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How Haptics and Drawing Enhance the Learning of Anatomy

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Students' engagement with two-dimensional (2D) representations as opposed to three-dimensional (3D) representations of anatomy such as in dissection, is significant in terms of the depth of their comprehension. This qualitative study aimed to understand how students learned anatomy using observational and drawing activities that included touch, called haptics. Five volunteer second year medical students at the University of Cape Town participated in a six-day educational intervention in which a novel "haptico-visual observation and drawing" (HVOD) method was employed. Data were collected through individual interviews as well as a focus group discussion. The HVOD method was successfully applied by all the participants, who reported an improvement of their cognitive understanding and memorization of the 3D form of the anatomical part. All the five participants described the development of a "mental picture" of the object as being central to "deep learning." The use of the haptic senses coupled with the simultaneous act of drawing enrolled sources of information that were reported by the participants to have enabled better memorization. We postulate that the more sources of information about an object, the greater degree of complexity could be appreciated, and therefore the more clearly it could be captured and memorized. The inclusion of haptics has implications for cadaveric dissection versus non-cadaveric forms of learning. This study was limited by its sample size as well as the bias and position of the researchers, but the sample of five produced a sufficient amount of data to generate a conceptual model and hypothesis.

Key words: gross anatomy education; medical education; undergraduate education; cadaveric dissection; anatomical drawing; cognition; haptics; touch

"Let someone say of a doctor that he really knows his physiology or anatomy, that he is dynamic – these are real compliments; but if you say he is an observer, a man who really knows how to see, this is perhaps the greatest compliment one can make".

Jean-Martin Charcot (1825–1893)
(Huth and Murray, 2006)

INTRODUCTION

The role of the arts in medical education is growing (Doley et al., 2001; Stewart and Charon, 2002; Elder et al., 2006; Shapiro et al., 2006; de la Croix et al., 2011; Jasani and Saks, 2013; Slominski et al., 2017), for clinical observation (Boudreau et al., 2008) and specifically in anatomy education (Collett and McLachlan, 2005). Drawing has been recognized for some time as a helpful adjunct to other aids to learning, possibly by forcing students to slow down and pay careful attention to detail (Matern and Feliciano, 2000). Early anatomists such as Andreas Vesalius employed drawing as a means of observation and recording the findings of their explorations of the anatomy through dissection (Saunders and O'Malley, 1982). The positive effect of drawing on learning generally (Coates, 1984; Adams, 2002; Alkaslassy and O'Day, 2002; Weekes, 2005), in medical students (Bardes et al., 2001; Rodenhauser et al., 2004; Shapiro et al., 2006; Coles et al., 2011; Barsom et al., 2016) and specifically in the learning of anatomy has already been well described (Flannery, 1994; Phillips, 2000; Nayak and Kodimajalu, 2010; Ranaweera and Montplaisir, 2010; Moore et al., 2011; Clavert et al., 2012; Backhouse et al., 2016; Balemans et al., 2016). In a randomized, blinded, and controlled study of 416 medical students, Alsaid and Bertrand (2016) showed statistically significant improvements in memorization of an anatomical region after one and seven weeks, as a result of drawing before and after a dissection session.

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Learner-generated drawing is a strategy that can improve learning from expository text (Van Meter et al., 2006). These authors used a model of drawing construction in young learners under three experimental conditions including varying degrees of support. On a problem solving posttest, both supported drawing groups scored higher than the non-drawing control group. Overall, the results of this study supported the hypotheses from the generative theory of drawing construction derived by Van Meter et al. (2006). The addition of external support allowed learners to use drawing effectively to improve learning from content area text. The authors conclude that their study supports the use of drawing as a strategy for learning from content area text (Van Meter et al., 2006). The generative theory of drawing construction has since evolved into the cognitive theory of multimedia learning, where drawing demands that the learner engage in generative learning (Van Meter and Firetto, 2013). The learner generates new conceptual representations as well as connections between the new representation and prior knowledge, with dual coding because drawing leads to the construction of an internal nonverbal representation that is connected to the internal representation of verbal text (Van Meter and Firetto, 2013).

