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Paul M. Rea *Editor*

Biomedical Visualisation

Volume 6

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Preface

The utilisation of technologies in the biomedical and life sciences, medicine, dentistry, surgery and the allied health professions has been at an exponential rate over recent years. The way we view and examine data now is significantly different to what has been done perhaps 10 or 20 years ago.

With the growth, development and improvement of imaging and data visualisation techniques, the way we are able to interact with data is much more engaging than it has ever been.

These technologies have been used to enable improved visualisation in the biomedical fields but also how we engage our future generations of practitioners when they are students within our educational environment. Never before have we had such a wide range of tools and technologies available to engage our end-stage user. Therefore, it is a perfect time to bring this together to showcase and highlight the great investigative works that are going on globally.

This book will truly showcase the amazing work that our global colleagues are investigating, and researching, ultimately to improve student and patient education, understanding and engagement. By sharing best practice and innovation, we can truly aid our global development in understanding how best to use technology for the benefit of society as a whole.

Glasgow, UK Paul M. Rea

Acknowledgements

I would like to truly thank every author who has contributed to the third edition of *Biomedical Visualisation*. By sharing our innovative approaches, we can truly benefit students, faculty, researchers, industry and beyond in our quest for the best uses of technologies and computers in the field of life sciences, medicine, the allied health professions and beyond. In doing so, we can truly improve our global engagement and understanding about best practice in the use of these technologies for everyone. Thank you!

I would also like to extend out a personal note of thanks to the team at Springer Nature who have helped make this possible. The team I have been working with has been so incredibly kind and supportive, and without them, this would not have been possible. Thank you kindly!

About the Book

Following on from the success of the first five volumes, *Biomedical Visualisation*, *Volume 6*, will demonstrate the numerous options we have in using technology to enhance, support and challenge education. The chapters presented here highlight the wide use of tools, techniques and methodologies we have at our disposal in the digital age. These can be used to image the human body and educate patients, the public, faculty and students in the plethora of how to use cutting-edge technologies in visualising the human body and its processes, creation and integration of platforms for teaching and education, and in visualising biological structures and pathological processes.

The first eight chapters examine a variety of tools, techniques, methodologies and technologies which can be utilised to visualise and understand biological and medical data. This includes web-based 3D visualisation, ultrasound, virtual and augmented reality as well as functional connectivity magnetic resonance imaging, storyboarding and a variety of stereoscopic and 2D-3D transitions in learning. The final two chapters examine the pedagogy behind digital techniques and tools from social media to online distance learning techniques.

Contents

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About the Editor

Paul M. Rea is a Professor of Digital and Anatomical Education at the University of Glasgow. He holds a medical degree (MBChB), an MSc (by research) in Craniofacial Anatomy/Surgery, a PhD in Neuroscience, a Diploma in Forensic Medical Science (DipFMS) and an MEd with Merit (Learning and Teaching in Higher Education). He is an elected Fellow of the Royal Society for the encouragement of Arts, Manufactures and Commerce (FRSA), elected Fellow of the Royal Society of Biology (FRSB), Senior Fellow of the Higher Education Academy, professional member of the Institute of Medical Illustrators (MIMI) and a registered medical illustrator with the Academy for Healthcare Science.

He has published widely and presented at many national and international meetings, including invited talks. He sits on the Executive Editorial Committee for the *Journal of Visual Communication in Medicine*, is Associate Editor for the *European Journal of Anatomy* and reviews for 24 different journals/publishers.

He is the Public Engagement and Outreach Lead for anatomy coordinating collaborative projects with the Glasgow Science Centre, NHS and Royal College of Physicians and Surgeons of Glasgow. He is also a STEM Ambassador and has visited numerous schools to undertake outreach work.

His research involves a long-standing strategic partnership with The Glasgow School of Art, School of Simulation and Visualisation. This has led to multimillion pound investments in creating world's leading 3D digital datasets to be used in undergraduate and postgraduate teaching to enhance learning and assessment. This successful collaboration resulted in the creation of the world's first taught MSc Medical Visualisation and Human Anatomy, combining anatomy and digital technologies. The Institute of Medical Illustrators also accredits it. This degree, now into its eighth year, has graduated almost 100 people and created college-wide, industry, multi-institutional and NHS research-linked projects for students. Paul is the Programme Director for this degree.

1 Web-Based 3D Visualisation of Biological and Medical Data

Ciril Bohak, Žiga Lesar, Primož Lavric, and Matija Marolt

Abstract

In this chapter we present an overview of web-based frameworks for visualisation of medical and biological data, with emphasis on visualisation of volumetric data such as radiological data (e.g. magnetic resonance imaging, computed tomography or positron emission tomography) and microscopy data (e.g. focused ion beam scanning electron microscopy). We compare web-based frameworks with state-of-the-art standalone visualisation tools and point out the advantages and disadvantages of both. We also present our open-source web-based visualisation environment Med3D.

Keywords

Volumetric data · Collaborative visualisation · Web-based visualisation · WebGL 2.0 · Volumetric rendering

1.1 Introduction

In recent years, the advances in computer graphics hardware and software, as well as the development of novel visualisation techniques, have allowed the implementation of real-time visualisation systems for 3D medical radiological data obtained with magnetic resonance imaging – MRI (Rinck et al. 1990), computed tomography – CT (Crawford and King 1990; Kalender et al. 1990), positron emission tomography – PET (Ollinger and Fessler 1997) and 3D ultrasound (Krakow et al. 2003). It is also possible to visualise the biological 3D microscopy data obtained with electronic microscopy such as focused ion beam scanning electron microscopy – FIB-SEM (Briggman and Bock 2012). This is possible due to the larger system memory size which allows storing large amounts of data obtained with the above-mentioned techniques, due to the increased computational performance of graphical processing units – GPUs and due to the improved software systems which enable the development of highly optimised visualisation software products.

Such data is typically represented in the form of 3D scalar or vector fields where the values represent different properties of the scanned object. Depending on the scanning technique the values could represent various tissues inside the human body or inside the biological sample. In

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some cases the desired tissues can be additionally expressed using a contrast agent.

The first attempt of visualising volumetric data was developed in the late 1980s by Levoy (1988). The paper presents a direct surface rendering technique for volumetric data, which is briefly presented in Sect. 1.2.3.2. An in-depth review of volumetric rendering related work from the beginning until 2007 is presented in Šrámek (2006). Most notable techniques of that time were:

- **Volume Ray Casting** (Levoy 1988; Ke and Chang 1993), which is derived directly from the rendering equation (Kajiya 1986);
- **Splatting** (Westover 1991), a technique where all the elements of the volume are splatted on the canvas in back to front order as disks with diametrically varied properties (e.g. colour and/or transparency) according to normal distribution;
- **Shear Warp** (Cameron and Undrill 1992; Lacroute and Levoy 1994), a technique which decomposes the viewing transformation into a 3D shear component parallel to the data slices, projects the data to form an intermediate distorted image and finally uses a 2D warp to create an undistorted final image;
- **Texture-Based Rendering** (Hibbard and Santek 1989), a technique which exploits the functionality of dedicated hardware (later GPUs) for mapping the textures (in this case slices of volumetric data) onto parallel planes.

In the following years many improvements of the above techniques were presented and the methods were integrated into the end-user applications presented in the following subsections. Further development of some methods have also resulted in special purpose hardware implementations for achieving real-time performance. Such example is a family of Cube products (Bakalash et al. 1992; Pfister et al. 1994; Kanus et al. 1997) designed for real-time volume data visualisation which in the latest edition enabled users to interactively visualise volumes of sizes up to 128^3. The development of custom hardware has ended when support for general purpose computing (GPGPU) was brought to the GPUs in 2001. Afterwards, the visualisation systems were implemented for the GPU hardware using OpenCL[1] or CUDA[2] APIs for computation and OpenGL[3] or DirectX[4] for visualisation purposes.

1.1.1 Stand-Alone Visualisation Applications

With development of GPGPUs the implementation of newly developed visualisation methods into an end-user application became more viable and, due to broad access and affordability of the hardware, visualisation applications could be used on high-end desktop computers without the need for dedicated hardware. The selection of such software products, which are still being developed and maintained, is presented below.

1.1.1.1 VTK

The Visualisation Toolkit[5] – VTK (Schroeder et al. 2000) is a collection of software tools that allows development of customised visualisation applications on top of the implemented visualisation pipeline. While the toolkit is not intended for end-use it simplifies the development of end-user application, such as ParaView and 3D Slicer presented in the following subsections. It is one of the most wide-spread toolkits used in numerous commercial applications, since it is independent of the operating system. Unfortunately, it is based on an outdated version of the OpenGL standard (version 2.1), which means that many features cannot be optimised and the interactive rendering methods cannot be significantly improved performance-wise. Moreover, the toolkit does not support any physically-based volumetric rendering and thus does not offer state-of-the-art volumetric rendering capabilities.

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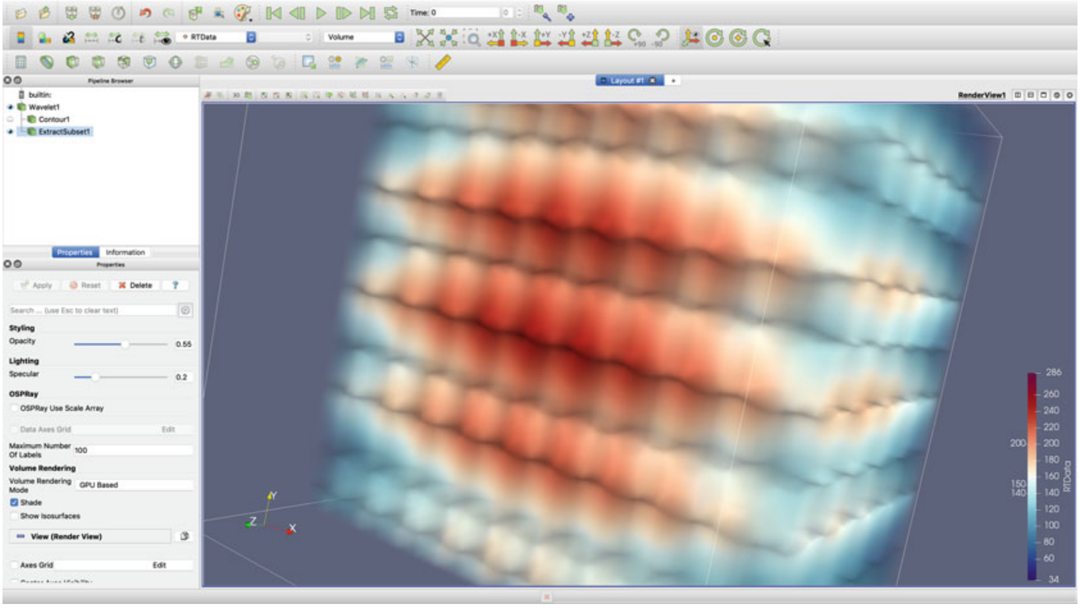
[1] https://www.khronos.org/opencl/

[2] https://www.nvidia.com/cuda/

[3] https://www.opengl.org/

[4] http://msdn.microsoft.com/directx

[5] https://vtk.org/



Opacity 0.55

Specular 0.2

☐ OSPRay Use Scale Array

Maximum Number Of Labels 100

Volume Rendering Mode GPU Based

☑ Shade

☐ Show Isosurfaces

☐ Axes Grid

Fig. 1.1 ParaView application window displaying sample volumetric data

1.1.1.2 ParaView

Built on top of VTK, ParaView[6] (Ahrens et al. 2005) is a general data analysis and visualisation application used in a variety of research fields such as engineering, geology, climate science, astrophysics, etc. The application is open-source and runs on all major platforms. It is presented in Fig. 1.1 for a sample dataset. Its main purpose is to support large-scale datasets (up to terascale) and to exploit the power of distributed computing. It is designed as an application framework as well as an end-user application, and can be modified by developers for specific use cases. While the application can be used for visualisation of data from the medical and biological domains, it does not offer state-of-the-art volumetric rendering capabilities since it is built on top of VTK.

1.1.1.3 Voreen and Inviwo

Voreen[7] (Meyer-Spradow et al. 2009) is an open source application development framework for visualisation of multi-modal volumetric datasets. It supports GPU accelerated volume rendering and data analysis and allows users high flexibility with the development of custom data analysis and visualisation workflows. The development of the framework split into two branches: Voreen and Invivo[8] (Jönsson et al. 2018). While both current versions offer better volumetric rendering capabilities implementing ray casting with global illumination, it is not defined how global illumination is implemented and none of the application is using volumetric path tracing or equivalent state-of-the-art volumetric rendering techniques. A sample data visualisations using both applications are presented in Fig. 1.2.

1.1.1.4 3D Slicer

3D Slicer[9] (Fedorov et al. 2012) is a visualisation and analysis software platform for medical image informatics, image processing and 3D visualisation. It is an open source cross-platform tool for physicians, and other researchers connected to biological and medical domains. The tool supports plugin development in Python using the provided API. It is build on top of VTK which is also the reason why it does not offer any state-of-the-art volumetric rendering capabilities. It is

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[6] https://www.paraview.org/

[7] https://www.uni-muenster.de/Voreen

[8] http://www.inviwo.org

[9] https://www.slicer.org/

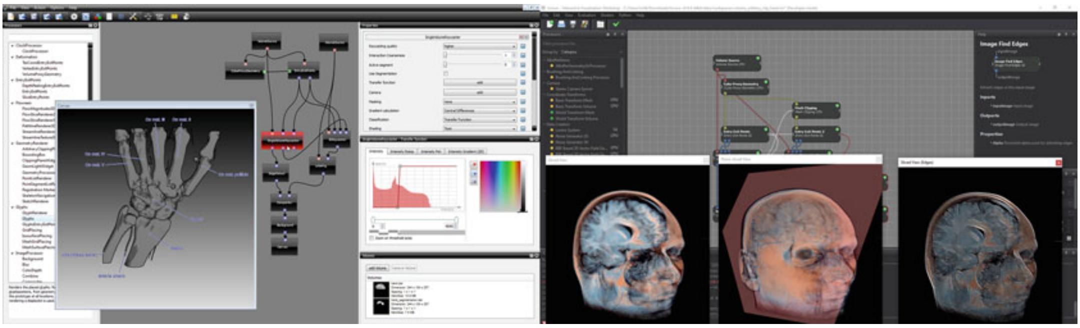

Fig. 1.2 Voreen application (left) and Inviwo application (right) displaying sample volumetric data visualisation

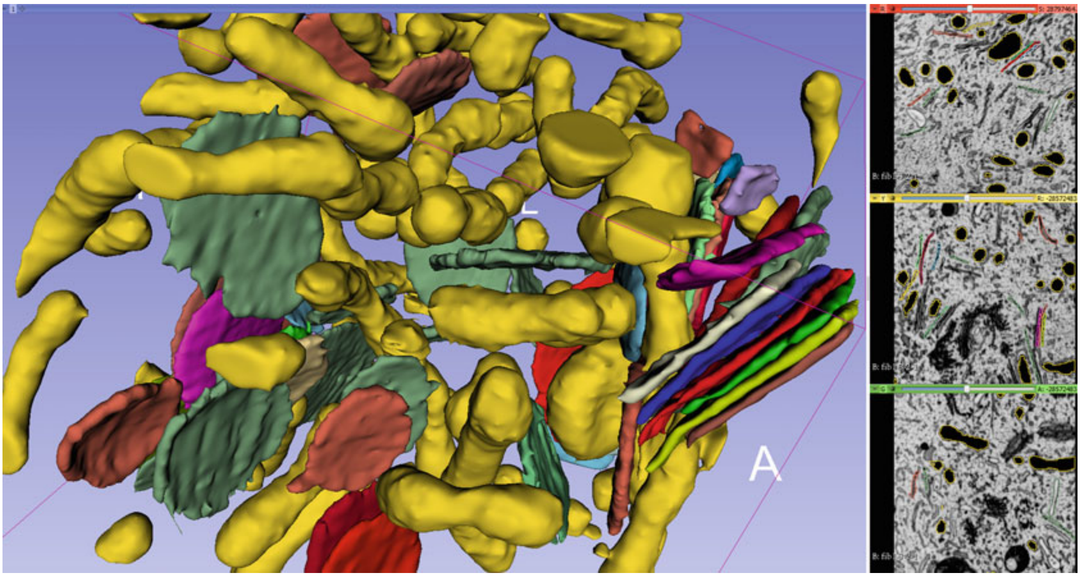

Fig. 1.3 3D Slicer application displaying segmented electronic microscopy volumetric data visualisation

broadly accepted analysis tool and has very active developer community. An example data visualisation of segmented electronic microscopy data is displayed in Fig. 1.3.

1.1.1.5 SimVascular

An example of very specialised application for simulation and visualisation of blood flow in vessels SimVascular[10] (Updegrove et al. 2017) was designed for specific purpose: providing a complete pipeline from segmented medical images to patient specific blood flow simulation, analysis and visualisation. It is build on top of VTK and has same limitations regarding the volumetric rendering, but offers good composed visualisation of the vessel data and simulation results. An example use-case is presented in Fig. 1.4.

1.1.1.6 NeckVeins

A specialised, platform-independent framework, developed in Java, is intended for fast volume-to-mesh conversion (Bohak et al. 2014) and indirect visualisation of volumetric data converted to mesh geometry for the interactive vessels visualisation. The tool supports visualisation of complex mesh geometry obtained form volume data using Marching Cubes (Lorensen and Cline 1987) or MPUI (Ohtake et al. 2003). The application with sample data is presented in Fig. 1.5.

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[10] http://simvascular.github.io/

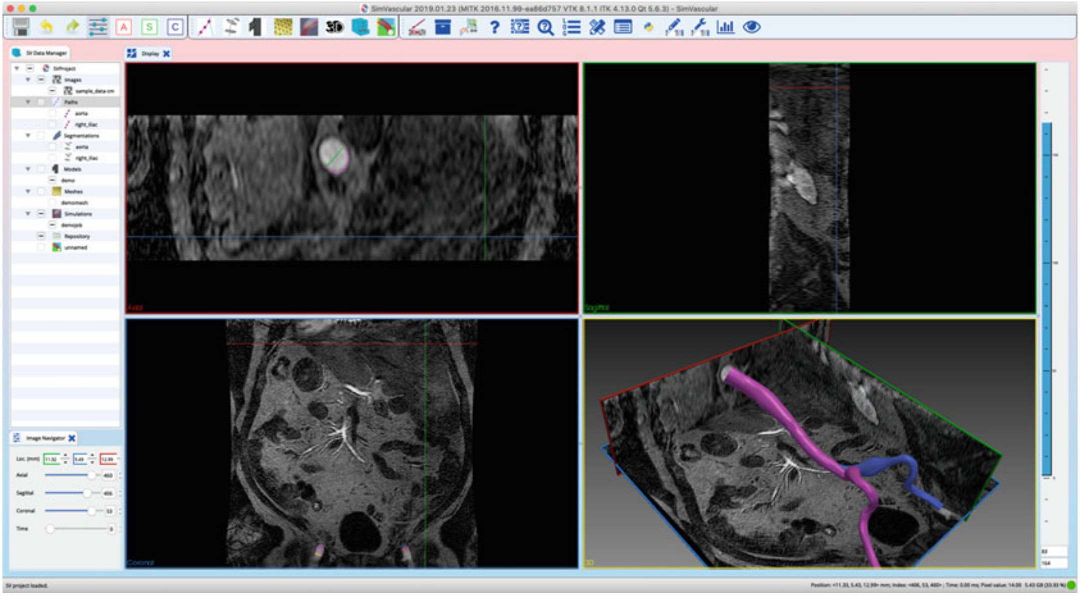


Fig. 1.4 SimVacular application displaying sample data visualisation

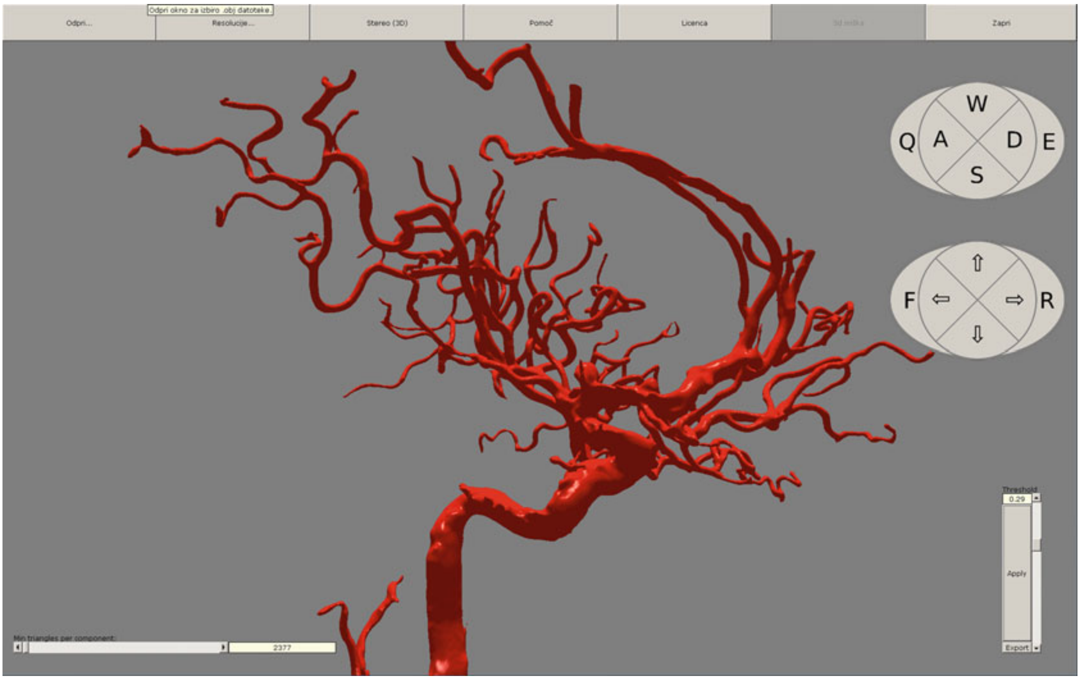
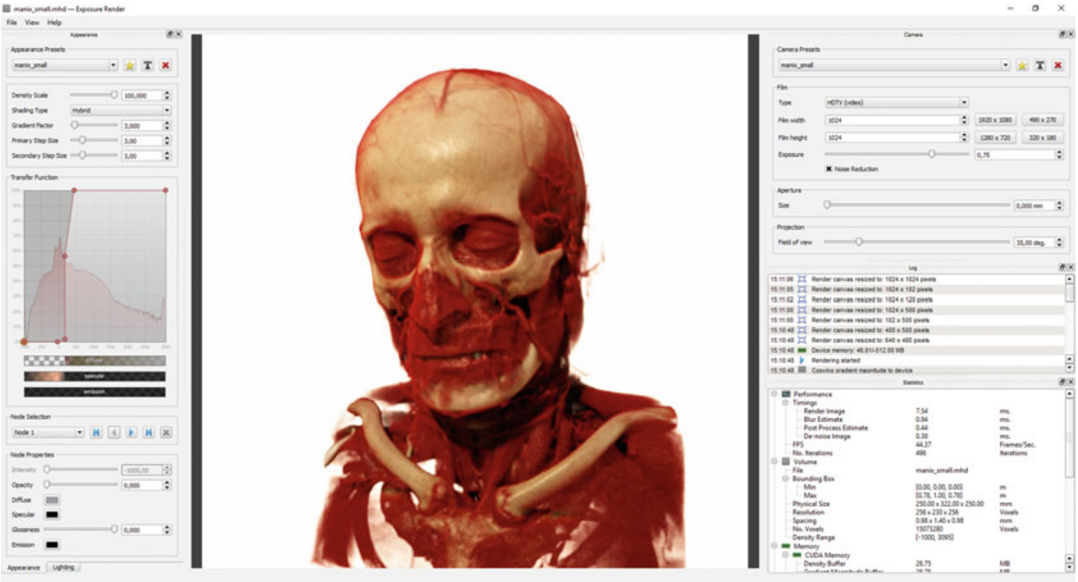


Fig. 1.5 Neckveins application displaying sample data visualisation



Appearance Presets: manix_small
Density Scale: 100,000
Shading Type: Hybrid
Gradient Factor: 3,000
Primary Step Size: 3,00
Secondary Step Size: 3,00
Node Selection: Node 1
Node Properties
Intensity: -1000,00
Opacity: 0,000
Glossiness: 0,000

Camera Presets: manix_small
Film
Type: HDTV (video)
Film width: 1024 1920 x 1080 480 x 270
Film height: 1024 1280 x 720 320 x 180
Exposure: 0,75
☒ Noise Reduction
Aperture
Size: 0,000 mm
Projection
Field of view: 35,00 deg.

```
15:11:06  Render canvas resized to: 1024 x 1024 pixels
15:11:05  Render canvas resized to: 1024 x 102 pixels
15:11:02  Render canvas resized to: 1024 x 120 pixels
15:11:00  Render canvas resized to: 1024 x 500 pixels
15:11:00  Render canvas resized to: 102 x 500 pixels
15:10:48  Render canvas resized to: 400 x 500 pixels
15:10:48  Render canvas resized to: 640 x 480 pixels
15:10:48  Device memory: 46.81/-512.00 MB
15:10:48  Rendering started
15:10:48  Copying gradient magnitude to device
```

```
Performance
  Timings
    Render Image              7.54                        ms.
    Blur Estimate             0.04                        ms.
    Post Process Estimate     0.44                        ms.
    De-noise Image            0.38                        ms.
  FPS                         44.37                       Frames/Sec.
  No. Iterations              496                         Iterations
Volume
  File                        manix_small.mhd
  Bounding Box
    Min                       [0.00, 0.00, 0.00]          m
    Max                       [0.78, 1.00, 0.78]          m
  Physical Size               250.00 x 322.00 x 250.00    mm
  Resolution                  256 x 230 x 256             Voxels
  Spacing                     0.98 x 1.40 x 0.98          mm
  No. Voxels                  15073280                    Voxels
  Density Range               [-1000, 3095]
Memory
  CUDA Memory
    Density Buffer            28.75                       MB
```

Fig. 1.6 Exposure Render application displaying sample data visualisation

1.1.1.7 Exposure Render

Exposure Render[11] (Kroes et al. 2012) is the first open source physically based volumetric ray tracing renderer for medical domain which combines volumetric and surface rendering capabilities in a single solution. The application focuses on increasing the visual realism using light occlusion, depth of field and realistic lighting. This also has a positive effect on user perception. The presented work was basis for development of many commercial products used in clinical domain (e.g. Cinematic rendering (Eid et al. 2018)). An example of rendering output using Exposure Renderer is presented in Fig. 1.6. The downside is that the application is platform dependant (Microsoft Windows only) and requires Nivida CUDA support, meaning that end-users have to buy the specific hardware and software.

All the presented applications are open-sourced and available to users for free of charge. While VTK and ParaView are developed for very broad range of use-cases and domains, others are more specialised for medical use-cases. The realistic and even hyper-realistic rendering is now also being used by radiologists (Eid et al. 2018).

There are also numerous commercial applications developed for similar purposes (e.g. Amira,[12] MeVisLab,[13] and ScanIp[14]).

While the presented applications are useful for visualisation of medical and biological volumetric data, they are still a stand-alone applications where users are limited to their use on the machine(s) where they are installed. Nowadays, this problem is mostly tackled by developing web-based applications which can run on almost any platform, including tablets and mobile phones and from any location with adequate internet connection. Users only need the web-browser, internet connection and the access to the data. In this book chapter we present such web-based solutions which are being made possible due to the fast development of accessibility of hardware acceleration in the web browsers using WebGL

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[11] https://graphics.tudelft.nl/exposure-render/

[12] https://www.thermofisher.com/si/en/home/industrial/electron-microscopy/electron-microscopy-instruments-workflow-solutions/3d-visualization-analysis-software/amira-life-sciences-biomedical.html

[13] https://www.mevislab.de/

[14] https://www.synopsys.com/simpleware/products/software/scanip.html

standard.[15] With modern graphical APIs for web-browsers the computational power of the GPUs is accessible from the web applications allowing the developers to implement solutions similar to the stand-alone ones presented above.

In the following sections we first present background methods. Next we present the web-based implementations of volume data visualisation in Sect. 1.3, we discuss their use-cases in Sect. 1.4, and in the conclusions we present the upsides and downsides of existing approaches. We give some pointers for what can be expected in the future and which directions should be pursued.

1.2 Background

In this section we give a basic background of the volumetric data, the techniques and the methods used for their visualisation.

1.2.1 Volumetric Data

Volumetric data is a 3D regular grid representation (see Fig. 1.7) of a desired object or part of the object, expressing its specific property. Such data can be obtained using different techniques as was already presented in the Introduction section and thus the data represents different properties. In most cases the data is scalar data, where individual element (voxel) represents the property value at the specific location in the object. In some cases we can even obtain multiple properties per element making the data multi-modal (e.g. CT value and segmentation annotations).

The resolution of the data depends on the acquisition hardware, the acquisition process and the technique used, and can exceed the sizes of 2048^3 elements. Even for a 8-bit precision scalar data of such resolution, this results in more than 8.5 GB of data. While this is not a problem for a modern workstation systems, where working memory (RAM) reaches 64 or in some cases even 512 GB, it still poses a big challenge for mobile devices where high-end devices offer up to 12 GB of RAM, which is party already used by system, leaving hardly enough space for storing such large volumetric data for processing.

Fig. 1.7 Example volumetric data

1.2.2 Indirect Volume Rendering

First techniques for visualising volumetric data were designed so that the data was first converted into more appropriate form and then rendered. Most popular was the transformation into mesh geometry using different surface extraction techniques such as already mentioned Marching Cubes or its derivatives (e.g. Marching tetrahedra (Doi and Koide 1991; Bagley et al. 2016)) or more prominent methods such as multi-level partition of unity implicits (Ohtake et al. 2003; Berger et al. 2017).

The advantage of using such methods is the possibility of using existing hardware for accelerated rendering. The downside, is that such methods can be usually used only to visualise the surfaces, which is not always what we want to achieve. In some cases there is also the need of

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[15] https://www.khronos.org/registry/webgl/specs/latest/2.0/

visualising translucent/transparent materials with its non-uniform structure. This is typically not possible using indirect rendering techniques and is the main reason for using direct volume rendering techniques. An example of indirect rendering is implemented in NeckVeins and SimVascular applications (some other applications also offer such a visualisation option – e.g. 3D Slicer and ParaView).

1.2.3 Direct Volume Rendering

Direct volume rendering (DVR) takes every sample value and maps it to opacity and colour. This is usually done with a so-called *transfer function* which defines how the values of the volumetric data remap to colour and opacity values. The final image is a projection and composition of these values for each pixel of the output image. We already presented basic methods in the Introduction section. In the following subsections we present the most common methods used in direct volume rendering which can be implemented in different ways (e.g. using ray casting, splatting, shear warping or other direct rendering technique).

1.2.3.1 Maximum Intensity Projection

One of the simplest direct rendering methods is the Maximum intensity projection (MIP) (Wallis et al. 1989). The method projects the data so that only maximum values along the selected path is projected onto the canvas and all the other values are ignored. The data is projected using desired projection transformation (either perspective or orthographic). The main benefit of this method is that it is fast and can be easily implemented even for large volumetric data. The downside on the other hand is the fact that we only see the maximum values in the data. Sometimes this might not be good enough for specific use cases. The method also does not provide any shading information which means that 3D structures in the data are often hard to recognise without the need of rotating the data. The method also lacks the depth perception since all the values are treated the same regardless of their distance from the user (Fig. 1.8).

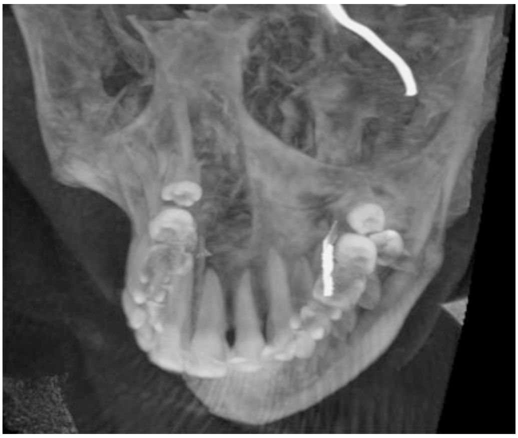

Fig. 1.8 An example of maximum intensity projection

1.2.3.2 ISO Surface Rendering

Extracting the surface from the volumetric data is what is mostly done in Indirect volumetric rendering. However, this was also one of the first DVR methods (Levoy 1988). The method can be implemented using different techniques the most common one being ray casting. The implementation using ray casting sends a ray through every pixel of the canvas and finds the first value in the volumetric data which exceeds the specified threshold. Several researchers have presented the improvements and different implementations of this method such as Parker et al. (1998) and Marmitt et al. (2004). The method can be further extended with surface normal calculation which are used in shading process, as can be see in an example in Fig. 1.9.

1.2.3.3 Emission-Absorption Model

MIP and ISO surface rendering only use single value of the volumetric data along the traced path through the volume for final rendering output and thus cannot present the transmittive media. Emission-Absorption Model (Max 1995b) is one of the most often used method that also supports the visualisation of transmittive media in the volume. It is based on the rendering equation (Kajiya 1986) but only uses the emission and absorption parts, neglecting in- and out-scattering contributions. This method is very useful for rendering continuous volumetric data. The data from medi-

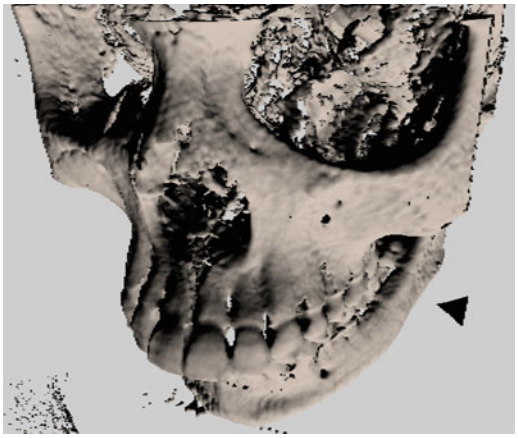

Fig. 1.9 An example of ISO surface rendering

Fig. 1.10 An example of rendering using Emission-Absorption Model

cal and biological domain fit well in this category due to the nature of tissue structure. Users can define different emission and absorption weights for different value ranges and thus emphasise desired tissues. While the method can be implemented for fast computation and gives good insight into the data due to the absorption, it still lacks good depth perception due to the lack of phenomena such as shading and shadows, which can be seen in Fig. 1.10.

1.2.3.4 Multiple Scattering Model

Best state-of-the-art volumetric rendering techniques cover all aspects of the rendering equation: emission, absorption, in-scattering and out-scattering. While first attempts were developed (Kajiya and Von Herzen 1984) even before the rendering equation was published, many methods were developed as can be seen in an overview of early physically based volumetric rendering approaches (Max 1995a). The implementation of the rendering equation obsolete was implemented in many ways, such as: path-tracing (Kajiya 1986; Lafortune and Willems 1993), photon-mapping (Jarosz et al. 2008; Bitterli and Jarosz 2017) and Metropolis light transport simulation (Veach and Guibas 1997; Pauly et al. 2000).

The main problem of the multiple scattering models is their computational complexity. Most of them use approximation techniques such as Monte Carlo integration for calculating rendering equation integration estimates, which is computationally heavy. Still there is no implementation capable of real-time visualisation of a complex data using affordable hardware. There are some attempts of implementing interactive incremental visualisations such as already mentioned Exposure render (Kroes et al. 2012) and Volumetric path tracing framework (Lesar et al. 2018) presented in one of the following sections. The state of the art of physically-based volumetric rendering methods is presented in Novák et al. (2018a,b) (Fig. 1.11).

