlled study of a computer generated three-dimensional anatomical ear model. Med Educ 40:1081–1087.

Nilsson T, Hedman L, Ahlqvist J. 2007. Visual-spatial ability and interpretation of three-dimensional information in radiographs. Dentomaxillofac Rad 36:86-91.

Nguyen N, Nelson AJ, Wilson TD. 2012. Computer visualizations: Factors that influence spatial anatomy comprehension. Anat Sci Educ 5:98-108.

Oh CS, Kim JY, Choe YH. 2009. Learning of cross- sectional anatomy using clay models. Anat Sci Educ 2:156-159.

Olive T. 2004. Working memory in writing: Empirical evidence from the dual-task technique. Eur Psychol, 9:32-42.

Peters M, Laeng B, Latham K, Jackson M, Zaiyouna R, Richardson C. 1995. A redrawn Vandenberg & Kuse mental rotations test: Different versions and factors that affect performance. Brain Cognit 28:39–58.

Preece D, Williams SB, Lam R, Weller R. 2013. “Let's Get Physical”: Advantages of a physical model over 3D computer models and textbooks in learning imaging anatomy. Anat Sci Educ 6:216-224.

Qayumi AK, Kurihara Y, Imai M, Pachev G, Seo H, Hoshino Y, Cheifetz R, Matsuura K, Momoi M, Saleem M, Lara-Guerra H, Miki Y, Kariya Y. 2004. Comparison of computer-assisted instruction (CAI) versus traditional textbook methods for training in abdominal examination (Japanese experience). Med Ed 38:1080-1088.

Reiner M. 1999. Conceptual construction of fields through tactile interface. Interact Learn Envir 7:31-55.

Richardson D. 2011. Is virtual reality a useful tool in the teaching of physiology? Adv Physiol Educ 35:117–119.

Rizzolo LJ, Stewart WB. 2006. Should we continue teaching anatomy by dissection when ...?. Anat Rec 289B:215–218.

Rochford K. 1985. Spatial learning disabilities and underachievement among university anatomy students. Med Educ 19:13–26.

Saltarelli AJ, Roseth CJ, Saltarelli WA. 2014. Human cadavers vs. multimedia simulation: A study of student learning in anatomy. Anat Sci Educ 7:331-339.

Savoldelli GL, Naik VN, Joo HS, Houstin PL, Graham M, Yee B, Hamstra SJ. 2006. Evaluation of patient simulator performance as an adjunct to the oral examination for senior anesthesia residents. Anesthesiology 104:475– 81.

Scerbo MW, Schmidt EA, Bliss JP. 2006. Comparison of a virtual reality simulator and simulated limbs for phlebotomy training. J Infus Nurs 29:214-224.

Seitz AR, Dinse HR. 2007. A common framework for perceptual learning. Curr Opin Neurobiol 17:148–153.

Seitz AR, Kim R, Shams L. 2006. Sound facilitates visual learning. Curr Biol 16:1422–1427.

Shafqat A, Ferguson E, Thanawala V, Bedforth NM, Hardman JG, McCahon RA. 2015. Visuospatial ability as a predictor of novice performance in ultrasound-guided regional anesthesia. J Am Soc of Anesthesiol 123:1188-1197.

Shams L, Seitz AR. 2008. Benefits of multisensory learning. Trends Cogn Sci 12:411-417.

Smith CF, Martinez-Álvarez C, McHanwell S. 2014. The context of learning anatomy: does it make a difference?. J Anat 224:270-278.

Smith CF, Mathias HS. 2010. Medical students' approaches to learning anatomy: students' experiences and relations to the learning environment. Clin Anat 23:106-114.

Stankov L, Seizova-Cajić T, Roberts RD. 2001. Tactile and kinesthetic perceptual processes within the taxonomy of human cognitive abilities. Intelligence 29:1-29.

Trelease RB. 2016. From chalkboard, slides, and paper to e-learning: How computing technologies have transformed anatomical sciences education. Anat Sci Educ 9:583-602.

van Merriënboer JJG, Sweller J. 2010. Cognitive load theory in health professional education: Design principles and strategies. Med Educ 44:85–93.

Van Nuland SE, Rogers KA. 2016. The Anatomy of E-Learning Tools: Does software usability influence learning outcomes?. Anat Sci Educ 9:378-390.

Venail F, Deveze A, Lallemant B, Guevara N, Mondain M. 2010. Enhancement of temporal bone anatomy learning with computer 3D rendered imaging softwares. Med Teach 32:e282-e288.

Wanzel KR, Hamstra SJ, Anastakis DJ, Matsumoto ED, Cusimano MD. 2002. Effect of visual-spatial ability on learning of spatially-complex surgical skills. Lancet 359:230-231.

Wayne DB, Fudala MJ, Butter J, Siddall VJ, Feinglass J, Wade LD, McGaghie WC. 2005. Comparison of two standard-setting methods for advanced cardiac life support training. Acad Med 80:S63– 6.

Webb AL, Choi S. 2014. Interactive radiological anatomy eLearning solution for first year medical students: Development, integration, and impact on learning. Anat Sci Educ 7:350-360.

Wiebe EN, Minogue J, Jones MG, Cowley J, Krebs D. 2009. Haptic feedback and students' learning about levers: Unraveling the effect of simulated touch. Comput Educ 53:667-676.

Wilson TD. 2015. Role of image and cognitive load in anatomical multimedia. In: Chan LK, Pawlina W (Editors). Teaching Anatomy. New York, NY: Springer International Publishing, p 237-246.

Yammine K, Violato C. 2015. A meta-analysis of the educational effectiveness of three-dimensional visualization technologies in teaching anatomy. Anat Sci Educ 8:525-538.

Yang EM, Andre T, Greenbowe TJ. 2003. Spatial ability and the impact of visualization/animation on learning electrochemistry. Int J Sci Educ 25:329–350.

Zacharia ZC, Olympiou G. 2011. Physical versus virtual manipulative experimentation in physics learning. Learn Instr 21:317-331.

Chapter 5

5 Empirical Contributions, Implications and Future Directions

5.1 General Discussion

The landscape of anatomical sciences education has undergone substantial transformations over the past three decades (Trelease, 2016). Administrators, educators and students have advocated for the greater use of anatomical e-learning tools in an effort to reduce costs, and provide a high quality virtual learning environment with high definition graphics (Pin et al., 2011; EU, 2014). Despite the fact that e-learning tools have broadened the concept and reach of the traditional anatomy classroom, uncertainty remains: are we headed in the right direction? Is there an educational goal we are trying to achieve with these tools, and if so, what are the metrics of success to which we ascribe (Van Nuland et al., 2017)?