A students' notion of human anatomy is built up cumulatively as a result of repetitions of verbal descriptions, images, and sensations from multiple sources until a more or less fixed conception is achieved that is then retained, and taken forward into subsequent areas of clinical study. In the constructivist paradigm of education, learning consists of a to-and-fro process between a phenomenon that is sensed, observed or experienced, and any preexisting conception of that phenomenon in the learner's mind (Piaget and Inhelder, 1973; Vygotsky, 1978). The concept of learners actively constructing knowledge in their own minds was further developed by Sweller (1988), who distinguished between the synthesis of new knowledge and its storage as a mental "schema." Based on Hitch and Baddeley's model of working memory (1976), the Cognitive Load Theory in the fields of education, and instructional design (Sweller, 1988), assumes that storage and information processing are based on two interdependent systems, namely that the working memory is dealing with information processing while the long-term memory stores information in the form of schemata (Debue and van der Leemput, 2014). Cognitive load theory is concerned with the manner in which cognitive resources are focused and used during learning and problem-solving (Chandler and Sweller, 1991). The acquisition of domain-specific knowledge is affected by intrinsic factors (the inherent difficulty) and extrinsic/extraneous factors (the way information is presented to the learner, and the type of learning environment) in order to produce the schema (germane load), through which knowledge will become permanently stored (Chandler and Sweller, 1991). Many learning and problem-solving procedures encouraged by instructional formats result in students engaging in cognitive activities far removed from the predetermined goals of the task. The cognitive load generated by these irrelevant activities (extrinsic factors) can impede skill acquisition but are also able to be modified by the teacher and the learner (Chandler and Sweller, 1991).

Drawing is a complex activity involving visual and spatial coordination, linked to the fine motor ability to represent a 3D object on a sheet of paper, in two dimensions. Spatial ability and mental rotation are held to be important capabilities for this task (Vorstenbosch et al., 2013). Haptics, the sense of touch, is needed to fully engage the third dimension (Klatzky and Lederman, 2011). Haptic sensation not only involves the immediate area of tactile contact, but also includes weight and texture as well as proprioception, balance, and movement (Lederman and Klatsky, 1987; Wolfe et al., 2015). Decades of scientific research in the field of haptics attest that touch is fundamental to our observation and understanding of the physical world (Klatzky and Lederman, 1992). Recent digital technological advances incorporating haptics into computer hardware and software design are just beginning to develop applications (Schneider et al., 2017). Recent advances in the development of haptic devices in simulators allow the perception of an object through an active examination by the sense of touch, feeling and palpating its shape and texture (Hu et al., 2006). This technology is already being implemented in many different fields, including simulators for learning clinical procedures (Yovanoff et al., 2016), surgery (Singapogu et al., 2015), and more specifically virtual reality training for minimal invasive surgery (Van der Meijden and Schijven, 2009). Virtual environments for training that incorporate haptic devices pose an important alternative for hand-operated skills (Escobar-Castillejos et al., 2016). A recent review of haptic feedback during skill acquisition using simulation for minimally invasive surgery concludes that haptic feedback provides the greatest benefit to surgical novices in the early stages of their training, using new technology (Pinzon et al, 2016). Another review claims that advanced technology simulation is on the verge of dramatically affecting health care education, specifically through the science and technology of haptics in virtual reality-based simulation (Kapoor et al., 2014). By contrast, other virtual reality technologies to simulate 3D learning of anatomy such as stereoscopic headsets that omit a haptic component, have had mixed results (Luursema et al., 2017).

The Cognitive Theory of Multimedia Learning proposed by Mayer (2014) is based on three main assumptions: that there are two separate channels (auditory and visual) for processing information; that there is limited channel capacity; and that learning is an active process of filtering, selecting, organizing, and integrating information (Mayer, 2009). Mayer's theory of learning proposes that the brain does not interpret a multimedia presentation of words, pictures, and auditory information in a mutually exclusive fashion, but that these elements are selected and organized dynamically to produce logical mental constructs (Mayer, 2014). Touch could be considered in the same way as one of a number of senses that contributes to the development of mental "schemata." Pickering (2015) applied these theories by examining the learning gain that is made when using technology-enhanced learning (TEL) resources, which he states is now a common tool across a variety of health care programs. The change in learning gains observed with anatomy drawing screencasts was measured in comparison to a traditional paper-based resource (Pickering, 2017). The results at all test points revealed a significant increase in learning gain and large effect sizes for the screencast group compared to the textbook group. He claims that this work adds to the growing area of research that supports the effective design of TEL resources which are complimentary to the cognitive theory of multimedia learning in order to achieve both an effective and efficient learning resource for anatomical education (Pickering, 2017).