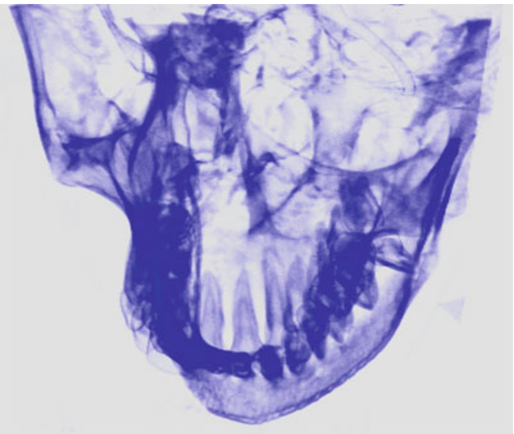

Fig. 1.11 An example of rendering using Multiple Scattering Model

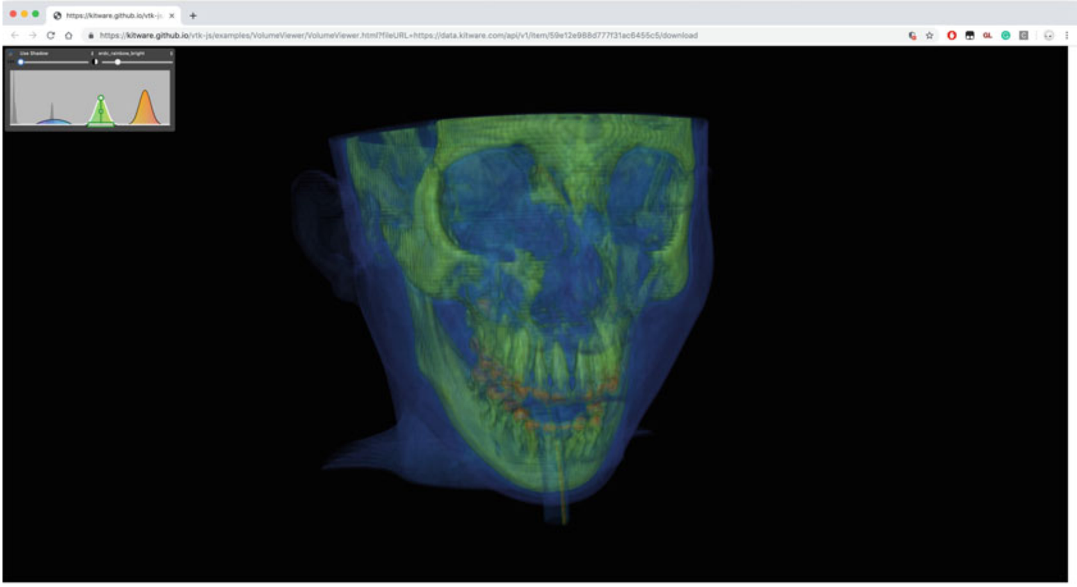

Fig. 1.12 An example of visualisation using VTK.js framework

1.3 Web Based Visualisation Systems

In the introduction section we presented a selection of stand-alone applications for visualisation of volumetric data for general or specialised use-cases. One of the main downsides of these application is their platform and hardware dependence. To overcome this problem several attempts were made to use the web platform for implementation of visualisation systems. In this section we present the selection of web-based visualisation systems for volumetric data. While some are the reimplementations of the existing stand-alone systems, other were build on top of general web-based visualisation systems and some were designed and developed from scratch.

1.3.1 VTK.js

VTK.js[16] – The Visualisation Toolkit developed in JavaScript, which is a subset of the original VTK C++ library and is intended for 3D graphics, volumetric rendering and visualisation. It includes several data processing algorithms and rendering techniques. VTK.js includes hardware accelerated volume rendering using ray casting developed in WebGL 1.0, which can be seen in Fig. 1.12. It also supports combining volumetric and mesh geometry rendering. The framework is not intended for end-users but for developers who can easily transition the application developed using original VTK framework on to the web platform. An example of such application is ParaViewWeb presented in the following section. Like original VTK, VTK.js is also missing state-of-the-art volumetric rendering methods. Since it is developed using WebGL 1.0 standard it does not exploit more advanced functionalities being introduced in WebGL 2.0 resulting in lower rendering performance.

1.3.2 ParaViewWeb

Built on top of VTK-js, ParaViewWeb,[17] a JavaScript Library, is not a reimplemntation of the original ParaView application, but a web

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[16] https://kitware.github.io/vtk-js/

[17] https://www.paraview.org/web/

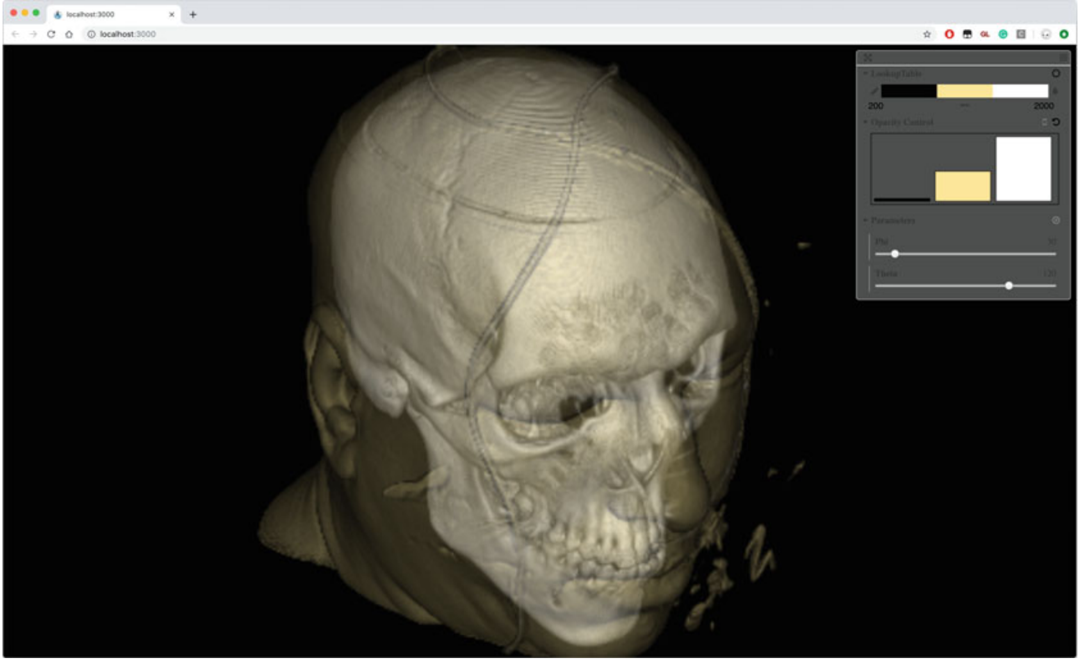

Fig. 1.13 An example application build using ParaViewWeb framework

framework designed for building interactive scientific visualisations for the web platform. It extends the functionalities implemented in VTK.js with overlaid modules for user interaction and connection with the original ParaView application which can provide the visualisation data and acts as backend for data processing as well as rendering.

It includes:

- **Visualisation components**, which is a set of interactive 2D visualisation tools for exploring the data including: a field selector, histograms, and parallel coordinates.
- **Interaction** support, which is a crucial property of all the implemented components and allows uses to interact with the data using standard inputs such as mouse, keyboard and touch input.
- **Data access**, which supports loading the data from the online sources using: (1) XHR (XML http request built into web browsers) for downloading any kind of data, (2) WebSockets for persistent communication with backend systems (e.g. ParaView server) and (3) Girder[18] – a consistent interface to KitWare Girder data management backend system.
- **UI widgets**, which is a collection of interactive widgets that allows the development of complex interactive UIs for interactive visualisation parameter settings (e.g. equaliser editor, light properties, editor, transfer function editor etc.).
- **Rendering viewers**, which is a set of dedicated viewing components such as: image viewer, WebGL image compositing viewer, and WebGL viewer for geometry. While originally ParaViewWeb was using Three.js[19] library for visualisation purposes, it migrated to VTK.js.

The authors have provided users/developers with a collection of example applications for different scientific domains (e.g. CT head sample visualisation presented in Fig. 1.13) covering variety of use-cases. The presented visualisation

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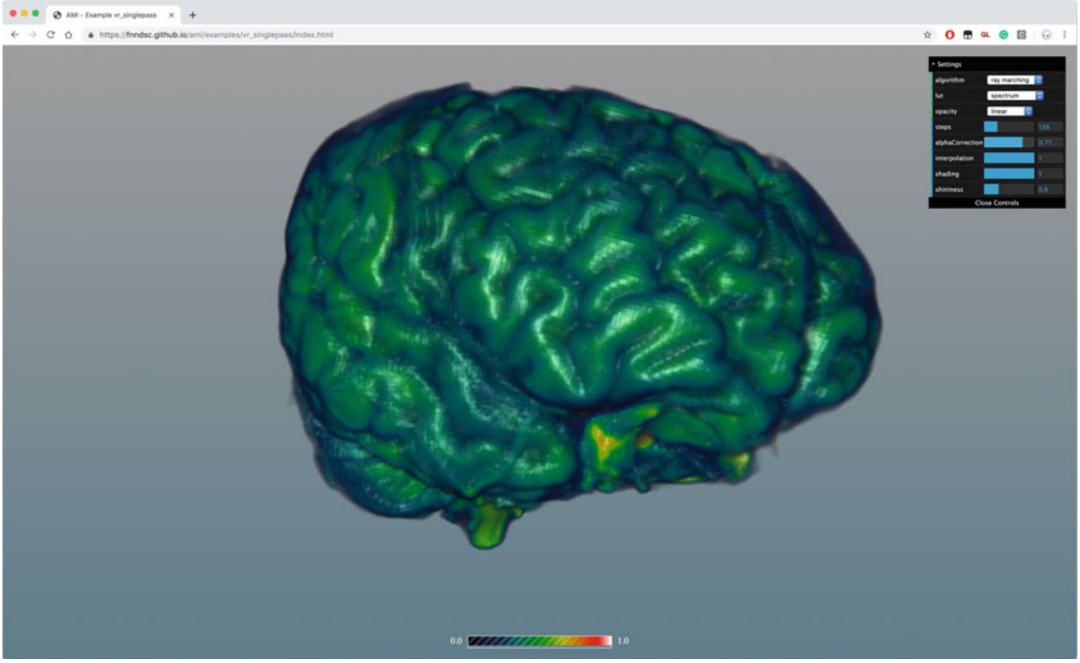
[18] https://girder.readthedocs.io/en/stable/

[19] https://threejs.org/



algorithm: ray marching
lut: spectrum
opacity: linear
steps: 138
alphaCorrection: 0.77
interpolation: 1
shading: 1
shininess: 5.8

Fig. 1.14 An example visualisation of DICOM volumetric data using Ami.js toolkit

system offers many functionalities for data processing, analysis and visualisation, but lacks the support of modern visualisation standard and implementation of state-of-the-art volumetric rendering techniques. The downside is also the use of custom dataset format which is not compatible with other applications.

1.3.3 Ami.js

Ami.js – a Medical Imaging JavaScript Toolkit[20] (Rannou et al. 2017; Arbelaiz et al. 2017) includes 2D and 3D visualisation of medical data supporting most popular medical imaging formats (e.g. DICOM, NRRD, NIFTI and MHD). It is build on top of Three.js and integrates several libraries for parsing the data from different formats. It supports the composition of 2D images and 3D model visualisations in the same view. The toolkit also supports real-time interaction and provides a set of UI elements for visualisation system setting (Fig. 1.14).

While Ami.js is a lightweight visualisation toolkit build on top of Three.js framework it offers additional ray marching volumetric rendering with predefined transfer functions. Currently it does not support user-defined transfer functions, but they can be implemented during the development stage. It is not intended as a stand-alone tool, but as a basis for developing custom visualisation systems. It relies on existing libraries for loading volumetric data. Since it is build on top of Three.js it does not support the use of WebGL 2.0. Also, the UI is less adaptable than the one implemented in ParaViewWeb.

Ami.js has been used in several web-based visualisation systems and was also integrated into a collaborative web-based real-time neuroimage visualisation system (Bernal-Rusiel et al. 2017).

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[20] https://github.com/FNNDSC/ami

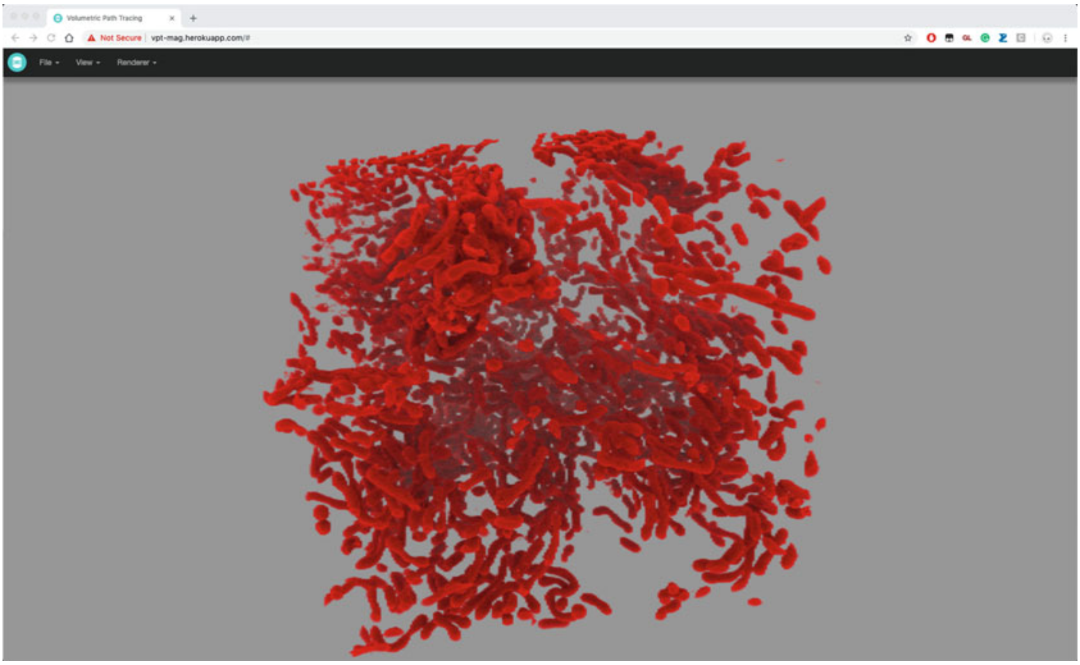

Fig. 1.15 Multiple scattering Monte Carlo path tracing of segmented biomedical microscopy data of mitochondria in mouse urinary bladder cell

1.3.4 VPT

VPT – Volumetric path tracing[21] (Lesar et al. 2018) is a web-based visualisation toolkit designed for visualisation of volumetric data supporting different techniques implemented with support for incremental rendering and is developed in JavaScript with WebGL 2.0 support. It supports visualisation using MIP, ISO surface rendering, EAM, single and multiple scattering Monte Carlo based volumetric path tracing, which is state-of-the-art web-based implementation. The path tracing implementation supports the use of user-defined 2D transfer functions and heterogeneous data. It was developed for interactive, real-time visualisation on mobile and desktop devices. An example of path traced biomedical microscopy data is presented in Fig. 1.15.

The visualisation techniques are implemented incrementally, taking the more complex methods to converge over multiple sequential frames. While simple techniques (e.g. MIP, ISO surface rendering and EAM) converge in few frames, more complex techniques need more time for converging, depending on the used hardware. The benefit of such implementation is that the visualisation is fully interactive even with use of complex rendering techniques. Once the user stops interacting (e.g. moving, rotation or zooming) the image converges to its final version. The system is extendable and can also be used as a plug-in in other visualisation systems, as is presented for the Med3D case in the following section.

1.3.5 Med3D

Med3D[22] (Bohak et al. 2016; Lavrič et al. 2017) is a lightweight web-based visualisation system developed for medical use-cases. It is developed in JavaScript with WebGL 2.0 and implements deferred rendering pipeline, unlike Three.js and VTK.js, which allows easy multipass rendering

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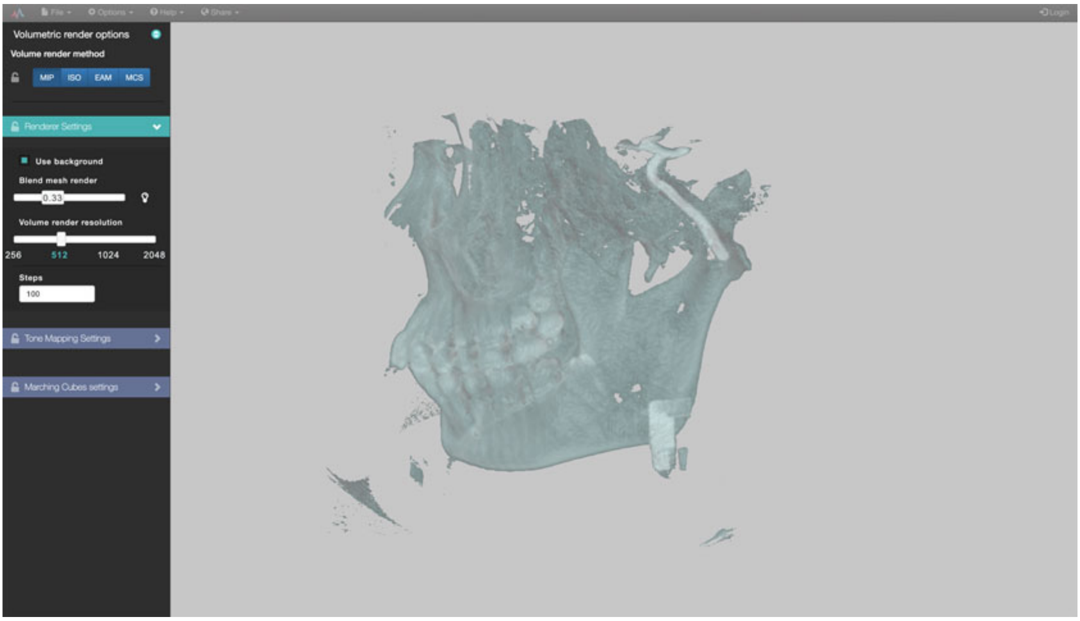
[21] https://github.com/terier/vpt

[22] https://github.com/UL-FRI-LGM/Med3D



Blend mesh render
0.33

Steps
100

Fig. 1.16 A rendering composed of mesh geometry rendered using Med3D integrated renderer overlaid by maximum intensity projection rendered using VPT

and composition of several output rendering images into a seamless final image. This also allows the use of external rendering systems used in specified rendering pass (Bohak et al. 2019) as can be seen in Fig. 1.16, where basic mesh geometry is overlaid with maximum intensity projection obtained with VPT.

On top of fast and customisable rendering pipeline the framework offers an intuitive easy-to-use UI. It also implements the use of arbitrary input devices, which are handled by the underneath system (such as 3D mouse, Leap motion controller, game-pad, etc.). The framework supports the use of remote rendering system in a selected rendering pass of the pipeline (Lavrič et al. 2018). It supports loading of mesh geometry data and volumetric data. The volumetric data can be transformed into mesh geometry using Marching Cubes surface extraction algorithm for the user-defined ISO value or sent to volumetric render plug-in. The framework also implements two types of annotations: (1) 3D pinned annotations, which can be pinned to a selected region in 3D space on a mesh geometry and (2) view-aligned hand-drawn annotations which can be drawn on top of the current camera view. Both types of annotation can be seen in Fig. 1.17.

The framework was used for web-based vascular flow simulation visualisation (Oblak et al. 2018) and medical volumetric data visualisation. It offers remote user collaboration (Lavrič et al. 2017), where a user can share his current scene with other users. Collaborative functionality includes:

- **data sharing**, which allows users to share their own data (or data already stored on the server) with other users;
- **annotation sharing**, where a user can decide which annotations to share with other users (it works for 3D pinned as well as view-aligned annotations);
- **camera view sharing**, where a user can share his view of the data, which is very important when discussing the structure of the data or possible abnormalities;
- **visualisation properties sharing**, where a user can share their rendering setup (the selected rendering technique and its properties);

Fig. 1.17 Collaborative visualisation with annotations in Med3D visualisation framework

- **interactive chat**, where users can chat using text messages.

While the framework is very extendable and offers the use in many use-cases it also supports the integration with other rendering libraries (such as VPT) for providing state-of-the-art volumetric rendering on the web platform.

1.4 Discussion

Majority of the presented solutions are general purpose visualisation frameworks or toolkits, not suited for end-use. There are example applications available for specific use-cases with ParaViewWeb, Ami.js and Med3D, however the out-of-the-box solutions would increase the overall acceptance by the communities. The biggest community is behind the ParaViewWeb and VTK.js, due to their long lasting history in form of stand-alone application. On the other hand these are the solutions that do not offer state-of-the-art volumetric rendering implementations.

Most off the presented solutions support some kind of composed visualisations using mesh geometry and volumetric input data (apart from VPT which is designed for volume rendering only). VPT is the only solution offering a state-of-the-art physically based volumetric rendering support, which is more common in dedicated systems (mostly the commercial ones).

While the web platform offers great basis for implementation of collaborative visualisation environments only two solutions (Med3D and to some extend Ami.js) have these capabilities integrated into the system. Since visualisation in medical domain is often used for diagnostic purposes where more than single physician is involved, this poses a great advantage in the real-life scenarios (e.g. getting second opinion at the distance or use in distance learning environments).

Even though the web platform is well accepted in the everyday life, there are still a lot of opportunities where it can be used in professional scenarios, such as visualisation of medical and biological data. Such solutions allow users to access and visualise the data at the distance on the low-end laptops or even on mobile devices.

1.5 Conclusions

In this book chapter we have presented a short overview of current open source stand-alone visualisation systems used for medical and biological visualisations and have presented the overview of comparable web-based solutions. While some web-based solutions are reimplementations of the presented stand-alone solutions with a subset of features (e.g. VTK.js and ParaViewWeb), others were developed using existing web-based libraries and additionally adapted for medical domain specifics (Ami.js) or are developed from scratch and designed for such visualisation scenarios (VPT and Med3D). The later are also the only solutions that make use of the WebGL

2.0 standard for best GPU performance gain. Only one solution was developed with extensive support for collaborative scenarios in its core (Med3D).

The hardware accelerated rendering has made a new leap with Khronos' Vulkan,[23] Apple's Metal[24] and Microsoft's DirectX 12 graphics APIs. While this APIs offer even better exploitation of the GPUs processing power, they are not available for the web platform. This lead to the development of a new API by W3C group, called WebGPU. It is based on the above mentioned APIs for native development. This API will allow developers to create even more optimised implementations of visualisation systems making web-based real-time physically based volumetric rendering a step closer to the practical use.

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[23] https://www.khronos.org/vulkan/

[24] https://developer.apple.com/metal/

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2

Ultrasound-Guided Regional Anaesthesia: Visualising the Nerve and Needle

James Bowness and Alasdair Taylor

Abstract

Regional anaesthesia involves targeting specific peripheral nerves with local anaesthetic. It facilitates the delivery of anaesthesia and analgesia to an increasingly complex, elderly and co-morbid patient population. Regional anaesthesia practice has been transformed by the use of ultrasound, which confers advantages such as accuracy of needle placement, visualisation of local anaesthetic spread, avoidance of intraneural injection and the ability to accommodate for anatomical variation.

An US beam is generated by the application of electrical current to an array of piezoelectric crystals, causing vibration and consequential production of high-frequency sound waves. The sound energy is reflected at tissue interfaces, detected by the piezoelectric crystals in the ultrasound probe, and most frequently displayed as a 2D image.

Optimising image acquisition involves selection of the appropriate US frequency: this represents a trade-off between image resolution (better with high frequency) and tissue penetration/beam attenuation (better with low frequency). Altering alignment, rotation and tilt of the probe is often required to optimise the view as nerves are best visualised when the ultrasound beam is directly perpendicular to their fibres. Adjusting the focus, depth, and gain (brightness) of the image display can also help in this matter.

Three key challenges exist in regional anaesthesia; image optimisation, image interpretation (nerve visualisation) and needle visualisation. There are characteristic sonographic appearances of the nerve structures for peripheral nerve blocks, as discussed in this chapter, and the above techniques can be used to enhance their appearance. Much research has been done, and is ongoing, with the aim of improving needle visualisation; this is also reviewed. Image interpretation requires the application of anatomical knowledge and understanding of the typical sonographic appearance of different tissues (as well as the needle). Years of practice are required to attain expertise, although it is hoped that continuing

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advances in nerve and needle visualisation, as described in this chapter, will expedite that process.

Keywords
Ultrasound · Regional anaesthesia · Anatomy · Visualisation · Anatomical variation · Image analysis · Nerve · Needle

Abbreviations

CNB	central neuroaxial blockade
GA	general anaesthesia/anaesthetic
LA	local anaesthesia/anaesthetic
RA	regional anaesthesia/anaesthetic
UGRA	ultrasound-guided regional anaesthesia
US	ultrasound

2.1 Introduction

The triad of anaesthesia includes hypnosis (reduction of awareness), analgesia, and paralysis/lack of movement. This aims to achieve a state that is acceptable to patients undergoing a controlled trauma (i.e. surgical procedure), and provide optimal conditions for the operating surgeon (e.g. lack of movement, bleeding etc).

There are several methods to achieve this. **General anaesthesia** (GA) uses intravenous and/or inhalational pharmacological agents to induce a controlled state of unconsciousness. These drugs, with or without the addition of agents to produce muscle paralysis and analgesia, achieve the conditions described above. For **central neuraxial blockade** (CNB), local anaesthetic (LA) is deposited around nerves of the central nervous system to block sensory stimuli conveyed to the brain and motor stimuli conveyed to the muscles. It may be used to achieve anaesthesia suitable for surgical procedures (e.g. caesarean section under spinal anaesthesia) or analgesia (e.g. epidural in labour). Examples of CNB include spinal, epidural and caudal anaesthesia. During **regional anaesthesia** (RA), anaesthetists target specific peripheral nerves with LA injections in order to block the sensorimotor stimuli conveyed. This allows selective anaesthesia of body regions during surgery and for analgesia in the post-operative period. This can be advantageous for patients in whom GA presents a high risk of morbidity or mortality, and for particularly painful procedures or patients with chronic pain conditions. **Local anaesthesia** involves infiltration of LA within tissues targeted during a surgical procedure (e.g. LA infiltration into cutaneous tissue to remove a skin lesion). These techniques may be used in isolation or, more commonly, in combination – often with the addition of other systemic agents such as analgesics and anti-emetics.

Ultrasound (US) guidance has transformed RA in the twenty-first century, allowing direct and real-time visualisation of the structures involved. It has enabled anaesthetists to employ RA techniques, more frequently and in more diverse scenarios, as a tool to combat the challenges presented by an increasingly elderly, co-morbid and obese patient population. This chapter will review the principles of US used in **ultrasound-guided regional anaesthesia** (UGRA) and the descriptions of US images for specific **peripheral nerve blocks** (PNBs) of the upper and lower limb. Particular focus will be on the appearance of nerve structures and methods to optimise visualisation of the nerve which demonstrate the principles first discussed. The difficulties in needle identification will also be reviewed, as well as strategies and new technologies that are in development to help identify needles on ultrasound.

2.2 Regional Anaesthesia

Historically, such techniques relied on knowledge of anatomical landmarks to guide needle placement and deposition of LA. However, this approach was prone to inadequate efficacy and associated with greater potential risks, partly because peripheral nerves are naturally subject to structural variation meaning that accurate perineurial deposition of LA was not always achieved. Equally, variation in the vascular anatomy can predispose to inadvertent blood vessel trauma, with potential bleeding and intravascular injection of LA, risking LA systemic toxicity.

Initial attempts to improve accuracy of perineurial LA deposition included the use of nerve stimulators to elicit a motor (muscle twitch) or sensory (paraesthesia) response of the target nerve. This improved efficacy but did not mitigate for anatomical variance or inadvertent damage to surrounding structures. More recently US has emerged as the predominant strategy to guide RA techniques. Potential advantages of visualising the area of interest in real time include accuracy of needle placement, visualisation of LA spread, avoidance of intraneural injection and reduced complications/trauma to surrounding structures by observing the needle along its entire course (Coventry and Raju 2016; Munimara and McLeod 2015; Henderson and Dolan 2018). Also, and fundamentally, UGRA is intended to allow compensation for anatomical variation by directly visualising the anatomy and so allow appropriate direction of the needle/injection toward target nerves (Coventry and Raju 2016; Henderson and Dolan 2018; Griffin and Nicholls 2010). Such benefits have been demonstrated to improve efficacy (Munimara and McLeod 2015), and US is known to be safe, non-ionising and non-painful. However, it is also known to be subjective and published data demonstrates that nerve identification on ultrasound is imperfect even by experienced anaesthetists with advanced training in regional anaesthesia (Bowness et al. 2019). Identification of needle position is another challenge in UGRA, particularly when the needle is inserted at a steep angle to the US probe as is necessary in some deeper blocks (e.g. infraclavicular brachial plexus block).

2.3 Principles of Ultrasound Used in Regional Anaesthesia

The principles of US have been discussed elsewhere in this series, hence only a brief review will be included here. For more details see (Varsou 2019).

Ultrasound uses electrical current to cause vibration in piezoelectric crystals on the end of a transducer probe. This vibration generates a beam of high-frequency sound waves (2–18 MHz in UGRA), which are inaudible to the human ear. As they travel through the body, they are reflected at tissue interfaces as different tissue types/densities transmit or reflect the sound waves to differing extents. Reflected sound waves are received at the probe and generate a separate vibration in the piezoelectric crystals of the ultrasound probe (proportional to the strength of the sound waves received). These, in turn, generate an electrical current in the transducer, the amplitude of which is proportional to the vibration of the piezoeletric crystals (A-mode). When a series of transducers are placed in alignment on a probe, this can be displayed on a screen as a two-dimensional image, with the strength of signal received (amplitude, A-mode) expressed as brightness on a screen (B-mode). Other modes are used in clinical practice but B-mode is the most common, particularly in UGRA. As sound waves travel at almost constant speed through body tissues (1540 m/sec +/−5%) (Townsley et al. 2014; Smith et al. 2017), the depth at which sound waves are reflected is calculated by the time taken for a signal to return to the transducer.

The frequency of US represents a trade-off between resolution (i.e. the ability to distinguish between two points at a particular depth) and attenuation (i.e. the reduction in amplitude of the US beam as it passes through the body tissue). Higher frequency, shorter wavelength, sound waves provide better image resolution, but undergo greater attenuation as they pass through the tissues. In practical terms, this means that high US frequencies are most appropriate for superficial structures, with a greater ability to visualise small structure (e.g. small nerves, fine needles). Conversely, lower frequencies are better for imaging deeper structures but have a lower resolution (and consequently a lesser ability to visualise small anatomical detail and fine needles).

2.4 Image Optimistion

One can adjust the **pressure** with which the transducer probe is applied to the skin, to achieve the optimal tissue visualisation whilst minimising tissue distortion. Intermittent pressure can be helpful to confirm identification of tissues visualised, as blood vessels and nerves can be similar in appearance. Veins are compressible due to their low pressure, therefore gentle pressure applied through the probe will obliterate a venous lumen, whereas arteries and nerves cannot be easily compressed. Pressure can augment the characteristic expansile/pulsatile appearance of arteries, which is not a feature of neural tissue.

Moving (sliding) the probe over the skin enables one to trace structures proximally or distally, and therefore aid in confirming their identity, and determine the orientation of nerve fibres (or muscle fibres/the lumen of blood vessels). This allows the operator to **align** the probe appropriately and identify the optimal site for needle entry during nerve block. It should be emphasised that US identification of structures is a **dynamic** process and it is often difficult to confidently identify structures on a single image. Tracing the hyper/hypoechoic focus along its course, and comparing it to anatomical relations, is an important component of confirming structure identification. Note that US machines display magnified images and very small movements are amplified on screen. Thus, very small probe movements may translate to large changes in the image displayed, including losing view of the target nerve (or needle) altogether. Mitigating unwanted movements during block performance comes with increasing operator experience.

Rotation (twisting) the US probe allows operators to confirm the orientation of fibres in a nerve or muscle, or the lumen of a blood vessels. This enables visualisation of the nerve in short axis (cross section) or long axis (longitudinal) view (Fig. 2.1). In UGRA, target nerves are most commonly visualised in short axis/cross section: this allows better identification of the structure during needle advancement as well as perineurial spread of local anaesthetic. Nerve trauma and intra-neural injection is also more readily identified in short axis.

Tilting the angle of **insonation** (angle of incidence) of the US probe to the skin

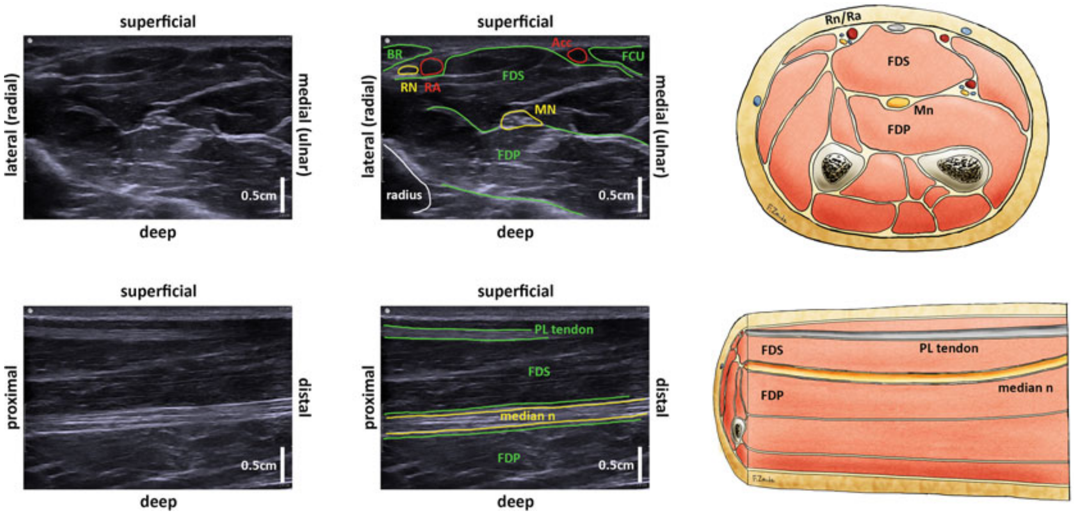

Fig. 2.1 Median nerve
Top: median nerve in short axis (L to R: unlabelled US; labelled US; illustration)
Bottom: median nerve in long axis (L to R: unlabelled US; labelled US; illustration)
(*Acc* accessory artery; *BR* brachioradialis, *FCU* flexor carpi ulnaris; *FDP* flexor digitorum profundus; *FDS* flexor digitorum superficialis; *Mn/MN/median* n median nerve; *PL* palmaris longus; *Ra/RA* radial artery; *Rn/RN* radial nerve)

alters the visualisation of target structures seen in short axis. Nerves display anisotropy (their visualisation by ultrasound is dependent upon the angle of inclination of the ultrasound beam); they are best visualised with the probe at 90° to them to maximise the amount of signal returned. They are poorly visualised with an angle of insonation of <60° (Townsley et al. 2014). Carefully rocking the US probe (adjusting the angle of insonation of the long axis) can be used to improve visualisation of structures seen in long axis.

Other features of US, which can be used to confirm identification of structures visualised include the **Doppler effect** (discussed in more detail elsewhere in this series – Varsou 2019). Objects travelling toward the transducer reflect US waves back toward it at a higher frequency/shorter wavelength than when they struck the object. The opposite is true of objects travelling away from the transducer (a common example is an ambulance passing an observer: the tone of the siren changes as the vehicle approaches and then drives past). The most common example of this in the human body is blood flow in blood vessels: the change in frequency can be detected and colour applied to the altered frequency. Reduced frequency (movement away from the scanner) is shown in blue, with increased frequency (movement towards the transducer) in red. This leads to the acronym BART (blue away, red towards) and can be applied to real-time images to identify blood flow in vessels, which helps distinguish them from nerves (which show no Doppler shift). It is important to note that a Doppler shift will not occur when the angle of insonation is exactly 90°, as movement of structures in a purely perpendicular plane will not change the frequency of soundwaves reflected.

Setting the **focus** of the US beam alters the pattern of US waves emitted by the transducer, so the sound waves are at the greatest intensity a set depth, to optimise resolution at the **depth** of the target tissue. The **gain** (brightness) of the display can also be used to optimise the display of the image acquired.