Historically, assessments of anatomical e-learning tools have either been absent (Crossingham et al., 2009; Nguyen and Wilson, 2009; Lu et al., 2010; Sergovich et al., 2010; Yeung et al., 2011; Adams and Wilson, 2011; Richardson-Hatcher et al., 2014) or limited to user satisfaction surveys (O'Bryne et al., 2008; Hassinger et al., 2010; Venali et al., 2010; Wright and Hendricson, 2010; Guy et al., 2015). More recently, however, evaluations of these tools have become more extensive and have included usability tests and learner knowledge outcomes (Nicholson et al., 2006; Hu et al., 2009; Levinson et al., 2007; Codd and Choudhury, 2011; Doubleday et al., 2011; Keedy et al., 2011; Alfieri et al., 2012; Khot et al., 2013; Preece et al., 2013; Rich and Guy, 2013; Hoyek et al., 2014; Allen et al., 2016; Mathiowetz et al., 2016).

Yet, what is concerning about the numerous studies referenced above is that they all involve e-learning tools that were designed and developed by professors and/or students at various educational institutions, with no consideration for the commercial anatomical e-learning tools that so many institutions invest in. The disadvantage of anatomical e-learning tools designed and developed by individual academics is the time, resources and financial investments required to fully develop these tools into complete entities, and as a result the end-products are often limited in scope and have little overall applicability outside of the explicit purpose they were designed for. The Cranial Nerve Skywalk (Richardson-Hatcher et al., 2014), which is an e-learning tool that enables students to visualize select cranial nerves and the associated autonomic pathways, and the Virtual Cerebral Ventricular System (Adams and Wilson, 2011), which offers a 3D reconstruction of a ventricular system and surrounding structures, are examples of two such tools developed by individual groups. From the publications, it is clear that neither tool was designed with low spatial ability learners or cognitive load principles in mind, as demonstrated by the highly interactive interfaces and multiple viewing angle. In fact, Adams and Wilson (2011) do not mention cognitive load or spatial ability in their paper, but rather seem to have created the Virtual Cerebral Ventricular System to exploit the aesthetics of the rendering technology itself, rather than designing this tool for an educational purpose. Similarly, Richardson-Hatcher and colleagues (2014) fail to mention learner spatial ability, and the principles of cognitive load are only discussed in hindsight of the design. Despite both studies implying that virtual models and e-learning tools may be better suited for teaching the complex spatial relationships of neuroanatomy, neither actually assesses knowledge recall, learning outcomes or spatial ability. Furthermore, no subsequent studies have been published indicating that these tools have been or are currently used for educational purposes within curricula.

Due to the time, resources and financial investments required to fully develop and validate anatomical e-learning tools designed by individual academics, educators and administrators often see commercially produced anatomical e-learning tools as preferable alternatives. However, commercial e-learning tools also lack objective and reliable evidence of their effectiveness, especially when compared to existing teaching methods. Yet, these tools are routinely purchased by libraries and integrated into curricula by educators based on perceptions that they are useful and equally effective as existing teaching methods (Rogers, 2003; Trelease, 2016). As a result of these assumptions, commercial anatomical e-learning tool selection is often made by academics who may not be aware of the cognitive load impact that different software interfaces can impose and the differential impact that designs may have on learners with low spatial ability

(Van Nuland and Rogers, 2016a). The research presented in this dissertation compared the impact of two commercial anatomical e-learning tools and a traditional, anatomical visual-kinesthetic learning tool on knowledge recall, and examined how spatial ability could influence performance outcomes, using working memory, cognitive load theory, and dual-task assessment as guiding principles

5.2 Empirical Contributions

Chapter 2 attempted to measure cognitive load changes when students used two commercial anatomical e-learning tools, using a standard dual-task paradigm designed based on existing literature. It is important to note that the few studies that had previously used dual-task paradigms to assess the design of science-based e-learning tools shared important commonalities that were inherently different from the study presented in Chapter 2 (Brünken et al., 2002; DeLeeuw and Mayer, 2008). In the studies by Brünken et al. (2002) and DeLeeuw and Mayer (2008): (1) each study used a science-based learning tool developed by the individual authors; (2) each e-learning tool showed a dynamic educational concept (i.e. how the cardiovascular system works, including physiological and electrochemical processes (Brünken et al., 2002), or how an electric motor works (DeLeeuw and Mayer, 2008)); and, (3) each tool was passively viewed by the learner, as both were essentially videos. These studies used a simple colour change as a visual observation task to measure cognitive load, and did not include single-task conditions involving a learning task in isolation or a visual observation task in isolation in the design. While this paradigm was used successfully by both Brünken et al. (2002) and DeLeeuw and Mayer (2008), the results of Chapter 2 demonstrated that such a paradigm was problematic when applied to the study of commercially built anatomical e-learning tools that showed static anatomical concepts and allowed full virtual interaction. Essentially, what researchers thought to be a suitable approach for measuring cognitive load during science-based e-learning tool use, was developed based on passive multimedia learning, which is fundamentally different from the standard interactive e-learning tools in science, and particularly within anatomy. It will be essential to test future dual-task instruments for the confounding variables identified in Chapter 2, particularly for dual-task research in current multimedia educational research, which has become increasingly concerned with the cognitive load impacts of multimedia learning. The recommendations in this chapter provide evidence-based guidance for how future research could successfully measure the impact of cognitive load during interactive e-learning tool use.

Chapter 3 utilized the recommended solutions from Chapter 2 to redesign the dual-task paradigm and overall methodology to create a novel dual-task approach to: (1) assess the effect of two commercial anatomical e-learning tools (Netter's 3D Interactive Anatomy and A.D.A.M. Interactive Anatomy) on learner cognitive load and knowledge recall; and, (2) investigate the impact learner spatial ability may have on learning. Interestingly, the dual-task and performance results suggested that the cognitive load imposed by the starkly different, commercial e-learning tools was similar. Although these findings diverge from previous studies and cognitive load theory that indicate highly interactive tools may impose higher extraneous cognitive load (Grunwald and Corsbie-Massay, 2006; Levinson et al., 2007; van Merriënboer and Sweller, 2010; Dindar et al., 2014), our results suggest today's tech-savvy learners may be more comfortable navigating within and "reading" from starkly different yet novel multimedia interfaces than their predecessors (Brown, 2000; Oblinger and Oblinger, 2005; Oblinger et al., 2005; Skiba and Barton, 2006). As a result of this comfort level, the impact that cognitive load may have on learner knowledge recall, particularly when students use content matched e-learning tools like A.D.A.M. Interactive Anatomy and Netter's 3D Interactive Anatomy, may not be as significant as is hypothesized in the literature, especially for students of the digital generation.

Though cognitive load may not be an important factor to consider when choosing between commercial e-learning tools that deliver the same, basic information, understanding the impact a tool may have on learners with low spatial ability is essential. As discussed in Chapter 3, a complex commercial e-learning tool, like Netter's 3D Interactive Anatomy, which enables the virtual rotation, transformation and manipulation of unfamiliar anatomical objects, can negatively impact knowledge acquisition for learners with lower spatial abilities. Though studies have demonstrated a similar impact that multiple views of an anatomical structure can have on low spatial ability learners, these studies involved anatomical e-learning tools that were designed and developed by individual academics, and did not assess commercially developed anatomical e-learning tools (Garg et al., 1999; Levinson et al., 2007; Stull, 2009). To this end, our study marks the first time that learner spatial ability has been shown to influence anatomy knowledge recall when using a commercial anatomical software program. Ensuring that both commercial developers and individual academics are aware of the impact e-learning tool design can have on different learners is essential in making e-learning tools and associated learning objectives attainable for all students.