In allowing for a 3D understanding of an anatomical component, haptics may also be important in the distinction between cadaveric and non-cadaveric forms of learning anatomy. In the ongoing debate about the need for cadaveric dissection in the learning of anatomy (Guttmann et al., 2004; McLachlan et al., 2004; Turney, 2007; Sugand et al., 2010; Bergman, 2015), there appears to be some consensus that further separation of educational philosophies into cadaveric versus non-cadaveric teaching and learning is unhelpful, as other forms of learning should be complementary rather than substitute for dissection (McLachlan and Patten, 2006; Patel et al., 2015; Ghosh, 2017). One UK study of medical students' perceptions of the learning outcomes resulting from anatomy teaching within the curriculum in general, concluded that "no single teaching modality met all aspects of the curriculum" (Kerby et al., 2011). A recent review concludes that "the best way to teach modern anatomy is by combining multiple pedagogical resources to complement one another" and that a more selective approach is needed as "certain professions would have more benefit from certain educational methods or strategies than others." (Estai and Bunt, 2016). In their systematic review of articles published over a period of 50 years, Wilson et al. (2017) found that in the context of short-term knowledge gains alone, dissection is no better, and no worse, than alternative instructional modalities. They argue that the educational design process may carry more weight in fostering student success than the innate attributes of the chosen method itself.

Within this discourse, the distinction between two-dimensional and 3D representations is central. Non-cadaveric forms of learning rely to a greater extent on 2D representations of anatomy in text, illustration and computer software programs, together with a set of assumptions that the student will be able to translate these images into learning and memory. The 3D aspects of perception can be simulated by computer-generated images on a 2D screen (Lewis et al., 2014), however, a systematic review found that there is insufficient evidence to show that these resources have a true place for replacing traditional methods in teaching anatomy (Tam et al., 2009). Plastic models that can be touched and manipulated are also promising, however a recent review of studies exploring 3D anatomy models and their impact on learning found that there was no solid evidence that the use of 3D models is superior to traditional teaching that includes dissection (Azer and Azer, 2016).

This study aimed to explore and understand how the addition of haptics to observational drawing might enhance the learning of anatomy by medical students. The aim was not to assess the effect of the method on the extent of their anatomical knowledge, but rather to understand phenomenologically what was happening in the learning process. The haptico-visual observation and drawing (HVOD) method employed in this study was specific to the observation of the 3D form of the anatomy in order to promote a more detailed understanding.

MATERIALS AND METHODS

Study Design and Sampling

A descriptive study was undertaken using qualitative methods. All 230 second-year medical students were offered a month-long Special Studies Module (SSM) in which they were given a choice of 65 projects in small groups across a wide range of topics within the faculty. Out of the class of 230, 5 students elected to undertake the SSM entitled "Drawing and Anatomy," and all five were invited to participate in the study.

Learning Environment

Anatomy education for medical students at the University of Cape Town is integrated into problem-based learning (PBL) with a biopsychosocial philosophy. Clinical Anatomy is one of many subjects are taught in Years 1–3 of the program, with robust horizontal and vertical integration, and early exposure of the students to the clinical setting. In their first year, the students study osteology in detail and are introduced to all the systems of the body through models and bottled, wet, and plastinated prosected specimens. The students perform full body dissection in their second and third years of study. A group of six second-year students shares the body with a group of six third-year students, dissecting at different times of the day. The total number of hours of structured study for clinical anatomy across the three years of the program amounts to approximately 300 hours, including whole class lectures, pre-practical session talks, dissection slots, and practical sessions (about 200 hours), computer-based learning activities, and formative assessments. The summative assessments have an integrated format across all the disciplines and therefore clinical anatomy is a portion of each type of assessment.