2.5 General Appearance of Peripheral Nerves on Ultrasound

Neural tissue is hypoechoic and connective tissue hyperechoic. Therefore, nerves contain both of these elements in their appearance. They generally contain a higher proportion of neural tissue at locations more proximate to the central nervous system and so appear as round hypoechoic structures (in short axis). More distally, they have a heterogeneous ‘speckled’ or ‘honeycomb’ appearance; a hyperechoic outline (epineurium) with matrix of perineurium and connective tissue, and hypoechoic speckles of neural tissue within (Fig. 2.1). More peripheral nerves are also shaped by the surrounding structures, and so less rounded. In long axis, these nerves display a striated appearance.

Muscle tissue also contains hypoechoic fascicles with hyperechoic epimysium and perimysium. It is generally relatively easy to distinguish between this and the nerve tissue, however, as muscles generally have a much greater cross sectional area and their fascicles are larger. Muscle tendons can appear similar to peripheral nerves, but become more hyperchoic as they approach their insertion (and blend with the body of the muscle, with a flatter appearance, when scanning away from it). Blood vessels are anechoic, as fluid is a very weak reflector of US, appearing black on a B-mode image. As discussed above, veins are easily compressible whilst arteries are pulsatile (they are actually expansile, but this can sometimes be harder to see than the pulsation). Arteries are also round, with thicker walls, whereas veins have a more irregular outline which is shaped somewhat by the surrounding structures due to the thin venous wall and low pressure.

2.6 Nerve Appearance: Upper Limb Nerve Blocks

2.6.1 Interscalene Block

This block is commonly performed for surgery on the shoulder as it aims to deposit LA around the C5/6/7 nerve roots in the plane between scalenus anterior and medius (Raju and Bowness 2019). It uses a linear transducer, placed transversely on the anterolateral skin of the neck, approximately at the level of C6 (the cricoid cartilage). This is an example of imaging proximate peripheral nerves, which contain only a small amount of connective tissue and hence appear as rounded hypoechoic structures (Fig. 2.2). The phrenic nerve can be seen anteromedial to the cervical nerve roots, as a small hypoechoic region on the superficial surface of scalenus anterior. The vertebral artery and vein lie deep to scalenus anterior and the nerve roots, and can be identified with colour flow Doppler and by the arterial pulsation.

2.6.2 Supraclavicular Block

This block allows injection of LA around the distal trunks/proximal divisions of the brachial plexus. By placing a linear transducer in a coronal oblique orientation in the supraclavicular fossa, one can view the brachial plexus nerve trunks/divisions lying superior and posterolateral to the subclavian artery (Raju and Bowness 2019). The nerves again appear as hypoechoic structures, often in a common fascial sheath (with an appearance resembling a 'bunch of grapes'), lying above the dome of the pleural and over the first rib (Fig. 2.3). Anterior to them is the insertion of

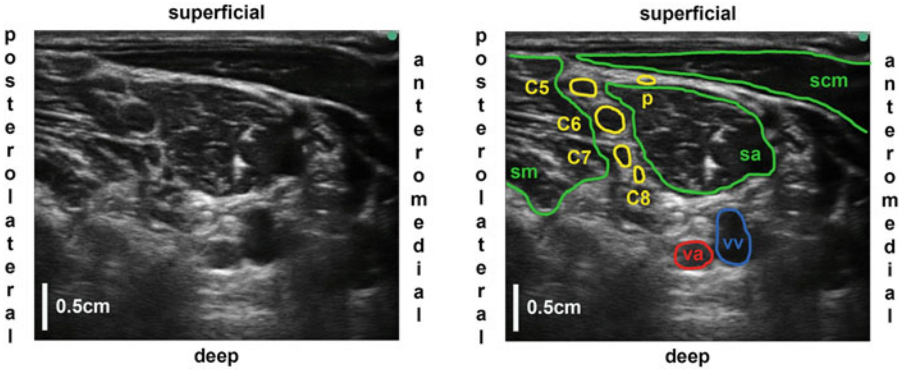

Fig. 2.2 US view during an interscalene block. (Reproduced with permission from Bowness & Taylor, Anatomy for the FRCA, 2019 ©)
(*p* phrenic nerve; *sa* scalenus anterior; *scm* sternocleidomastoid; *sm* scalenus medius; *va* vertebral artery; *vv* vertebral vein)
Note: Directing the probe slightly inferiorly may enhance visualisation of the nerve roots, as they themselves travel somewhat inferiorly as they leave the intervertebral foramina. Also, the nerves may not lie in the typical distribution described above. It is not infrequent to find them lying in another pattern, sometimes travelling through one of the scalene muscles

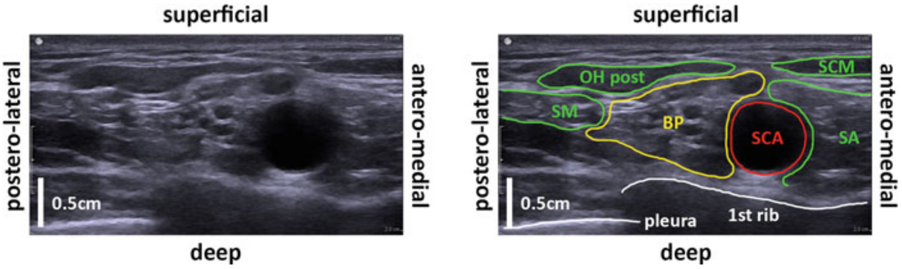

Fig. 2.3 US view during a supraclavicular block
(*BP* brachial plexus, *OH* post posterior belly of omohyoid, *SA* scalenus anterior, *SCA* subclavian artery, *SCM* sternocleidomastoid, *SM* scalenus medius)
Note: It is important to avoid damage to underlying pleura when inserting the block needle. Bone has a high acoustic impedance and so reflects sound waves effectively. It therefore appears hyperechoic with an acoustic shadow deep to it. The pleura also appears bright, but without the same degree of hypoechoic signal deep to it – the two layers of pleural can also be seen to move during respiration. The dorsal scapular and transverse cervical arteries are in the vicinity of the needle route - it may be possible to recognise these by identifying the characteristic arterial features on ultrasound, including colour Doppler

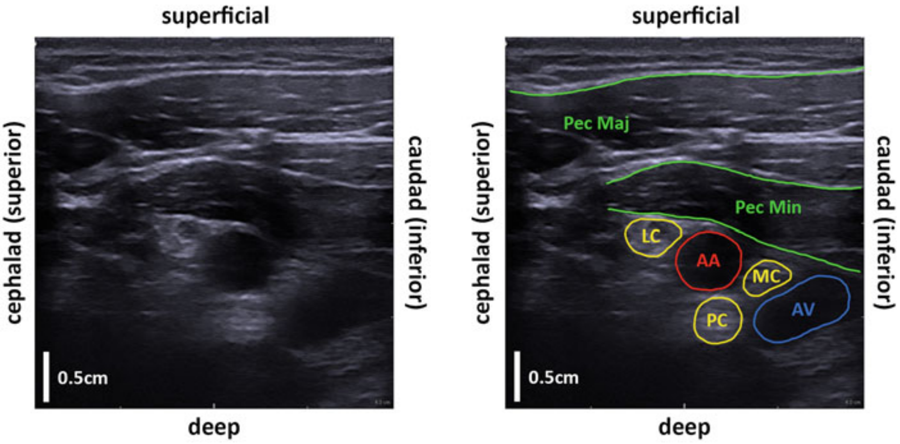

Fig. 2.4 US view during an infraclavicular block (*AA* axillary artery; *AV* axillary vein; *LC* lateral cord; *MC* medial cord; *PC* posterior cord; *Pec maj* pectoralis major muscle; *Pec Min* pectorals minor muscle)
Note: The cords initially lie lateral to the axillary artery, then in the characteristic distribution surrounding the artery as they move inferolaterally. The posterior cord can be difficult to visualise, masked by an area of image artefact deep to the artery (post-cystic enhancement). If this is the case, visualising a perivascular spread of LA deposition can be used to achieve the required block. The angle of needle insertion required can make needle visualisation difficult; as is it inserted caudad to the clavicle and travels steeply, deep to the probe. Techniques to overcome this include use of an echogenic needle (see below), curvilinear probe and rocking the probe (applying greater pressure at the inferior end of the probe to align it to the axis of the needle)

scalenus anterior (onto the scalene tubercle of the first rib) and then the subclavian vein. Scalenus medius can be seen posteriorly.

2.6.3 Infraclavicular Block

To best view the cords of the brachial plexus around the artery, align the probe with the long axis in the sagittal plane and place it in the infraclavicular fossa (below the coracoid process). The pectoralis muscles are the most superficial major structures encountered, with their muscle fibres travelling in different planes: pectoralis major visualised in short axis and pectoralis minor in long axis. Deep to this lie the cords and artery, and at this point the nerves have begun to develop the speckled appearance of hyperechoic connective tissue containing hypoechoic neural tissue (Fig. 2.4). The lateral cord lies cephalad to the artery (lateral, anterior and superior), in the 9–11 o'clock position on the US view described. The posterior cord lies deep (inferomedial, 6 o'clock) and the medial cord lies inferomedial (2–3 o'clock) (Raju and Bowness 2019).

2.6.4 Axillary Brachial Plexus Block

This block is performed at the level of the proximal, medial arm (begin by visualising the axillary artery as proximally as possible). The nerves targeted are the musculocutaneous, median, ulnar and radial nerves.[1] Interestingly, they often appear not as one structure itself, but a number of neural bundles – often larger than one would expect. The musculocutaneous nerve no longer lies in a perivascular location and is found in a fascial plane between the short head of biceps and coracobrachialis (Fig. 2.5). This is an example of the benefit of dynamic scanning: following the nerve proximally and distally can allow it to be viewed moving laterally as it leaves the neurovascular bundle and takes up its position between the two muscle bellies more distally in the arm. The median nerve is usually seen on the anterolateral side of the artery, in the 9–12 o'clock

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[1] The medial cutaneous nerves of the arm and forearm, as well as the intercostobrachial nerves, are not usually seen but targeted by a subcutaneous infiltration of LA in the proximal, medial arm.

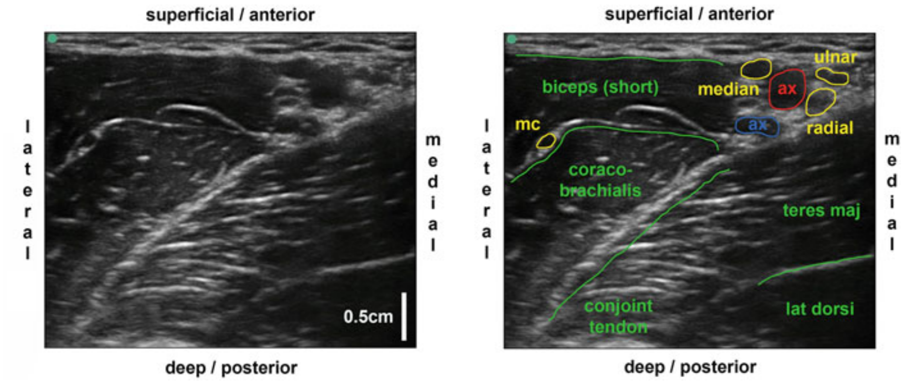

Fig. 2.5 US view during an axillary level brachial plexus block. (Reproduced with permission from Bowness & Taylor, Anatomy for the FRCA, 2019 ©)
(*mc* musculocutaneous nerve, *ax* (blue) axillary vein, *ax* (red) axillary artery)
Note: The radial nerve is most difficult to visualise because it does not lie perpendicular to the probe position: performing the block proximally in the arm and adjusting the rotation/tilt of the probe may aid in viewing it. Post-cystic enhancement, deep to the artery, may further compound difficulties with image interpretation. To help with identification, all the nerves can be traced from more distal positions to their final locations relative to the artery (Raju and Bowness 2019). The number and distribution of nerves and blood vessels in the region is variable (Townsley et al. 2014) and they can have a similar appearance. Colour Doppler can be used to discriminate between vascular and neural structures, and compression of veins allows better visualisation of deep structures (eliminating the post-cystic enhancement)

position (on the biceps side). The ulnar nerve is more varied: it is usually found on the medial side, but may lie anterolateral (1–3 o'clock) or slightly posterior/deeper (on the triceps side of the artery). The radial nerve is generally found deep to the ulnar nerve, sometimes on the anterior surface of the conjoint tendon of teres major/latissimus dorsi (Raju and Bowness 2019).

2.6.5 Forearm Blocks

The radial, median and ulnar nerves can be identified and blocked at or below the elbow. The radial nerve is best found on the lateral side of the limb, just above the elbow crease (on the lateral border of brachialis muscle, between it and coracobrachialis). The median nerve can be found in the mid-forearm, on the deep surface of flexor digitorum superficialis (superficial to flexor digitorum profundus). The ulnar nerve lies deep to flexor carpi ulnaris and approaches the medial side of the ulnar artery: this can be a useful landmark to find the nerve, which can then be traced proximally until the artery and nerve diverge. At these point, all the nerves appear heterogenous in short axis, with hyperechoic borders and elements of hypoechoic neural tissue within (Fig. 2.1).

2.7 Nerve Appearance: Lower Limb Nerve Blocks

2.7.1 Femoral Nerve Block

The femoral nerve passes into the thigh under the mid-point of the inguinal ligament (midway between the pubic tubercle and anterior superior iliac spine), lateral to the femoral artery (which travels under the ligament at the mid-inguinal point; midway between the pubic symphysis and the anterior superior iliac spine) (Bowness and Taylor 2019). As a branch of the lumbosacral plexus, it receives contributions from the nerve roots of L2/3/4, and fours within psoas major muscle. It therefore passes into the lower limb deep to the fascia iliaca (the fascia over iliacus muscle), which is continuous with psoas fascia (the fascia over psoas major) as these two muscles have a common tendinous insertion on the lesser trochanter of the femur.

Using a linear transducer placed transversely across the proximal anterior thigh, the femoral

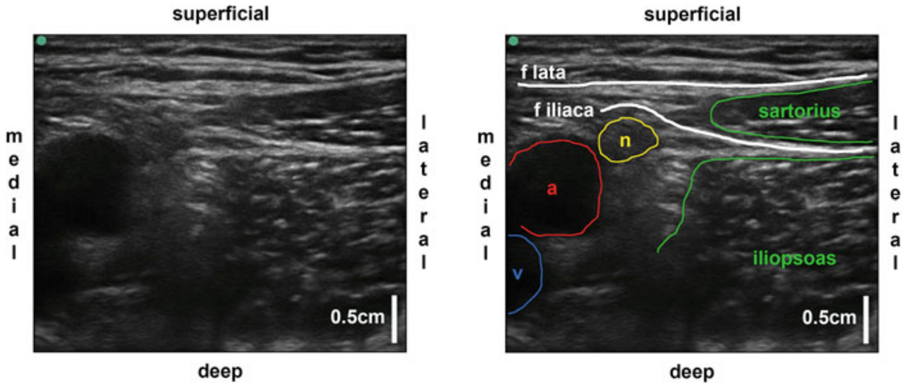

Fig. 2.6 US view during a femoral nerve block. (Reproduced with permission from Bowness & Taylor, Anatomy for the FRCA, 2019 ©)
(*a* femoral artery; *n* femoral nerve; *v* femoral vein)
Note: As the femoral nerve does not travel exactly parallel to the femoral vessels, it may be difficult to obtain a single image that optimises the view for all three. The nerve is often best visualised in the same plane at the fascia iliaca, and tilting the probe slowly back and forth may aid identification. The nerve boundaries often become clearer after beginning to inject LA at which point it can separate from the fascia (hydrodissection)

vessels are a useful landmark to visualise. The artery can be seen pulsating (and identified with colour Doppler) and, on its medial side, lies the femoral vein (it may lie slightly deep to the artery and is compressible). Lateral to these vessels it is possible to identify two fascial layers: the fascia lata (the deep investing fascia of the thigh) and fascia iliaca (the fascia overlying iliacus/iliopsoas muscle). The fascia lata is the more superficial layer and can be followed medially, passing anterior to the femoral artery. The fascia iliaca passes deep to the artery (Fig. 2.6). Deep to both, and lateral to the artery, lies the femoral nerve (on the superficial surface of iliacus/iliopsoas), which is said to travel in a tunnel on the deep surface of fascia iliaca. It often appears hyperechoic, and oval or triangular in cross-section (Grant 2019).

2.7.2 Popliteal Sciatic Nerve Block

This block targets the sciatic nerve, at the point where it divides into the tibial and common peroneal nerves (Grant 2019). This division is traditionally said to occur at the apex above the popliteal fossa, where the muscle bellies of semimembranosus (medially) and biceps femoris (laterally) come together. However, the nerve can separate into these two discrete structures at any point in the posterior thigh, although usually travels in a common epineurial sheath to a point within about a hand’s breath above the popliteal skin crease.

By placing a linear transducer transversely on the posterior skin of the thigh, just above the popliteal skin crease, one can view the neurovascular bundle. The popliteal artery is the deepest structure in the popliteal fossa, with the compressible popliteal vein superficial to it. The tibial nerve has the classical ‘honeycomb’ spiculated appearance, with a bright echogenic architecture containing hypoechoic nerve fascicles (Fig. 2.7). Again, the nerve displays anisotropy, so altering the tilt of the probe (without moving it proximally/distally along the limb) will enhance/degrade the visualisation of the nerve. After optimising the view of the tibial nerve, it can be traced proximally to the point at which the common peroneal nerve joins it from the lateral side (from adjacent to/under the biceps femoris muscle).

2.7.3 Ankle Block

Five nerves are targeted in this block: the tibial, deep peroneal (fibular), superficial peroneal (fibular), saphenous and sural nerves. They display the typical ‘honeycomb’ appearance of distal

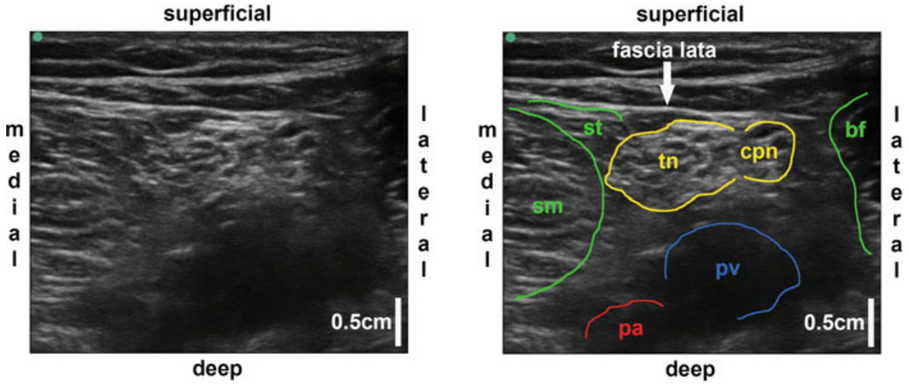

Fig. 2.7 US view during a popliteal level sciatic nerve block. (Reproduced with permission from Bowness & Taylor, Anatomy for the FRCA, 2019 ©)
(*sm* semimembranosus muscle; *st* semitendinosus muscle; *tn* tibial nerve; *cpn* common peroneal nerve; *pa* popliteal artery; *pv* popliteal vein; *bf* biceps femoris)
Note: This block is another example where hydrodissection enhances visualisation of the nerves following injection of LA under the surrounding fascial sheath - giving a classic dark 'halo' of LA with the bright nerve structures in the middle

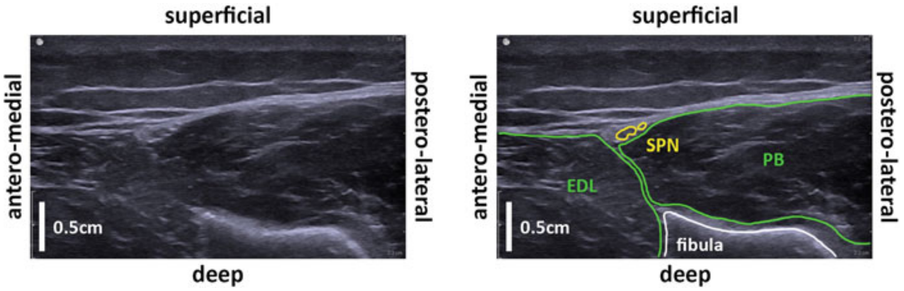

Fig. 2.8 US view of the superficial peroneal nerve on US
(*EDL* extensor digitorum longus; *PB* peroneus brevis; *SPN* superficial peroneal nerve)

peripheral nerves on ultrasound, with echogenic connective tissue (accounting for a steadily larger portion of the nerve) and hypoechoic nerve fascicles (Fig. 2.8).

2.8 Strategies to Aid Nerve Identification on Ultrasound

As is seen from the figures above, US image interpretation during UGRA takes training and experience. However, training in UGRA is often *ad hoc*, with experience gained incrementally over many years (often with different trainers and without structured, specific goals). Therefore, the pedagogical practice may contribute to this problem and education/training can play a significant role to overcome the difficulties in needle (and nerve) visualisation. A recent trend of mastery learning, with deliberate and iterative practice, is one example of such training.

In addition, the US image obtained in the same patient/PNB will vary considerably with small changes in position or angulation of the probe, and interpretation still involves a degree of subjectivity. Publications demonstrate imperfect human analysis of medical images, even amongst experts attempting to identify very obvious anomalies (Drew et al. 2013). This is particularly pertinent to UGRA when anatomical variation presents anomalous topography of peripheral nerves – expert identification of peripheral nerves is known to be imperfect and may contribute to the failure rate of RA techniques (Bowness et al.

2019). Therefore, the field is in need of strategies to improve nerve identification during UGRA.

One method to compliment nerve identification, and avoid nerve trauma/intraneural injection, is the practice of placing nerve blocks in awake patients where possible. Although this does not improve visualisation of the nerve (or needle), early detection of complications (e.g. pain or paraesthesia on injection/nerve contact by the needle) can aid in minimising the risk of serious nerve injury. However, awake patients are more prone to moving and it therefore is important to maintain a dialogue with the patient throughout the procedure to improve patient compliance and reduce unwanted movement.

Unfortunately, despite the potential for inaccuracy in nerve identification on US to impair the efficacy of UGRA techniques, there is a relative paucity of research on new technologies to aid in this task. Although there are individual benefits of nerve stimulation and US-guidance, combining these existing technologies when performing PNB does not appear to further reduce the rate of nerve injury (Munimara and McLeod 2015). Recent work on the use of micro-ultrasound as a tool to image peripheral nerves during regional anaesthesia shows promise (Chandra et al. 2017). However, the definition of micro-ultrasound in this study was anatomical resolution better than 100 μm, and nerve fascicles are reported as having a diameter of 0.5–20 μm (Marhofer and Fritsch 2017). Furthermore, the micro-ultrasound assessed here required placement of the US transducer directly onto a resected nerve, which is clearly not feasible in clinical practice. Thus this technology will require further study and development before its clinical value becomes clear. Nevertheless, future advances in US technology are likely to improve image resolution and aid interpretation, through development of US transducers, image processing and imaging modalities (e.g. sonoelastography) (Munimara and McLeod 2013). The increasing interest in the use of artificial intelligence systems for medical image analysis is likely to extend to US used in RA. Early studies in this field are already published (Hadjerci et al. 2016), albeit much work is needed to develop these systems, and prove their accuracy and safety.

2.9 Challenges in Visualising the Needle During Ultrasound-Guided Regional Anaesthesia

Ultrasound-guided regional anaesthesia procedures largely require clear needle visualisation and fine adjustment of the needle tip. Loss of view of the needle tip, and consequent needle misplacement, can result in trauma to nerves, blood vessels (and potential intravascular injection) and damage to other nearby structures (e.g. pleura, peritoneum). Key differences in aspects of needle visibility have been demonstrated between different needles, angles of insertion and US machines (Maecken et al. 2007). For example, for every 10 degrees increase in insertion angle, for an in-plane technique, the proportion of time spent visualising the needle falls by 12% (Hebard and Hocking 2011). However this is sometimes necessitated, for example an infraclavicular brachial plexus block requires a steep angle of insertion in order to pass the needle caudad to the clavicle but posterior to the axillary artery (to reach the posterior cord of the brachial plexus). Equally, US artefact may impair visualisation. As just discussed, the posterior cord of the brachial plexus lies behind the axillary artery in the infraclavicular fossa: post-acoustic enhancement, deep to the artery, can make identification of this structure a challenging task. Also, when teaching UGRA, it is recommended to move either the needle or US probe at any one time (not both). Once the optimal view has been obtained, which visualises the needle, it is recommended that the operator does not move the US probe. However, some PNBs require movement of the probe during the procedure. For example, during the axillary level brachial plexus block, the musculocutaneous nerve is often some distance from the other nerves at the level of the block.

Finally, it is recommended that most blocks are performed ‘in plane’, i.e. the needle in line with and parallel to the US transducer probe (so

Table 2.1 Strategies to aid visualisation of the needle

Fixed probe position (rest hypothenar eminence of the probe hand on the patient)
In-plane approach
Skin insertion point close to the probe (to ease centralisation of the probe)
Avoid steep needle insertion angle (where possible)
Use of an echogenic needle
Pulse advancement of the needle
Hydrodissection
If the needle view is lost, alter the probe alignment (rather than rotation or tilt)

the tip and shaft of the needle can be visualised throughout) (Taylor and Grant 2019). However, some blocks (e.g. for catheter insertion during interscalene block) are best served using an 'out of plane' technique, i.e. needle perpendicular to the US probe (so the tip or shaft, at any point, are visualised as a hyperechoic dot). As a result, only a cross-section of the needle under the US probe is seen, with the potential that the tip of the needle may be beyond the US probe, not visualised, and causing trauma to surrounding tissues. As with nerve visualisation, ability to visualise the needle and awareness of needle tip position (especially for out-of-plane techniques) correlates positively with training and experience. Other strategies to aid needle visualisation are summarised in Table 2.1.

2.10 Technologies to Aid Visualisation

2.10.1 Needle Shaft

Larger needles are easier to visualise with US but cause greater patient discomfort – for example, a Touhy needle is often used to place a nerve catheter (Fig. 2.9). However, smaller needles provide improved patient comfort and can avoid the need altogether for applying local anaesthetic to the skin insertion site (Purushothaman et al. 2013).

A standard hypodermic needle is round in section and therefore tends to dispersion of the US waves rather than reflecting them back to the ultrasound probe. Sono-etched needles have laser grooves cut into their surface. The uneven surface allows for greater reflection of US back to the probe when compared to standard needles (van de Berg et al. 2019). This translates to a brighter signal and improved distinction from surrounding structures.

2.10.2 Needle Tip

Blunt tip needles are used in UGRA because they provide greater tactile feedback of tissue interfaces than hypodermic needles. This was particularly useful in the era of landmark and electrical stimulation techniques, prior to the widespread practice of US-guided procedures. The blunt needle causes tethering of fascial planes before advancing through them. The tissue distortion gives additional information regarding the location of the needle tip, and provides an indirect method of visualising the needle tip.

The needle tip design effects how US is reflected back to the probe, and so consequently is important in determining the needle echogenicity. Bevelled needles have been demonstrated to have greater echogenicity than conical tipped needles, and are therefore easier to visualise when using ultrasound (van de Berg et al. 2019).

There has also been interest in using bioimpedance to improve needle tip localisation and visualisation (Helen et al. 2015). The invasive measurement of tissue bioimpedance using a miniaturised electrical circuit at the tip of the needle could be used to identify the tissue type encountered.

Further recent developments of needle tip design include Onvision, a novel needle developed through collaboration between BBraun and Philips (Taylor et al. 2019). A piezoelectric crystal is incorporated into the needle 3 mm from the tip; when it lies within the US beam it interacts with the US. A signal is then generated and transmitted back to the US machine via the needle and an electrical connection. The position of the needle tip is then plotted onto the US image to aid needle tip

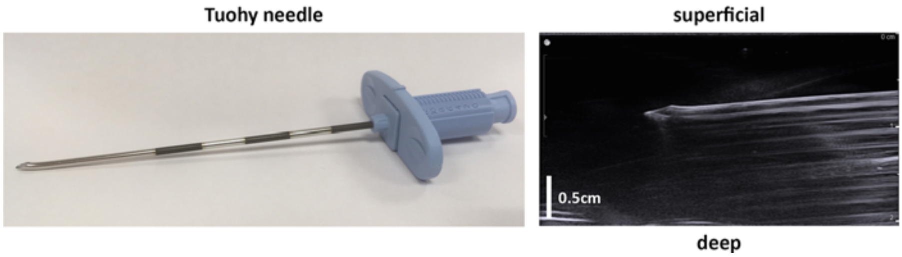

Fig. 2.9 Touhy needle
(L: photograph; R: seen on ultrasound)

localisation. This technology has been shown to improve performance of US-guided sciatic nerve blockade (Taylor et al. 2019).

2.10.3 Alignment

A key challenge of needle visualisation is alignment. For in-plane procedures the intention is to visualise all of the needle. This is only possible if the US beam is directed precisely at the needle. Several technologies have been developed to overcome this problem including probe markings, needle guides and laser guides.

Markings on the probe simply allow the operator to align the needle insertion site with the centre of the probe. The larger the probe, the more useful this becomes.

A needle guide is a device that attaches on to the US probe and facilitates one or two-dimensional movement of the needle. The needle is held in central alignment on the probe, with freedom in depth and angle of approach (on some models). This reduces the variables that confront the operator in order to perform the procedure, and has been shown in novices to reduce the time taken and improve the needle visualisation when performing a simulated US-guided nerve block (Gupta et al. 2013). However, the guide gives unwanted restriction and disruption of ergonomics for the experienced operator.

Needle alignment can be aided during US-guided PNB using a laser guide. A laser generator is attached to the US probe, with a narrow flat beam directed in the same plane as the US beam. The laser is visible on the skin to indicate the plane of the US beam. When appropriately aligned, the laser beam cannot be seen on the skin as it strikes the needle instead. Laser guides may disrupt the ergonomics by restricting how the operator can hold the US probe, but they allow for freeform movement unlike needle guides (Tsui 2007).

2.10.4 Robotic Assistance

Fully automated systems exist for venepuncture. In contrast, development of automated systems for UGRA is in its infancy. Robotic assistance provides improved probe stability and more precise needling, thus enhancing needle visualisation. However, US-guided PNBs are more time consuming using robotic assistance than freehand, although there is some evidence to suggest that robotic assistance accelerates learning (Morse et al. 2014).

2.10.5 Magnetisation

Passive needle magnetisation can be used to give a real time graphical overlay on the US image of needle tip location and needle trajectory. Magnets are embedded on the needle adding minimal bulk. This technology has been demonstrated in a porcine model to improve accuracy, especially for out of plane procedures (Johnson et al. 2017).

An external field generator can be used to create a magnetic field that induces a small current in sensors attached to the probe and needle. The current can be used to estimate needle position and direction. Again, the needle tip position and trajectory is projected onto the US image. The accuracy of this reduces with increasing distance between the field generator and the needle. However, this necessitates placing the field generator close to the patient, potentially disrupting the workflow.

2.10.6 Optical Tracking

The relative position of the needle and US transducer is determined by a camera or series of cameras, with the needle and trajectory projected on to the US image. This uses similar technology to what is used in stereotactic neurosurgery, although no clinical studies were found using this technology in regional anaesthesia. Phantom-based research has demonstrated accurate display of needle tip position and shorter procedure times. However, optical tracking is costly and direct, unobstructed camera views are required. This will restrict translation to clinical practice (Scholten et al. 2017).

2.10.7 Immersive Technology

Augmented reality is a technology that superimposes a computer-generated image on a user's view of the real world. Whilst a combination of imaging modalities may allow better for anatomical orientation, there are few examples in the literature of augmented reality applied to UGRA. One such example of applied augmented reality is in relation to epidural anaesthesia, where tracked US imaging helped to identify vertebral levels. Information was displayed on a live video feed during epidural insertion (Ashab et al. 2012). It is likely that augmented reality applications to UGRA will become most useful as educational tools.

2.10.8 Nerve Stimulation

Using nerve stimulation techniques to locate peripheral nerves was practiced widely in the UK, however this has declined with the rise of US guidance. Some clinicians still advocate its use to identify deeper nerve structures and to aid identification of inadvertent intra-neural needle tip position. Whilst the pulsed electrical stimulation may aid in the localisation of the needle tip it does not assist in visualisation. Outcomes of PNB performed under US guidance are superior to those under nerve stimulation guidance, and addition of nerve stimulation does not enhance the outcomes of UGRA (Munimara and McLeod 2015).

2.10.9 Ultrasound Technology

Movement can be used to localise the needle tip using colour Doppler imaging. This can be achieved by pulsed needle advancement (as indicated in Table 2.1), rotation of a stylet or by piezoelectric actuators. A number of needles have been designed to incorporate piezoelectric actuators that create either flexural or longitudinal vibration on application of an electrical current. With flexural vibration, the Doppler image tends to bleed into the tissue beyond the needle, resulting in difficulty in determining needle position accurately. Longitudinal mode creates only a small degree of flexural vibration. For needle design using longitudinal mode, intimate knowledge of the resonant frequency and behaviour of the block needle is required to optimally tune vibration amplitude and frequency. This minimises flexural vibration and improves needle localisation (Kuang et al. 2016).

Local anaesthetic injection creates a characteristic strain tissue strain pattern, based on the location and volume of LA injected combined with the tissue elasticity/stiffness. Elastography is an US-based technology that presents colour images of tissue strain, which can be integrated with B-mode US into a single live image. It has been demonstrated to improve the accuracy, reliability and confidence in diagnosing intraneural injection in a cohort of trainee anaesthetists, although has not yet reached widespread use in clinical practice (Munimara et al. 2016).

Tracked 2D US imaging can be reconstructed to give 3D images. This can be used to monitor the spread of LA and identify nerve catheter position, albeit not in real time. Four dimensional US refers to real time 3D imaging. In a cadaver based epidural catheter insertion study, 4D US was found to give improved operator orientation of the vertebral column, although the Touhy needle could only be reliably seen in a single imaging plane (Belavy et al. 2011). Also, compared to 2D US, 4D gives lower resolution images with lower frame rates, owing to the huge data acquisition. In turn, the operator then has the challenge of interpreting complex images.

2.11 Summary

Regional anaesthesia facilitates the delivery of anaesthesia and analgesia to an increasingly complex, elderly and co-morbid patient population. The use of ultrasound has transformed this practice, and confers significant advantages. However, it presents new challenges, including nerve and needle visualisation, and image interpretation. There are several strategies to improve image acquisition (and therefore nerve visualisation) and numerous areas of research aimed at improving needle visualisation. Image interpretation is still underpinned by sound anatomical knowledge and understanding of the typical sonographic appearance of different tissues, although advances in nerve and needle visualisation technologies aid this endeavour.

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Scanning Conditions in Functional Connectivity Magnetic Resonance Imaging: How to Standardise Resting-State for Optimal Data Acquisition and Visualisation?

3

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Abstract

Functional connectivity magnetic resonance imaging (fcMRI), performed during resting wakefulness without tasks or stimulation, is a non-invasive technique to assess and visualise functional brain networks *in vivo*. Acquisition of resting-state imaging data has become increasingly common in longitudinal studies to investigate brain health and disease. However, the scanning protocols vary considerably across different institutions creating challenges for comparability especially for the interpretation of findings in patient cohorts and establishment of diagnostic or prognostic imaging biomarkers. The aim of this chapter is to discuss the effect of two experimental conditions (i.e. a low cognitive demand paradigm and a pure resting-state fcMRI) on the reproducibility of brain networks between a baseline and a follow-up session, 30 (±5) days later, acquired from 12 right-handed volunteers (29 ± 5 yrs). A novel method was developed and used for a direct statistical comparison of the test-retest reliability using 28 well-established functional brain networks. Overall, both scanning conditions produced good levels of test-retest reliability. While the pure resting-state condition showed higher test-retest reliability for 18 of the 28 analysed networks, the low cognitive demand paradigm produced higher test-retest reliability for 8 of the 28 brain networks (i.e. visual, sensorimotor and frontal areas); in 2 of the 28 brain networks no significant changes could be detected. These results are relevant to planning of longitudinal studies, as higher test-retest reliability generally increases statistical power. This work also makes an important contribution to neuroimaging where optimising fcMRI experimental scanning conditions, and hence data visualisation of brain function, remains an on-going topic

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of interest. In this chapter, we provide a full methodological explanation of the two paradigms and our analysis so that readers can apply them to their own scanning protocols.