Chapter 4 extended our evaluation of the educational efficacy of commercial anatomical e-learning tools by comparing a simple, commercial 2D e-learning tool (A.D.A.M. Interactive Anatomy) to a traditional teaching method such as physically manipulating a skeleton. While this study confirmed that A.D.A.M. Interactive Anatomy does not disadvantage low spatial ability learners, it also demonstrated that, regardless of which joint is studied and the level of e-learning tool interactivity, commercial anatomical e-learning tools do not provide an educational advantage over 2D textbook images, a result echoed in Chapter 3 (Table 3.3 and 4.3). Furthermore, the results of this study also showed that the performance scores that followed a visual-kinesthetic learning experience (i.e. physical manipulation of a skeleton) dwarfed the performance scores when students used a simple commercial e-learning tool or a 2D textbook image. The educational significance of these findings are noteworthy, especially considering that commercial e-learning tools are often purchased based on assumptions that they are as effective as traditional teaching practices. Studies from Codd and Choudhury (2011), Keedy et al., (2011) and Preece et al. (2013) also found that anatomical e-learning tools did not provide any significant advantage over traditional anatomy learning methods, such as dissection and textbook images. However, unlike the study presented here, which capitalized on a cross over design (with an alternating order) to reduce bias, in order to assess the impact of commercial anatomical e-learning tools on knowledge recall, Codd and Choudhury (2011), Keedy et al., (2011) and Preece et al. (2013) used independent testing groups and a specifically designed, non-commercial e-learning tool. Furthermore, all three studies tested spatially complex anatomical concepts, which often included more than one body system (i.e. vessels, organs, muscles and bones), or covered concepts that were difficult to teach due to inaccessibility during dissection. For example, Codd and Choudhury's (2011) virtual model of the forearm included muscles, arteries, nerves and bones, while Keedy et al.'s (2011) virtual hepatobiliary model covered spatial and factual information regarding abdominal vasculature, the anatomy of the biliary system and anatomy of surgical liver segments. Conversely, our study sought to assess the effectiveness of a commercial e-learning tool for teaching simple anatomical concepts when compared to a traditional physical skeleton. This study clearly demonstrated that handing physical specimens yields major, positive impacts on anatomy knowledge recall about basic bony joint anatomy that a content matched commercial e-learning tool failed to deliver.

While Chapter 3 showed that spatial ability impacts how well a student can recall knowledge from a commercial e-learning tool that enables multiple viewing angles, the results of Chapter 4 also suggests that low spatial ability may impair a learner's ability to transform their anatomical knowledge to the contralateral side. The implications of this novel result could easily extend to textbooks and medical simulators, whose creators have the tendency to assume that if a student understands the ipsilateral side then they will be confident in their knowledge application and competent in skill execution on the contralateral side. The spatial results of Chapter 3 and 4 have implications for educators as well, and demonstrate that without considering factors such as e-learning tool selection, a student's study strategies and potential test images, educators could unknowingly disadvantage low spatial ability learners. The results of this research serve to inform educators about potential biases that may be built into textbook images and simulators.

Lastly, of particular interest across Chapter 3 and 4, is the reoccurring ceiling effect that happens when students use commercial anatomical e-learning tools to study the basic elements of human joints. Across both chapters, students attain a strikingly similar level of post-test knowledge following commercial e-learning tool use, regardless of what joint is studied or the amount of baseline knowledge learners have (Tables 3.5, and 4.5).

Remarkably, this 'knowledge ceiling' appears to vanish when the element of physicality is introduced into the learning session through the manipulation of a physical skeleton. As discussed in Chapter 4, the visual-kinesthetic learning that occurs while physically handling a specimen, and which is consequently absent during e-learning tool use, generates major positive impacts on anatomy knowledge recall. This effect, which others have hypothesized is due to reduced cognitive load (Jones et al., 2003; 2006; Minogue and Jones, 2006; Zacharia and Olympiou, 2011; Khot et al., 2013; Preece et al., 2013), has yet to be supported by peer-reviewed literature. In this respect, the suggested modifications to the dual-task paradigm described in Chapter 4 are critical steps forward in understanding if the benefit of visual-kinesthetic learning arises from a reduction in cognitive load or not.

5.3 Implications in the Anatomical Sciences

The technological culture of post-secondary institutions and the growing market for educational software have attracted a number of companies that have developed commercial anatomical e-learning tools as a solution to alleviate the strain on traditional cadaveric laboratories (UNESCO, 2009; Irby et al., 2010; Soliman and Karia, 2015; Trelease, 2016). The influence of popular student opinion and the need to set courses from one institution apart from others can lead to a pressure to invest in commercial e-learning tools. However, assumptions are often made that such commercial e-learning tools have been designed, developed and evaluated to be cognitively and pedagogically appropriate for students (Higgins et al., 2000; Williams et al., 2004; Van Nuland and Rogers, 2016b). Yet, there is little evidence to suggest that educational software companies use summative and/or formative evaluations to test the instructional designs of their products or their learning outcomes (Williams et al., 2004; Van Nuland et al., 2017). The lack of peer-reviewed evidence regarding the effectiveness of commercial anatomical e-learning is particularly concerning considering their pervasive acceptance and often extended use within anatomical sciences curricula tools (Squires and Preece, 1999; Van Nuland et al., 2017). The decisions regarding which e-learning tool to select often lies with the educators themselves, however many educators lack the experience, technical skills and training necessary to evaluate the effectiveness of e-learning tools (Williams et al., 2004). Instead, decisions are made based on the marketing materials provided by the commercial vendors themselves and an educator's perceptions (Squires and Preece, 1999; Williams et al., 2004; Holden and Rada, 2011; Van Nuland et al., 2017). While it is unreasonable to expect that all e-learning tools be fully tested prior to implementation, there should be a practical expectation that they be tested within the first years of use, for the effectiveness that educators and administrators assume they have.

The first contribution of this dissertation was to the modification of the Systemic Human Anatomy course at the University of Western Ontario, described by Attardi and Rogers (2015). While the authors of this study clearly outline the decision matrix used to select the commercial anatomical e-learning tool for this course, no assessment of comparative effectiveness was made, rather, Netter's 3D interactive Anatomy was chosen based on the educator's perceptions of usefulness. Although the use of a decision matrix goes far beyond what most educators undertake when choosing an e-learning tool, there remains the inherent assumption within the study that the commercial e-learning tools evaluated had been designed, developed and evaluated to meet the learning needs of the target population. The conclusions reached in Chapter 3 challenged this preconceived notion, suggesting that the unlimited viewing angles offered by Netter's 3D Interactive Anatomy, and valued by Attardi and Rogers (2015), did not benefit all learners, and in fact disadvantaged those with low spatial ability. On an institutional level, the findings of this research contributed to a decision to cease Systemic Human Anatomy's subscription to Netter's 3D Interactive Anatomy.