For a period of four weeks in the second half of second year, every student completes a SSM. The modules are located in various departments with different supervisors involved, and students volunteer for the SSM they would like to work on from a list that is supplied by the faculty. The SSM on HVOD is just one of the options and is therefore not formalized into the clinical anatomy curriculum for the whole class. Some of the students who selected the HVOD SSM assumed that they needed to have some experience of art-making in order to benefit from this SSM. However, the two students who had taken art as a high school subject, and consequently had some drawing experience, needed to ignore their mark-making style in order to learn the HVOD method which involved a different mark-making style. The HVOD method is primarily about observation and memorization, with mark-making (i.e. drawing) reinforcing haptic object observation. The marks that the observer makes while exploring the object using the haptic senses also functions as a means of verifying to the observer the accuracy of their observations of the object.

Intervention: Haptico-Visual Observation and Drawing Method

The HVOD method used in this study couples haptic and visual exploration with the simultaneous act of drawing an object, such that the object being haptically explored with the sensing hand is being simultaneously reflected by the drawing hand as graphite marks on paper. As the sensing hand explores the object, this sensory information informs and guides the motor actions of the drawing hand. The participants were taught how to observe and draw using the HVOD method by a specialist drawing teacher (L.S.) in three distinct and sequential learning stages (Figure 1):

Stage 1: This preparatory stage focuses on the identification and countering of automatic, predictable upper limb movements; movements that are predicated on the functional anatomy of the upper limb and hand alone, rather than on consciously determined, deliberate upper limb movements and hand gestures. Exercises included inter alia, making marks with graphite on paper at various speeds (from very slowly to very quickly) as well as making marks with varying degrees of pressure.

These exercises were employed to prepare the participant's upper limb and hand to make marks on paper (i.e. draw) with a piece of graphite in their drawing hand, such that those marks made would reflect the 3D form of what is being observed haptically with the observing hand. This mark-making method is useful for describing the 3D form and volume of objects using the HVOD method.

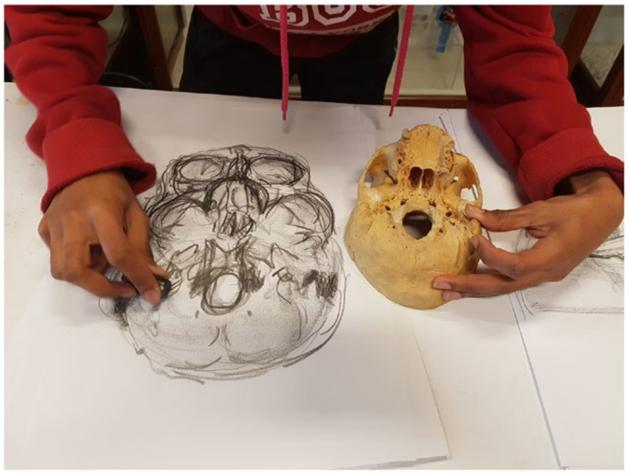

Figure 1.

A student drawing the base of the skull during haptico-visual observation and drawing (HVOD) special studies module (SSM) using graphite on 80 gsm paper. Permission was obtained from the student to publish the image.

Stage 2: Haptic and visual observation (HVO) of the 3D form of the object. This was executed with the eyes open as well as closed while exploring the object using the haptic sense. A 200-gram ball-peen hammer was the object used for this stage.

Stage 3: HVOD of the form of the object onto paper with graphite using conscious upper limb movements and hand gestures.

Following Stage 3, HVOD was employed using a humerus followed by other osteological material.

This method does not require any prior drawing experience and the technique was mastered by all participants within the first nine hours of the intervention in three sessions of three hours each.

Data Collection

Each participant was interviewed separately mid-way through the HVOD intervention by one of the authors (S.R.) with the same questions being put to each participant. A focus group discussion was conducted by S.R. at the end of the intervention, using an interview guide (Appendix 1). The individual interviews and focus group discussion were conducted in English, audio-recorded, and thereafter transcribed. Analysis of this qualitative data was carried out by two researchers independently using an inductive approach following grounded theory to code major and minor themes in the framework method (Gale et al., 2013). These major and minor themes were defined by the frequency and similarities of the participant's experiences and perceptions of the HVOD process; major themes were defined by responses that were raised more frequently and convincingly by the participants, including examples, while minor themes were only occasionally mentioned with less import.

Ethical Considerations

All participants agreed to participate in the study and to have their interviews recorded, transcribed and used as data in this study. Ethical approval was granted the UCT Human Research Ethics Committee (ref 582/2015) and permission to conduct research on students was obtained from the UCT Department of Student Affairs (Figure 2).