Keywords
Brain · Magnetic resonance imaging · Functional connectivity · Resting-state

3.1 Functional Magnetic Resonance Imaging

Functional magnetic resonance imaging (fMRI) utilises the magnetic properties of haemoglobin to indirectly visualise brain activation during a task/stimulation (i.e. task-based fMRI) or at rest (i.e. resting-state fMRI). Specifically, during a task or stimulation cerebral blood flow increases to meet the oxygen and metabolic demands in the activated parts of the brain. For instance, a visual task will stimulate the visual cortex in the occipital lobe increasing its oxygen/glucose demands and therefore its cerebral blood flow. During the activation period, there is a disproportionate increase in the supply of oxyhaemoglobin (i.e. haemoglobin bound to oxygen) to the relevant brain area that exceeds the metabolic need and is subsequently followed by a relative "drop" in the deoxyhaemoglobin (i.e. unbound haemoglobin not carrying oxygen) levels. While oxyhaemoglobin is typically weakly diamagnetic (i.e. repelled by magnetic fields or nonmagnetic), deoxyhaemoglobin is paramagnetic (i.e. attracted by magnetic fields) relative to the surrounding tissue. In practice, the paramagnetic deoxyhaemoglobin in deoxygenated blood creates localised field inhomogeneities leading to lower MR signal than oxygenated blood (Huettel et al. 2009; McRobbie et al. 2011). For example, in a visual stimulation task, the MR signal will increase upon the influx of oxygenated blood (i.e. oxyhaemoglobin). Thus, brain activation can be indirectly visualised based on the corresponding MR signal change, which is generally referred to as the blood oxygen level dependent (BOLD) contrast (Chavhan 2007; Huettel et al. 2009; McRobbie et al. 2011; Westbrook et al. 2011).

3.1.1 Resting-State Functional Connectivity Magnetic Resonance Imaging

Resting-state functional connectivity MRI (rs-fcMRI) is a technique used to visualise brain connectivity by measuring the low frequency (nominally <0.1 Hz) and spontaneous, but synchronous, fluctuations of the BOLD signal during periods of resting wakefulness without a task or stimulation. Functional connectivity analysis methods attempt to establish the connections between different spatial regions by assessing temporal correlations of fluctuations in the BOLD signal. This imaging technique is regarded as a valid research tool in clinical neuroscience (Lowe 2010; Snyder and Raichle 2012) and has been used to investigate the functional architecture of the brain in health and disease (Harrison et al. 2007; Calhoun et al. 2009; Zhang and Raichle 2010).

3.1.2 Resting-State Networks

Brain areas with temporally correlated BOLD signal oscillations are hypothesised to be involved in the same process. Figure 3.1 depicts a typical BOLD time course in a single subject obtained in a voxel within the left (green) and right (red) primary motor cortex where a pattern of correlated fluctuations can be observed.

These distinct patterns of brain connections, representing neural circuits with specific functions (Greicius et al. 2003; Raichle and Mintun 2006), are named resting-state networks. The patterns of activated regions have been demonstrated to be consistent across healthy subjects (Damoiseaux et al. 2006), degrees of consciousness (Horovitz et al. 2009), and under pharmacological manipulation (Schrouff et al. 2011).

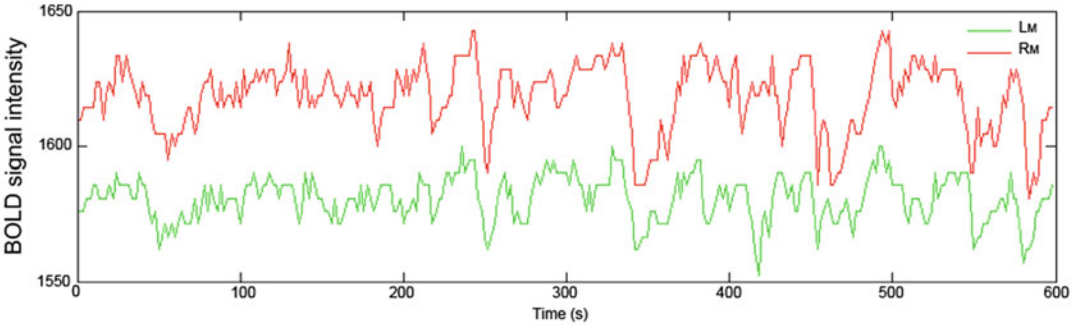

Fig. 3.1 Representative BOLD time course in a single subject. (Adapted and reproduced from Dinis Fernandes et al. 2013)

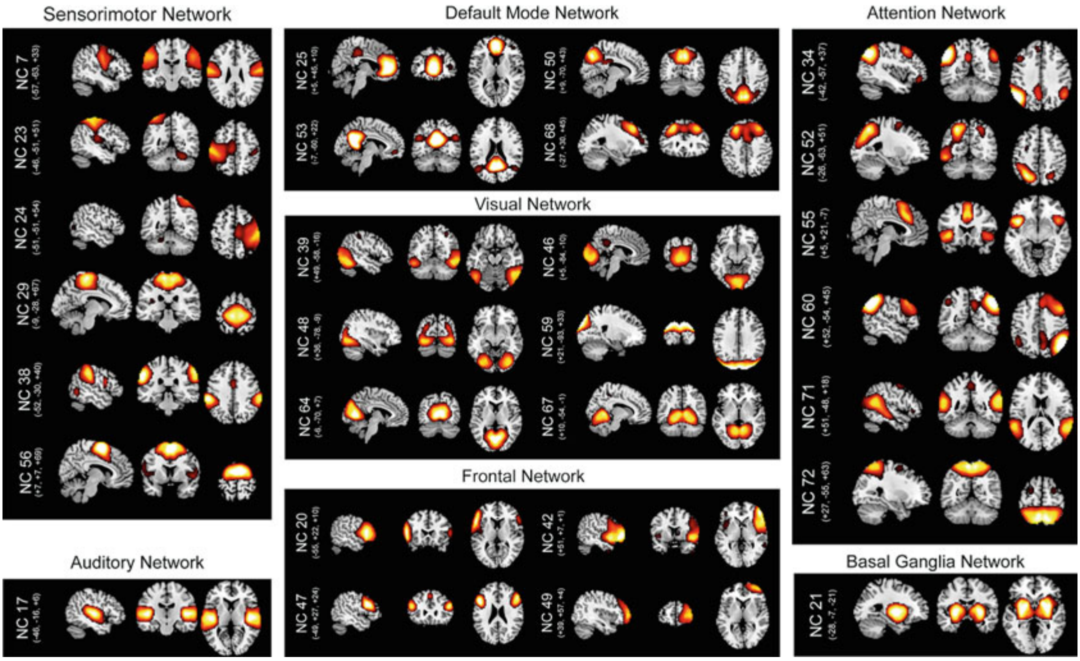

Fig. 3.2 Well-established resting state networks previously described by Allen et al. (2011). Individual network components were superimposed onto normalised three-dimensional high-resolution structural images and displayed using the original categorisation, binarisation thresholds and component numbering utilised by Allen et al. Brain images are displayed in neurological convention (i.e. the left side of the image corresponds to the left side of the brain). (Reproduced from Dinis Fernandes et al. 2013)

Analysis of resting-state functional connectivity MRI (rs-fcMRI) data has consistently identified several resting-state brain networks. The most widely studied is the default mode network, first identified from positron emission tomography (PET) data by Raichle et al. (2001) and subsequently by Greicius et al. (2003) using fcMRI. Since then, several other resting-state networks have been identified, with evidence suggesting the existence of at least six consistent networks: visual; auditory; dorsal and ventral attention; default mode network; somatosensory; and frontoparietal network. Figure 3.2 illustrates a number of well-established resting-state networks reported by Allen and colleagues (Allen et al. 2011).

3.2 Scanning Conditions

To date, most fcMRI studies have relied on an experimental paradigm known as “resting-state”. During this condition no experimental task is presented with the participant typically being instructed to relax and not to think of anything in particular (Biswal et al. 1995; Greicius et al. 2003; Fox et al. 2005; Salvador et al. 2005; Damoiseaux et al. 2006). From the perspective of the researcher, this paradigm is attractive because it is easy to implement with no stimulus delivery equipment being required and lacks any obvious task-specific bias.

A number of studies have assessed the effects of various scanning conditions on the resting-state brain networks (Marx et al. 2004; Bianciardi et al. 2009; Cole et al. 2010; Logothetis et al. 2009). However, due to the heterogeneity of the research findings, there is an on-going debate regarding the influence of experimental conditions on functional connectivity (Cole et al. 2010). When compared to the eyes open approach, having participants keep their eyes closed has the potential to minimise visual confounders arising from the surrounding lighting within the scanner suite (Logothetis et al. 2009). On the other hand, instructing the participants to keep the eyes open allows monitoring with infrared cameras to prevent individuals from drifting to sleep. However, under both conditions it is not possible to guarantee that a person will not daydream. The human mind can be “restless”, especially if left unrestrained.

3.2.1 Reproducibility of Resting-State Imaging Data

High inter-subject variability unrelated to the effect of interest will increase the standard deviation within the group thus decreasing the statistical power to detect potential differences between different groups or treatments. High test-retest reliability is therefore crucial in the context of using functional connectivity measures as potential imaging biomarkers for longitudinal studies. Test-retest reliability refers to the longitudinal or intra-individual stability of a measure across multiple occasions in a group of subjects (Zuo and Xing 2014). The intraclass correlation coefficient (ICC) is widely used to quantify test-retest reliability, as it provides a measure of the absolute agreement between two different acquisition points (McGraw and Wong 1996). Recent studies investigating test-retest reliability of longitudinal resting-state fcMRI studies have reported moderate to good test-retest reliability in healthy adults using the ICC approach (Shehzad et al. 2009; Zuo et al. 2010; Schwarz and McGonigle 2011; Wang et al. 2011; Braun et al. 2012; Chou et al. 2012; Guo et al. 2012; Liang et al. 2012; Fiecas et al. 2013; Patriat et al. 2013). Test-retest reliability can be significantly improved by an appropriate choice of study design and data processing methods (Zuo and Xing 2014; Andellini et al. 2015). However, it remains unclear whether the widely used “resting-state” scanning condition provides optimum test-retest reliability.

Researchers have employed alternative resting-state data acquisition methods, such as fixating on a cross or other object projected within the scanner’s bore. For instance, Patriat et al. (2013) evaluated the impact of three different resting-state conditions (i.e. eyes open, eyes closed and eyes fixating on a cross) on the test-retest reliability of fcMRI data. The study showed that there was significantly greater reliability for the majority of the assessed networks when the participants were fixating on the cross. The only exception was the primary visual network that was more consistent when individuals had their eyes open and not fixated (Patriat et al. 2013).

As pointed out by Morcom and Fletcher (Morcom and Fletcher 2007a, b), the characterisation of a resting-state or baseline in the human brain is conceptually challenging. In the absence of a specific task, functional brain network dynamics are likely to exhibit wider variability because different subjects will be thinking about different things while being scanned and some participants may even fall asleep. Based on these considerations, it has been argued that replacing conventional resting-state paradigms with a low-cognitive demand condition during which the participants carry out a simple task could improve test-retest reliability by reducing within group variability (Perrin et al. 2012).

3.3 Chapter Scope

The aim of this chapter is to discuss whether a suitably designed low-cognitive demand task improves the test-retest reliability when compared to a standard resting-state condition. A novel method was developed and used for analysing the test-retest reliability, which relies on the histogram distribution of ICC values within a specific functional brain network component. Unlike ICC analyses used in previous functional connectivity studies, this approach allows for a direct statistical comparison of the test-retest reliability between different experimental conditions.

3.4 Methods

3.4.1 Study Design

Twelve right-handed participants (7 females; mean age and standard deviation: 29 ± 5) were recruited for this study. Functional connectivity MRI data were acquired on two occasions (i.e. baseline and follow-up). The time span between the two visits was 30 (± 5) days with a minimum to a maximum range of 27 to 35 days. The experimental scanning procedure was identical for both sessions, during which data was acquired using standard resting-state and a low-cognitive demand paradigm. The order, however, of the two experimental conditions was randomised. The study was approved by the North of Scotland Research Ethics Committee (reference number: 11/NS/0030) and reviewed by the NHS Grampian Research and Development Department (reference number: 2011ST003). Written informed consent was obtained from all participants prior to taking part in this study.

3.4.2 Image Acquisition

Magnetic resonance imaging data were acquired on a Philips 3 T Achieva X-series scanner (Philips Medical Systems, Best, The Netherlands; http://www.philips.com/global/index.page) using a Siemens 32-channel receive-only phased-array head coil (Siemens Medical Systems, Iselin, New Jersey; http://www.healthcare.siemens.co.uk) at the Aberdeen Biomedical Imaging Centre, Scotland UK. For the functional connectivity, a gradient-echo echo-planar imaging (EPI) sequence was used with a total acquisition time of 10 minutes, a TR/TE of 2000/30 ms, voxel size of $2.5 \times 2.5\ \mathrm{mm}^2$ and a slice thickness of 3.5 mm. A high-resolution T1-weighted structural scan was obtained in 5 minutes and 35 seconds, using a 3D fast gradient-echo sequence with a TR/TE of 8200/3.8 ms and voxel size of $1.0 \times 1.0 \times 1.0\ \mathrm{mm}^3$.

3.4.3 Experimental Conditions

3.4.3.1 Pure Resting-State

For the pure resting-state condition (RC) a commonly used experimental paradigm was employed in which participants were instructed to keep their eyes open, to relax and not to think of anything in particular. No auditory or visual stimuli presented were presented during acquisition.

3.4.3.2 Low-Cognitive Demand Paradigm

For the low-cognitive demand condition (LC), images of landscapes (e.g. mountains, etc.) and buildings (e.g. tower blocks, etc.) were presented in a randomly alternating sequence, as shown in Fig. 3.3, with these switching every 2.9 seconds. Before entering the scanner, participants were asked to respond by clicking a button using their right (i.e. dominant) index finger whenever an image of a building was shown, while they were to make no response to landscapes. At each visit, the researchers also discussed with the participants that the task was not competitive in nature with the aim of alleviating any potential concerns or anxiety in relation to giving the “wrong” response. No reward value was attached to any of the scores and the researchers were blinded to the overall performance of the participants during analysis.

For the LC, a research active clinical psychologist selected all the images (i.e. 100 buildings and 100 landscapes) that were also balanced for light and colour levels. No pictures showing animals or humans were included, as previous studies have shown these may induce specific activation in regions involved with facial recognition, emotions and retrieval of memories (Smith et al. 2004). A consistent 70% grey background was used to display all of the images (Fig. 3.3). Upon pressing the button, a message providing neutral feedback (“button pressed”) appeared. Programming of the paradigm was performed using the Presentation® Software (Neuro Behavioural Systems, Berkeley, CA, USA; http://www.neurobs.com). The paradigm was displayed within the scanner bore and synchronised using Nordic NeuroLab equipment (Bergen, Norway; http://www.nordicneurolab.com) (Varsou 2014).

3.4.3.3 Scanner Suite

To maximise control of extraneous variables and reduce the chance of environmental confounds with the potential to affect fcMRI results, the same headphones and brand of earplugs were used for all participants across all sessions providing consistent reduction of peripheral scanner noise. Additionally, a consistent light level was maintained in the scanner suite during all of the scans.

3.5 Analysis

3.5.1 False Response Rate

During the LC paradigm, participants were to press a response button when they saw a picture of a building, but not when they saw a picture of a landscape. For each participant and scanning session (i.e. baseline and follow-up), the false response rate was calculated by dividing the number of false button presses by the total number of pictures presented (i.e. 200). The corresponding mean values and standard deviations (σ) were calculated for each imaging session and a post-hoc paired t-test was carried out to test for significant differences between baseline and follow-up. One subject was excluded from the false response rate analysis, as the false response rate during the follow-up session was not within the 3σ interval of the corresponding distribution.

3.5.2 Data Pre-Processing

Functional MRI data were pre-processed using the statistical parametric mapping software (SPM) package (SPM8, London, UK; http://www.fil.ion.ucl.ac.uk/spm). Pre-processing steps included realignment and reslicing, slice-timing correction, co-registration, as well as combined

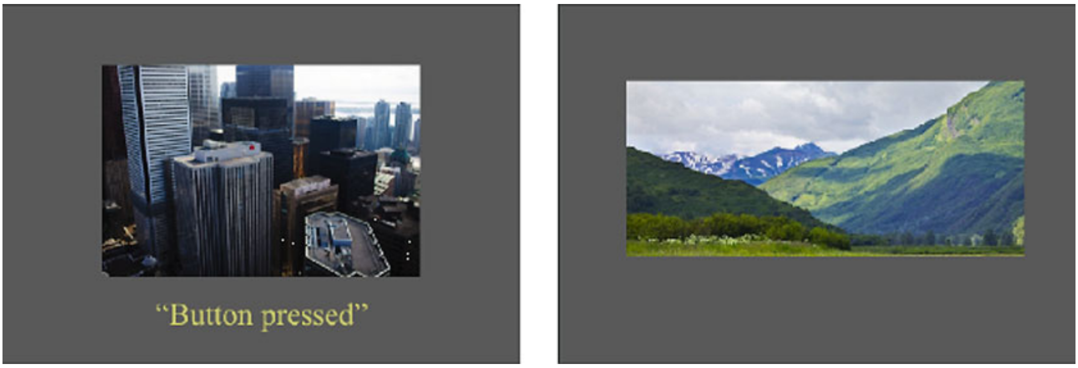

Fig. 3.3 Example LC paradigm images displayed during scanning. (Reproduced from Dinis 2013 and Varsou 2014)

segmentation and spatial normalisation to the Montreal Neurological Institute (MNI) space before applying spatial smoothing with an 8 × 8 × 8 mm^3 full width at half maximum (FWHM) Gaussian isotropic kernel (Penny et al. 2006). Voxels were resampled at 3 × 3 × 3 mm^3 to reduce computational complexity. A study-specific binary grey matter mask was created by taking the mean of the participant specific grey matter maps, generated during the segmentation procedure, and applying a probability threshold of 0.3 for inclusion within the mask. The time courses of all grey matter voxels identified by the binary grey matter mask were extracted from the imaging data and stored in a 2D N_{vox} x T array with N_{vox} of 36,226 grey matter voxels and a T of 300 time points. Each voxel time course was low-pass filtered (i.e. cut-off frequency of 0.1 Hz) and baseline corrected using a second order cosine basis set to remove low-frequency signal drifts.

Unwanted signal variance, due to head movement or white matter (WM) and cerebrospinal fluid (CSF) signal variations, was removed from all time courses by means of linear regression (Di Martino et al. 2008; Shehzad et al. 2009; Fiecas et al. 2013; Patriat et al. 2013). The following covariates of no interest (i.e. nuisance regressors) were included: six affine realignment parameters generated by the SPM realignment procedure; a reference WM time course; and a reference CSF time course. The WM and CSF reference time courses were calculated by averaging all of the WM and CSF voxel time courses. White matter and CSF voxels were identified by means of a binary mask, created by applying a 0.3 probability threshold to the corresponding WM and CSF probability maps. These were automatically generated during the SPM segmentation process. For improved accuracy, the WM map was eroded by one voxel and the CSF map by two voxels both in every direction.

Global signal regression was not applied to this dataset, as there is an increasing body of evidence indicating that the inclusion of this step may increase the rate of false negative correlations, decrease test-retest reliability and affect group level analyses (Murphy et al. 2009; Weissenbacher et al. 2009; Cole et al. 2010; Liang et al. 2012; Saad et al. 2012; Song et al. 2012; Andellini et al. 2015).

3.5.3 Functional Brain Network Template

Previously established functional brain network templates consisting of 28 network components (Allen et al. 2011) were used in this study. This template was originally generated from 603 healthy adolescents and adults, with a mean age of 23.4 years and a range from 12 to 71 years, for the study of the intrinsic reliability of functional brain networks under resting-state conditions (Allen et al. 2011). The set of 28 functional brain network components was identified based on the results of a 75-component group independent component analysis (GICA), visual inspection and, power spectra analysis. For a detailed description of the component selection, please review section two of Allen et al. (2011). The unthresholded t-maps for the 28 resting-state components are available online (http://trendscenter.org/data/). In this study, the functional connectivity maps were thresholded using the same t-thresholds applied by Allen et al. (2011) to create 28 binary masks. The 28 functional brain network components were grouped according to their anatomical and functional properties into: basal ganglia (BG); auditory (AUD); sensorimotor (MOT); visual (VIS); default-mode (DMN); attention (ATTN); and frontal (FRONT) networks (Fig. 3.2). Binary masks for the 28 functional networks were used to select the corresponding voxelwise fMRI time courses to be subjected to the voxelwise connectivity analysis. Only voxels included within both the binary masks and the study specific grey matter mask were selected for further analysis.

3.5.4 Similarity Matrix

A similarity matrix was calculated for each subject and functional brain network component, experimental condition (i.e. RC and LC), and scanning session (i.e. baseline and follow-up) by calculating the Pearson product-moment correlation coefficient between all the selected voxel time courses and a Fisher z-transform was applied to all correlation values. The resulting N x N similarity matrix was symmetrical giving a total of $N' = N \times (N-1) / 2$ unique correlation values, where N is the number of voxels for a specific component. For further analysis, these unique correlation values were extracted from the similarity matrix and stored in a single vector V (consisting of N′ elements).

3.5.5 Intraclass Correlation Coefficient Calculation

The ICC was applied to assess test-retest reliability, as this measure has been used extensively to investigate the reproducibility of both task-based and resting-state fMRI experiments (Shehzad et al. 2009; Telesford et al. 2010; Zuo et al. 2010; Schwarz and McGonigle 2011; Wang et al. 2011; Braun et al. 2012; Guo et al. 2012; Liang et al. 2012; Song et al. 2012; Gorgolewski et al. 2013; Patriat et al. 2013). For each element of the z-transformed V vector (Shehzad et al. 2009; Patriat et al. 2013), an $n \times m$ test-retest matrix was created, where n was the number of subjects (12) and m the number of scans (2). This procedure was repeated for all 28 components of the functional brain network template. The ICC values were calculated using a publically available MATLAB script developed by the University of Wisconsin (Birn Laboratory, Department of Psychology, Madison, USA; http://birnlab.psychiatry.wisc.edu/) and used in previous studies (Patriat et al. 2013). A one-way ANOVA with random subject effects was used to compute the between-subject mean square (BMS) and within-subject mean square (WMS) values. The ICC values were subsequently calculated for each test-retest matrix according to the following equation as proposed by Shrout and Fleiss (Shrout PE, Fleiss JL, 1979) where m was the number of repeated measurements per voxel and in this case it was m equal to 2:

Table 3.1 Levels of agreement for different ICC values based on the paper by Landis and Koch (1997)

ICC Value	Level of agreement
ICC < 0.2	Poor
0.2 < ICC < 0.39	Fair
0.4 < ICC < 0.59	Moderate
0.6 < ICC < 0.79	High
ICC > 0.8	Excellent

$$ICC = \frac{(BMS - WMS)}{(BMS + (m-1)\,WMS)}$$

ICC values can range from 0 to 1 with values close to 1 indicating high reproducibility as a result of low within-subject variance compared to between-subject variance. As described in previous studies (Schwarz and McGonigle 2011; Wang et al. 2011; Braun et al. 2012; Chou et al. 2012; Fiecas et al. 2013; Guo et al. 2012; Liang et al. 2012; Song et al. 2012; Patriat et al. 2013), the ICC values were categorised into five levels of agreement as shown in Table 3.1.

3.5.6 Test-Retest Reliability Analysis

In order to investigate the test-retest reliability for each experimental condition, two different types of analyses were carried out: (i) a global comparison of averaged ICC values and (ii) a component-wise comparison of ICC distributions. The first method has been widely used in previous studies to assess the test-retest reliability of both functional connectivity and conventional task-based fMRI longitudinal designs. However, the averaging procedure results in a single ICC value per functional brain network component, and therefore does not permit direct component-wise statistical comparison. The averaging process also eliminates a large amount of voxel-wise information that may reveal relevant regional differences in test-retest reliability. To overcome the aforementioned limitations, we developed a novel method, based on component-wise comparison of ICC distributions using a standard chi-squared test.

3.5.6.1 Global Comparison

Following a common approach from previous studies, the ICC values were averaged for each of the 28 individual network components. Normality was tested using a Kolmogorov-Smirnov test for both experimental conditions, which showed that the ICC values for the RC and LC experimental conditions were normally distributed ($p > 0.05$). The corresponding mean values and standard deviations were calculated and a paired t-test was used to test for mean difference.

3.5.6.2 Component-Wise Comparison

For each experimental condition (i.e. RC and LC), histogram distributions of ICC values were calculated for each functional brain network component. A chi-squared test was used to test for differences in the distributions of ICC values between these two paradigms. The chi-squared test was carried out with a subdivision of ten intervals per distribution corresponding to nine degrees of freedom. To account for the spatial smoothness of the data, the obtained chi-squared values were divided by a correction factor, which was calculated from the FWHM of the isotropic smoothing kernel (i.e. $8 \times 8 \times 8$ mm^3) and the voxel size (i.e. $3 \times 3 \times 3$ mm^3) to give $(8/3)^6 \cong 359.59$. The results of the chi-squared test were considered significant at a level of $\alpha < 0.01$. To account for multiple comparisons (i.e. a chi-squared test was carried out for each of the 28 functional brain network components), a Bonferroni correction was applied ($\alpha' = \alpha/28$) and the corresponding chi-squared cut-off-value (30.52) was calculated using the MATLAB function 'chi2inv'.

3.6 Results

3.6.1 False Response Rate

For both imaging sessions (i.e. baseline and follow-up), the false response rate was of the order of 1%, within the expected range for a low-cognitive demand task. The difference in the corresponding mean false response rate values for baseline (0.73 ± 0.64%) and follow-up (1.1 ± 1.2%) was not significant ($p = 0.588$).

Table 3.2 Average ICC values for each functional brain network component and experimental condition (i.e. RC and LC)

		Average ICC value	
Network	Network component	RC	LC
Default mode	25	0.3578	0.3557
	50	0.604	0.6045
	53	0.6171	0.4979
	68	0.527	0.4954
Auditory	17	0.5132	0.4284
Attention	34	0.5437	0.5038
	52	0.5849	0.5111
	55	0.5231	0.4752
	60	0.5733	0.5362
	71	0.5842	0.5521
	72	0.5534	0.5207
Frontal	20	0.5027	0.438
	42	0.4698	0.4577
	47	0.5137	0.4838
	49	0.4924	0.5169
Basal ganglia	21	0.4196	0.361
Sensorimotor	7	0.5003	0.4764
	23	0.491	0.4612
	24	0.4899	0.4599
	29	0.5326	0.4596
	38	0.4913	0.4919
	56	0.4122	0.4704
Visual	39	0.5116	0.5038
	46	0.5144	0.5471
	48	0.4718	0.5346
	59	0.5591	0.5903
	64	0.5897	0.5439
	67	0.5191	0.4962

For ease of reference, the original numbering of the network components used by Allen et al. (2011) was adopted. *ICC* intraclass correlation coefficient, *RC* resting-state condition, *LC* low cognitive demand condition

3.6.2 Test-Retest Reliability

3.6.2.1 Global Comparison

Table 3.2 displays the average ICC values for both experimental conditions obtained for each of the 28 functional brain network components investigated. The spatial extent of the 28 functional brain network components is illustrated in Fig. 3.2. For both experimental conditions, the obtained average ICC values, ranging from 0.356

to 0.617 (Table 3.2), are in good agreement with previously published literature values (Shehzad et al. 2009; Aron et al. 2006) and show predominantly moderate test-retest reliability. The corresponding mean values are 0.517 ± 0.059 (RC) and 0.492 ± 0.056 (LC). The difference in the means is small, but statistically significant ($p < 0.0043$), demonstrating a slightly lower test-retest reliability of LC compared to RC.

3.6.2.2 Component-Wise Comparison

Figures 3.4 to 3.9 show the histogram distributions of ICC values for each functional brain network component. The corresponding experimental conditions are colour coded in black (RC) and orange (LC). The number in the title of each histogram distribution refers to the corresponding functional network component displayed in Fig. 3.2**.** For the graphical representation, a histogram bin size of 1000 was used. The results of the component-wise statistical comparison are summarised in Table 3.3. For 26 of the 28 functional brain network components significant differences in the distributions of ICC values were observed between the two experimental conditions.

The LC resulted in higher test-retest reliability when compared to the RC for the following functional brain network components: frontal (components 47 and 49; Fig. 3.5); visual (components 39, 46, 48 and 59; Fig. 3.6 and Table 3.3); sensorimotor (components 23 and 56; Fig. 3.7 and Table 3.3). Conversely, the LC resulted in lower test-retest reliability when compared to the RS for the following functional brain network components: default mode (components 53 and 68; Fig. 3.4 and Table 3.3); frontal (components 20 and 42; Fig. 3.5 and Table 3.3); visual (components 64 and 67; Fig. 3.6 and Table 3.3); sensorimotor (components 7, 24, 29 and 38; Fig. 3.7 and Table 3.3); attention (components 34, 52, 55, 60, 71 and 72; Fig. 3.8 and Table 3.3); auditory (component 17; Fig. 3.9 and Table 3.3); and basal ganglia (component 21; Fig. 3.9 and Table 3.3). Finally, no statistical differences were observed for two functional brain network components both of which are part of the default mode network (component 25 and 50; Fig. 3.4 and Table 3.3).

3.7 Summary

This study compared rs-fcMRI test-retest reliability under two different experimental conditions: i) a low-cognitive demand task and ii) a standard resting-state condition. The comparison was performed using a set of 28 well-characterised functional brain network components (Allen et al. 2011). To evaluate the test-retest reliability, two different methods were employed with a conventional analysis of averaged ICC values, which has been widely used to investigate the test-retest reliability of resting-state fMRI studies, as well as a novel method that relies on the histogram distribution of ICC values within each functional brain network component.

The conventional approach is based on calculating the average ICC value for each functional brain network component. This results in a single ICC value per functional brain network component and experimental condition (i.e. LC and RC). Therefore, a direct component-wise statistical comparison of both experimental conditions is not possible. A pair-wise comparison of all 28 components exhibited a slightly lower test-retest reliability of LC compared to RC. While this global comparison is generally useful, it does not provide any information about the regional, component-wise test-retest reliability.

The novel ICC analysis method successfully addressed the above issue. This revealed relevant regional differences showing that the test-retest reliability was actually significantly higher for the LC when compared to RC in eight of the 28 functional brain network components, while the converse was the case for 18 of the 28 functional brain network components with no significant difference for only two of the 28 functional brain network components (Table 3.3). These findings are consistent with the results of the global comparison of averaged ICC values and are not only interesting from a conceptual point of view, but also potentially highly relevant for the planning of future longitudinal study designs.