The theme of this dissertation has been to comparatively assess the impact of commercial anatomical e-learning tools to each other and to traditional visual-kinesthetic methods of studying anatomy. By doing so, this thesis has sought to provide a mechanism for educators to objectively and comparatively assess the learning tools they are considering for student use. To this end, this research is the only collection I am aware of that makes a direct comparison of *commercial* anatomical e-learning tools, and thus it provides an important understanding regarding the impact that commercial e-learning tool design, and our assumptions of it, can have on learner knowledge recall. By providing educators and administrators with research-based evidence and an experimental paradigm for testing the comparative effectiveness of anatomical e-learning tools, it may be possible to moderate assumptions and diminish reliance on marketing resources used during decision-making. Examples of the impact of this work can be seen in recent publications; for example, Backhouse and colleagues (2017) and Bakr et al. (2016) recognized that simple e-learning tools can be just as effective for teaching anatomy as more complex resources. Moreover, Backhouse et al. (2017) and Kijpokin (2017) acknowledged the importance of e-learning tool features that reduce cognitive load while maintaining usability.

As demonstrated throughout this dissertation, the shortage of objective cognitive load evidence is an alarming commonality among learning tool studies. This body of work represents the first time that dual-task paradigms have been investigated as a tool for cognitive load assessment across different commercial anatomical learning tools. As such, the methods described in this thesis provide a new mechanism for educators to assess the cognitive load impacts on learning when using new technologies and multimedia resources, and may provide a tool for assessing cognitive load across different learning modalities with further development (Drake and Pawlina, 2017).

5.4 Future Directions

Although this dissertation is an important first step in understanding the impact of spatial ability on knowledge recall following anatomical learning tool use, and the impact of anatomical learning tools on learners working memory systems, there exist several future studies that could extend the generalizability of these findings.

To understand if the benefit of visual-kinesthetic learning in anatomy arises from a reduction in cognitive load, a future study should seek to clarify if a modified dual-task design could be used to assess cognitive load differences across different learning modalities. In such a study, secondary task responses could be monitored through a foot pedal response to reduce structural interference. Furthermore, such a study should again test simplistic anatomical concepts and consider increasing the knowledge tests to 15 questions (rather than 10) in order to ensure a broader performance range, as many students were able to achieve 100% on the knowledge post-test when they used a physical skeleton to study.

It is also the opinion of this author that other cognitive load researchers should consider directly measuring the working memory capacity of the participants they test. Though dual-task paradigms provide a relative measure of the cognitive load imposed by a tool on a specific learner, they do not provide a direct measure of an individuals working memory capacity itself. Rather researchers, including myself, have relied upon previous studies, which generalizes working memory capacities to be 7 ± 2 informational elements. Though these studies have suggested that there is a positive correlation between working memory capacity and science learning, the relationship of working memory capacity and cognitive load during learning tool use has not been investigated (Gathercole et al., 2004; Danili and Reid, 2004; Tsaparlis, 2005).

Does a novice student's working memory capacity limit their ability to learn anatomy from an e-learning tool, and could this explain the reoccurring knowledge ceiling following e-learning tool use? Do novice learners with a lower working memory capacity benefit from visual-kinesthetic learning experiences? Is lower working memory capacity related to an individual's spatial ability? One task that may measure a learner's working memory capacity is known as a digit span (Case et al, 1982; Conway et al., 2005). In this task participants see a sequence of numbers and are asked to recall the sequence correctly (either forwards or backwards), with subsequent sequences becoming longer. The average number of items that a person can repeat back in correct order immediately after presentation provides a measure of that learner's working memory storage capacity. Understanding what a student's working memory limitations are may help an educator to facilitate that student's learning, for example by showing them how best to breakdown difficult anatomical and clinical concepts into more manageable pieces, known as chunking material, or by showing a worked example, which involves a step-by-step demonstration of how to solve to a clinical problem using anatomical concepts (Clark et al., 2006; Yuan et al., 2006).

Another future study is also warranted to verify the generalizability of the spatial ability findings presented in Chapter 4. By removing the visual-observation component of the methodology outlined in Chapter 4 and including both a left and a right skeleton of the ankle and wrist joints, as well as an even number of ipsilateral and contralateral images in the corresponding knowledge tests, it may be possible to further clarify the impact of sidedness and learning methodology on students with low spatial ability. Subsequent studies should also seek to test other anatomical structures/concepts that could also be affected by ipsilateral versus contralateral images (i.e. neck structures, musculature of the limbs). Studies should also be extended to include images like radiographs and CT scans which are also highly spatial in order to chart the effect spatial ability may have on applying anatomical knowledge to these imaging modalities. This type of research may help physicians and educators alike to understand why particular residents or students struggle with basic surgical procedures and their underlying anatomical concepts. It should be noted that future studies should not be restricted to the ideas presented here. Rather, this thesis, its limitations and its potential future directions represent new avenues for educational researchers to pursue.

5.5 Conclusion

One of the biggest challenges in education is the tendency to assume that new technologies are as effective, if not more so, than traditionally salient teaching practices. In the anatomical sciences, commercial e-learning tools have capitalized on these assumptions, and the adoption of these e-learning tools into curricula has rapidly outpaced the production of any objective evidence regarding their effectiveness. The inherent belief that commercial e-learning tools are designed and tested to be cognitively and perceptually appropriate for novice learners, and are comparable to traditional visual-kinesthetic learning methods, were challenged by the results of this dissertation.

Spatial ability was shown to be one important variable that impacts anatomical knowledge recall. Students with low spatial ability were uniquely disadvantaged when learning from the complex, highly interactive commercial e-learning tool Netter’s 3D

Interactive Anatomy, while their highly spatial counterparts were not, suggesting that simpler e-learning tools, which limit interactivity, are a more effective tool for a broader range of learners. Moreover, the results in Chapter 4 demonstrate that low spatial ability learners also struggle to apply their anatomical knowledge to the contralateral side of the body, specifically when they study using a physical skeleton of the ankle. This suggests that learners with low spatial ability need to study both sides of the human body to apply their anatomical knowledge effectively and that future textbooks and simulators may need to be designed with this in mind.

The modality used to learn human anatomy was another important variable that impacted knowledge recall. The work presented in this dissertation showed that traditional textbooks images generated the same learning outcomes as commercial anatomical e-learning tools. Furthermore, studying using a traditional physical skeleton that enabled visual-kinesthetic learning, generated significantly better knowledge outcomes than either traditional anatomy textbook images or commercial anatomical e-learning tools. These results suggest that traditionally salient teaching practices are sufficient for novice undergraduate students learning human anatomy.

As a whole this dissertation suggests that the value of commercial e-learning tools cannot be assessed adequately on the basis of an educator's, or a software developer's, intuitions alone. Instead, commercial anatomical e-learning tools must be critically and objectively assessed against existing standards in order to justify their continued integration into undergraduate curriculums and subsidization by higher educational institutions.

5.6 Literature Cited

Adams CM, Wilson TD. 2011. Virtual cerebral ventricular system: An MR-based three-dimensional computer model. Anat Sci Educ 4:340–347.