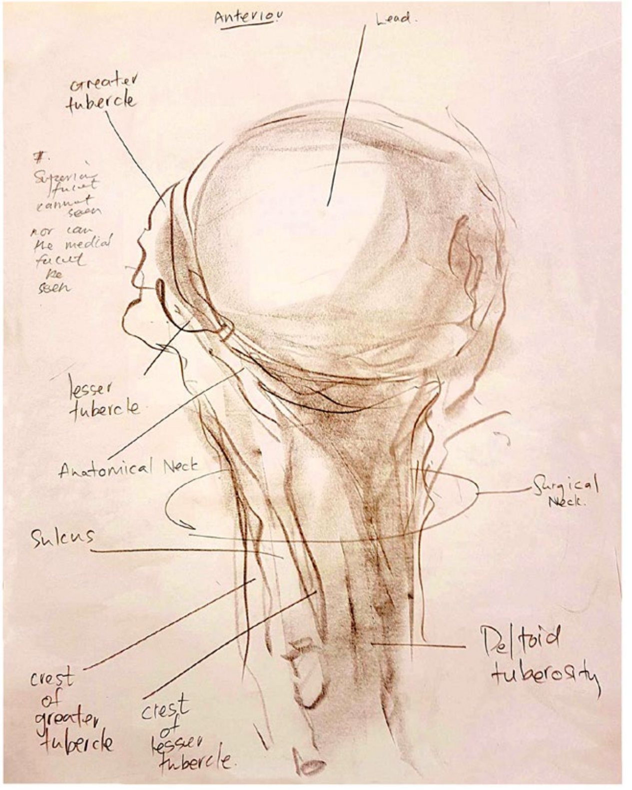

Figure 2.

A student's haptico-visual observation and drawing (HVOD) special studies module (SSM) drawing of the head and neck of the humerus using graphite on 80 gsm paper. The student subsequently annotated their drawing according to an anatomy atlas. Permission was obtained from the student to publish the image.

RESULTS

The participants were five second-year medical students, four female, and one male, studying at the University of Cape Town, with an average age of 20 (SD ±1.5) years. A summary of their responses is represented diagrammatically in Figure 3. They described the central process as one of visualizing a mental picture of the object that they were drawing, that was built from deep observation arising from the method of drawing while touching the object. This was linked to better memorization of the object in three dimensions and in detail. They reported that this approach emphasized an immediacy resulting in a descriptive mark-making accuracy.

Major Themes

Creating a mental picture. The participants described the process of observation and of learning this method of drawing arising from the creation of a mental picture through careful observation, not just visually but also through touch

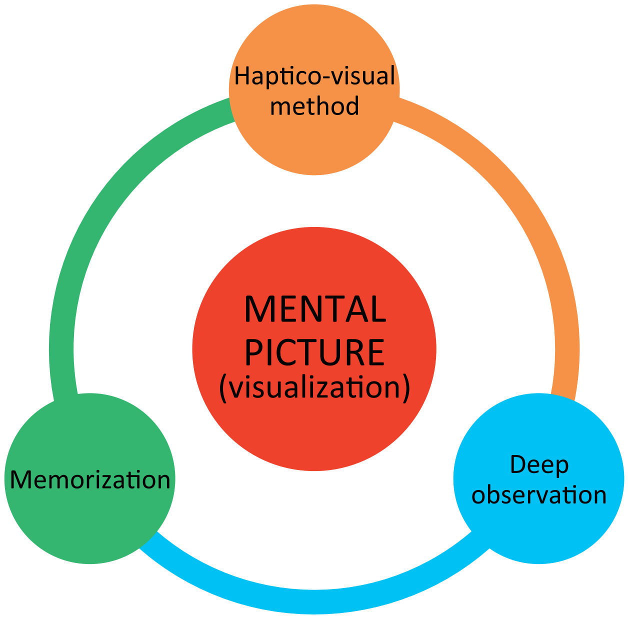

Figure 3.

Diagrammatic representation of the major themes extrapolated from the individual interviews and focus group discussion with the students who participated in the haptico-visual observation and drawing (HVOD) special studies module (SSM).

and the simultaneous act of making marks on paper that corresponded with the form of what was being observed.