Overall, the RC resulted in better test-retest reliability compared to the LC. This may appear surprising, as one could argue that the RC gen-

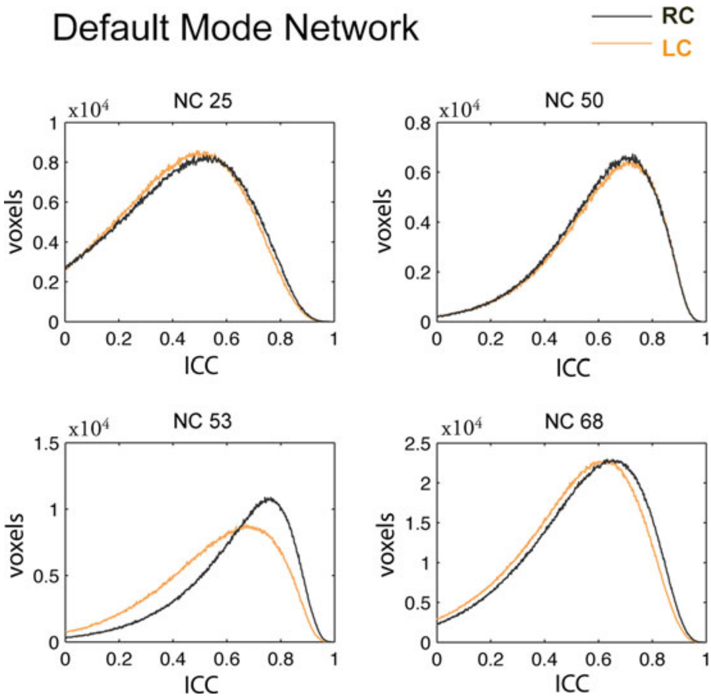

Fig. 3.4 Histogram distributions of ICC values comparing resting-state and low-cognitive condition for the components of the default mode network

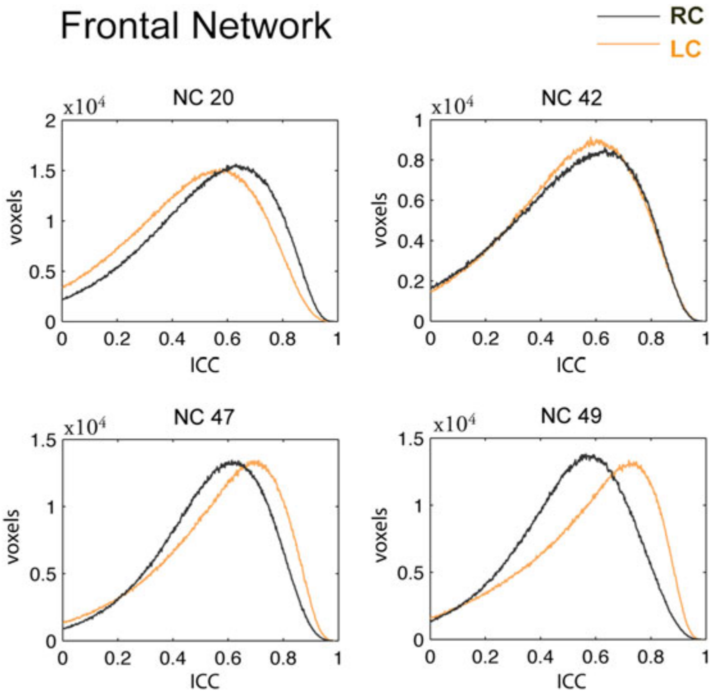

Fig. 3.5 Histogram distributions of ICC values comparing resting-state and low-cognitive condition for the components of the frontal network

erally presents a less well-defined experimental condition compared to the LC. Intuitively, one would expect higher within-group variability in the RC, resulting in lower test-retest reliability of RC compared to LC. Habituation or learning effects (Lewis et al. 2009) during the LC may partly explain this finding. However, given the simplicity of the task, the relatively long timespan

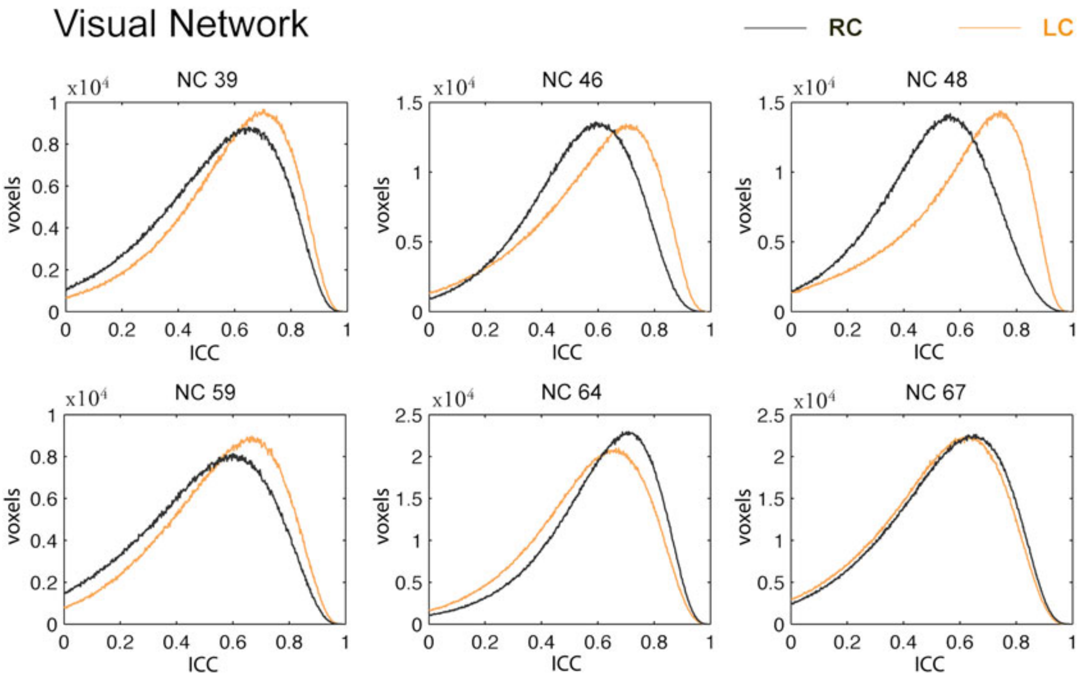

Fig. 3.6 Histogram distributions of ICC values comparing resting-state and low-cognitive condition for the components of the visual network

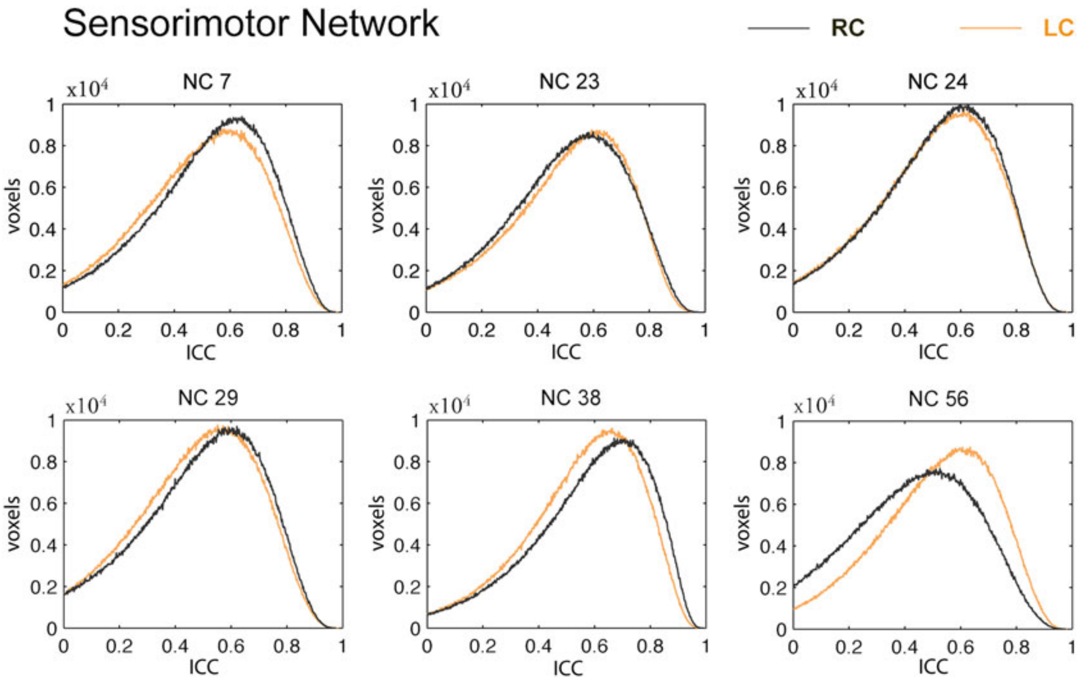

Fig. 3.7 Histogram distributions of ICC values comparing resting-state and low-cognitive condition for the components of the sensorimotor network

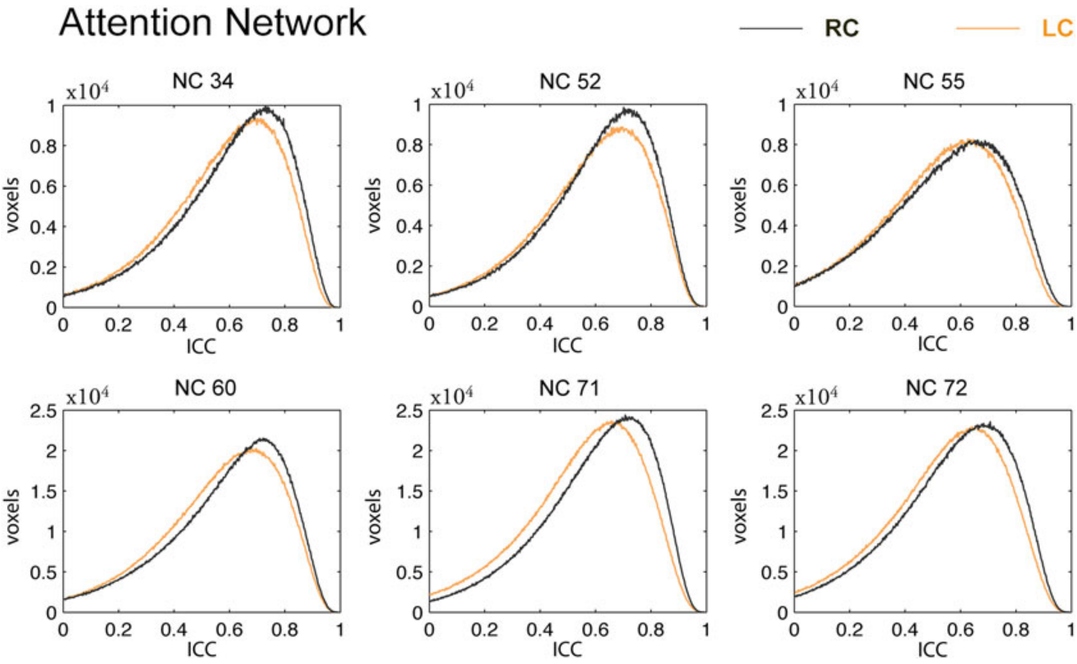

Fig. 3.8 Histogram distributions of ICC values comparing resting-state and low-cognitive condition for the components of the attention network

between the two imaging session (i.e. 30 days), and that no significant differences in the false response rate were observed between baseline and follow-up, habituation/learning effects are unlikely in this instance. Higher test-retest reliability of the LC compared to the RC was found for two of the four frontal, two of six sensorimotor, and four of six visual network components. The findings of this study are broadly consistent with previous work that has showed improved test-retest reliability when participants were instructed to fixate their eyes as opposed to simply keeping their eyes open or shut (Patriat et al. 2013). The simple task of fixating the eyes or, as is the case in this study, looking at pictures of landscapes or buildings appears to stabilise certain visual network components and reduces the variability between both imaging sessions (i.e. baseline and follow-up) therefore resulting in a higher test-retest reliability. A similar argument can be made with regard to the sensorimotor components, as the LC involved pressing a response button. The two frontal network components that showed higher test-retest stability for the LC (i.e. components 47 and 49) are generally involved in cognitive processing as well as executive, language and memory functions (Koechlin et al. 2003; Ridderinkhof et al. 2004), and more specifically in mediating motor action in response to external stimuli (D'Ostilio and Garraux 2012). Along the same lines as the aforementioned argument, this could explain the higher test-retest reliability of the LC when compared to the RC for these network components.

The LC was designed to avoid activation of higher levels of cognition, as overly rigorous tasks are known to modulate functional connectivity within and across resting-state brain networks (Fransson 2005; Hampson et al. 2006; Harrison et al. 2007; Kelly et al. 2008; Yan et al. 2009). Specifically, working memory tasks have been found to decrease functional connectivity within the default mode network, while increasing functional connectivity within lateral prefrontal areas (Greicius et al. 2003), which have been termed "task-positive networks". Furthermore, higher cognitive load is likely to result in significant habituation or learning effects, as demonstrated by a large number of task-based fMRI studies (McGonigle et al.

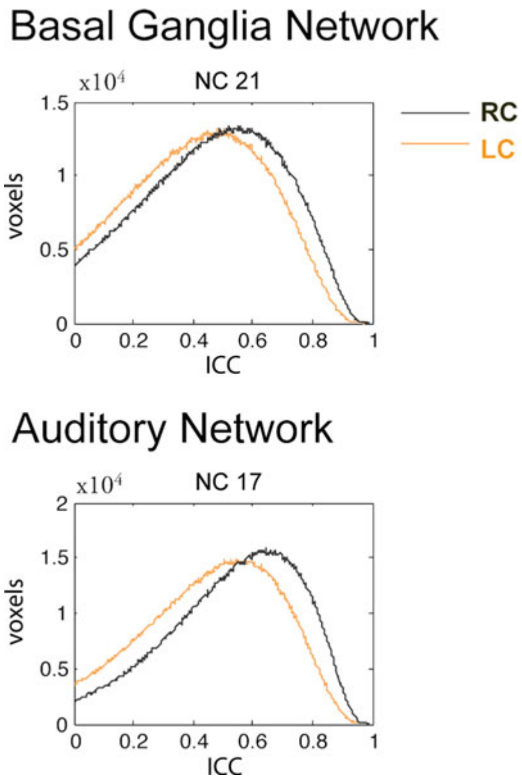

Fig. 3.9 Histogram distributions of ICC values comparing resting-state and low-cognitive condition for the components of the basal ganglia and auditory networks

2000; Manoach et al. 2001; Kelly and Garavan 2005). Due to its low-level nature, this task is likely to preserve the individual variations in resting-state activity. Inter-individual variations have been hypothesised to play an important role in the context of individual functional anatomy, cognition, and risk for disease (Buckner and Vincent 2007). The simplicity of the LC may make it applicable in a wide range of clinical studies including many applications in neurology and psychiatry. However there may be a potential confounder to use in cognitive neuroscience studies that investigate object or pattern recognition.

The results from this study have to be interpreted with the following caveats in mind. The study was based on a relatively small cohort of twelve volunteers who were all drawn from a single institution potentially affecting the generalisability of the findings. Improvements in repeatability and reproducibility are most likely not only dependent on the resting-state condition, but also on other parameters such as the duration of the scanning session (Birn et al. 2013) or the approach chosen to analyse the data (Franco et al. 2013). Another potential limitation is that the signal of interest was low-pass filtered before the nuisance parameter regression was conducted and therefore the regressors were unfiltered. It has been suggested by Hallquist et al. (2013) that the data as well as the nuisance regressors should be filtered, as omitting this step could reintroduce noise and overestimate functional connectivity. This is an important step to consider for any researcher wanting to utilise the method proposed in this chapter.

Compared to the conventional ICC analysis method used in previous functional connectivity MRI studies (Shehzad et al. 2009; Zhang and Raichle 2010; Schwarz and McGonigle 2011; Wang et al. 2011; Braun et al. 2012; Guo et al. 2012; Liang et al. 2012; Fiecas et al. 2013; Patriat et al. 2013), the novel method proposed in this chapter allows for a direct statistical comparison of ICC values between two experimental conditions on a regional level. This method was applied to investigate the test-retest reliability at the level of individual network components derived from a previous independent component analysis approach (ICA) (Allen et al. 2011). However, in principle our method can be applied to any set of voxels that is sufficiently large to produce a suitable histogram distribution for a Chi-squared test.

3.8 How Can We Standardise the Resting-State Condition?

The present study compared two experimental conditions, resting-state and a low-cognitive demand paradigm in terms of their test-retest reliability. A novel analysis method was employed that allowed for a direct statistical comparison using a set of previously established functional brain network components. The pure resting-state condition resulted in higher test-retest reliability

Table 3.3 Statistical comparison of the two experimental conditions based on the corresponding histogram distributions of ICC values for each network component

Network	Network component	X^2 value	Corrected X^2 value	Significance	Result
Default mode	25	7428.6	20.66	Not sig.	–
	50	6536.19	18.18	Not sig.	–
	53	179719.3	499.78	Sig.	RC > LC
	68	33867.25	94.18	Sig.	RC > LC
Auditory	17	241221.2	670.82	Sig.	RC > LC
Attention	34	44949.8	125	Sig.	RC > LC
	52	76140.4	211.74	Sig.	RC > LC
	55	25454.11	70.79	Sig.	RC > LC
	60	39377.44	109.51	Sig.	RC > LC
	71	151043.8	420.04	Sig.	RC > LC
	72	70320.62	195.56	Sig.	RC > LC
Frontal	20	119,338	331.87	Sig.	RC > LC
	42	14601.66	40.61	Sig.	RC > LC
	47	322706.6	897.42	Sig.	LC > RC
	49	672001.5	1868.78	Sig.	LC > RC
Basal ganglia	21	176749.5	491.53	Sig.	RC > LC
Sensorimotor	7	89540.65	249	Sig.	RC > LC
	23	14903.17	41.44	Sig.	LC > RC
	24	20057.64	55.78	Sig.	RC > LC
	29	38112.02	105.99	Sig.	RC > LC
	38	39830.63	110.77	Sig.	RC > LC
	56	281113.1	781.75	Sig.	LC > RC
Visual	39	86283.72	239.95	Sig.	LC > RC
	46	678640.6	1887.24	Sig.	LC > RC
	48	1,545,101	4296.79	Sig.	LC > RC
	59	150,279	417.91	Sig.	LC > RC
	64	191098.8	531.43	Sig.	RC > LC
	67	26362.66	73.31	Sig.	RC > LC

For ease of reference, the original numbering of the network components used by Allen et al. (2011) was adopted. *ICC* intraclass correlation coefficient, *RC* resting-state condition, *LC* low cognitive demand condition

for 18 of the 28 analysed networks. Conversely, in 8 of the 28 brain networks such as the visual, sensorimotor and frontal areas, the low cognitive demand paradigm produced higher test-retest reliability. For 2 of the 28 regions no significant differences could be detected (cf. Table 3.3). These findings have implications for the experimental design of longitudinal studies, as they demonstrate that the use of a low-cognitive demand paradigm, as opposed to the widely used resting-state condition, can improve test-retest reliability for specific brain regions. This is particularly relevant as higher test-retest reliability generally results in increased statistical power. These findings also provide further data supporting the moderate to high test-retest reliability of resting-state functional connectivity MRI, regardless of the precise experimental condition employed, which is a crucial requirement for the successful use of this tool as an imaging biomarker in disease.

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4 Virtual Reality Design for Stroke Rehabilitation

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Abstract

Stroke is a leading cause of disability, and with the stroke survivor population rising in most countries it is increasingly difficult to provide optimal treatment to patients once they return home. Assistive technology solutions can potentially contribute to meeting demand, and also be cost effective. In this chapter, we consider the design and development of engaging serious virtual reality (VR) games for upper arm stroke rehabilitation. Fundamental design principles are summarised and related to our experience of creating game-based VR rehabilitation. The application of ideas from psychology, particularly behavioural change and flow theory are discussed, as well as related learning and gamification principles. We address how to manage differences between people through design, user profiling, and intelligent dynamic system behaviour, and we also explore how to account for variation in stroke survivor capability and personality. The idea of a hero's journey as a metaphor for stroke recovery is introduced and we discuss how this metaphor may guide system design, its relationship to game design principles, and how patient narratives and embedded stories might support engagement with treatment. An overview of our previous work is summarised and we discuss how our experience and increased knowledge and capability has informed improved approaches to development processes. Finally, our approach is illustrated with reference to a recent EU project.

Keywords

Stroke rehabilitation · Upper limb · Virtual reality · Gamification · Design

4.1 Effects of Stroke and Treatment

Stroke survivors have varying degrees of physical impairment following a stroke; it is vital that a person with an onset stroke, who is medically stable, receives frequent, short daily mobilisation during their time in hospital. Early mobilisation

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aims to minimise the risk of the complications of immobility and improve functional recovery quicker. Typical mobilisation will begin 24–48 h of an onset stroke (Intercollegiate Stroke Working Party 2012). Early rehabilitation of physical impairments is vital in the first months after stroke to increase the chances of a rapid recovery. Physiotherapists focus on restoring a person's functional movement, by helping the person learn to use their paretic limbs again through exercise, manipulation, massage and electrical treatments. These treatments help regain muscle control and strength in the paretic limbs as much as possible. Occupational therapists focus on evaluating, managing and improving functional abilities that the person often uses during their daily life. They do this by assessing their strengths and weaknesses during activities of daily living (ADL), for example, dressing, making dinner, or brushing their teeth.

After an initial assessment of the stroke survivor's movement skills, physiotherapist and occupational therapists design a rehabilitation plan tailored to the individual. Part of this program is setting rehabilitation goals to monitor the person's progress towards recovery. Practical goal setting should include family and carers wherever possible; goals should be meaningful, challenging and have personal value to the person. Goals should be assigned a timeframe, depending on the person's condition, these goals can be short-term, long-term or both. As rehabilitation continues, therapists may change or adapt a person's current goals depending on their continued assessment of the person's condition (Hurn et al. 2006; Intercollegiate Stroke Working Party 2012). Meeting these goals usually require intensified rehabilitation; guidelines suggest that the person should ideally receive a minimum of 45 min of rehabilitation (optimally 5 h per day) for a minimum of 5 days per week for people that with an ability to do so. Repetitive exercise facilitates the re-wiring of the brain, creating new neurological pathways in parts of the brain that are not damaged is known as neuroplasticity. This refers to a brain's capacity to reorganise neural processing to improve various types of physical function, including arm motion (McBean and Wijck 2013). Upper limb impairment is a common effect after a stroke, with over three-quarters of people experiencing some level of arm impairment. Common symptoms associated with upper limb impairment include paresis, loss of fractionated movement, abnormal muscle tone and spasticity. These symptoms can severely affect the patient's ability to perform ADLs, so intense and frequent upper limb rehabilitation must be performed to improve arm function and reduce the effect of these symptoms.

The focus of rehabilitation of the paretic upper limbs is on relearning specific motor skills to support fuller engagement with ADLs and to reduce the reliance on others for help and gives the person increased independence. After upper limb assessment and rehabilitation goals have been set for the upper limbs, depending on the assessment results, a physiotherapist and occupational therapist will devise personalised training exercises. If a therapist identifies movement limitations, they will usually offer repetitive task training. Usually, the training involves reaching, grasping, manipulation, releasing and daily task-specific activities such as lifting a cup. *Reaching* – to lengthen the arm out toward a specific location to touch or grasp something; locations can be in varies distances and heights to target specific arm movements. *Grasping and manipulation* – the aim of touching and holding on to an object using fingers and wrist. Object size and shape can vary to improve grasp strength, precision and size. Typically, when grasping is performed, a person is usually asked to move the grasped object to a different location and release it. The paretic upper limb can be exercised separately, although most ADLs require both limbs to move in unison, either in symmetrical or bimanual actions such as pouring water into a glass from a jug. Many ADLs require reaching motion towards objects before they can be grasped, or manipulated, PTs and OTs will generally start with reaching to grasping exercises or tasks for the person to perform their ADLs (Stroke Association 2009).

4.2 Potential Benefits of Virtual Reality for Rehabilitation

Conventional upper limb stroke rehabilitation exercises have been effective in maintaining and improving functional upper limb mobility and ADLs. However, one limitation of conventional rehabilitation is that stroke survivors tend to find the exercises monotonous and tiring. Motivation to perform the exercises may be reduced, causing a lack of engagement in their rehabilitation program. Therefore, the person often becomes complacent with respect to the frequency and intensity of their rehabilitation exercises, or they stop altogether. This lethargy can have an impact on their functional recovery resulting in no improvements or in some cases, deterioration in their upper limb mobility. Much research has been undertaken over the last two decades, investigating how Virtual Reality (VR) and games can increase people's engagement and motivation to maintain their stroke rehabilitation (Levin et al. 2015; McNulty et al. 2015; Webster and Celik 2014). It provides users with the opportunity to practice intensive repetition of meaningful task-related activities necessary for effective rehabilitation (Crosbie et al. 2007). A recent Cochrane review found evidence that VR and games might be beneficial in improving upper limb function and ADLs as an adjunct to usual care or when compared with the same dose of conventional therapy (K. Laver et al. 2017). There is an increasing number of studies mainly focused on using commercially available hardware devices to support upper limb rehabilitation (Laver et al. 2015). VR systems are effective in supporting feedback, have the capability adapt to individual needs, can deliver high intensity and meaningful repetitive exercises to encourage motor control and motor learning. Recent advancements in commercially available VR and games hardware has provided opportunities for less expensive and more useable rehabilitation technology solutions. These technologies have the potential to improve the accuracy of performance monitoring and reporting. A user interface (UI) is one of the most important aspects of any VR or gaming experience. Modes of interaction can vary from a mouse to natural body motion tracking viathe Kinect or speech-based interfaces using devices such as Amazon's Alexia. A VR system with a poorly designed UI can lessen usability. An important factor of usability from a rehabilitation perspective is that a system can adapt to a range of individual motor skills over time (J. W. Burke et al. 2009a). Adaptation is essential as a user may become frustrated if the tasks are too challenging, or become bored if tasks are too easy.

4.3 Game Design Fundamentals

The games industry is now quite mature, and game design theory and practice are well established and understood by professionals. This section covers the basic game design ideas, and in the next section, we consider some of the main differences in designing for VR.

4.3.1 Games and Play

Fun, enjoyment, pleasure, joy, relaxation, and escapism are some of the positive feelings that we would wish a player to experience playing a game. Schell "states that fun is pleasure with surprises" (Schell 2008), which is strongly related to Koster's idea that fun "is the feedback the brain gives us when we are absorbing patterns for learning purposes" (Koster 2004). A game is designed to attain these goals and typically comprises six 'c's: conflict, choice, change, chance, connections, and control. By definition, a game is interactive and should have some form of *conflict* – challenges to overcome – with meaningful *choices* that *change* the perceptible game world's state. A game should also have a degree of uncertainty that reflects *chance* or serendipity in the real world (Costikyan 2013). Games are more social than casual observers tend to understand, and social *connections* are crucial in modern game design to maintain traction with players. Games are interactive, and so the design of a player's *control* within the game world is crucial to their enjoyment and immersion. The player is responsible for success or failure through the choices and actions that they take to affect the environment. The following definitions of a game provide good coverage of a range of key ideas for game design: "*A game is a problem-solving activity, approached with a playful attitude*" (Schell 2008), and noting win-lose states a game may be thought of as "*a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome*" (Salen and Zimmerman 2003), and as a game is typically unproductive then the "*playing of a game is the voluntary attempt to overcome unnecessary obstacles*" (Suits 1990). These definitions collectively hold several of the essential ideas that provide a foundation for effective game design. A player learns the rules of the game through integrated gameplay teaching in games and autonomous player learning. In this way, through practice and discovery, a player increases skill towards mastery. Frequent just-in-time feedback is crucial, as well as summative guidance on outcomes. Lack of real-world consequence is a common component of many game definitions. However, a serious game blurs the boundary of this design principle, which has a specific objective to improve some aspect of a person's real-world knowledge or skill. For example, physical games offer exercise tasks that can have real-world benefits.

Play typically differs from gameplay in that it generally has subjective outcomes and no fixed rules; consider how young children play. The design of playful interactive experiences (i.e. no rule-based challenge) must not be overlooked for rehabilitation systems as it provides freedom for people to express themselves at their own pace. In some cases, this approach may be more suitable than a game. For example, a creative process involving free painting or exploring an environment offers a person more autonomy. Autonomy is one of the core factors that can enhance someone's intrinsic motivation to play. However, it must be noted that a disabled person may require or desire less autonomy, e.g. due to reduced concentration or cognitive ability, but might require a much more directed approach.

Man, Play and Games (Caillois 2001) groups games into four categories: *Agôn*, *Alea*, *Ilinx* and *Mimicry*. Where Agôn represents games that are based around competition, such as chess or racing games, and players try to gain an advantage over each other. Alea oriented gameplay emphasises chance more than competition. On the other hand, Ilinx comprises games based on the pursuit of 'giddiness' such as spinning on a merry-go-round or jumping. Mimicry type gameplay encompasses role-playing games, in which the players immerse themselves in an invented world. Within each category, games are ordered by placing them on a scale between *paidia* and *Ludus*. With Ludus the quality of the play experience is governed by rules, while with paidia games are characterised by inventiveness and play (Bateman and Boon 2006). We consider these variations of play preferences when we discuss personality later.

4.3.2 Game Design Principles and Patterns

Schell sets out the importance of listening in game design; listening to team, audience, game, financial stakeholders, and yourself (Schell 2008). Later we discuss the importance of this attitude to person-centred design and related challenges. However, the central matter of game design is to create an aesthetic experience for players that instils some form of emotional response (Schell 2008). The nature of this experience may be different for people with disability within a serious game. We consider this in more detail at the end of this section.

A common model often used in game design thinking is the MDA (Mechanics, Dynamics, Aesthetics) framework (Hunicke et al. 2004) or more recently Schell's similar Elemental Tedrad: Mechanics, Aesthetics, Story, Technology (Schell 2008). The MDA framework is helpful in that it represents the dynamic play process or cyclical structure in which a player resides. Mechanics are central to what defines a game. They are the rules, purpose and scope of gameplay. They intentionally restrict the player to enhance the gameplay experience and set out progressively more complex challenges to overcome. Games are inherently learning and teaching machines;

where one purpose of a game is to help a player learn how to play and increase their ability within the game.

Dynamics define the nature of player interaction within a game, which give rise to a change of game state both in terms of the underlying data and the game's interface to the player. Aesthetics has a clear relationship to player experience and emotional or intellectual response to sensory feedback from games (graphics, audio, and haptics). Schell adds Technology to his version of the framework, as modern game design is highly influenced (perhaps always has been) by the platform on which is it played: what kind of display is used? What sort of control is required?

Games can have a linear or non-linear progression design. Story and quest-based games tend to be more non-linear, whereas action-adventure games tend to be more linear. Progression is often structured using convexity design where the options are limited at the beginning of a game (or level). As the player learns the necessary skills and becomes increasingly comfortable with the game mechanics, then more possibilities are offered. Player choice increases toward the midpoint of a game level/game and then decrease towards the climax of the game/level. In this way, the player's learning and progression are managed, and each level has a difficulty/intensity curve that resembles the dramatic structure of a movie or play – this is especially true in story-rich games. Choices should have meaning or consequences and not be completely random. The pace of gameplay should also be controlled to offer the player time-limited slices of controlled intensity, followed by periods of rest, reflection, preparation and planning. Learning to play effectively is essential to success in any game.

"Gameplay is a crucial element in any skill-and-action game ... [and] everyone agrees that good gameplay is essential to the success of a game and that gameplay has something to do with the quality of the player's interaction with the game. ... I suggest that this elusive trait is derived from the combination of pace and cognitive effort required by the game" (Crawford 1984). This definition, by one of the forefathers of modern digital game design, helps expose core issues in designing for people with disability; that of how to manage gameplay pace and cognitive difficulty. For example, a stroke survivor may have cognitive issues as well as physical impairments that result in reduced *physical strength, speed of movement,* or *reflexes*. Several of the common design factors that we have encountered in our research as requiring modification due to disability include *game session length, interaction timing, accuracy, repetition, challenge, problem solving and cognitive ability, autonomy, reward, cheating, identity, user personality and preference, control design,* and other *VR specific issues*. Serious game design also often needs to take external factors into consideration such as: *cost-effectiveness*, *transferability to meaningful activities of daily life*, *alignment with existing clinical structures and rehabilitation outcomes*. Provision for a range of *psychological profiles*, *play preferences*, *capabilities*, and a *balance between recovery and entertainment benefits*. As disability can vary considerably between people, it's important to be able to profile users in terms of a range of factors including movement capability, movement articulation, strength, cognitive ability, play preference and others. Profiles can be used to tailor interactions and games to individuals. As ability can change over time, ideally with a trend upwards, then it is also preferable to have dynamic difficulty adjustment and other progressive modifications to the interactive experience based on improved behaviour and task achievement.

4.3.3 Learning and Engagement

Learning is central to progression is a game and is also crucial to patients performing tasks appropriately and improving. Learning outcomes. The inherent rule-bound structure of a computer game has a goal of immersing a player within a temporary world, in increasing skills and knowledge serves to help overcome challenges and achieve specific goals. This is essentially a learning process (Gee 2003, 2005; Koster 2004; Oblinger 2008; Prensky 2001), and so it seems conceivable that techniques from game design might be used to improve engagement in non-game contexts, such as physiotherapy or occupational therapy. Games are intended to provide an experience that intrinsically motivates players to progress in the absence of extrinsic rewards (Malone et al. 1987). This can mean that players spend hours mastering a game that is often difficult, complex and long (Gee 2003; Oblinger et al. 2005; Prensky 2006). The motivational qualities of games have led some to argue that games have the potential to motivate, engage and ultimately enhance the way in which people learn (Shaffer 2005; Squire and Jenkins 2004).

There are many engagement characteristics in common between game playing and learning for a real-world purpose. These may be condensed into several common factors: *fun*, *structure*, *challenge*, *feedback*, *relationships*, *identity* (McGinnis et al. 2008), *narrative* and *uncertainty*. *Fun*: Engagement is more natural if the experience is enjoyable. Fun can be 'hard' in that it relates to overcoming increasingly difficult challenges, but it can also be 'soft' and be more about feelings such as joy, pleasure, or surprise. *Relationships*: Engagement is reinforced by the social support and cooperation of others going through the same experience. Social features help enhance relatedness and make status more visible and meaningful. *Identity*: Engagement can be encouraged if everyone has a visible role in the learning environment. Identity can relate to escapism, fantasy, presence, role play (expressiveness), recognition by others. *Challenge*: Engagement can build on the human desire to learn and improve and is arguably central to the pursuit of optimal life experience. Challenge factors include competency, competition, and problem-solving. *Structure*: Engagement is more likely if objectives and constraints are clear and acceptable. Structural factors include choice, control, goals, and rules. *Feedback*: Engagement is reinforced by making achievements explicit and timely. Reward is a part of this, which may have endogenous value or real-world. *Narrative*: The communication of progress as a story, mainly when related to meaningful goals, can be impowering. *Uncertainty*: Engagement may be increased with an appropriate level of risk, having an opportunity for exploration and discovery, or when the extent of success is unknown. The key difference between serious games and entertainment-focused games is the lack of consequence in entertainment games. Both positive and negative feedback is essential; arguably people can learn more from failure than success!

4.3.4 Learning and Engagement Based Game Design Framework

Figure 4.1 illustrates how the four common elements of a game design framework relate to game components, typically resident in the game mechanics, and engagement factors which are

Fig. 4.1 Showing the relationship between common aspects of game design framework (yellow/italics), essential functional game components (white), and experiential characteristics related to engagement, gameplay progression and fun (black)

most evident in the player's aesthetic experience. All processes and elements of design should be user-centred, except for designer creativity. A designer should be afforded some autonomy to innovate within the scope of the project; otherwise, gameplay can be stale and uninteresting. The diagram is purposely in 3D to reinforce the fact that design also depends considerably on the hardware and software upon which it with operate. For example, current mobile VR has battery and performance limits over PC "wired" VR. Input controller can also vary widely between platforms. Structure is the next layer of our design foundation; designing structure for learning, play, and progression. Providing meaningful, understandable structure about how to progress, and frequent feedback on progress is vital to engagement and the learning process. The design focus should be on building a useable user interface (UI), an enjoyable user experience (UX), supportive learning design and providing informative feedback. Understanding game mechanics and learning gameplay are at the core of all games, and player fun is a common objective. Fun is intangible to define, but we may say it depends on learning and experience. It also depends on the interplay between our three disks (Fig. 4.1): the design of gameplay rules (*Mechanics*), game choices and interactions (*Dynamics*), and a player's sensory and emotional experience (*Aesthetics*).

In a game, a player has the autonomy to control the state of their environment (within bounds) and to co-author their own experience (story). Immediate feedback informs the consequences of actions, mediates their choices, and stimulates learning. This experience-driven control loop is central to the definition of gameplay. The designer should also consider that there is a range of learning preferences, including visual, aural, verbal, physical, logical, social, solitary learning. There are also different learning styles; for example, Kolb (1983, p. 26) states that "*learning is the process whereby knowledge is created through the transformation of experience*". He argues that successful learning requires a cycle of concrete experience (*feeling*), abstract conceptualisation (*thinking*), reflective observation (*watching/listening*) and active experimentation (*doing*). Kolb describes the union of feeling and watching as a *diverging* learning style. Accounting for this type of player in a game we might consider them preferring an aesthetic experience. Learners with a preference for *thinking* ∪ *doing* are known as *converging* types, and we might consider this group as being more engaged by game mechanics. *Doing* ∪ *feeling* people are known as *accommodating* types and they may be more attracted to game dynamics (the interactive experience) within a game. *Watching* ∪ *thinking* people are considered as *assimilating* types because they are more cautious than other types. These people may be more suited to less dynamic games, and perhaps are akin to people who enjoy watching other people play.

4.3.5 Flow

Csíkszentmihályi's Flow theory (Csikszentmihalyi 1991) is concerned with how to achieve optimal life experience and enjoyment in all of life's activities. An understanding of the psychology of Flow can help us understand how to design games that support a player to attain mastery. However, it is less clear how well people with disability can aspire to optimal experience within their rehabilitation.

The idea of Flow is intuitively comprehensible since the related phrase "in the flow" is in everyday use. Csíkszentmihályi's underlying idea is that enjoyment may be attained through the deliberate process of becoming increasingly proficient in any task, even if this is a repetitive and potentially dull task at work or in the home. An autotelic person is best at this; since once they chose a goal to achieve, or a skill to master, they commit to it and are focused its attainment. An autotelic person may apply a flow principle naturally to all parts of their life, and not get distracted by tasks that they have not prioritised. Autotelic people have a unique sense of curiosity and purpose that helps provide them with the structure and drive to be successful in much of what they set out to achieve. Learning about how an autotelic person manages their daily life can provide an insight into one way a person can adapt their mindset to enhance their enjoyment of life and general contentment. This knowledge can also inform task design within a system.

Flow is related to learning theories and attitudes to tackling challenges by placing emphasis on task achievement and overcoming challenges. If the challenge is too high, a person may become anxious and discouraged, but if it is well within their capabilities, they may lose interest. Csíkszentmihályi describes the path between these two extremes as the *flow channel*. As a person becomes more competent at a task, then the challenge difficulty should increase. This adjustment to suit a person's skill provides him/her with a 'pleasant degree of frustration'. The game is neither too hard that it becomes exasperating or too easy to become tedious. diSessa (2000) argues that pleasant frustration is an optimal state for learning. Koster (2004) applies similar ideas to game design when he more abstractly refers to the experience and challenges within a game as unfamiliar patterns to be consumed; once the pattern within the game becomes too familiar, then a player may become bored, whereas if the pattern appears too chaotic then the player may also become unengaged. Csíkszentmihályi uses the phrase *psychic entropy* to explain how people see there is "more to do than one can actually accomplish and feeling able to accomplish more than what conditions allow". High psychic entropy is a state of disorder within the conscious mind, which may lead to unhappiness. High entropy equates to high levels of uncertainty in information-theoretic terms. It is, therefore, possible to draw a link between psychic entropy and experiential entropy within a game. According to Koster a significant reason that we enjoy games is that we are reducing disorder in the patterns presented by a game. Learning to overcome increasingly difficult challenges is part of this. A person's *psychic entropy* and their perception of *gameplay entropy* are thus closely linked. A stroke patient's psychic entropy level is potentially quite high due to mental and cognitive issues. Therefore, initial game complexity should probably be lower for a stroke patient than for non-disabled people and increase more gradually.

4.3.6 Virtual Reality Design and Development

The term virtual reality (VR) is generally credited to Jaron Lanier who used it to describe the experience afforded by goggles, gloves and other technologies in 1989. However, Charles Wheatstone's Stereoscope might be the first physical device that bore some resemblance to modern VR.