Alfieri J, Portelance L, Souhami L, Steinert Y, McLeod P, Gallant F, Artho G. 2012. Development and impact evaluation of an e-learning radiation oncology module. Int J Radiat Oncol Biol Phys 82:e573–e580.

Allen LK, Eagleson R, de Ribaupierre S. 2016. Evaluation of an online three-dimensional interactive resource for undergraduate neuroanatomy education. Anat Sci Educ 9:431-439.

Attardi SM, Rogers KA. 2015. Design and implementation of an online systemic human anatomy course with laboratory. Anat Sci Educ 8:53–62.

Backhouse M, Fitzpatrick M, Hutchinson J, Charankumal ST, Keenan ID. 2017. Improvements in anatomy knowledge when utilizing a novel cyclical “observe-reflect-draw-edit-repeat” learning process. Anat Sci Educ 10:7-22.

Bakr MM, Massey WL, Massa HM. 2016. Digital Cadavers: Online 2D learning resources enhance student learning in practical head and neck anatomy within dental programs. Educ Res Int 1-10.

Brown JS. 2000. Growing up digital: How the web changes work, education and the ways people learn. Change 32:10–20.

Brünken R, Steinbacher S, Plass JL, Leutner D. 2002. Assessment of cognitive load in multimedia learning using dual-task methodology. Exp Psychol 49: 109–119.

Case R, Kurland MD, Goldberg J. 1982. Operational efficiency and the growth of short-term memory span. J Exp Child Psychol 33:386-404.

Clark RC, Nguyen F, Sweller J. 2006. Efficiency in learning evidence-based guidelines to manage cognitive load. San Francisco, CA: Pfeiffer.

Codd AM, Choudhury B. 2011. Virtual reality anatomy: Is it comparable with traditional methods in the teaching of human forearm musculoskeletal anatomy? Anat Sci Educ 4:119–125.

Conway AR, Kane MJ, Bunting MF, Hambrick DZ, Wilhelm O, Engle RW. 2005. Working memory span tasks: A methodological review and user’s guide. Psychon B Rev 12:769-786.

Crossingham JL, Jenkinson J, Woolridge N, Gallinger S, Tait GA, Moulton CAE. 2009. Interpreting three-dimensional structures from two-dimensional images: A web-based interactive 3D teaching model of surgical liver anatomy. HPB (Oxford) 11:523–528.

Danili E, Reid N. 2004. Some strategies to improve performance in school chemistry, based on two cognitive factors. Res Sci Technol Educ 22:203–226.

DeLeeuw KE, Mayer RE. 2008. A comparison of three measures of cognitive load: Evidence for separable measures of intrinsic, extraneous, and germane load. J Educ Psychol 100:223–234.

Dindar M, Kabakçı Yurdakul I, İnan Dönmez F. 2015. Measuring cognitive load in test items: static graphics versus animated graphics. J Comput Assist Learn 31:148–161.

Doubleday EG, O'Loughlin VD, Doubleday AF. 2011. The virtual anatomy laboratory: Usability testing to improve an online learning resource for anatomy education. Anat Sci Educ 4:318–326.

Drake RL, Pawlina W. 2017. A growing voice for anatomy educators. Anat Sci Educ 10:5-6.

EU. 2014. European Union. Report to the European Commission on New Modes of Learning and Teaching in Higher Education. 1st Ed. Luxembourg: Publications Office of the European Union. 67 p. URL: http://ec.europa.eu/education/library/reports/modernisation-universities_en.pdf [accessed 25 January 2016].

Garg A, Norman GR, Spero L, Taylor I. 1999. Learning anatomy: Do new computer models improve spatial understanding? Med Teach 21:519–522.

Gathercole SE, Pickering SJ, Knight C, Stegmann Z. 2004. Working memory skills and educational attainment: Evidence from national curriculum assessments at 7 and 14 years of age. Appl Cognitive Psych 18:1–16.

Grunwald T, Corsbie-Massay C. 2006. Guidelines for cognitively efficient multimedia learning tools: Educational strategies, cognitive load, and interface design. Acad Med 81:213–223.

Guy R, Pisani HR, Rich P, Leahy C, Mandarano G, Molyneux T. 2015. Less is more: Development and evaluation of an interactive e- atlas to support anatomy learning. Anat Sci Educ 8:126–132.

Hassinger JP, Dozois EJ, Holubar SD, Camp JC, Farley DR, Fidler JL, Pawlina W, Robb RA, Larson DW. 2010. Virtual pelvic anatomy simulator: A pilot study of usability and perceived effectiveness. J Surg Res 161:23–27.

Higgins K, Randall B, Diana LW. 2000. Evaluating educational software for special education. Technol Tr, 36:109-115.

Holden HK, Rada R. 2011. Understanding the influence of perceived usability and technology self-efficacy on teachers' technology acceptance. J Res Tech Educ 43:343–367.

Hoyek N, Collet C, Rienzo F, Almeida M, Guillot A. 2014. Effectiveness of three-dimensional digital animation in teaching human anatomy in an authentic classroom context. Anat Sci Educ 7:430–437.

Hu A, Wilson T, Ladak H, Haase P, Fung K. 2009. Three-dimensional educational computer model of the larynx: Voicing a new direction. Arch Otolaryngol 135:677–681.

Irby DM, Cooke M, O'Brien BC. 2010. Calls for reform of medical education by the Carnegie Foundation for the Advancement of Teaching: 1910 and 2010. Acad Med 85:220-227.

Jones GM, Andre T, Superfine R, Taylor R. 2003. Learning at the nanoscale: the impact of students' use of remote microscopy on concepts of viruses, scale, and microscopy. J Res Sci Teach 40:303-322.

Jones GM, Minogue J, Tretter TR, Negishi A, Taylor R. 2006. Haptic augmentation of science instruction: does touch matter? Sci Educ 90:111-123.

Keedy AW, Durack JC, Sandhu P, Chen EM, O'Sullivan PS, Breiman RS. 2011. Comparison of traditional methods with 3D computer models in the instruction of hepatobiliary anatomy. Anat Sci Educ 4:84–91.

Khot Z, Quinlan K, Norman GR, Wainman B. 2013. The relative effectiveness of computer-based and traditional resources for education in anatomy. Anat Sci Educ 6:211–215.

Kijpokin K. 2017. Electronic Learning: Theory and Applications. In: Vu P, Fredrickson S, Moore C. Handbook of Research on Innovative Pedagogies and Technologies for Online Learning in Higher Education. Hershey, PA: IGI Global, p. 367-392.

Levinson AJ, Weaver B, Garside S, McGinn H, Norman GR. 2007. Virtual reality and brain anatomy: A randomized trial of e-learning instructional designs. Med Educ 41:495–501.

Lu J, Li L, Sun GP. 2010. A multimodal virtual anatomy e-learning tool for medical education. In: Zhang X, Zhong S, Pan Z, Yun R (Editors). Entertainment for Education: Digital Techniques and Systems. 1st Ed. Berlin, Germany: Springer Berlin Heidelberg. p 278–287.