> "I think the biggest thing is not creating a picture … the point was to get a mental picture. That was like the main point is that if you can close your eyes and even if you were scribbling on the paper, I think just to facilitate the picturing of the object three dimensionally but ja [sic], the point was more to get that mental picture than more than anything else and I think …. sometimes you focus so much on the line and the drawing of it … that is not where the focus is meant to be." [Participant A]

Another expressed a similar experience, which was confirmed by the focus group:

> "Whereas if you close your eyes and you're thinking about the object you really are creating that, that 3D perception in your mind. So it's all great having it on paper but the point is to mentally be able to see… what's retained in your mind." [Participant C]

In this way, the participants linked the "mental pictures," called "schema" in Cognitive Load Theory by Sweller (1988), directly to the process of memorization.

The haptico-visual observation and drawing method. The HVOD approach employed in this study was described in terms of the sense of touch (haptics) enhancing the means of gathering data from the object being observed, in this case a 200-gram ball-peen hammer, a humerus, and upper limb prosection.

> "… it isn't just about looking at something. You have to use all your senses. Touch it, smell it if you'd like, …all those things and that's how you understand something. That it is not just about me looking at it, at its surface". [Participant D]

Participants expressed how they could "see" the object without only using their eyes:

> "…actually focusing your attention on something and feeling it with your eyes open and closed and kind of just a lot more intimately you … I was able to kind of see a lot more of it. Also the abnormalities with it". [Participant B]

One morning the ball-peen hammers that the participants had drawn the day before, were switched with others of the same size and shape without their knowledge, but they immediately established that these were different hammers, indicating the level of detail and nuance that they had internalized:

> "…I know the texture, I know the various characteristics that distinguish my hammer from everyone else's hammer…". [Participant A]

and

> "… you actually notice the things that you wouldn't have seen straight away and then you feel those grooves that you wouldn't see and then you put them on paper". [Participant F]

On another occasion, at the start of a workshop session, a humerus was discovered to have gone missing from the workshop room. This became evident when one of the participants reported not being able to locate the particular humerus that he had been observing and drawing the day before. The humerus was eventually located in an adjoining lecture room (it had been used by a lecturer in a demonstration) and when it was handed to the participant, he examined it by holding and feeling it before announcing that it was "his"; the one that he had been previously observing and drawing. The level of detail required to recognize a particular humerus using touch attests to the amount of nuanced information that had been absorbed through the haptic sense.

This degree of sensitivity to detail also had an impact outside of the anatomical drawing class:

> "I think it was like I found just because our minds have been focused on observational skills and really like looking at things like I found it's in everyday life now I tend to be a lot more aware of observing things and even with people like just, you know, picking up on small things and remembering it for the next time … just those observational skills." [Participant E].

Attention to detail is a pivotal part of accurate observation, and the participants reported that were able to extend this outside of the drawing class, which is a significant finding.

The HVOD method benefited the participants in that they were not only able to improve their ability to observe a part of the anatomy by drawing it and memorizing it, but also to retrieve the memorized image and redraw it on paper in the absence of the object. They could also annotate their drawing by comparing it with an illustration in an anatomy atlas and note which specific aspects of the anatomy they had observed inaccurately.

> "... not just observing necessarily with your eyes but observing with your hands and you, you get to feel like the texture and the curvature of the hammer. So then when you draw it you can get that across in your drawing and then when you remember it later on you don't remember it as just like a … you don't remember the drawing necessarily, you remember the actual object. So it's not about the end product, it's about what you're seeing... you start to notice all of these things that you didn't know were there". [Participant C]

Other participants reported noticing "more" of the humerus than through previous study methods:

> "... this style of drawing, it got through to me differently...I got more of an accurate sense of everything that encompasses the object". [Participant B]

> "...feeling it with your eyes open and closed and kind of just a lot more intimately, I was able to kind of see a lot more of it...also the abnormalities with it". [Participant C]

Deep 3D observation. Participants found that haptic observation led to a greater understanding of the anatomy in three dimensions.

> "... So this way you kind of get more of a 3D sense of what you're studying but at the same time it increases your memory of the object whereas before it would be more about association. Here you are kind of taking it from the primary point being the object". [Participant E]

Extending the distinction between 2D and 3D appreciations of anatomy, the HVOD method was found to complement the study of illustrations in an anatomy atlas.