We may consider VR as a 3D virtual space that a person enters via a VR headset or by another name, a head-mounted display (HMD). A person is immersed in the aesthetic experience of a 3D artificial world (reality-like or fantasy-based), and the HMD and affords them control of a camera to unrestricted 360° world view. As these worlds are dynamic, a person can interact with virtual objects and move around the world using hand-held controllers, image processed hand gestures, or VR treadmills. World physics, lighting and shadows, and weather are simulated, and Artificial intelligence may be used to create dynamic or ambient intelligent behaviour for non-player character (NPC) creatures, people, or objects. A virtual world is additionally defined as persistent and shared with other real people (Bartle 2003). A virtual world also provides a person with a virtual representation of themselves and they can interact within the world in real-time. Feelings of embodiment and agency that a person experiences within a virtual world can be very empowering. Dale's cone of experience (Dale 1963) illustrates how direct, purposeful experiences are the most concrete, and the most likely to have a lasting impact on learning (relating to Kolb's *accommodating* or *converging* learner type).

4.3.7 The VR Experience

VR provides a particularly direct experience for the user compared to other digital media, with only a thin layer between the user senses and the representation of reality via an HMD as an artificial intermediary (Jerald 2015, Chapter 1). Within VR, a person can have a very visceral experience due to *immersion* and heightened *presence*. The more a person is immersed, the more they feel present in the moment within the artificial medium. VR can immerse a person within a virtual context, so they are less aware of the real-world context; they become absorbed within the virtual space via their senses. Immersion is "the objective degree to which a VR system and application projects stimuli onto the sensory receptors of users in a way that is extensive, matching, surrounding, vivid, interactive, and plot informing" (Slater and Wilbur 1997). That is, there is a wide range of user sensory modalities, with good matching correspondence between observed and expected sensory response (e.g. low motion lag), wide field of view, believable aesthetics, logically interactive. Where there is a story, it seems embedded within the virtual environment. Presence is related to immersion, but a person may become immersed without experiencing heightened presence. Presence is about the "psychological state or subjective perception in which even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience" (https://ispr.info/about-presence-2/about-presence). Presence is more readily attained within an immersive VR world than a casual mobile game experience on a small 2D screen due to the varying type of viewports. Similarly, some people are more likely to experience presence than others, depending on their personality, prior experiences, and personal preferences. *Agency* is a pivotal contributor to feelings of presence, where high agency reflects a person's capability to affect change through interactions within the virtual space. The illusion of *self-embodiment* within VR can also heighten a person's experience of presence. If a person has an avatar in VR that matches their actual real-world physical movement, via inverse kinematics, this can have a significant impact on agency and presence. Real-world physical haptic feedback experienced when a person's avatar interacts with a virtual object can further enhance the illusion of 'being there' – see the rubber hand illusion (Botvinick and Cohen 1998).

4.3.8 VR Design Factors

There are some potential issues or risks that often have to be considered in non-VR software that is more pertinent in VR. For example, as the VR representation of the real-world approaches the fidelity of real-life, the more disturbing it can be to a person's perception of what they see. The region of realism that significantly reduces an observer's comfort level is called the uncanny valley. It is often better to design for believability than realism as this reduces the issue of the uncanny valley, and people are generally comfortable to accept an unreal context if the content is consistent and meaningful within the context. Motion sickness can occur if there is too much lag in processing the visual response to user input interactions, e.g. moving their head to alter the viewport into the virtual scene or grasping an object with their virtual hand by moving their actual hand. The correspondence between virtual and real motion/interactions needs to be high due to the human body's reafference process within the nervous system (Jerald 2015). The lag between a user moving their head and observing it should be better than 15 ms (equates to mobile VR), with closer to 7 ms being ideal (current high-end wired VR) (Kjetil Raaen 2015).

"Learned helplessness" can be an issue in using VR with some demographics, who may have a previously adopted the attitude that they are not competent with technology. There is also a risk that if the VR experience is not accessible and successful from the beginning that a person would feel that they are not able to use the technology at all. Induction, orientation and training are crucial for new users; as is the adoption of appropriate user-centred design, and suitable development and testing processes. Proprioception is the sense of one's body moving and its position in space. This sense could be required to induce feelings of self-embodiment within an avatar in virtual space. Modern VR interactive systems with full-body inverse kinematic systems can play a part in higher levels of user agency. Exercise, particularly balance tasks, can help improve proprioception. Proprioception effects may be necessary for recovery using virtual physical therapy systems (Giroux et al. 2018) and so needs to be considered carefully in design. It may be even more critical to virtual mirror therapy since this treatment relies heavily on the illusion that an impaired arm is moving more freely.

Depth perception is important in VR, especially for reach and touch/grasp tasks on upper arm stroke rehabilitation. Depth perception is more naturally experienced within VR than on a 2D display (Sakata et al. 2017), but still more challenging than in the real environment due to the multitude of cues that assist depth assessment within the real world. Various cues are helpful to improve depth perception including object occlusion, perspective projection, relative scaling of objects by depth in a scene, surface texturing, lighting and shadow effects, motion parallax, and colour shading. Perceptual capacity and load are important factors in designing VR for stroke survivors due to attention problems, brightness aversion, lower cognition, and other sensory issues.

4.3.9 VR Health Effects

There are a few health effects that are potentially more prominent in VR than in using 2D displays. The most well-known is VR sickness, which is predominantly due to the motion of VR objects relative to the player view or motion of the camera view into VR. This feeling ill due to poor correspondence between movement in VR and a person’s conscious or subconscious expectation of that movement might be called simulator sickness. Factors that can affect this condition are poor render framerate, input lag, poor VR camera design, display flicker, fatigue, length of a play session, and prior health conditions. An example of poor camera design in VR is the game Lucky’s Tale. In this game, the player observes and controls the actions of the player character (Lucky) from a view that is above and behind Lucky The player view is the camera view into in the VR world, and so when the player character moves the camera follows – thus so does the player view. The player is moving through the world as they would in many modern 3D games, but the view is entirely different in VR because the player inhabits the world and thus experiences a greater sense of agency. In Lucky’s Tale, the problem is less about the motion of player view in following Lucky, though this can be disorienting to some people, instead it is about how the camera comes to a stop gradually when the Lucky halts. The camera motion is decelerated until the camera position comes to rest behind Lucky. So, when Lucky stops suddenly, the player view continues to move (decelerating) until it is closer to Lucky. The purpose of this dampened camera motion is to reduce a state hysteresis problem concerning vacillation of movement directions and between animation states. However, the disassociation between Lucky’s movement and that of the camera can cause motion sickness. The award-winning VR game Moss deals with this issue for a similar type of game by fixing the camera view to the side of the character and using a mainly static camera position within each game zone. A wide field of view can increase the chances of motion sickness due to people being more sensitive to vection in the periphery of their vision. This visual effect appears to be more of an issue when a user moves their camera view through a VR environment. The VR version of the commercial game Skyrim attempts to address this problem by narrowing the player field of view as they move forward (essentially applying a dark vignette at the edges of the view).

Other issues may include eye strain, physical fatigue (due to standing or holding/moving controllers away from the body), or discomfort due to the HMD (weight, warmth, fit). Care must be taken with HMD hygiene, particularly in cleaning and replacing the soft padded inserts at the back of the HMD. As with all entertainment media, the designer must account for game effects that might trigger epilepsy in their design and use appropriate warnings.

4.3.10 VR Development Principles

In addition to the established system and game design principles, there are many VR design-specific aspects to consider. However, in general, the overriding goal is the same, to create an engaging and enjoyable user experience. Additionally, the main serious game objective is to be effective; in the case of upper arm stroke rehabilitation, the ultimate goal is to contribute to improved arm and hand function, so that a person can function better in activities of daily life.

Optimising experience within VR may be achieved in a range of ways. For example, increase immersion to help enhance presence, while using techniques to minimise loss of presence. Minimise the risk of the "uncanny valley", by focusing more on believability and suspension of disbelief than on realism. Prioritise fidelity type: representational, interaction or experiential. In many gameplay scenarios, the quality of interaction is more important to immersion and presence than representation fidelity. Design a range of consistent, associative sensory cues and use appropriate feedback for guidance. Use colour theory for environmental and semiotic design (bearing in mind disability). Use binaural cues for enhanced perception of sound location, and salience (shiny, colourful, audible) or out of place objects to help capture a user's attention. Create intuitive interfaces that are suited to VR, e.g. curved information UI displays and logical input control. Collect data to validate what users have their attention on to improve UI implementation. Increase user performance by simplifying a scene, increase a game's difficulty by adding distractors. Use Flow theory to optimise challenge. Make use of computer-controlled characters to support the player. Encourage reflection after tasks and ensure that users end their experience on a high, so they are more likely to return.

Health-related issues carry more concern in VR due to the immersive nature of the HMD, particularly with the possibility of motion sickness. For stroke users and other people with disability, the HMD needs to be chosen carefully based on its expected use, e.g. watching movie content or playing a 3D interactive game. Choose the HMD with the best display frame rate, latency and controller tracking resolution. It should be light and balanced on the head, easy to put on, be comfortable and cool to wear and be wireless if possible. Users should begin with short sessions then gradually increase exposure over time. Design short, chained experiences, with interactive arm movement sessions adapted to each user, providing adequate rest time between each game or exercise set. Input modes may be varied, e.g. between head gaze selection, button presses and input controller movement. Encourage slow head movements and maintain appropriate latency level and stability through intensive testing and adaptive game framerate management. Minimise forward and rotational accelerations/decelerations and use a fixed camera position in 3D space if possible, e.g. a seated position for the user. Leading indicators can help with motion sickness and camera orientation, i.e. showing the path that must be taken. Minimise visual stimulation close to the eyes and use darker scenes to minimise flicker while avoiding flashing lights. Manage low latency issues by fading the screen when this occurs and manage any loss of controller tracking.

A designer should focus on user experience and believability rather than photorealism in content and level creation. Use real-world similes or metaphors to help users relate virtual achievements to real-world benefit. Make a story clear, relatable and focus on emotional impact. Focus on the purpose for people to be in VR and eliminate redundant content. Use affordances and indicators as cues and guidance for interactions.

4.4 Story and Personal Narratives

A story can be a controversial component of a game design framework. Not all games have stories, and indeed, game stories should not be used excessively in non-interactive ways such as with cut-scenes. We have a focus on future narratives that can be powerful and empowering, encouraging a person to imagine possible future scenarios (beyond the short term) while consciously minimising negative thoughts about the past and present. People can be encouraged to construct a mental image of a reinvented future-self in new roles or participating in their most enjoyable experiences in new ways. In its purest form, this is about setting goals and visualising achieving them.

When someone survives a stroke, they often undergo significant physical and psychological change. A catastrophe has rocked the known world and forced personal transformation. In a sense, the stroke survivor receives a call to adventure; to take on the new challenge that is rehabilitation. They are asked to take a leap of faith into the unknown, for their own sake as well as family and friends. Rehabilitation is a voluntary journey, and the choice may be psychologically tough due to unknown challenges and uncertain outcomes. They may be fearful, depressed, or have the instinct to admit defeat. However, to acquiesce to their current plight is not an option and so they begin their quest to improve their condition. However, as support wanes and their progress continues to be difficult, many can become despondent and unenthusiastic to persevere. This sequence has a parallel to the classic Hero's Journey narrative, which can be used to influence system design.

4.4.1 The Hero

We may utilise the metaphor of a stroke survivor as a Hero who is called to undertake a journey of recovery through rehabilitation. There are limits to this metaphor, but the imagery may be useful in guiding design. Campbell (Luomala and Campbell 1950) contends that the structure of the familiar Monomyth tale strongly relates to the human experience over the millennia. Moreover, there is an evident relationship to narrative-based game design. A narrative design structure created on the principle of the Monomyth may help develop a resonance for the user between therapy-inspired virtual tasks and their real-world objectives.

Our hero is the central person in the narrative; however, each stroke survivor has an individual personality, needs, capabilities and desires, and so they will each develop their own unique personal story arc. One way to consider story generation is that it is created based on the actions that users take, an action's outcome and its implications. Each person has a unique experience that may be relayed to their friends and family, but it can also be recorded by the system and replayed to them. In-game design, this is called a player story. The system can also include a designer created story, with a story development that has a familiar narrative structure using a traditional drama curve, and has a convexity design for game progression as discussed earlier.

Let us consider *Free Will vs Determinism*. In designing games, particularly serious games, we need to understand the conflict about who is the author/director of the action and storyline. There may be a mismatch between designer intention and player choice. In rehabilitation games, a designer's challenge is to accommodate tailored rehabilitation alongside a user's freedom to choose activities. Games are inherently interactive, and so a player takes actions and makes choices to affect outcomes. Therefore, authorship of the experience is more complicated than for other forms of interactive media. For serious game stories, there is a clear need for the designer to craft an interactive story with a positive narrative to encourage progress, but this needs to be blended with individual stories that are created through player interaction and choices. The narrative should thus be developed using an intelligent interactive story system. As with action-based game design, a balance needs to be struck between a player's assurance and comfort of known play patterns against the excitement of new opportunities. For disabled peopåle, it is less risky to be more deterministic in design but to offer limited opportunities for free choice. An illusion of freedom is quite common in game design and interactive storytelling. For example, by using the convexity design pattern, players have choices in the middle of a game or level, but they always end up at the same exit point or story climax (though this may be tailored based on choices made). Exaggerated performance is also a helpful design pattern for disabled users with its positive psychological approach to engagement, it can increase subsequent performance, and it relates well to the Hero metaphor.

4.4.2 The Hero's Journey

Our hero (the stroke survivor), like many protagonists in stories, is an unexpected participant in the development of a dynamic narrative; choices made affect the outcome of their story. They have an altered perception of reality as they now must contend with multiple new realities. The old world that they have known from birth has changed, which we may think of as the hero's village, and a new unexplored world beckons across the boundary limits of the village. As a hero leaves their village (their prior reality), they experience a degree of trepidation. There may also be a fear of failure. Thus, the notion of a hero leaving their village to seek adventure is a simile for a stroke survivor's physical and mental adjustment to their disability, their rehabilitation, and altered means of interaction with the real world. The structure of a hero's journey and its narrative can be used to express the story of a person's journey towards their objectives. Below, we consider the phases of a traditional hero's journey.

The Departure: In a traditional hero's journey, the protagonist's perception of the world and their place in it is disturbed by a dramatic event. Their faith is tested, and status compromised. They are challenged to go on a quest to remedy the situation, for their sake as well as others. The hero is usually reluctant and initially refuses the call but eventually is persuaded that this is the only course of action. The awakening to a new state of being may be thought to be like a person waking after a stroke, faced with a changed world state, and difficult mental and physical challenges ahead of them. The hero decides to leave the comfort of their "village", fearful of failure, but taking one uncertain step at a time to cross the "first threshold". Breaking through this barrier is internally transformative. At this point, our hero typically meets a supernatural aid, perhaps a godlike spiritual character, who appears at just the right time to provide advice, equipment, nourishment, and to mentor them on their journey. We can think of this entity as the VR system (with clinical support as part of this). This guide appears at just the right time and provides the means to move forward with the quest.

The Challenge: As our hero progresses, they have trials (exercises) as they encounter enemies (effects of a stroke), but they also meet allies (friends, carers, other stroke survivors) who join the hero's party and onward quest. Ultimately, the hero approaches the "inmost cave" which locates the core objective of their quest and their most significant challenge; and it may seem insurmountable. This is also a metaphor for a person's inward demons and internal emotional and mental struggle and is the main ordeal and crisis point for the hero. Overcoming this challenge provides the "ultimate boon" and a magnificent reward for saving the world! The stroke survivor has met their goal(s) and can now return to a better life.

The Return: The hero may at first refuse to return to their previous life and may need "rescue from without" from their guide. The key for returning to the "real world" requires a crossing of the "return threshold" transformed but retaining the knowledge and skill attained on their quest. The stroke survivor should return from VR to the real world with knowledge and skills to be happy and successful in performing activities of everyday life. They progress with their rehabilitation and continue to improve, and so become "master of two worlds" which is like a "resurrection" or rebirth. The boon or elixir gained on the quest empowers the hero with the "freedom to live" a less fearful life. It is the reintegration into society and work.

4.5 Psychology and Game Design

Psychological theories have a large part to play in game design, gamification and serious game design. Continuing from the previous section and considering how to reward a player adequately; cognitive evaluation theory and reinforcement schedules are particularly relevant to game design.

4.5.1 Personality

Personality type can influence the types of games we like to play and the playing style that we adopt. Personality comprises characteristic patterns of thoughts, feelings, and behaviours that make a person unique. The research of prominent psychologists (Allport 1937; Briggs 1976; Cattell and Drevdahl 1955; Eysenck and Eysenck 1965; Jung 1923) has proved influential in understanding personality and its relationship with player types. Jung's work is considered one of the foundations for theories of player types. Jung proposed four functions through which we experience the world: sensing, intuition, feeling and thinking (Jung 1923). These functions are paired into opposites and then applied an attitude to describe the underlying direction of person's interests and energy flow, either inward to subjective (introversion) or outward to the environment (extraversion). Myers-Briggs extended Jung's work into a more practical methodology producing a 16-element model, known as the Myers-Briggs Type Indicator (MBTI) (Briggs 1976). The MBTI applies an extra dimension, Judging-Perceiving, and uses this additional dimension as a type indicator and as a means of determining functional dominance directed via introversion or extraversion. More recently (Keirsey and Bates 1984) built upon the MBTI model and identified four basic patterns or temperaments, Artisan, Guardian, Rational, and Idealist, divided along two axes based on Communication and Action. Keirsey asserts that people communicate concretely or abstractly, with those communicating in a concrete fashion focusing more on reality, compared to those who communicate abstractly and tend to focus on ideas and theories and the possibilities that exist in the world. Research suggests that there is a connection between personality types and player motivation (Bartle 1996; Caillois 2001; Lazzaro 2004), and several player typologies and have been proposed that combine various aspects of the most well-known theories (Ferro et al. 2013; Stewart 2011). Stewart proposes links Bartle's player personality types to Keirsey's temperaments as well as identifying the Myers-Briggs types that would be associated with the correlated pairings. For example, Bartle's Killer and Keirsey's Achiever types are linked by their acting and sensing behaviours, implying that players who act within a game world do so based on senses within their environment.

4.5.2 Motivation and Persuasion

As the reader may have gathered by our initial discussion, player motivation is one prerequisite to understanding how to design a fun experience. This understanding is even more pertinent in a serious game, such as in the VR games that we build for stroke rehabilitation. While designing systems for extrinsic motivation can provide immediate and accessible fun, designing with intrinsic motivation in mind is more important. Extrinsic motivational systems encourage people to initiate play sessions and scaffold basic learning processes. Whereas intrinsic motivational schemes help guide more sophisticated skill development and increased levels of enjoyment. Four common factors tied to enhanced self-determinism and intrinsic motivation are (Deci and Ryan 2010), *Relatedness* (social factors): Relationships and building friendships can become motivating. Group dynamics can stimulate interest in learning and improve retention with an activity, such as physical rehabilitation. *Autonomy* (freedom and choice): As well as feeling part of a team or group, people may also be highly motivated by the freedom to express themselves and to make their own choices. Striking a balance between structural guidance for a player and offering a degree of freedom for each to explore and develop in their own way is a fundamental skill of a designer. This understanding is especially useful in serious game design due to the importance of developing a patient's capability for performing activities in the real world. *Mastery* (learning/attainment): The quest for mastery of an activity, skill or understanding is central to much of human enjoyment. Enjoyment is central to Csíkszentmihályi's Flow theory (Csikszentmihalyi 1991), which has been applied to game design numerous times. *Purpose* (meaning and knowing why): Having an understanding of why something has to be done, why no one else can do it, and what it will achieve is crucial. When a person's goals align with broader objectives, they can become highly motivated. A lack of understanding about the purpose of their task is demotivating. Games are commercial digital games are particularly good at explaining the purpose of an activity. With regards to physical therapy such as in stroke rehabilitation, linkage of the specifics of VR/game tasks to functional improvement is especially important in developing intrinsic motivation.

Perhaps the less positive side of psychology is the use of influence, coercion and persuasion in marketing or selling products and other situations that involve changing someone from one mindset to another. Cialdini summarises six facets of persuasion: *Reciprocity*: If someone gives you some of their time, a loan of equipment, or a present, then you are more likely to reciprocate. *Commitment and consistency*: Once a person has committed to do something, they are more likely to remain committed due to an inbuilt desire for consistency. *Social Proof*: We are more likely to do something if we see others doing it. *Liking*: We are more likely to be influenced by people that we like. In this way, peer support may improve engagement (and use of positive feedback). *Authority*: Similarly, we often feel obliged to respond to authority figures or people in uniform. Clinical staff can have a significant impact on adherence to a programme. Connected health audio/visual connections can help improve someone's feeling of isolation and provide access to support. *Scarcity*: Items and activities are often more attractive when they seem to have restricted access. Scarcity can be manufactured to make an activity seem more popular than it otherwise would be, e.g. an online multi-user social club with limited occupancy.

It is our experience that influencing techniques are not used very often to enhance engagement with serious games. However, they offer some attractive possibilities, particularly as a novel gamification approach to improve retention. In the next section, we discuss behaviour change, which has a relationship with persuasion and coercion.

4.5.3 Gamification and Reward Structures

Digital games have always rewarded players for attainment and overcoming challenges. A modern game now typically offers a wider variety of play experiences and challenges within the same game, and different forms of rewards to suit diverse play preferences. We may also think of a modern game as having a layer of gamification on top of the main game design. Gamification is a new label for the use of game design principles or patterns to enhance human engagement with a process. It is typically applied to a non-game process such as learning, exercise, or rehabilitation, but can also be recursively applied to games. Gamification, in its most basic form, comprises a reward system based on points (P), badges (B), and leader boards (L). These are often centred on extrinsic motivation, but just as with Microsoft's Xbox gamer points and achievements system, the attainment of these can be fun, particularly from a social perspective in sharing attainments with friends. PBL can mark progress so that it is visible outside the game through player profiles and leader boards. The gamification system can help a player identify aspects of gameplay challenge that can enhance or prove their skill, and so be more intrinsically motivating. This technique can be used to motivate a person to become more expert, providing features and feedback that are most engaging to the user. When well designed, gamification can enhance retention levels and improve progression. For it to be successful in health technologies, gamification design should be tightly coupled with clinical processes and personal goals. It is evident that while effective gamification design owes much to game design, it also strongly relates to core ideas within psychology. Bartle makes a pertinent point concerning gamification, that good game designers reward players for doing what they already enjoy and want to achieve (http://mud.co.uk/richard/Shoreditch.pdf). This objective should be the same in serious game design. This later consideration relates to what Schell (2008) calls the endogenous value of a game reward. That is, the designer should focus on understanding and implementing a reward system based on what is valuable to a player within the context of the game.

A designer should consider how reward can be made more valuable to the player. The following are some of the variations of reward structures. *Tangible/intangible*: trophies or status symbols can be fun but more tangible rewards such as player upgrades (health, wealth, items, item power) can have more endogenous value. Tangible rewards can help a player achieve their objectives more effectively/efficiently, and so their receipt may be more intrinsically motivating. *Expected/unexpected*: while surprise rewards are very engaging, it is also essential to include structured expected rewards that provide clear objectives to which a player can progress. Unexpected rewards can add variation to the gameplay and increases player anticipation. *Contingency*: Where task non-contingence is a reward not connected to any player attainment, but more of a surprise reward. For example, a random reward box appearing in front of the player. *Engagement contingent* is a reward to maintain game traction and player retention. For example, spin a reward wheel once a day, or exponentially increasing game cash rewards based on consecutive days/weeks of play. *Completion contingent,* for example, rewards for completing levels, quests or defeating enemies are essential. *Performance contingent* is the quality or quantity of rewards related to the performance of a task. For example, finishing a level and collecting all items would reward additional game cash, achievements, and other unique items of endogenous value.

Reward schedules should also be considered and include different combinations of schedules to enhanced gameplay variety. *Fixed interval*: Providing reward or reinforcement at fixed time intervals, e.g. 1, 2, 3, 4, or 5 min. This schedule might be appropriate for infinite scrolling type games – in which the main objective is to continue playing for as long (or travel as far) as possible. It is also appropriate for physical tasks. *Variable interval* (non-patterned can be more motivating): This could be task non-contingent or based on a random or unpredictable fixed temporal pattern. *Fixed ratio*: Reward is delivered after an expected set of task completions. Like fixed interval, this forms the basis for much of the rules embedded in the game mechanics. *Variable ratio*: Reward is delivered after an unpredictable number of actions or task completions. This schedule is best used in combination with others to avoid player frustration, but when used can help engage due to heightened expectancy. *Exaggerated feedback*: It has been shown that if a 10% higher reward is provided than deserved, a person can improve their performance by that amount on the next attempt (Wulf et al. 2012).

4.6 Behaviour Change

Behaviour change is also a key consideration in the design of rehabilitation systems. The ABC of Behaviour Change Theories book (Michie et al. 2014b) outlines 83 fundamental theories, which influenced the design of the behaviour change wheel (BCW) (Michie et al. 2014a). The approach with the BCW may be summarised as: (1) Define the behavioural problem, to target/specify the target behaviour, then identify what needs to change; (2) Identify interventions options; (3) Identify appropriate behavioural change techniques (BCTs) and delivery strategy.

Central to the BCW approach is the COM-B model: that a person's capability, motivation, and opportunity may potentially present barriers to behaviour change. Thus, the design focus for an effective solution should minimise the impact of these factors as they might have a negative impact on system traction and user retention. Action triggers are also important (Fogg 2009), especially to help inspire the use of new technology. A sudden crisis or improved understanding can trigger someone into action that can lead to changed behaviour. Chapter 3 of (Michie et al. 2011) provides and comprehensive list of 93 potential BCTs and groups them by taxonomy, theoretical domain framework (TDF), and intervention techniques. BCTs are incorporated into our

Rehabilitation Game Model (below) for guiding serious game design.

4.7 Gamification Typologies

Several authors have addressed the problem that as people have different personalities, so they may be motivated by different gamification schemes. Bartle's (1996) taxonomy of player types was one of the first developed and has been particularly influential. (Marczewski 2013) influenced by Bartle and other psychological/motivational models, has produced a practical typology for classifying players by gamification type:

1. *Disruptor*: motivated by *change*, they enjoy exploiting flaws in-game mechanics or modding software or hardware.
2. *Free Spirit*: motivated by *autonomy,* they enjoy exploring, being creative, and not being bound by rules.
3. *Achiever*: motivated by *mastery,* they focus on self-improvement and enjoy being challenged in order to better themselves.
4. *Player*: motivated by *rewards,* they do what is necessary to win or be better than others.
5. *Socializer*: motivated by *relatedness,* they enjoy social connections with others.
6. *Philanthropist*: motivated by a *purpose,* they prefer to understand the reason for their undertaking challenges and are also more altruistic (Fig. 4.2).

We have explored the application of this gamification approach within education (Herbert et al. 2014) and stroke rehabilitation (Boureaud et al. 2016). As part of our investigation, we performed an exploratory analysis of several well-known commercial and rehabilitation games to consider how well they are designed for this variation in motivation preference. Five popular commercial games from core genres were evaluated along with three relevant rehabilitation games by our research team (D. Holmes 2014). Commercial games typically exhibited more variety in accounting for player type, though as expected all games demonstrated the importance of the achiever player type (Fig. 4.3 left). Evaluated rehabilitation games contained well-designed and entertaining gameplay. However, they appeared to have a narrower design focus on achievement orientated rewards than commercially designed games (Fig. 4.3 right). This may be expected due to the strong linkage between goal-orientated structures in rehabilitation programs, and generally less experienced design teams. However, arguably, variation inmotivation and play prefer-

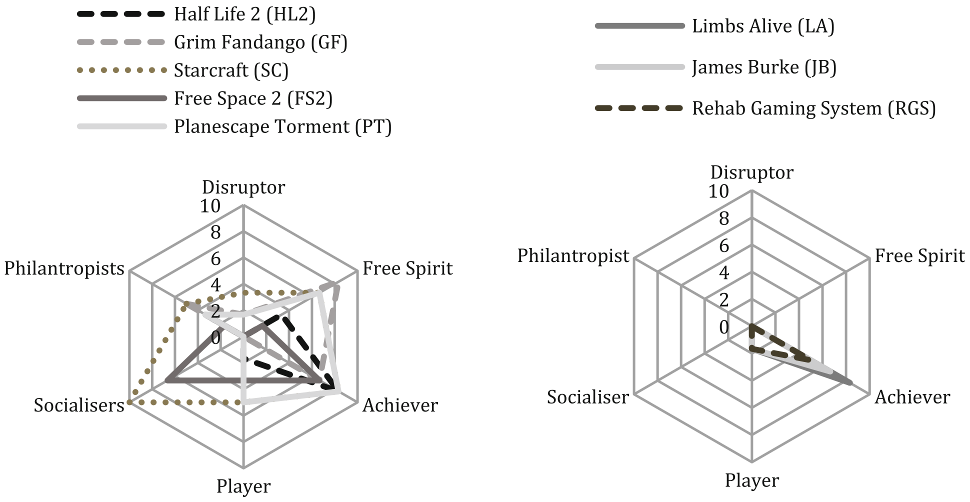

Fig. 4.2 Gamification type evaluation of commercial (left) and rehabilitation games (right)

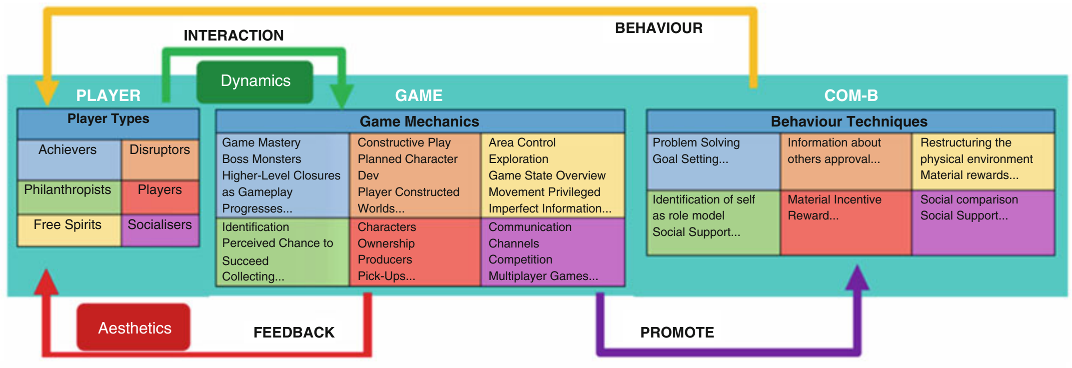

Fig. 4.3 The rehabilitation game model

ence should be accounted for to be more inclusive of different players.

The rehabilitation Gaming Model (RGM) is a tool (see Fig. 4.3) which we developed a tool for the design and evaluation of games or gamified solutions for rehabilitation. Our first practical implementation (Holmes 2014) contains three core aspects: a gamification typology (Marczewski 2013), a game design pattern ontology y (Marczewski 2013), a game design pattern ontology) (Bjork and Holopainen 2004), and a behaviour change framework) (Bjork and Holopainen 2004). The gamification typology built into the first version of the RGM is Marczewski's Hexad model of motivation for different personality types. Bjork's game design pattern ontology was incorporated due to its comprehensive ontology of 295 game design patterns. The RGM also utilises a Behaviour Change Wheel framework, created from 19 other established behaviour change frameworks, utilising 93 behavioural change techniques (Appendix B).

The RGM can be used to identify gamification elements and game design patterns that map to BCTs, and vice versa. It also helps the designer to account for different personalities, play preferences and gamification types. Table 4.1 shows the mapping for an Achiever personality (other types in Appendix A, BCT groups in Appendix B). BCTs that may be embedded into a gamification scheme for an Achiever type are quite comprehensive; not surprising bearing in mind achievement is a challengeand task-oriented and games may be thought of and teaching and learning machines (Gee 2005; Koster 2004). Also, bear in mind that we are identifying BCTs that help positively modify a person behaviour to physical rehabilitation and use of technology that supports this. There needs to be a real-world message of progress associated with virtual success. This mapping is critical.

Let's consider an example – a clone of Angry Birds in which the player must activate a catapult with their hands to launch a missile at a stacked set of blocks to topple and destroy them. A camera tracks their real hands, and they see a virtual copy of their hands moving within VR. Reaching and touching a launch button beside the catapult results in a missile being fired, and also enables them to get some beneficial exercise. A serious game may be designed to provide progressive difficulty with in-game challenges. So, for example, in this case, the missile may become smaller, and the stacked blocks placed further away (and later with obstacles obstructed the player missile), and the missile type can change to reflect the increase in cognitive and tactile skill. As a player progresses, their arm strength and stamina may improve, and they also may be able to perform increasingly tricky hand gestures. Table 4.1 provides may ways to engage the player, but they require specific information to help them relate their achievements to the real world and motivate them to return to the system. Leader boards, message boards, and chat areas allow players to connect social, which for many is enough motivation, but having the progress on display offers them

Table 4.1 Achiever gamification type. Mapping relevant BCTs to gamification element

Gamification element	Game design patterns	BCT opportunities (Appendix B) that can alter rehab behaviour through the VR system and games.
Challenges	Alignment, deadly traps, enemies, evade, guard, limited resources, Manoeuvring, obstacles, puzzle solving, race, time limits.	1.1, 1.3–1.9, 2.2–2.7, 3.1–3.3, 4.4, 6.2–6.3, 7.1–7.4, 8.1, 8.3, 8.7, 9.1, 9.3, 10.1–10.11, 12.2, 12.6, 13.1–13.4, 14.1–14.10, 15.1–15.4.
Certificates	Competence areas, game mastery, producers.	1.3, 1.5, 1.7, 6.2, 6.3, 7.2, 10.8, 10.10, 13.1, 13.2, 14.1–14.10, 15.3, 16.1, 16.2.
Quests	Collection, committed goals, continuous goals, ephemeral goals, goal points, hierarchy of goals, king of the Hill, mutual goals, near miss indicators, optional goals, predefined goals, selectable sets of goals, supporting. Goals, unknown goals.	1.1–1.9, 2.2–2.7, 3.1–3.3, 4.4, 6.2–6.3, 7.1–7.4, 8.1, 8.3, 8.7, 9.1, 9.3, 10.1–10.11, 13.1–13.4, 14.1–14.10, 15.1–15.4.
Learning/new skills	Character development, experimenting, gain competence, gain information, handicaps, memorizing, new abilities, perceived chance to succeed, power-ups, privileged abilities, reconnaissance, role reversal, skills, symmetry.	1.1–1.9, 2.2–2.7, 7.1–7.4, 8.1, 8.3, 8.6, 8.7, 10.1–10.11, 12.1, 12.2, 12.5, 12.6, 13.5, 14.1–14.10, 15.3.
Boss battles	Boss monsters, bragging rights, higher-level closures as gameplay progresses.	1.7, 2.7, 3.2, 6.2, 8.1, 8.7, 10.5, 10.6, 10.7, 13.2, 13.4, 13.5, 14.1–14.10, 15.1–15.4, 16.2, 16.3.
Levels/ progression	Diminishing returns, improved abilities, levels, obstacles, resources, score, skills, smooth learning curves.	1.1–1.9, 2.2–2.7, 7.1–7.4, 8.1, 8.3, 8.6, 8.7, 10.1–10.11, 12.1, 12.2, 12.5, 12.6, 13.5, 14.1–14.10.

the opportunity to feel proud and for others to praise them. Any interaction with the system and the rehab games should be considered a success and positive messages (and rewards/awards) be given based on the player's consistency, effort and progress. It should be clear to participants that there is a link between their progress in the game and their potential improved capability in activities of daily living. Tasks and difficulty curves should be adapted to each person, and reward systems (gamification) may also be adapted to their preference. Even within the Achiever gamification type, there is variation between people, for example, some people may be obsessive about collections while others may prefer to beat other players (akin to Bartle's Killer type).

Appendix A shows 5 other gamification types, with player and socialiser type being the most common player types. In an unreported recent experiment with 68 healthy users (predominantly 18–20-year-old, mixed-sex students) of a virtual learning world we found that there were few pure gamification types, but rather we identified 19 typical gamification profiles that were combinations of the core gamification archetypes.