Mathiowetz V, Yu CH, Quake-Rapp C. 2016. Comparison of a gross anatomy laboratory to online anatomy software for teaching anatomy. Anat Sci Educ 9:52–59.

Minogue J, Jones G. 2009. Measuring the impact of haptic feedback using the SOLO taxonomy. Int J Sci Educ 31:1359-1378.

Nguyen N, Wilson TD. 2009. A head in virtual reality: Development of a dynamic head and neck model. Anat Sci Educ 2:294–301.

Nicholson DT, Chalk C, Funnell WRJ, Daniel SJ. 2006. Can virtual reality improve anatomy education? A randomised controlled study of a computer-generated three-dimensional anatomical ear model. Med Educ 40:1081–1087.

Oblinger DG, Oblinger JL. 2005. Is it age or IT: First steps toward understanding the Net Generation. In: Oblinger DG, Oblinger JL (Editors). Educating the Net Generation. Boulder, CO: EDUCAUSE. p 2.1–2.20.

Oblinger DG, Oblinger JL, Lippincott JK (Editors). 2005. Educating the Net Generation. 1st Ed. Boulder, CO: EDUCAUSE. 264 p.

O'Bryne PJ, Patry A, Carnegie JA. 2008. The development of interactive online learning tools for the study of anatomy. Med Teach 30:e260–e271.

Pin L, Martin C, Andrey S. 2011. Rising Costs: A Look at Spending at Ontario Universities. 1st Ed. Toronto, ON, Canada: Ontario Undergraduate Student Alliance Research Contributions. 48 p.

Preece D, Williams SB, Lam R, Weller R. 2013. "Let's Get Physical": Advantages of a physical model over 3D computer models and textbooks in learning imaging anatomy. Anat Sci Educ 6:216–224.

Rich P, Guy R. 2013. A "Do-It-Yourself" interactive bone structure module: Development and evaluation of an online teaching resource. Anat Sci Educ 6:107–113.

Richardson-Hatcher A, Hazzard M, Ramirez-Yanez G. 2014. The cranial nerve skywalk: A 3D tutorial of cranial nerves in a virtual platform. Anat Sci Educ 7:469–478.

Rogers EM. 2003. Diffusion of Innovations. 5th Ed. New York, NY: Free Press, 576 p.

Sergovich A, Johnson M, Wilson TD. 2010. Explorable three-dimensional digital model of the female pelvis, pelvic contents, and perineum for anatomical education. Anat Sci Educ 3:127–133.

Skiba DJ, Barton AJ. 2006. Adapting your teaching to accommodate the net generation of learners. Online J Issues Nurs 11:15.

Soliman M, Karia N. 2015. Enterprise Resource Planning Systems in Higher Education Context: Functionalities and Characteristics. Int J Innov Res Sci En Technol 4:10408-10413.

Squires D, Preece J. 1999. Predicting quality in educational software: Evaluating for learning, usability and the synergy between them. Interact Comput 11:467–483.

Stull AT. 2009. Anatomy learning in virtual reality: A cognitive investigation. University of California: Santa Barbara, CA. Doctorate of Philosophy Dissertation. 184 p.

Trelease RB. 2016. From chalkboard, slides, and paper to e-learning: How computing technologies have transformed anatomical sciences education. Anat Sci Educ 9:583-602.

Tsaparlis G. 2005. Non-algorithmic quantitative problem solving in university physical chemistry: A correlation study of the role of selective cognitive factors. Res Sci Technol Educ 23:125–148.

UNESCO. 2009. United Nations Educational, Scientific and Cultural Organization. Higher education, research and innovation: Changing dynamics. In: Meek VL, Teichler U, Kearney ML (Editors). Report on the UNESCO Forum on Higher Education, Research and Knowledge 2001–2009. Kassel, Germany: International Centre for Higher Education Research Kassel. 242 p.

van Merriënboer JJG, Sweller J. 2010. Cognitive load theory in health professional education: Design principles and strategies. Med Educ 44:85–93.

Van Nuland SE, Eagleson R, Rogers KA. 2017. Educational Software Interface Usability: Artifact or Design?. Anat Sci Educ 10:190-199.

Van Nuland SE, Rogers KA. 2016a. The Anatomy of E-Learning Tools: Does software usability influence learning outcomes? Anat Sci Educ 9:378-390.

Van Nuland SE, Rogers KA. 2016b. E-Learning, Dual-task and Cognitive Load: The anatomy of a failed experiment. Anat Sci Educ 9:186-196.

Venail F, Deveze A, Lallemant B, Guevara N, Mondain M. 2010. Enhancement of temporal bone anatomy learning with computer 3D rendered imaging softwares. Med Teach 32:e282–e288.

Williams DL, Boone R, Kingsley KV. 2004. Teacher beliefs about educational software. J Res Technol Educ 36:213-229.

Wright EF, Hendricson WD. 2010. Evaluation of a 3-D interactive tooth atlas by dental students in dental anatomy and endodontics courses. J Dent Educ 74:110–122.

Yeung JC, Fung K, Wilson TD. 2011. Development of a computer-assisted cranial nerve simulation from the visible human dataset. Anat Sci Educ 4:92–97.

Yuan K, Steedle J, Shavelson R, Alonzo A, Oppezzo M. 2006. Working memory, fluid intelligence, and science learning. Educ Res Rev 1:83-98.

Zacharia ZC, Olympiou G. 2011. Physical versus virtual manipulative experimentation in physics learning. Learn Instr 21:317-331.

Appendices

Appendix A: Permission Approval Notice for "E-Learning, Dual-Task and Cognitive Load: The Anatomy of a Failed Experiment"

JOHN WILEY AND SONS LICENSE
TERMS AND CONDITIONS

Mar 13, 2017

This Agreement between Sonya Van Nuland ("You") and John Wiley and Sons ("John Wiley and Sons") consists of your license details and the terms and conditions provided by John Wiley and Sons and Copyright Clearance Center.

License Number	4067071070340
License date	Mar 13, 2017
Licensed Content Publisher	John Wiley and Sons
Licensed Content Publication	ANATOMICAL SCIENCES EDUCATION
Licensed Content Title	E-learning, dual-task, and cognitive load: The anatomy of a failed experiment
Licensed Content Author	Sonya E. Van Nuland,Kem A. Rogers
Licensed Content Date	Oct 19, 2015
Licensed Content Pages	11
Type of use	Dissertation/Thesis
Requestor type	Author of this Wiley article
Format	Print and electronic
Portion	Full article
Will you be translating?	No
Title of your thesis / dissertation	The Cognitive Load of Learning Anatomy: The design and implementation of a novel dual-task paradigm
Expected completion date	Jul 2017
Expected size (number of pages)	250

Print This Page

Appendix B: Permission Approval Notice for "The Anatomy of E-Learning Tools: Does software usability influence learning outcomes?"

JOHN WILEY AND SONS LICENSE
TERMS AND CONDITIONS

Mar 13, 2017

This Agreement between Sonya Van Nuland ("You") and John Wiley and Sons ("John Wiley and Sons") consists of your license details and the terms and conditions provided by John Wiley and Sons and Copyright Clearance Center.