> "...as opposed to just opening a book and looking at the pictures and learning the labels it's better to interact with the object; not just looking at it, but touching it and drawing it as you touch it. So then once you've had a good understanding of what...the humerus looks like, the different grooves and the indentations for the attachment of muscles and everything...when you see an abnormality in another bone it is a lot easier to identify. You can more intuitively tell that this is different as opposed to someone having to point it out to you or having to study it for a long period of time to tell that this is abnormal". [Participant D]

Memorization. Participants also experienced improved memory retention of the object observed.

> "...if we were to have a test, you know, to test if we understood the object better, you know, I feel like we… would be able to pass that with flying colors basically because I still remember all the objects perfectly in my head from the observation part of it...Here the reference is in your mind...I mean you could close your eyes and draw a humerus. Now I can see it in my mind's eye..." [Participant C]

Participants built onto their existing knowledge of the anatomy.

> "So you're supposed to take that prior knowledge and incorporate it into what you're seeing now because it is not like you're going in completely blind and you don't know the anatomy to begin with. You have a reasonable understanding and the point of the drawing is just to build on that understanding". [Participant A]

One participant explicitly contrasted the HVOD method with the traditional textbook approach of learning, indicating the limits of cognitive load through the latter.

> "... it makes it more familiar because when you learn through the textbook method, I think depending on how good your memory is, you usually forget it and then you have to go back and look at it again". [Participant A]

Minor Themes

In addition to these major themes, the following minor themes emerged.

Personal drawing styles. Some participants, particularly those who were experienced in drawing, needed to overcome a conventionally accepted definition of what is "beautiful":

> "... when you are taught art it's about making something look pretty... aesthetics don't matter here...it's about the form of the subject" [Participant C]

> "... the point, the point isn't to be able to draw a beautiful picture, the point is to have it in your mind, to have that picture in your mind so you can understand it and discuss it, probably in a clinical setting, or, well that's the thing, so I like the idea of visualizing it in my mind and having all the grooves, and draw it like drawing a very flimsy sketch on a piece of paper, but more to make sure that I've got the concept in my mind, not to spend hours on a beautiful picture". [Participant B]

For other participants, an additional benefit was finding their own unique drawing style or "signature" (similar to a unique handwriting).

> "... I think that once you've perfected it and you've perfected your personal technique, your personal way of applying the technique in your own style you can produce something that's very beautiful". [Participant E]

Time-saving. When questioned about the time that it takes to observe using drawing, participants felt that the long-term benefit of dependably retaining a mental picture outweighed the investment in time taken to learn the technique:

> "... I think the reward after a period of time is much greater than if you hadn't had that at all". [Participant F]

> "Even though you do have to put in more time (learning this method) I think at the end it saves you a lot more of it because it's easier to bring out the memory than...it was before". [Participant A]

DISCUSSION

This is the first study of haptic exploration coupled with the simultaneous act of drawing as a method of observation resulting in the increased comprehension of the 3D form and detail of anatomical parts, as well as the cavities within different organs (e.g. the chambers of the heart) and bones (e.g. the skull). In understanding the process of learning, the results reveal the centrality of the "mental picture" of the anatomical part, developed through looking, drawing, and touching in an iterative cycle. Although the participants reported that the drawing intervention using the HVOD method increased their understanding and memorization of the 3D form of an object, the study was not as concerned with the results as with understanding how that process occurred. The use of the haptic senses coupled with the simultaneous act of drawing the form of the object enrolled entirely different sources of information that enabled a much more detailed mental picture than visual perception alone could generate. The ability of each student to distinguish their unique humerus from the others was noteworthy as it indicates the level of nuance that haptics introduces, and consequently the intensity of imprinting of the mental picture that they described.

Researchers have distinguished deep approaches from surface approaches to learning (Marton and Säljö, 1976). Surface approaches to learning are associated with an intention to commit facts and information to memory and recite them back in response to questions. By contrast, deep approaches to learning involve an understanding of the underlying concepts in order to "make meaning" of information. The engagement with multiple sources of information including haptics could contribute to a deeper level of understanding anatomy, in this case through the direct appreciation of the third dimension. The psychomotor and cognitive domains are merged when the student observes an anatomical part using their haptic senses, draws it, and follows this process by referring to an anatomy atlas in order to annotate their drawing. This results in a deeper cognitive understanding and memorization of the anatomical part.