4.7.1 Design and Development Processes

The creation of serious VR game for stroke rehabilitation is by its very nature a collaborative affair. It is to be expected that the design process should be user-centred, ideally with the target group playing an integral part in the design and development. Co-design practice should be used with contributions from practising clinicians, stroke survivors, carers, designers, developers, academics, and other stakeholders. One of the primary challenges in creating an effective and high quality product is in the project management for such a diverse group, and communication issues due to variation in digital and traditional literacy, differences in terminology between disciplines, experienced in the use of technology or playing games, or lack of understanding of clinical processes by technical staff. Our participatory framework is shown in Fig. 4.4, and mapping of the behavioural wheel components COM-B (Michie et al. 2011) to PACT is shown in Table 4.2. An implementation of PACT is illustrated in (Charles and McDonough 2015), which

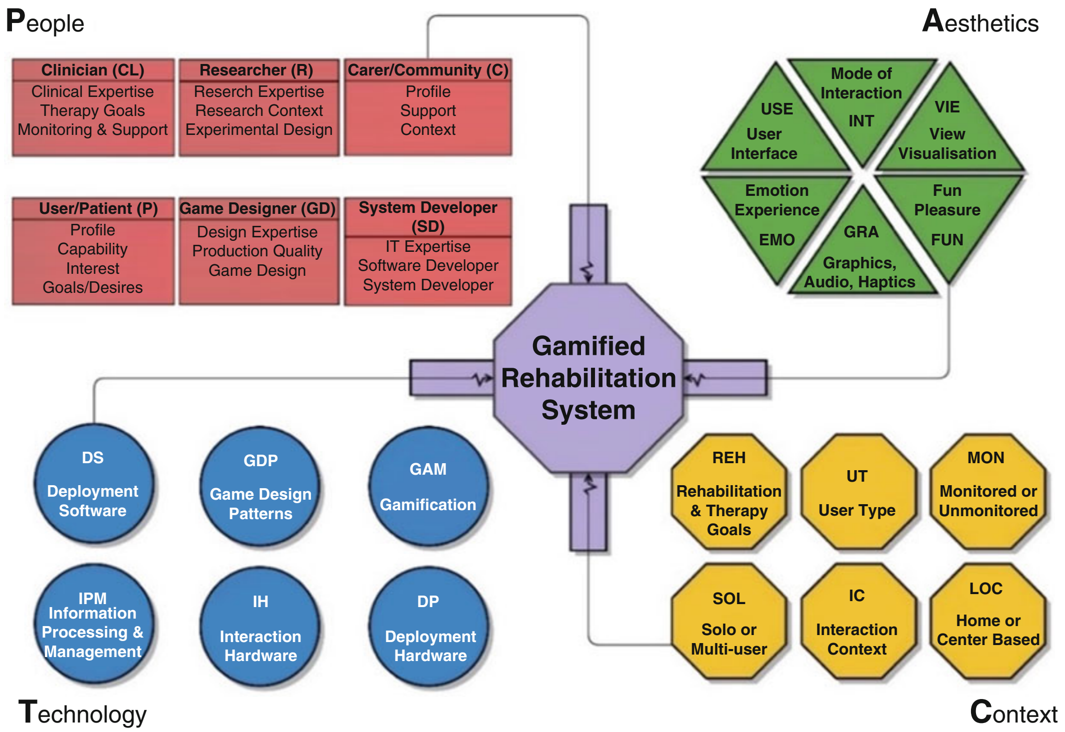

Fig. 4.4 Four PACT components for a participatory design framework (Charles and McDonough 2015)

Table 4.2 PACT-B COM-B mappings to PACT

PACT attribute	Capability	Opportunity	Motivation
People	*	*	*
Aesthetics			*
Context		*	
Technology	*	*	*

demonstrates how to integrate the essential PACT elements into a design and development process. We discuss this later in an extension to PACT to encouraging behaviour change (PACT-B) with respect to regularly engaging with rehabilitation exercise.

Communication and understanding can be improved through a willingness of all parties to invest time in understanding terminology and practices in other disciplines and through the use of non-technical language if possible. Regular meetings are essential for this. Both the design and development processes can be lean, iterative and evolutionary using the well-established Agile software development methodology. In essence, this can be achieved through a series of design and testing workshops with representatives of all stakeholders being presented at these workshops. It is vital to give experienced VR game designers and developers time and space to be creative with the scope of the project. Though, it is equally important that their design ideas are tested on paper and through iterative early prototyping. It has been shown that if a game is tested at the Vertical Slice that is more likely to succeed, where the Vertical Slice (McAllister and White 2015) is the point where the core features of a game can be thoroughly tested (i.e. early in the development phase). Practical project management tools should be adopted, and the team trained in its use, e.g. Asana, and modes of communication established along with appropriate document and software storage strategies (e.g. Office 365 Skype, OneDrive, Outlook, Calendar). Project management can be more challenging in an inter-disciplinary team due to project tasks, clinical and technical, not always having well-aligned priorities.

4.7.2 Previous Experiments

Our research group has been investigating games, virtual and assistive technologies to enhance stroke rehabilitation since 2004. Here we summarise several of the experiments undertaken, provide an overview of the changing nature of technologies, and discuss what we have learned about developing software systems and games over this period (Appendix C).

Much of the focus of our research has been on making rehabilitation more accessible and motivating to perform at home, with appropriate quality, regularity, and intensity. We look to create systems that optimise engagement using by using game design patterns, psychological principles, gamification techniques, and accessible inspiring new technologies in our design. We continue to be watchful about the possibility of using commercial off the shelf (COTS) games, and we initially tested a wide range of games and games hardware with the support of health professionals to assess their applicability to stroke rehabilitation (e.g. PS2 EyeToy, Wii games, dance mats). Feedback from testers was that while these games were fun, the exercises did not coincide with the required rehab exercises enough, some games may have been unsuitable for some people (e.g. type and length of exercise, an opportunity for breaks, visual issues). Feedback from this evaluation confirmed Rand's findings (Rand et al. 2004) – although there was a great deal of potential in these off-the-shelf games for stroke rehabilitation, the pacing of the games was too fast for all but the ablest of stroke users. New VR games may provide excellent opportunities for general exercise, but a lot of curating of suitable games and optimising their parameters would be required. So, we have instead concentrated on making bespoke games through co-designing with patients, clinicians and technical experts.

Our first experiments with VR, games and stroke physical therapy was with Ascension's Flock of Birds system. VR HMDs at that time were bulky and imbalanced on the head. They had lower resolution, higher latency tracking and lower render frame rate. The gloves that a user wore for hand and finger tracking were effective for that time period but were challenging for a disabled person to put on, and they had clumsy wires connected from them to the computer. The magnetic tracking system used magnetic so powerful that they could interfere with a pacemaker and other electronic devices.

We made several casual games including a Whack-a-Mole style game and a game involving catch apples/oranges in a basket falling from a tree. In the first game, the person could hold a small physical hammer, and the second they could hold a basket. As they were wearing trackable gloves, there was no issue with occlusion that might occur with camera tracking. This mix of the virtual with the real physical world, moving an actual basket and seeing a virtual basket move, was a potent mix for physiotherapy due to the increase in immersion, presence, and proprioception. Holding an actual object had obvious physiotherapy benefits that would otherwise require force feedback in the glove or another device, though we only developed games for coarse arm movement. The games proved fun, but there was potential for these to be enhanced. One of the issues for developing games in a research project is that there is generally not enough time, expertise and development resources allocated to make a game close to commercial quality.

During the next phase of stroke rehabilitation research, we decided to adopt COTS game hardware and controllers as these were mass-produced for use in the home and so were cheaper due to economies of scale, and generally more useable than a bespoke controller would be. Free and less expensive commercial level game development engines were beginning to emerge towards 2010 and decided to adopt a new 'indie' game development toolset, Microsoft's XNA, that enabled a rapid prototyping and development process. A higher aesthetic gameplay quality also became more affordably achieved. A trial using Nintendo's highly accessible Wiimote was an obvious option at that time, as the Wii game console had massive popularity with over 100 million units sold worldwide. Indeed, several stroke survivors in our current trial have referenced the Wii in feedback to our physio team when discussing our new system. We created several Wiimote controlled XNA games (Appendix C, (Burke et al. 2008)), which were designed in the spirit of the casual games that made the Wii console popular. A wireless connection and ease of use of the controller were a key benefit, as well as that many people were already familiar with this controller. However, potential intermittent loss of controller tracking and the cost of developer licenses were drawbacks of this approach at that time. Thus, webcam tracking of natural hand motion was investigated instead.

Four webcam games were created for upper arm rehabilitation (gross movement), *Rabbit Chase*, *Arrow Attack*, *Bubble Trouble*, and *Double Bubble Trouble* (Burke et al. 2009b). In each game the user reached and touched a target, in some cases they had to use both hands to hit two separate targets, and in Rabbit Chase they had to hit a rabbit before it got back to its rabbit hole. A webcam tracked their hands and distinguished right from left hands through the user wearing different coloured gloves (green and red). Range of movement was calibrated before each game, and difficulty adapted based on performance by increasing game complexity, speeding up the action, or making targets smaller. These games were popular with healthy and impaired users with most participants saying that the games were both useable and playable (fun and easy to play). In a three-week trial, results also suggested that the games could motivate better rehabilitation adherence. This has been one of our key goals in our research. As with any object detection task, occlusion could be an issue, and with RGB colour recognition, lighting conditions could affect detection reliability.

Experiments with webcam games were followed up with an experiment to investigate augmented reality (AR) games (Burke et al. 2010). Also using a webcam for motion tracking, this time the webcam detected patterns on the top of physical blocks (black and white QR codes). This method had the advantage of the previous approach in that users would reach, grasp, and move a physical object. The QR code enables the software to recognise the black position and track it as the user moved it. On-screen, the plain physical block was superimposed by suitable virtual 3D models such as aeroplanes to fit game themes and enhance immersion. Four games were created: *Break-a-Ball*, *Whack Attack*, *Target Trails*, and *Ping Pong*. The design of these was influenced by popular games: Breakout, Whack-a-Mole, Guitar Hero, and Pong, respectively. In each of the games the player held and moved a physical block to control the position of a 3D object or character on the screen. The advantages of this form of AR were that the user would feel the weight and texture of the object, thus potentially enhancing proprioceptive effects of rehabilitation. The weight of the object could also be used for strength conditioning for able participants. This method of hand tracking had similar issues to the previous approach including loss of tracking due to occlusion, the casting of shadows on the QR code, lack of sharpness of the captured images because of motion blur. Loss of tracking could affect scores and so were frustrating for users. Predictive tracking or sensor redundancy might help with this issue. Results were encouraging in the same areas as the previous experiment. Participants also reported a positive change in their ability to grip objects. Profiling and adaptive difficulty proved as important as with previous experiments as users demonstrated improvement over time.

Around 2012/2013, we got access to the Leap Motion sensor/controller beta hardware. We were keen to investigate this sensor as it uses an infrared-based depth camera to accurately detect hands and finger positions for gestural control systems. The Leap is highly responsive (can capture up to 200 frames per second), high spatial precision (0.01 mm), and is much less affected by changing light conditions. We ran an initial trial with eight practising physiotherapists and occupational therapists in which they provided feedback on three simulated common clinical tasks: *Cotton Balls*, *Stacking Blocks*, and the *Nine Hole Peg Test*. In this first trial, the Leap was table-mounted, and a standard screen was used rather than VR. The tasks involved lifting virtual balls from one box to another, stacking square blocks one upon another, and lifting and placing nine virtual pegs into holes. Feedback was very positive from most participants, saying that this approach could be motivating for patients, especially young people and in a home setting. We deliberately virtualised clinical tasks as we felt that clinicians would be more comfortable with this, though ironically, it was suggested that games would be more engaging for patients to maintain their exercise. We learned several important things from observation. Table mounting of the Leap was troublesome as it required a person to begin with their hand above the sensor, for those who did not completely perceive what the sensor did this could be confusing. If their hand was too close to the sensor, it couldn't be tracked, and similarly, hand tracking could be lost for the same reason. This issue may be mitigated through improved guidance, sensor mounting above the table pointing downward, or placed under a thing glass table (untested). Training for this setup is crucial, particularly due to the disconnect in relating their actual hand movement that of their virtual hands on a 2D screen. As the new generation of commercial VR HMDs became available, Leap Motion provided a software update to allow the Leap Motion sensor to be HMD mounted. This provided a generally better way to track hands, i.e. by looking at them, and within VR people experienced more agency and feeling of embodiment.

Our next two experiments over 2015–2016 (Appendix C: 6 and 7) used the Leap Motion in an HMD mounted position. The first experiment also used a Kinect for body position tracking and Myo armband sensor for additional arm tracking (also compared 2D screen vs VR). In the second experiment, we only used the Leap sensor as the HMD was used in place of the Kinect to infer body position, and the Myo sensor proved tricky to put on and calibrate. Our preference was for a technical set up with minimal physical footprint in a person's home. Our results over the two experiments were encouraging, with most users finding the experience enjoyable and the system useable. Performance improved in VR and participants considered the tasks to be easier to perform in VR, with visual and audio cues proving to be beneficial to improving performance. Some users said that VR helped them focus more clearly on tasks. Fatigue was evident for healthy and impaired users. Rest periods were more critical for impaired users than we had thought (from the technical team perspective), as were the importance of carefully designed induction, training, system calibration (to individuals) and guidance (in-game). Tracking of hands was challenging as a contrast between the table and hands could be an issue, and clenched/stiff hands proved hard to track with the built-in Leap Motion software (which is signed for healthy hands) – resulting in less reliable tracking in some cases. As in all experiments with the Leap sensor, hands that move outside the sensor range (left or right) can't be tracked (or similarly if the head points away from the hands). Ideally, a technical strategy needs to be in place to keep displaying the hand until tracking resumes, instructions for the user to move their hands back in front of them, and perhaps predictive motion. A second Leap sensor may also be used on a different axis. Though technical and clinical challenges (e.g. issues for people with visual or cognitive impairment) were identified, the formal and informal outcomes of these experiments encouraged us to continue to evolve the system with new technologies and our software enhancements.

4.7.3 Approach to Design and Development in a Large-Scale Project

Our current trial is the central focus for phase 3 of an EU project called Magic. Our existing VR rehab system was enhanced through phases 1 and 2 and extended with the addition of mirror therapy (Ramachandran and Rodgers-Ramachandran 1996). VR mirror therapy enables patients with very limited or no movement in one arm/hand to be still able to undergo rehabilitation with their other arm. Up to 150 stroke survivors are currently being recruited in Northern Ireland and Italy, and the experiment implemented using a method that supports evolutionary design and development within a user-centred software life cycle model. The overall goal of the project is to develop technology that can improve a stroke survivors' capability to engage in activities of everyday life with the assistance of rehabilitation technology in the home. Outcome measurements include clinical measures of improved performance, usability statistics, and engagement statistics. As the technical group of the consortium, our focus was on creating the most useable, accessible, technically reliable, beneficial, and fun experience. Subjective responses from users in structured interviews (as well as feedback from clinicians) have provided us with significant beneficial information already on the project (ending March 2020). In the following section, we discuss how we applied the lessons that we have learned over the years to the design and development of VR stroke rehabilitation software.

4.8 Implementing PACT-B

In this chapter, we have presented an approach in which behaviour change techniques are mapped to our recent PACT framework (PACT-B) to improve adherence to rehab. Here we summarise how we have used this in practice within our current VR upper limb mirror therapy stroke trial. This trial is part of a funded EU 2020 pre-commercial procurement project called Magic, and as such has a more commercial emphasis, and has proved beneficial in sharpening our focus on creating a system that is fit for purpose.

It is necessary to take a user-centred approach to system design and development; remembering who the system is for and develop an increasingly accurate understanding of variation in clinical capability and needs, and different personal hopes, goals and expectations. Interested parties can be quite diverse, including creative artists/designers, programmers, physios/OTs, nurses/doctors, psychologists, stroke survivors and their carers, family and friends, clinical administrators, purchasing officers. Loud voices from one context should not monopolise the creation process. For example, in our experience it is quite common for a person to use an individual opinion to extrapolate to a general population view of a feature – e.g. "my son doesn't like this feature, and he's a gamer" is only anecdotal evidence. Assignment of an experienced project manager and the application of robust processes are invaluable for operating within a complex co-design scenario, to account for all voices in a balanced and effective way.

Figure 4.5 Illustrates how integrating BCTs may be included as part of a design process (with a few examples). For example, the intensity required for upper arm rehab needs to be intense to maximise the opportunity for optimal recovery. Five hours a day, over 5 weekdays is very tough. So, encouraging a stroke survivor to engage in personal goal setting, and providing positive feedback can be very supportive. Good struc-

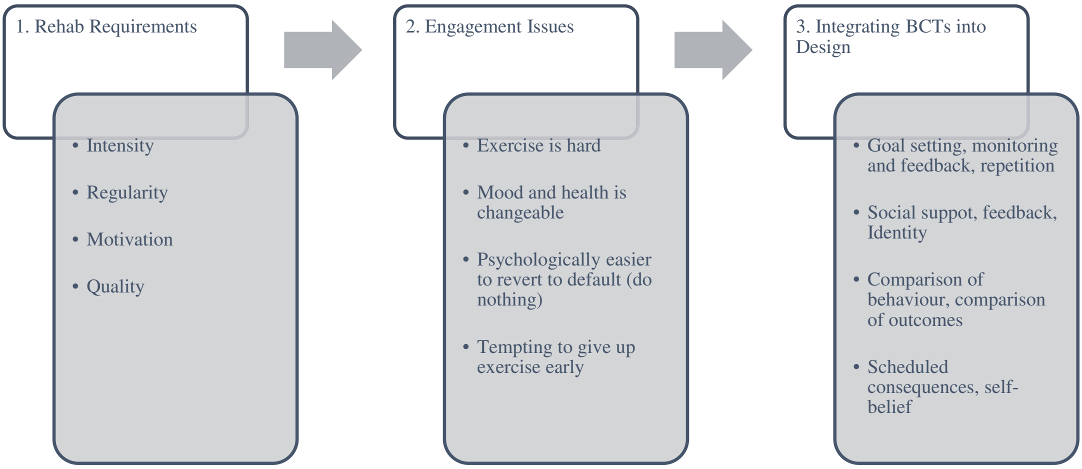

Fig. 4.5 Process of mapping BCTs to patient and clinical needs to improve rehabilitation retention

ture and tailored levels of repetition help guide them through programmes, so they don't have to think about it. Presenting engagement with exercise in a positive manner to show continual improvement and so providing an opportunity for user enjoyment. We need to encourage regular system use, as we don't want people to dread logging in but rather look forward to it. Receiving reward and positive reinforcement helps them look forward to it, and social support such as friend networks, multiuser meetups and exercise session can be an enticement to use the system. Giving them responsibility within a social setting is empowering and has consequences if they do not fulfil their role. Comparison with their past performance and collaborative tasks with other stroke survivors or carers helps maintain traction with system use (like exercise challenges and adventures in Fitbit smartwatches)

We use gamification, and various other positive psychology approaches such as persuasion within our design to reinforce productive behaviour. Gamification provides rewards/feedback that motivates, encourages and guides a person in their exercise. Users of the system can gain points and achievement badges for using the system regularly, for effort and improvement of physical performance in VR tasks.

Our experience is that it is best to create several games that cover a range of genres and from very casual and short, to a game with more depth and strategy. It is challenging to account for the full range of disabilities of stroke survivors within one game. Add to this that different exercise programmes suggest different types of gameplay. For example, coarse arm movement suits games such as Whac-Mole; moving an arm to hit a mole appearing at different locations in front of the player (in the space defined by a person's range of motion). Precise hand and finger exercise are often suggestive of games with repetition of tasks; e.g. tap a finger to open a door, open and close a hand to blow up a balloon. Knowledge of the six-game design c's and core game design patterns are essential in matching physical motion and cognitive difficulty to gameplay features. Progression in a serious game is important but can be challenging to design as a person may "flatline" their improvement graph after a while. It is perhaps best to represent progress both as improvement in gameplay and physical performance (so long as these are distinguishable), and through positive feedback on consistent engagement. Throughout, information messages are required, to help training, to provide health messages, and for positive encouragement. A person's rehab journey is their personal story. This personal story can form the basis for empowering narratives, primarily if a stroke survivor is engaged in the imagining of their future narrative.

The following is an outline of the process of system development that we now tend to adopt, including the integration of BCTs, gamification, effective game design best practice, and a strong focus on usability.

1. *Establish a core team.* Identify the people required to help the project be successful, including experts for key roles. Ideally, a group of stroke survivors and clinicians are identified who can help throughout the design and testing processes. Best practice is to recruit at least one stroke survivor and one practising physio or OT to be part of the core design team. A working group can be established, comprised of these end-user representatives, researchers, developers, designers, and project managers. A working group makes collective decisions and project management.
2. *Requirements gathering*. This process and the data obtained inform subsequent decisions and processes, particularly design. For upper limb stroke rehabilitation, requirements would account for the variation of user movement, user fatigue and attention issues, cognitive, and other potential stroke effects. Usability of user interfaces and any hardware (such as controllers) is crucial. Clinical requirements for rehabilitation must be gathered, summarised, and understood in terms of their integration into games. Technical aspects such as computing specification and any network/cloud services must be accounted for. Collection and processing of demographic data, technical background of the user

population, and entertainment preferences can inform design choices. The overall goal and objectives for the use of the system should be agreed, and the scope of the project limited on this basis. Requirements may be gathered in the usual way and illustrated through high-level visual graphics, rich pictures, user stories and other similar methods. Workshops are useful to refine requirements through iterative activities and group discussions. Existing team bespoke or commercial software may be used to aid communication and help improve understanding of potential opportunities. Risk management is a crucial part of planning, and cost, aspects of project failure, and the possibility of changing requirements must be accounted for. An Agile software development approach appropriate for health VR game technology development since the approach is necessarily a co-design/co-development process which requires regular feedback from a range of different experts and laypeople.

3. *Tools, technology platform and asset identification*. Based on requirements, scope and objectives, a technology platform can be identified for the system software and VR games (assuming VR is the most appropriate solution). For our current trial several VR HMDs including the Oculus Rift and HTC Vive, were tested by us and stroke survivors at various local stroke organisations. Though the Vive provided, arguably, more robust tracking (fewer occlusion issues) and more flexible operation (e.g. trackable objects), the Oculus Rift proved more user-friendly and useable for stroke survivors. The Oculus also has a less obtrusive set up in a home, is easier to put on (due to the head strap operation) and was found by users to be more balanced and lighter to wear on the head. Several stroke users, particularly older females, preferred the idea of the Oculus in their home. From a technical point of view, our team had tested both systems and felt that most of the requirements could be met on both VR systems. We had already committed to using the Unity development tool due to its widespread use, ease of programming and level of developer support. Unity can be used to create VR environments for all the leading commercial HMDs. Graphics and audio tools should also suit the team (or recruitment requirements). Most of the asset creation tools that we use are free and are widely adopted by developers. A decision should be made, based on team talent and a cost/benefit analysis, about which game or system assets should be purchased and which should be created in-house. For our Magic project, we bought most of the game environment assets to build our own bespoke game areas, as for our system, this was more cost-effective than contracting several creatives. Our team realises the gameplay and creates the game levels as due to our experience in serious VR game development. Project and development management tools are essential, as is the training of the team in their use. Apart from conventional office and email software, we use Excel for hardware and user feedback tracking, Asana for software development management, TeamViewer to remote login to user systems (for support), OneDrive for secure document storage, and Azure for GDPR compatible website hosting.
4. *Design*. Design is often rushed or completed through development, which is generally a mistake as project resources (time, people, money) may be committed too early to a flawed design. This careful design is the same for any software design, but there are a few differences between designing for VR stroke rehab compared mainstream software and games. Game design is a creative process and generally considered not very successful in being completed "by committee". However, in the case of a serious game, a designer needs to understand clinical requirements and variability in patient capability. Brainstorming, interviews and other information transfer methods help the designer to appreciate restrictions on input control and to understand appropriate approaches to UI graphics and interaction design. It helps the designer learn about setting suitable game difficulty, gameplay pacing, and setting the length of game sessions. If requirements are well detailed and understood

by the designer, then input from other team members during the design process is focused on providing periodic advice and feedback after each design Agile "sprint". The design process should be considered as multiple cycles of design/evaluation tuples. Where the evaluators are clinical team members or external clinical groups, stroke survivor team members or external stroke groups, as well as other people with experience on playing or designing games. Some feedback sessions can be informal and short; others can be more structured with more people involved. Design is often more difficult than expected. Communication of ideas can be tough to a multi-disciplinary team, so a "lo-fi" approach to tool adoption is recommended. We have found the following stages to be quite beneficial:

(a) Brainstorming with whiteboard sessions as a core team group. Agreement should be reached on the high-level structure and main components of the software and games. Build a shortlist of suitable games of a variety of gameplay styles, covering the range of rehab exercises required, and accounting for a range of different abilities.

(b) Paper prototypes are very effective. That is, the system and VR games are illustrated on paper with text, sketches and diagrams. Sketching designs helps communication and allows very rapid turnover of ideas. Works well for teams.

(c) A PowerPoint game design document. There are many other approaches but the use of PowerPoint helps develop a mindset of rapid and iterative design, and presenting the design more like a short, comprehensible pitch document. It is very unusual/unlikely that a first design document will accurately represent the final design, but rather a design document should be considered as a living document that is regularly updated. Thus, it should be easy to update and accessible to read. PowerPoint has a range of easy to use tools that help swiftly create a presentable design. Narration tools within PowerPoint are a bonus, for articulating the key ideas verbally.

(d) Rapid building of small functional prototypes. For example, test core gameplay, input control, and UI design. Games are often "grey boxed" (i.e. no graphics or audio) to assess if the game mechanics are fun and useable. Quickly creating throwaway portions of games and system software facilitates an early evaluation of functionality, usability and user experience. This helps refine architectural design and refine features before committing to full-scale development. For games it is good practice to follow this up with a fully working game portion that illustrates just enough to evaluate whether the core idea is working well. This test point is called the Vertical Slice.

5. *Further Team Recruitment*. It is better to expand the team after requirements and design are well established. Consider that a casual game such as the original Angry Birds cost approximately £100k to make, and usually game development costs significantly more than this. A VR system with embedded rehab games comprises a wide range of features (variety of games, information systems, cloud services) and so requires a broader range of talent to create and careful testing. So, recruitment must be undertaken carefully, staged if possible, and hiring people with more than one role in the team (e.g. documentation and testing, graphics and level design). In our current Magic project required expertise includes game coding, system development, UI and game design, level design, 2D and 3D graphics, web client and server development (including database expertise), upper arm stroke rehabilitation, ethics, user services (deployment, call support), game and system testing.
6. *Development and Testing*. If early prototyping is effective in mainly tying down the system features, then development can be completed in a phased release manner. This process involves the sequenced development of

separate independent subsystems (e.g. game 1, database, web dashboard). Testing, redesigning and fixing any issues with one subsystem before moving to the next, though if the team is large enough, some subsystems could be developed in parallel. Interoperability between systems can be tested throughout, and end-users can also test partial systems, e.g. games playtested and optimised for usability and enjoyment. When the full system is completed, it requires more in-depth technical tests (e.g. stress tests, unit code tests), and user testing (stroke survivors, clinician, healthy laypeople). If design still needs some real-world evaluation to improve, then an evolutionary development strategy would be more appropriate than a staged release approach, involving short cycles of system building, evaluation/tests, and redesign.

7. *Support and Maintenance*. Any system used over some time requires a strategy for end-user support, especially if they are using it at home independently. System flaws or bugs are quite common, especially the first deployed version. We support users via phone (they have a number to call), we have embedded support via calling in our rehab system, we can remotely access their computer via Microsoft Team Viewer, and we maintain an online software patch update server (to update home systems remotely). We also supply a web dashboard for clinicians to be able to monitor system use and patient data. A patient's rehab programme can be tailored to each person via the web dashboard. Our rehab system is adaptive, and rehab tasks and their difficulty are intelligently adapted based on user profiles.

4.8.1 Discussion

In this chapter, we presented a range of research and design principles that help guide the design of VR games for upper arm stroke rehabilitation and related this to our own experience. The core ideas are likely to apply to several other areas of physical rehabilitation.

Questions have arisen during our research and development. For example, who is the designer? The people that our system matters most to are stroke survivors; it is, therefore, essential that they have a say on how a system should operate and on game design features. However, we would only ever be able to recruit a small group of representative people, who may not represent the general view of the wider stroke community, and we have found that viewpoints vary between different countries. In gaining opinions from stroke survivors, some areas are more important to receive feedback than others. For example, ideas about VR hardware preferences for use in the home is useful. We found that people cared about how a system looked in their house, e.g. did it make it looked cluttered. Usability of hardware is also essential, e.g. ease of setup and start-up, ease of putting on VR headset. Listening too carefully to a small group of people about game preferences is fraught with problems; opinions are helpful, but an experienced designer must also account for general appeal, fun, and rehab worthiness. The game designer has needs to be an experienced moderating voice in design.

Clinicians provide valuable information on exercise requirements and well and physical, mental and cognitive limits. A person must be pushed in their rehabilitation for it to be effective but within bounds. This emphasis is a critical design issue. Games typically use repetition in gameplay, and arguably rehab requires more emphasis on repetition, with precise doses and careful set minimum/maximum periods. This scope is challenging for the game designer who attempts to make these repetitions enjoyable in gameplay. For example, we have made an Angry Birds styled game, in which a player performs rehab hand gestures (e.g. pinch) to fire projectiles at a castle and defeat an enemy repeatedly. We have found that working out an appropriate gameplay pace is also challenging, even though we intelligently adapt this through monitoring player performance. For a serious game, the Flow channel (see above), varies a lot between different people based on their prior game/technology experience and cognitive/mental capability. If tasks are too challenging a player becomes disillusioned, too easy, then they become bored. We have also found that, for a well-designed game, many stroke survivors learn how to play quite rapidly and so having enough content to prevent them from being bored is also an important goal. Content is expense. Therefore, smart design strategies are required to be able to reuse graphics, level areas, and code in several games. Another strategy is to make an "infinite scrolling" game, where the game potentially continues indefinitely. Content is procedurally placed in the game levels, and so design effort is more on procedural code design and less on graphics and level design. The third common gameplay component is in setting appropriate times for play sessions. The procedural content approach helps solve the development cost issue, but in our game River Run, we spent some time in design brainstorming how an infinite scroller type game can be limited to a maximum playtime. Rest periods are required and also a person's overall time in VR should be limited. One obvious approach is to have sections of the river run divided into periods suitable for each player; they continue along the river after rest periods and on starting the game again in a new VR session. If a person runs out of game lives (or player character health), then they must restart the river again – where there are several (potentially infinite) rivers to master.

We are often asked questions about or challenged on the use of VR rather than Augmented Reality or standard 2D monitors. While the use of games to help motivate people used be an issue for some observers in that past, we feel that most people are much more respective to what games can offer. However, VR is relatively new, and while the novel is quite exciting to many people, there can be reluctance among other people. We have found in practice that most people accept the technology quite well after a period of use, and many people enjoy the experience of putting it on and becoming immersed. AR allows a person to see their real environment while also seeing virtual objects and characters. AR has much potential for supporting stroke survivors and may be used for some people who do not like the experience of being immersed (i.e. not having a positive lusory attitude). AR may be more effective in encouraging a user to interact with real-world objects that are overlaid with information or virtual targets, as we have shown previously (Burke et al. 2010). However, VR allows us to immerse a person in a controlled environment, with controlled lighting and minimal distractions. This tailored approach can be necessary for many stroke survivors, and we have feedback from some patients in our current trial that they appreciate being able to 'escape' to VR. We have some evidence (Holmes et al. 2016) that healthy and impaired users enjoy the experience of VR and that it helps them feel more in control of their virtual tasks in comparison to completing them on 2D displays.

In the PACT framework, and during our broader discussion on design, we highlight the importance of people, aesthetics, context and technology to a design and development process. PACT-B reflects the focus of our recent work, which has a more deliberate emphasis on embedding behaviour change techniques into our system and game design. BCTs have much in common to game design patterns, gamification, and learning theories, but have more emphasis on a person taking ownership and being mindful of their engagement.

The technology landscape is changing rapidly, with new AR and VR HMDs being released regularly. Any physical rehabilitation solution needs to be mindful of this and be able to avail of new and improved features when they become available, e.g. wireless HMDs streaming high frame rate visuals from a PC or cloud servers (e.g. Google Stadia). AR HMDs that can become VR by darkening their lenses glass. More accessible controllers and higher quality hand/finger tracking. Higher bandwidth 5G mobile networks and broadband internet will hopefully support lower cost connected health hardware that supports more people recover effectively at home. Social support is a crucial area for stroke rehabilitation in the home and VR provides unique opportunities via a faster network to connect people.

Nonetheless, the design challenges will be the same. Intense rehabilitation has been shown to increase the chance of improved recovery significantly. However, it is practically impossible for a person to maintain the dose and quality of exercise unsupported within the home. VR rehabilitation can support stroke survivors by structuring their rehab, providing targeted feedback and intelligent adaptive processes, helping to motivate them with social factors, gamification and fun tailored games.

Appendices

Appendix A: Linking Gamification Types and Systems, Game Design Patterns, and Behaviour Change Techniques (Tables 4.3, 4.4, 4.5, 4.6, and 4.7)

Table 4.3 Disrupter gamification type

Gamification element	Game design patterns
Anarchy	Betrayal, player elimination.
Light touch	Bluffing, damage, limited planning ability, paper-rock-scissors, randomness, red herrings, role reversal, secret alliances, uncertainty of information.
Anonymity	Asymmetric information, bluffing, cards, fog of war, handles, paper-rock-scissors, role reversal, secret alliances, stealth.
Development tools	Constructive play, character development, tools.
Voting/voice	Betrayal
Innovation platform	Player constructed worlds, player decided results, player defined goals, player-decided distribution of rewards & penalties, reconfigurable game world

Table 4.4 Free spirit gamification type

Gamification element	Game design patterns
Exploration	Area control, exploration, game state overview, manoeuvring, movement, movement limitations, privileged movement, traces, controllers, imperfect information, inaccessible areas.
Branching choices	Analysis paralysis, asymmetric goals, attention swapping, betrayal, cognitive immersion, freedom of choice, illusion of influence, limited set of actions, planned character development, risk/reward, roleplaying, stimulated planning, trade-offs.
Easter eggs	Pick-ups, resource locations, secret resources, Easter eggs
Unlockable/rare content	Progress indicators, resource generators, rewards, surprises, ultra-powerful events
Customisation	Camping, construction, player defined goals, player constructed worlds, player-decided distribution of rewards & penalties, reconfigurable game world
Creativity tools	Creative control, empowerment, player constructed worlds, player decided results, player defined goals, player-decided distribution of rewards & penalties

Table 4.5 Philanthropist gamification type

Gamification element	Game design patterns
Access	Asymmetric goals, buttons, tools, controllers
Meaning/purpose	Identification, perceived chance to succeed
Caretaking	Helpers, safe havens, tension, tied results, mule
Collect & trade	Bidding, collecting, contact, converters, enclosure, gain ownership, negotiation, pick-ups, reconnaissance, safe havens, tools, trade-offs, trading.
Sharing knowledge	Cooperation.
Gifting/sharing	Cards, cooperation, card hands.

Table 4.6 Player gamification type

Gamification element	Game design patterns
Points/exp points (XP)	Budgeted action points, characters, consumers, container, outcome indicators, score
Physical rewards/prizes	Chargers, illusionary rewards, individual rewards, non-renewable resources, pick-ups, player decided distribution of rewards & penalties, power-ups, renewable resources, resource generators, resource locations, resources, rewards, secret resources, symmetric resource distribution.
Leader boards/ladders	High score lists, red queen dilemmas, tiebreakers.
Badges/achievements	Characters, ownership, producers
Virtual economy	Arithmetic rewards for investments, budgeted action points, consumers, container, geometric rewards for investments, investments, limited resources, ownership, pick-ups, renewable resources, resource locations, rewards.
Lottery/game of chance	Betting, leaps of faith, luck

Table 4.7 Socialiser gamification type

Gamification element	Game design patterns
Social status	Handles, high score lists, individual penalties, individual rewards, king of the hill, near miss indicators, privileged abilities, privileged movement, public information, red queen dilemmas, shared penalties, shared resources, shared rewards, social statuses, status indicators.
Social network	Alliances, asynchronous/synchronous games, collaborative actions, communication channels, indirect information, individual penalties, inferable goals, last man standing, multiplayer games, negotiation, public information, secret alliances, social dilemmas, social interaction, spectators, symmetric information, tiebreakers, tied results.
Social pressure	Betrayal, uncommitted alliances
Competition	Agents, balancing effects, capture, combat, competition, conflict, early elimination, eliminate, last man standing, multiplayer games, player killing, race, time limits, tournaments, varied gameplay.
Social discovery	Communication channels, social organizations.
Guilds/teams	Agents, alliances, betrayal, collaborative actions, dynamic alliances, multiplayer games, player decided results, secret alliances, shared penalties, shared resources, shared rewards, social interaction, social organizations, symmetric information, symmetric resource distribution, team balance, team development, team play, tiebreakers, tied results, tournaments, varied gameplay.