License Number	4067071290481
License date	Mar 13, 2017
Licensed Content Publisher	John Wiley and Sons
Licensed Content Publication	ANATOMICAL SCIENCES EDUCATION
Licensed Content Title	The anatomy of E-Learning tools: Does software usability influence learning outcomes?
Licensed Content Author	Sonya E. Van Nuland,Kem A. Rogers
Licensed Content Date	Dec 15, 2015
Licensed Content Pages	13
Type of use	Dissertation/Thesis
Requestor type	Author of this Wiley article
Format	Print and electronic
Portion	Full article
Will you be translating?	No
Title of your thesis / dissertation	The Cognitive Load of Learning Anatomy: The design and implementation of a novel dual-task paradigm
Expected completion date	Jul 2017
Expected size (number of pages)	250

Print This Page

Appendix C: Permission Approval Notice for "Educational Software Usability: Artifact or Design?"

JOHN WILEY AND SONS LICENSE
TERMS AND CONDITIONS

Mar 15, 2017

This Agreement between Sonya Van Nuland ("You") and John Wiley and Sons ("John Wiley and Sons") consists of your license details and the terms and conditions provided by John Wiley and Sons and Copyright Clearance Center.

License Number	4070390147512
License date	Mar 15, 2017
Licensed Content Publisher	John Wiley and Sons
Licensed Content Publication	ANATOMICAL SCIENCES EDUCATION
Licensed Content Title	Educational software usability: Artifact or Design?
Licensed Content Author	Sonya E. Van Nuland,Roy Eagleson,Kem A. Rogers
Licensed Content Date	Jul 29, 2016
Licensed Content Pages	10
Type of use	Dissertation/Thesis
Requestor type	Author of this Wiley article
Format	Print and electronic
Portion	Text extract
Number of Pages	2
Will you be translating?	No
Title of your thesis / dissertation	The Cognitive Load of Learning Anatomy: The design and implementation of a novel dual-task paradigm
Expected completion date	Jul 2017
Expected size (number of pages)	250

Appendix D: Ethics Approval Notice for Study 1

Western Research | **Research Ethics**

Use of Human Participants - Initial Ethics Approval Notice

Principal Investigator: Dr. Kem Rogers
File Number:104961
Review Level: Delegated
Protocol Title:E-Learning: Effective or Defective? The impact of commercial e-learning tools on learner cognitive load and anatomy instruction
Department & Institution: Schulich School of Medicine and Dentistry\Anatomy & Cell Biology,Western University
Sponsor:
Ethics Approval Date: March 10, 2014 **Expiry Date:**January 31, 2015
Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
Instruments	Demographic questionnaire	
Instruments	Anatomy of the Knee Pre & Post Test	
Instruments	Anatomy of the Elbow Pre & Post Test	
Recruitment Items	Email Script for Recruiting	
Recruitment Items	Verbal Announcement Transcript	
Instruments	Revised Dual-task Experimental Design Clean Copy (with Tracked changes accepted)	2014/03/03
Revised Letter of Information & Consent	Letter of Information Clean Copy (Tracked changes accepted)	2014/03/03
Response to Board Recommendations	Researcher Responses to Reccomendations	2014/03/03
Revised Western University Protocol	Revised Western Protocol Clean Copy (Tracked Changes Accepted)	2014/03/03

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the University of Western Ontario Updated Approval Request Form.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

The Chair of the HSREB is Dr. Joseph Gilbert. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Ethics Officer to Contact for Further Information

___ Erika Basile	✓ Grace Kelly	___Mina Mekhail	___Vikki Tran

Appendix E: Ethics Approval Notice for Study 2

Western Research

Research Ethics

Western University Health Science Research Ethics Board
HSREB Amendment Approval Notice

Principal Investigator: Dr. Kem Rogers
Department & Institution: Schulich School of Medicine and Dentistry\Anatomy & Cell Biology,Western University

HSREB File Number: 104961
Study Title: E-Learning: Effective or Defective? The impact of commercial e-learning tools on learner cognitive load and anatomy instruction
Sponsor:

HSREB Amendment Approval Date: September 03, 2014
HSREB Expiry Date: January 31, 2015

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Instruments	Recognition Quiz- Knee	
Revised Western University Protocol	Western Ethics Protocol- Clean Copy	
Instruments	Recognition Quiz- Wrist	
Instruments	Recognition Quiz- Elbow	
Revised Letter of Information & Consent	Letter of Information- Clean Copy	2014/07/22
Recruitment Items	Recruitment Email Script- Clean Copy	
Recruitment Items	Script for Classroom Announcement- Clean Copy	
Instruments	Dual Task #1 Participant Instructions	
Instruments	Learning task Participant Instructions	
Instruments	Monitoring Task Pariticpant Instructions	
Instruments	MRT Participant Instructions	
Instruments	Math Worksheet	
Other	Wrist Picture- Single-Task Image	
Instruments	Dual Task Experimental Design- Clean Copy	
Instruments	Mental Rotations Test	
Instruments	Demographic Questionnaire- Clean Copy	

The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the amendment to the above named study, as of the HSREB Amendment Approval Date noted above.

HSREB approval for this study remains valid until the HSREB Expiry Date noted above, conditional to timely submission and acceptance of HSREB Continuing Ethics Review. If an Updated Approval Notice is required prior to the HSREB Expiry Date, the Principal Investigator is responsible for completing and submitting an HSREB Updated Approval Form in a timely fashion.

The Western University HSREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use Guideline for Good Clinical Practice Practices (ICH E6 R1), the Ontario Personal Health Information Protection Act (PHIPA, 2004), Part 4 of the Natural Health Product Regulations, Health Canada Medical Device Regulations and Part C, Division 5, of the Food and Drug Regulations of Health Canada.

Members of the HSREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Ethics Officer to Contact for Further Information

___ Erika Basile	✓ Grace Kelly	___ Mina Mekhail	___ Vikki Tran

Appendix F: Sample Anatomy Quiz Questions of the Wrist Joint for Study 2

In this anterior view of the hand, identify the bone indicated by the arrow.

a) Hamate
b) Ulna
c) Pisiform
d) Scaphoid
e) Trapezium

Identify the bones that articulate at the wrist joint.

a) Scaphoid, lunate, radius
b) Scaphoid, ulna, radius
c) The first row of carpal bones, ulna, radius
d) The first row of carpal bones and the radius
e) All the carpal bones, ulna, radius

From the accompanying picture, identify the wrist joint as the skeleton's right wrist joint or left wrist joint.

a) Right wrist joint
b) Left wrist joint

Which of the following pictures shows the radial bone?

a) 

b) 

c) 

d) 

e) 

Appendix G: Sample Anatomy Quiz Questions of the Elbow Joint for Study 2 and 3

Identify the bony landmark indicated by the arrow.

a) Coronoid fossa

b) Olecranon fossa

c) Radial fossa

d) Intertubercular sulcus

e) Trochlear notch

Identify the bones that articulate at the elbow joint.