Haptics is more than just tactile sensation. Rincon-Gonzalez et al. (2011) investigated the interrelationship of tactile and proprioceptive senses, and their results suggest that "tactile sensation is encoded in a 2D map, but one which undergoes continual dynamic modification by an underlying [3D] proprioceptive map" to produce the whole haptic perception. A study using functional magnetic resonance imaging showed that sight and touch are linked in a cross-modal arrangement in the somato-sensory cortices (Hannson et al., 2009), suggesting that they are mutually enhancing. Only one other study appears to have deliberately utilized haptics in anatomy education, getting students to create plasticine models from memory without any cues, the so-called "blank-page" approach, which was judged as successful (Naug et al., 2011). Here the focus was on the effectiveness of this method rather than on understanding how it happened. Kooloos et al (2014) found little difference between students observing clay modeling and those observing video presentations, and concluded that the most important effect in terms of learning outcomes seemed to be the degree of engagement in the exercise, focusing attention, and time on the task rather than the haptics involved. Our finding that sensitivity and attention to detail was extended to other observations outside of the drawing class, echoed this important component of focusing attention.

The "mental picture" described by our participants echoes the description of the construction of an internal nonverbal representation through "dual coding" as explained by the generative theory of drawing construction (Van Meter and Firetto, 2013). Since drawing demands that the learners iteratively generate new conceptual representations for themselves, the schemata produced are more thoroughly established in long-term memory. The logical mental constructs that are organized dynamically in the cognitive theory of multimedia learning (Mayer, 2009) could be extended to include haptics. In alignment with cognitive load theory (Sweller, 1988; Chandler and Sweller, 1991), we postulate that perception through multiple senses such as vision, haptics, and drawing may have the effect of repeatedly replacing preconceptions of an object with detailed, directly observed "data" that are organized in the working memory. The more sources of information about an object, the higher a level of complexity can be integrated into a "schema" to be captured in long-term memory.

In terms of the implications of this study, the use of haptics may be more suited but not limited to osteology. While a bone is a dry solid object which can be easily handled, wet specimens are more challenging. The chambers of the heart are empty cavities but these can equally be explored with gloved hands and described through haptics and drawing, resulting in the memorization of the empty spaces and their relationship to each other. Similarly, HVOD can be applied to augment the study of cadavers while they are being dissected or after dissection. Further quantitative studies are needed to establish the educational outcomes of this approach in cadaveric dissection, compared to other methods of 3D perception such as prosections, models, or computer-assisted learning without dissection. In addition, further quantitative studies need to be undertaken before assuming that this method of observation can be recommended for introduction into curricula at other institutions.

Limitations of the Study

This study was limited by its sample size as well as the bias and position of the researchers, both of which are accepted as part of qualitative research. As subjective responses, the participants' reports that their knowledge of anatomy improved as a result of this method of learning cannot be validated, but this was not the primary objective of the study. The findings are valid for these participants and cannot be generalized, but the sample of five produced a sufficient amount of data to generate a conceptual model and hypothesis. Bias was mitigated by the process of analysis by the research team through robust discussion of the themes as they emerged. Finally, the study was not designed to demonstrate the feasibility or time-effectiveness of the HVOD method within an anatomy curriculum, which is a question for further research.

CONCLUSIONS

Students' mental image and memorization of anatomy arising from cadaveric dissection could be enhanced through drawing and touching specimens, by allowing haptics to complement visual sources of information to form a more detailed and comprehensive 3D mental picture, which is consistent with existing learning theories. The HVOD method appears to enhance existing curriculum-based knowledge of anatomy, but further research is needed to confirm this. The addition of haptics and drawing to complement existing methods of learning anatomy within the medical curriculum could add considerable value to the further study and career development of students who are motivated to explore alternatives.

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APPENDIX 1

Interview Guide for Individual Interviews and Focus Group Discussion

- Tell me about your experience of the drawing sessions.
- What was new or surprising for you? Why?
- What was difficult or challenging? Why?
- How does this experience relate to your learning of anatomy?
- What have you learned about observation? Can you describe how you learned?
- What other insights have you gained through this process?