a) Humerus, ulna, fibula

b) Scapula, ulna, carpals

c) Humerus, ulna, radius

d) Metacarpals, fibula, radius

e) Humerus, scapula, radius

From the accompanying picture, identify the elbow joint as the skeleton's right elbow joint or left elbow joint.

a) Right elbow joint

b) Left elbow joint

Which of the following pictures shows the radial bone?

a) 

b) 

c) 

d) 

e) 

Appendix H: Sample Anatomy Quiz Questions of the Knee Joint for Study 2

Identify the bony landmark indicated by the arrow in the picture.

a) Head of the fibula or proximal epiphysis
b) Medial condyle
c) Lateral malleolus
d) Tibial tuberosity
e) Greater trochanter

Identify the bones that articulate at the knee joint.

a) Femur, patella, tibia
b) Femur, patella, tibia, fibula
c) Humerus, femur, patella
d) Femur, fibula, tibia
e) Ulna, fibula, femur

From the accompanying picture, identify the knee joint as the skeleton's right knee joint or left knee joint.

a) Right knee joint
b) Left knee joint

Which of the following pictures shows the tibial bone?

a)


b)


c)


d)


e)


Appendix I: Ethics Approval Notice for Study 3

Western Research

Research Ethics

Western University Health Science Research Ethics Board
HSREB Amendment Approval Notice

Principal Investigator: Dr. Kem Rogers
Department & Institution: Schulich School of Medicine and Dentistry\Anatomy & Cell Biology,Western University

Review Type: Expedited
HSREB File Number: 104961
Study Title: E-Learning: Effective or Defective? The impact of commercial e-learning tools on learner cognitive load and anatomy instruction

HSREB Amendment Approval Date: December 15, 2015
HSREB Expiry Date: March 10, 2016

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Recruitment Items	Class Announcement for Dual-Task -Study 2 (non 3319)	2015/10/13
Recruitment Items	Class Announcement for Dual-Task -Study 2 (3319)	2015/10/13
Recruitment Items	Class Announcement for Survey Study - Study 2 (non-3319)	2015/10/13
Recruitment Items	Class Announcement for Survey Study - Study 2 (3319)	2015/10/13
Revised Letter of Information & Consent	Dual-Task Letter of Information (3319)- Study 2	2015/10/13
Revised Letter of Information & Consent	Dual-Task Letter of Information (non-3319)- Study 2	2015/10/13
Other	Wrist Recognition Test- Study 2	2015/10/13
Other	Ankle Recognition Test- Study 2	2015/10/13
Other	Elbow Pictures- Study 2	2015/10/13
Other	Learning Task Participant Instructions- Study 2	2015/10/13
Other	Dual Task #1 Participant Instructions- Study 2	2015/10/13
Other	Dual Task #2 Participant Instructions- Study 2	2015/10/13
Recruitment Items	Email Script to Accompany Verbal Recruitment- Study 2	2015/10/13
Revised Western University Protocol		2015/10/13
Revised Letter of Information & Consent	Survey Letter of Information (3319)- Study 2	2015/12/15

The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the amendment to the above named study, as of the HSREB Initial Approval Date noted above.

HSREB approval for this study remains valid until the HSREB Expiry Date noted above, conditional to timely submission and acceptance of HSREB Continuing Ethics Review.

The Western University HSREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use Guideline for Good Clinical Practice Practices (ICH E6 R1), the Ontario Personal Health Information Protection Act (PHIPA, 2004), Part 4 of the Natural Health Product Regulations, Health Canada Medical Device Regulations and Part C, Division 5, of the Food and Drug Regulations of Health Canada.

Members of the HSREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Ethics Officer to Contact for Further Information: Erika Basile __ Nicole Kaniki __ Grace Kelly __ Mina Mekhail __ Vikki Tran __

This is an official document. Please retain the original in your files

Appendix J: Sample Anatomy Quiz Questions of the Wrist Joint for Study 3

Identify the bone marked by the arrow.

a) Lunate

b) Triquetrum

c) Trapezium

d) Scaphoid

e) Pisiform

From the accompanying picture, identify which aspect of the hand is being viewed.

a) Anterior view

b) Posterior view

Appendix K: Sample Anatomy Quiz Questions of the Ankle Joint for Study 3

Identify the bone marked by the arrow.

a) Medial cuneiform
b) Navicular
c) Cuboid
d) Talus
e) Calcaneus

From the accompanying picture, identify which aspect of the ankle is being viewed

a) Superior view
b) Inferior view

Curriculum Vitae

Name:	Sonya E. Van Nuland
Post-secondary Education and Degrees:	University of Guelph Guelph, Ontario, Canada 2007-2011 B.Sc. Hons The University of Western Ontario London, Ontario, Canada 2011-2013 M.Sc. The University of Western Ontario London, Ontario, Canada 2013-2017 Ph.D.
Honours and Awards:	**Social Sciences and Humanities Research Council and Canada (SSHRC) Doctoral Fellowships** 2016-2018 **Drs. Madge and Charles Macklin Fellowship for Teaching & Research** 2016-2017 **Doctoral Excellence Research Award** 2016-2017 **University Student Council Teaching Honour Roll** 2014-2015, 2015-2016 **Ontario Graduate Scholarship** 2011-2012, 2012-2013, 2015-2016 **Queen Elizabeth II Scholarship** 2014-2015
Related Work Experience:	**Teaching Assistant** Medical Gross Anatomy & Undergraduate Mammalian Histology The University of Western Ontario, Anatomy and Cell Biology Schulich School of Medicine and Dentistry 2011-2017

Teaching Assistant
Medical Gross Anatomy & Medical Mammalian Histology
Mayo Clinic, Mayo Medical School
Department of Anatomy
2016

Student Director
Board of Directors
American Association of Anatomists
2016-2018

Anatomy Coordinator
Anatomy & Radiology Contouring (ARC) Bootcamp for Radiology Oncology Residents, The University of Western Ontario and London Health Sciences Centre in Conjunction with London Regional Cancer Program
2013-2016

Publications:

Van Nuland SE, Rogers KA. 2017. The Skeletons in Our Closet: E-Learning tools and what happens when one side doesn't fit all. Anat Sci Educ DOI: 10.1002/ase.1708.

Van Nuland SE, Rogers KA. 2016. Academic Nightmares: Predatory Publishing. Anat Sci Educ 10.1002/ase.1671.

Van Nuland SE, Eagleson R, Rogers KA. 2017. Educational Software Interface Usability: Artifact or Design?. Anat Sci Educ 10:190-199.

Van Nuland SE, Rogers KA. 2016. The Anatomy of E-Learning Tools: Does software usability influence learning outcomes?. Anat Sci Educ 9:378-390.

Van Nuland SE, Rogers, KA. 2016. E-Learning, Dual-task and Cognitive Load: The anatomy of a failed experiment. Anat Sci Educ 9:186-196.

Van Nuland SE, Roach VR, Wilson TD, Belliveau DJ. 2015. Head to Head: The Role of Competition in Undergraduate Education. Anat Sci Educ 8:404-412.