Appendix B: Grouping of Individual BCTs (Michie et al. 2011)

Group No.	Group label	BCTs
1	Goals and planning	1.1. Goal setting (behaviour) 1.2. Problem solving 1.3. Goal setting (outcome) 1.4. Action planning 1.5. Review behaviour goal(s) 1.6. Discrepancy between current behaviour and goal 1.7. Review outcome goal(s) 1.8. Behavioural contract 1.9. Commitment
2	Feedback and monitoring	2.1. Monitoring of behaviour by others without feedback 2.2. Feedback on behaviour 2.3. Self-monitoring of behaviour 2.4. Self-monitoring of outcome(s) of behaviour 2.5. Monitoring of outcome(s) of behaviour without feedback 2.6. Biofeedback 2.7. Feedback on outcome(s) of behaviour
3	Social support	3.1. Social support (unspecified) 3.2. Social support (practical) 3.3. Social support (emotional)
4	Shaping knowledge	4.1. Instruction on how to perform the behaviour 4.2. Information about antecedents 4.3. Re-attribution 4.4. Behavioural experiments

(continued)

Group No.	Group label	BCTs
5	Natural consequences	5.1. Information about health consequences 5.2. Salience of consequences 5.3. Information about social and environmental consequences 5.4. Monitoring of emotional consequences 5.5. Anticipated regret 5.6. Information about emotional consequences
6	Comparison of behaviour	6.1. Demonstration of the behaviour 6.2. Social comparison 6.3. Information about others' approval
7	Associations	7.1. Prompts/cues 7.2. Cue signalling reward 7.3. Reduce prompts/cues 7.4. Remove access to the reward 7.5. Remove aversive stimulus 7.6. Satiation 7.7. Exposure 7.8. Associative learning
8	Repetition and substitution	8.1. Behavioural practice/rehearsal 8.2. Behaviour substitution 8.3. Habit formation 8.4. Habit reversal 8.5. Overcorrection 8.6. Generalisation of target behaviour 8.7. Graded tasks
9	Comparison of outcomes	9.1. Credible source 9.2. Pros and cons 9.3. Comparative imagining of future outcomes
10	Reward and threat	10.1. Material incentive (behaviour) 10.2. Material reward (behaviour) 10.3. Non-specific reward 10.4. Social reward 10.5. Social incentive 10.6. Non-specific incentive 10.7. Self-incentive 10.8. Incentive (outcome) 10.9. Self-reward 10.10. Reward (outcome) 10.11. Future punishment
11	Regulation	11.1. Pharmacological support 11.2. Reduce negative emotions 11.3. Conserving mental resources 11.4. Paradoxical instructions
12	Antecedents	12.1. Restructuring the physical environment 12.2. Restructuring the social environment 12.3. Avoidance/reducing exposure to cues for the behaviour 12.4. Distraction 12.5. Adding objects to the environment 12.6. Body changes
13	Identity	13.1. Identification of self as role model 13.2. Framing/reframing 13.3. Incompatible beliefs 13.4. Valued self-identify 13.5. Identity associated with changed behaviour
14	Scheduled consequences	14.1. Behaviour cost 14.2. Punishment 14.3. Remove reward 14.4. Reward approximation 14.5. Rewarding completion 14.6. Situation-specific reward 14.7. Reward incompatible behaviour 14.8. Reward alternative behaviour 14.9. Reduce reward frequency 14.10. Remove punishment
15	Self-belief	15.1. Verbal persuasion about capability 15.2. Mental rehearsal of successful performance 15.3. Focus on past success 15.4. Self-talk
16	Covert learning	16.1. Imaginary punishment 16.2. Imaginary reward 16.3. Vicarious consequences

Appendix C: Experiments and Trials

Exp.	Equipment	Summary
1	*VR with Ascension Flock of Birds and MotionStar.* Glove tracking. (2005–2007)	Three games were made using a combination of the Ogre game engine with the PhysX physics engine integrated into it, and Sense8's WorldUp software. It was shown physically based VR can contribute to an effective post-stroke motor therapy system, which provides realistic and motivating tasks that can automatically adapt to individual patient's capabilities. VR HMD heavy and gloves difficult to put on and use.
2	*Nintendo Wiimote Tracking.* Two Wiimotes with Bluetooth connection to a PC and monitor. (2007)	Several prototypes constructed including a vibraphone music game in which the player hits the musical bars by moving their handheld Wiimotes to control the virtual hammers. Trial with healthy users (n = 10). A majority of users enjoyed the games, each scored 70%+. A majority of users found the control easy to use but at times the sensitivity of the controllers was too fine.

(continued)

Exp.	Equipment	Summary
3	*Webcam Games.* PC with DirectShow capability for capturing webcam video images. (2009)	Four casual games in the mode of Sony's PS2 EyeToy games using a webcam to track natural hand motion, and the hand used as a game controller. Experimental focus was on engagement, motivation, and improvement of performance in games. Healthy users and stroke survivors (including a 3-week trial). Results from each of these phases indicate that the games were usable and playable by the participants; results from the 3-week trial showed that the games were also motivating.
4	*Augmented Reality Games.* QR markers on objects for tracking and Vuforia AR SDK. (2010)	Four bespoke casual AR games with webcam tracking of QR marked objects. The same method and experimental procedure as in 3. The 3D games elicited reach, grasp and release movements were presented through three phases including a 3-week trial. Results indicated positive system usability and increased motivation with rehabilitation.
5	*Leap Motion Controller Games.* Leap Motion to sense hand motion. (2013)	Three hand focused rehabilitation tasks: Cotton balls, stacking blocks, and the nine hole peg test tasks were evaluated by practising physiotherapy and occupational therapists (n = 8). Investigating suitability of Leap Motion tracker for rehabilitation. In general, clinicians thought the prototypes provided a good illustration of the tasks required in their practice, and that patients would likely be motivated to use the system, especially young patients, and in the home environment.
6	*VR Game with Sensor Redundancy.* VR ready PC, Oculus DK1, Desk mounted Leap Motion, Myo armband, and Kinect V2. (2015)	This game included a plain room with simple reach and touch tasks for objects in random positions within the room. Healthy adults (n = 26) volunteered for single sessions. 77% of the participants commented that their experience using the VR headset was enjoyable and 43% of participants thought that their performance had improved over time. There were no reports of motion sickness. Visual and audio spatial cures helped performance. Only 19% of participants found their experience to be frustrating at times, mainly due to loss of hand tracking. 27% of the participants mentioned that they became fatigued at points during the experiments, which is not necessarily an issue if they get adequate rest.
7	*VR Game with Head Mounted Leap Motion hand tracker.* As above but the Leap Motion tracker was head mounted on the VR HMD. (2016)	Stroke survivors (n = 6) who had enough motor capacity and strength to lift their arm from a desk, could follow a two-step command and no underlying separate learning difficulties or arm impairment. Single session per person. Usability scores were quite good, though 75% said they got frustrated with accessing close targets and if tracking of their hand was temporarily lost. Tracking hands of disabled stroke survivors with the Leap depth camera proved challenging. Two participants said that the Oculus gave them better clarity to see the objects. All participants stated that they felt their movement performance had improved with the VR headset. One participant said that VR help her concentrate on tasks.
8	*Full Rehabilitation system.* As above but using the commercial release of the Oculus Rift CV1 and excluding Myo and Kinect. (2018)	The follow-on experiment from 3 and 4 was with healthy users (n = 10) with a VR system containing calibration and home areas and three prototype games ahead of our current major trial. Each participant took part in a total of 10 sessions over 5 weeks (two sessions a week. Most users improved performance over time and became accustomed to using VR. Usability scores were high though the HMD became warm and more uncomfortable after a while. Detailed feedback was received about the games, with the more orthodox game, Cannon grab, being the most popular. The repetitive fetch game and more complex knights being less popular.
9	*Magic Glass Rehabilitation System.* HTC vive & and oculus rift with head-mounted leap motion. VR ready PCs and laptops, plus custom VR table. (2018–2020)	Within the EU magic PCP project, taking our rehabilitation system TRL 4 (technology readiness level) though to TRL 7. Utilising PACT-B approach (see above) in system design and development and through the current trial (target n = 150 post-stroke 0–6 years). Through this project 6 new VR environments and 6 new games were constructed based on previous experience and ongoing user testing and feedback. The trial is still underway, but the interest in using the system is high as we approach our 90th recruit. The main user comment currently is that they would like more progression in games, and more game alternatives. As they have to play the games frequently, it is easier for them to become bored. We have learned that clear instructions for games are crucial and that balance needs to be struck between providing a tailored rehab programme and facilitating user choice.

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5

Augmented and Virtual Reality in Anatomical Education – A Systematic Review

Umaiyalini Uruthiralingam and Paul M. Rea

Abstract

Learning anatomy traditionally has depended on traditional techniques like human cadaveric dissection and the use of textbooks. As technology advances at an ever-rapid speed, there are revolutionary ways to learn anatomy. A number of technologies, techniques and methodologies are utilised in anatomical education, but ones specifically receiving a lot of interest and traction is that of augmented reality and virtual reality. Although there has been a surge in interest in the use of these technologies, the literature is sparse in terms of its evaluation as to the effectiveness of such tools. Therefore, the purpose of this study is to examine in greater detail the literature specifically to see what the best practice in this field could be. By undertaking a systematic review using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, we searched for articles in both Web of Science and PubMed. Using the terms "augmented reality and teaching anatomy" yielded 88 articles. We then used "virtual reality and teaching anatomy" which resulted in 200 articles. We examined these articles, including that on augmented reality and virtual reality used to teach anatomy to undergraduate and postgraduate students, residents, dentistry, nursing and veterinary students. Articles were excluded if they were systematic reviews, literature reviews, review articles, news articles, articles not written in English and any literature that presented how a virtual model was created without the evidence of students testing it. The inclusion and exclusion criteria for virtual reality were the same as augmented reality. In addition, we examined the articles to identify if they contained data which was quantitative, qualitative or both. The articles were further separated into those which were pro, neutral or against for the use of these digital technologies. Of the 288 articles, duplicate articles totalling 67 were removed and 134 articles were excluded according to our exclusion criteria. Of the 31 articles related to augmented reality, 30 were pro, one neutral and no articles against the use of this technology. Fifty-six articles related to virtual reality were categorised resulted in 45 pro, eight neutral and three against the use of this technology. Overall, the results indicate most articles identified related to both virtual and augmented reality were for the use of those technologies, than neutral or against. This systemic review highlights the recent advances

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of both augmented reality and virtual reality to implementing the technology into the anatomy course.

Keywords
Anatomical education · Augmented reality · Cognitive load · Virtual reality

5.1 Introduction

5.1.1 History of Teaching Anatomy

Traditional anatomy teaching has utilised dissection and prosections coupled with textbooks and didact methodologies. Human cadaveric dissection has a long history of use, and was utilised in ancient Greece in the third century BC, although dates back to ancient Egyptian times. Human dissection has had a long and rich history, and has shown great benefit in acquiring information related to the gross anatomy of the human body (Memon 2018).

In addition to this, typical teaching methods for anatomy consist of lectures and 2D images from anatomy textbooks (Peterson and Mlynarczyk 2016). Students can find these 2D images challenging to visualise in 3D and learn anatomy; therefore, the addition of cadaveric dissection into the anatomy module allows students to improve spatial understanding (von Staden 1992) and anatomical knowledge (Langlois et al. 2014). Cadaveric dissection brings many benefits to the anatomy including enhancing understanding of anatomy (Peterson and Mlynarczyk 2016); preparation of students for clinical practice (Estai and Bunt 2016); improving team working skills and improved hand-eye coordination through the use of instrumentation (Granger, 2004). However, cadaveric dissection is expesnive with maintaining dissection rooms (Estai and Bunt 2016), and some users can dislike the smell of the room. There is also difficulty for some students in being able to identify structures in a cadaver and this can result in frustration and lack of interest unless there is continual support (Dissabandara et al. 2015). Furthermore, cadavers and the necessary equipment prove expensive to maintain (Jang et al. 2017). In addition, systems that are more difficult to view, access or dissect in 3D using cadaveric dissection e.g. the ventricular system (Thomas et al. 2010) and the vestibular system (Jang et al. 2017) can prove an extra challenge in the laboratory classes. Both systems require a more modern approach to allow students to identify the anatomical structures and to acquire knowledge of spatial relationships of various structures.

5.1.2 Modern Learning

With the advances of technology, it has enabled a unique and novel way to present anatomical structures which engage students in learning anatomy (Lochner et al. 2016) and train residents (Breimer et al. 2016; Rahm et al. 2018). Anatomy can be presented in a variety of different ways by the use of technology and this can include, but not limited to e-tutorials, 3D printing, mobile learning, augmented reality (AR) and virtual reality (VR). However, this study will focus on two technologies which are growing in popularity and traction they are receiving – that of VR and AR.

Using augmented reality requires a screen (smartphone or tablet) to observe computer generated virtual images. The virtual image adds or enhances the surrounding environment; therefore, the user has the ability to distinguish between the real and digital worlds (Bacca et al. 2014; Moro et al. 2017). However, virtual reality allows users to wear head-mounted displays (HMD) to immerse into a virtual 3D world where the user will be unable to differentiate between the real and virtual worlds (Moro et al. 2017; Hamacher et al. 2018). This technologic advancement introduces students to anatomical structures in 3D instead of the 2D images from textbooks that are difficult to visualise (Azer and Azer 2016). Therefore, this provides a unique opportunity for students to easily learn complex anatomy and to understand spatial relationships between two anatomical structures (Kugelmann et al. 2018). It has also been shown that AR and VR allow students a golden opportunity to improve their assessment scores and increase student satisfaction (Ferrer-Torregrosa et al. 2016).

5.1.3 History of AR and VR

The development of both technologies arose from the first immersive machine dating back to 1950's when Morton Heilig invented the first machine called Sensorama. Sensorama was invented for the future of cinema as it allows the user to enter a more engaged cinematic experience where the users' senses were stimulated. The machine consiseds of a stereo- sound system, colour visuals, smell, a vibrating chair and fans for wind production (Srivastava et al. 2014). However, sensorama does not deliver an interactive experience (Mandal 2013).

The terminology VR was introduced later in 1987 by Jaron Lanier. After the Sensorama was the precursor to the HMD called Headsight by Philco Corporation in 1961. The Headsight consisted of a video screen and tracking system connected to a camera to observe the real world. Headsight was the first stage in the creation of a HMD. This led to the development of the Sword of Damocles system by Ivan Sutherland in 1968 (Mandel 2013). This system consisted of a HMD connected to the computer instead of a camera, which allowed the user to enter a virtual world. In addition, the computer enabled the user to sustain in the virtual environment by tracking their head positions. Therefore, the user's view of the virtual world will alter in accordance with their head movements (Srivastava et al. 2014). The HMD allows the interaction of objects in the virtual environment compared to the Sensorama (Mandel 2013). HMD were initially utilised for training military workforce, pilots and astronauts. The beginning of VR in medical teaching during 1990's was for colonoscopy and upper gastrointestinal tract endoscopy simulation (Srivastava et al. 2014). VR has also been used to train medical residents for ventriculostomy (Breimer et al. 2016) or for surgical training like a mastoidectomy (Wijewickrema et al. 2015), bronchoscopy training (Gopal et al. 2018; Latif et al. 2015) and more recently for educational purposes for undergraduates (Maresky et al. 2018; Moro et al. 2017).

AR terminology was coined by Thomas Caudell and David Mizell in the 1990's (Arth et al. 2015) and in 1997, the first survey was conducted for an AR technology (Azuma 1997). The breakthrough of the first ARToolKit and the introduction of the first mobile AR (mAR) occurred in 1999. In 2006, the accurate version of the tracking systems for AR was developed (Arth et al. 2015) and additional applications have arisen from this technology including mAR applications (Küçük et al. 2016; Sural 2018) and a simulator named Bangor Augmented Reality Education Tool for Anatomy (Thomas et al. 2010). Another popular AR tool was the augmented reality book (ARBOOK) which contains cards that are read by the computer's webcam and it displays a 3D image onto the computer screen (Ferrer-Torregrosa et al. 2014). The cards can be rotated to view the 3D images in different angles. The study of Kugelmann et al. (2018) used augmented reality magic mirror (ARMM), which allows students to visualise anatomy in relation to their own body while the user was standing in front of screen though tracking systems. Furthermore, Bork et al. (2017a, b) confirmed two different ways to present ARMM: non reversing magic mirror (NRMM) and reversing magic mirror (RMM). RMM was the traditional way of presenting images of organs which followed the same method as ARMM (Kugelmann et al. 2018) and as textbooks. Therefore, if a user stands in front of the magic mirror their virtual liver image in RMM screen was presented on the left side to the user. In contrast, the NRMM presents the organ images opposite to images in textbook. Therefore, if the user stands in front of the magic mirror their image does not reverse so the virtual liver image in NRMM screen was presented on the right side of the user. Additionally, AR could be also be used for teaching resident's surgical anatomy (Siff and Mehta 2018) or for training residents in gaining hand eye co-ordination skills that was required for lumbar puncture

(Keri et al. 2015). As well as education and medical training, AR simulation was also a valuable asset to other areas. Fields such as veterinary medicine and surgery also benefit from using the AR simulator (Lee et al. 2013) and nursing also uses AR simulations in education and training (Aebersold et al. 2018).

For any teaching tool such as AR or VR to be effective for learning, the inventor of the tool needs to refine the tool according to the cognitive load theory (CLT). A crucial factor for learning was CLT which was developed by Sweller in 1988. This means that when a student learns anatomy, the information travels to the temporary working memory or the short-term memory then the information will later be passed onto the long-term memory (Sweller, 1988). However, for the information to be processed into the working memory it was restricted by the capacity of that which was between three to four/five pieces of information at a time (Moro et al. 2017; Van Nuland and Rogers 2017). Therefore, if the information on any teaching tool for the student was considered greater than 4/5 pieces it leads to the working memory regarding it as cognitive overload. Therefore, this results in students being unable to transfer the information processed by the working memory to the long-term memory (Van Nuland and Rogers 2017). CLT should be taken into consideration as cognitive load impacts the student's performance in tests and student satisfaction, essentially if the student experiences cognitive overload this could potentially lead to an ineffective learning experience for students. However, if the student experiences low cognitive load, it could lead to a better learning experience which leads to students performing well in academic tests.

In addition, VR users should consider unfavourable side-effects experienced by the user when exposed to virtual reality simulator. These adverse side effects were named as virtual reality sickness or cybersickness (Moro et al. 2017). Cybersickness causes a range of symptoms such as "nausea, disorientation, discomfort, headache, fatigue, difficulty concentrating and issues with vision" (Rebenitsch and Owen 2016; Moro et al. 2017) that were related to travel sickness. This is because the visual system sends a moving message to the brain; however, the vestibular system transmits an unmoving message to the brain which results in the brain being confused of which signal was correct (Moro et al. 2017).

Therefore, the effectiveness of augmented and virtual reality to enhance learning anatomy was debatable. Therefore, the aim of this study was to present a systematic review of the literature which will report the effectiveness of AR and VR in anatomical education.

5.2 Methods

5.2.1 Search Strategy

A systematic search of articles on PubMed and Web of Science was performed adhering to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The first combination of keywords searched for were "augmented reality AND teaching anatomy" for articles in the past 11 years on PubMed and in the past 4 years on Web of Science. The second combination of keywords searched for "virtual reality AND teaching anatomy" on PubMed in the last 4 years and Web of Science in the last 3 years. This search covered these years for both AR and VR so that an adequate number of articles were examined. The search was not taken back prior to 2007 because the technology was still at its developing stage before that point.

5.2.2 Inclusion/Exclusion Criteria

The articles examined in this study were only original articles which had the search keywords and related to education, medicine, surgery or residents training, nursing, dentistry and veterinary medicine and surgery. We excluded articles which were news items, review articles and reviews of the literature. Abstracts (e.g. for conferences), articles not in English and case studies or methodology articles.

5.2.3 Data Collection

Articles were also examined to identify if they contained data which could be classified as quantitative, qualitative or contained both types of data. Those articles which were identified as containing test or training scores were identified as quantitative, and articles which identified items like engagement and enjoyment of using the simulator and motivation for learning anatomy were considered as qualitative. In addition, articles were categorised as pro, neutral or against the use of the technology.

5.3 Results

The search for "augmented reality AND teaching anatomy" on PubMed yielded 44 articles. 76 articles were identified when searching for "augmented reality AND teaching anatomy" on Web of Science. However only the first 44 articles were used to maintain the consistency of augmented reality searching. When searching for "virtual reality AND teaching anatomy" we identified 301 articles on PubMed but examined the first 100 were examined in detail. On Web of Science, when searching for "virtual reality AND teaching anatomy" 368 articles were identified but to ensure consistency, the first 100 were examined.

Therefore, a total of 288 articles were utilised for this study. We removed 67 articles due to due to duplication with another 134 removed with our exclusion criteria previously mentioned. This left a total of 87 articles which were able to be examined in sufficient detail. Of these articles 31 detailed "augmented reality AND teaching anatomy" and 56 examined "virtual reality AND teaching anatomy". This is summarised in Fig. 5.1.

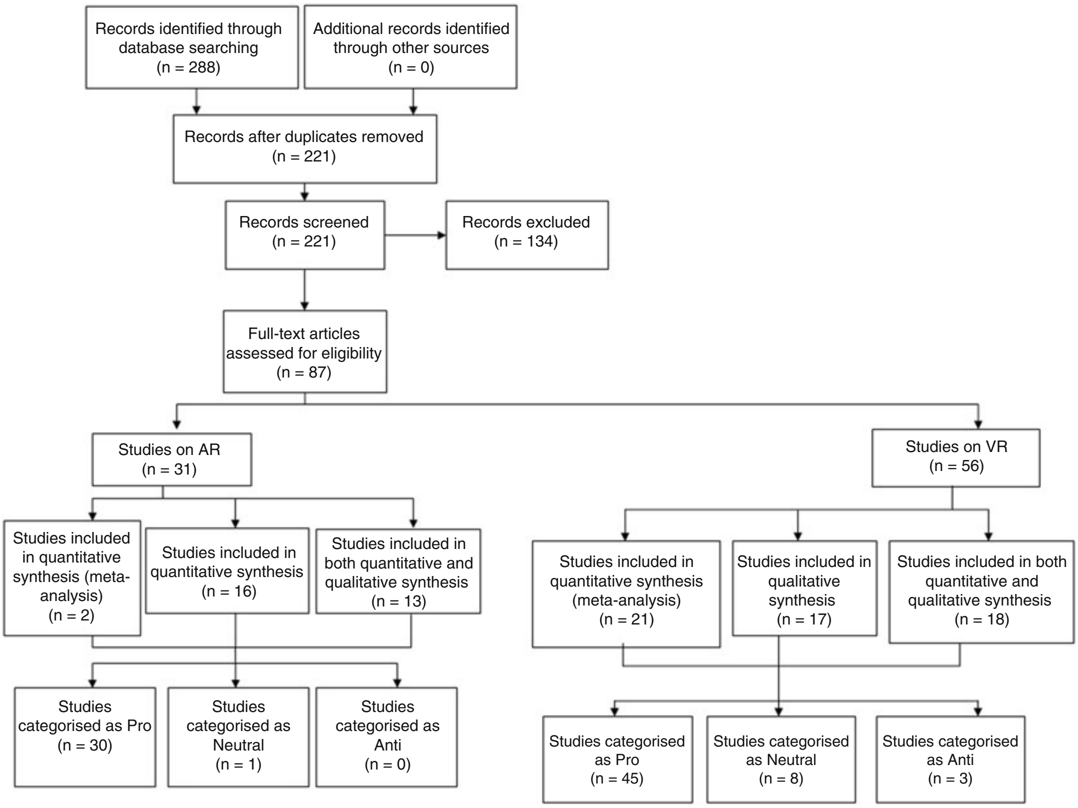

Fig. 5.1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram presenting the process of the search and the results

Of the 31 studies which described “augmented reality AND teaching anatomy”, those identified as supportive (pro) contained one article that was quantitative (3.3%), 40% that was both quantitative and qualitative, but the majority of the articles were found to be qualitative (56.7%). Only a single article was identified as neutral and none were against the use of this technology in anatomy education.

Of the 56 articles that were identified as “virtual reality AND teaching anatomy” those identified as supportive (pro) contained 17 (38.6%) quantitative articles, 13 (29.5%) articles which were qualitative and 14 (31.8%) articles were both quantitative and qualitative. For the neutral category two (25%) articles were quantitative, three articles (37.5%) qualitative and three articles (37.5%) both qualitative and quantitative. For those articles against the technology, one was quantitative, one was qualitative and two were both.

There was a fairly equal split between the augmented reality articles for education (students studying the anatomy course at university) and training (studying anatomy for training). A total of 18 articles for education were split into pro, neutral and against for the use of the technology. In the quantitative category for education were no pro studies. The education category had qualitative studies which contained 11 pro studies. The education “both” category was six (85.7%) pro and one (14.3%) neutral article. For training, a total of 31 articles were split into pro, neutral and against. The quantitative category was one pro article, the qualitative category had six pro articles and “both” category had six pro articles. The results indicate that the augmented reality articles confirmed this technology in education and training had more pro articles than neutral and against. For augmented reality, 31 articles found using “augmented reality and teaching anatomy” with two databases, resulted in 30 out of the 31 articles rated using AR as pro and one out of 31 articles rated AR as neutral. The AR articles had a greater number of articles in the pro than neutral and against categories.

There was an unequal split between the two categories, education and training, as only 14 (25%) articles were on education and 42 (75%) articles on training. All the VR articles were split into pro, neutral and against. Therefore, in the education quantitative group: two (66.7%) pro, one (33.3%) neutral and no against articles. The education qualitative group had one (50%) pro, one (50%) neutral and no against articles. The education “both” group consists of six (66.7%) pro, two (22.2%) neutral and one (11.1%) against. For the training quantitative group: 16 (84.2%) pro, two (10.5%) neutral and one (5.3%) against. The training qualitative group consists of 12 (80%) pro, two (13.3%) neutral and one (6.7%) against articles. For training “both” category consists of eight (88.9%) pro and one (11.1%) neutral articles. The results indicate that the virtual reality articles confirmed thistechnology in education and training had more pro articles than neutral and against. For “virtual reality and teaching anatomy”, the total of 56 articles found on the two databases, resulted in 45 out of 56 (80.4%) articles rated virtual reality as pro, eight (14.3%) articles rated virtual reality as neutral and three (5.4%) articles rated virtual reality as against. The results presented that the literature for both “virtual reality and teaching anatomy” and “virtual reality and teaching anatomy” demonstrate that the majority of articles are rating both digital technologies (augmented reality and virtual reality) as pro. Therefore, the results were supportive for the use of both augmented reality and virtual reality.

5.4 Discussion

5.4.1 Main Findings

Overall, this study has shown both augmented reality and virtual reality to be supported in anatomical education and training. The results present a total of 87 articles split into 56 virtual reality (VR) articles and 31 augmented reality (AR) articles. The majority of articles in the AR category were qualitative. For AR articles, the total qualitative articles was 17 and all of these were in the pro group. Similarly, the “both” category i.e. quantitative *and* qualitative, had a total of 13 articles and of that 12 (92.3%) articles were pro. The total quantitative article was one and that was pro.

For the 56 VR articles that were split into three groups (quantitative, qualitative and both) there were 20 quantitative studies, 17 (85%) of which were pro and most were qualitative studies (13 (76.5%)). From the total of 18 articles which were both quantitative and qualitative, 14 (77.8%) were pro. For VR, there were a greater number of quantitative studies for VR which indicates good evidence that VR was an effective tool for users to learn anatomy. Of those qualitative articles, it highlighted that student's motivation and engagement was high and encouraged the users to study anatomy.

Qualitative articles contain subjective response from users of the technology which was an important aspect to consider as it determines if individuals will use the technology to study anatomy. In addition, the positive response from qualitative articles may lead to the increase in the test scores of users (Ferrer-Torregrosa et al. 2016). However, motivation may not always lead to an improvement in the academic achievement tests. Articles that only provide positive qualitative feedback leads to the technology being categorised as pro, however the technology may not improve the test scores of students (Ellington et al. 2018). As a result, the technology may not be as effective for studying anatomy. Educators should be aware of such technologies that were not effective as a teaching tool for students as the technology may not enhance students' learning. In contrast, the articles including both the quantitative and "both" data provide further evidence that the tested technology was effective in students learning anatomy and acquiring knowledge.

From the results of the rating the use of technology, the 31 AR articles were categorised into 30 articles in the pro category, one article in the neutral category and no articles in the against category. The 56 VR articles were categorised into 45 articles in the pro group, eight articles in the neutral group and three articles in the against group. The majority of articles come under the pro group for the use of technology. Although the majority of articles were classed as pro not all the articles some were identified as neutral and some against the technology. This highlights that not all available AR and VR technologies were effective for students to use for educational and training purposes. Therefore, the educators should not blindly invest in AR or VR. However, the technologies in the literature identified as pro was greater than neutral and against which suggested the use of digital technology (AR and VR) could be beneficial and effective for learning anatomy.

5.4.2 AR for Education

The results indicate a positive response for AR as out of 18 articles for education, 17 (94.4%) articles were pro and one (5.6%) article was neutral. Of the 17 pro articles, 11 (64.7%) were on the education qualitative category and six (35.3%) articles in the education "both" category. Therefore, the results show most articles on AR as pro and could suggest this as a potential beneficial tool for students studying anatomy. However, 11 (64.7%) articles of the 17 articles were qualitative articles which indicate that the majority of the articles were based on subjective responses of students. Therefore, the technology of the majority of articles may not improve the students' test scores.

Currently in the literature, there were a wide variety of AR technologies for students. One of the types of AR was mAR. In 2016, in the Küsçük et al. study tested knowledge for students using mAR. The post-test for the mAR group was higher than the control group which shows promising results for mAR. The mAR provides students with the opportunity for flexible learning, allowing students to revise with the mAR repeatedly unlike cadaveric dissection which is limited in time.

AR allows students to visualise structures that are difficult to view using dissection and also improves students' spatial awareness. Through AR simulation, the majority of students found it useful in understanding the morphology and position of the ventricles (Thomas et al. 2010) and the vestibular system (Jang et al. 2017) as two specific focussed examples of challenging areas of anatomy. The ventricular and vestibular systems were difficult to observe in humans through dissection. Therefore, this can improve the spatial awareness of students. In addition, the ARBOOK enhances the spatial understanding and allows the user to create a 3D image for the student's mind. Therefore, the ARBOOK presents promising results as it enhances student's anatomical knowledge and develops their spatial understanding (Ferrer-Torregrosa et al. 2014). Another advantage of these AR simulations was that the students were able to use the simulation anytime and was not limited in time as in a dissection room.

The majority of individuals prefer AR as it was a useful, attractive and motivating tool for students (Sural 2018; Kugelmann et al. 2018; Manrique-Juan et al. 2017). AR improves 3D understanding and increased motivation for students (Kugelmann et al. 2018). In addition, AR enables students to work in a group with classmates to learn the contents. This can create a student-centred learning environment which will encourage all students to actively engage in anatomical education.

Another type of AR development has led to ARMM which was a system that the users mirror image and a section of the user's internal skeleton and organs was viewed. In Kugelmann et al. study (2018) revealed ARMM improved 3D understanding and increased motivation for students. Similarly, using ARMM in Ma et al. (2015) study found that 72 medical students stated ARMM was useful. In contrast to the advantages of AR, two studies of Bork et al. (2017a, b) confirmed ARMM was only liked by students when students used the non-reversing magic mirror (NRMM) rather than the traditional reversing magic mirror (RMM). Therefore, the test scores on organ identification for the students using NRMM were slightly higher than students using the RMM. Therefore, the students learn better using the NRMM than the RMM.

However, the use of AR in education could negatively impact the students. AR caused a minority of participants to experience cybersickness. In addition, students also deviated from the learning task by simply being distracted by the technology (Moro et al. 2017). Some students found minor faults with the technology which could be amended (Kugelmann et al. 2018).

5.4.3 AR for Training

AR technologies demonstrate positive outcomes for residents training (Keri et al. 2015; Siff and Mehta 2018; Lee et al. 2013). In Keri et al. (2015) study demonstrated that residents who used AR to provide a 3D image of the needle in the relative position performed quicker in insertion and procedure time. This was because the residents using AR acquired a mental 3D image which improved the residents' hand-eye co-ordination skill that was required for a lumbar puncture (Keri et al. 2015). Additionally, hand-eye co-ordination skill was also vital for ventriculostomy (to drain cerebrospinal fluid) as the procedure should not be performed multiple times for the patients' safety. Therefore, mastering this skill was essential for neurosurgery residents. The AR simulation used in Yudkowsky et al. (2013) trained the neurosurgery residents to perform ventriculostomy better as various virtual brains were provided for repetitive practice. In addition, the simulator had the option to perform this skill at varying difficulty levels. As a result, the residents' scores improved after training with the AR simulator.

Siff and Mehta (2018) taught surgical anatomy in 3D for residents. AR aids residents in learning and understanding the spatial relationships of the pelvic floor anatomy which presented as a challenging topic when learning with 2D images. The academic achievement scores doubled after using AR which demonstrates AR was a beneficial resource for learning surgical anatomy.

As well as education and medical training, AR was also an asset to other fields in science. Fields such as veterinary also benefit from using the AR simulator for students to complete canine venipuncture as the simulation was very realistic (Lee et al. 2013). In addition, the nursing field also use AR simulations to train inserting the nasogastric tube (Aebersold et al. 2018). AR simulations were easy to use, useful and effective for gaining various skills during individuals' training (Lee et al. 2013; Aebersold et al. 2018).

5.4.4 VR for Education

As the VR articles do not have an equal split between education and training; VR was used less for education than training. The educational VR articles contained only 14 articles out of 56 (25%) articles were on **education**. The majority of articles laid in the "education both" category. The pro category included 9 (64.3%) articles. The neutral category included 4 (28.6%) articles. The against category included one (7.14%) article. Only 2 out of the 14 articles were described as education qualitative category, therefore the results were more reliable as students test scores back up the other 12 articles. These results indicate that the majority of VR articles described the technology as a valuable asset for education.

In education, general feedback from individuals for VR was that VR was easy to use, useful and VR provides immediate feedback from quizzes. As VR manages to provide instant feedback to students so students have more time to work on their weaknesses in the topics. In addition, this relieves pressures of staff as they do not have to mark the quizzes.

Similarly, in education, the structure of the heart presents as a complex structure which leads students to view the cardiac anatomy using a VR simulator to provide a 3D image (Maresky et al. 2018). This results in students being able to enhance their spatial understanding and be able to create a mental 3D image. As a result, in the study of Maresky et al. (2018) the group using the VR simulator achieved a higher test mark than the group using textbooks. Another complex structure which students find challenging to study was neuroanatomy (Kockro et al. 2015; Stepan et al. 2017). Kockro et al. (2015) discovered that undergraduate medical students preferred 3D VR simulation rather than 2D. This was predictable as spatial understanding would be better on the 3D simulation. In addition, in the study of Stephan et al. (2017) students were engaged and motivated by the VR simulator, however student scores did not improve by using the simulator.

The articles that were categorised into neutral was Moro et al. (2017). In this study, the students were split into three groups: students using AR, students using VR and students using tablet-based learning. The students using VR achieved similar mean scores for the academic and spatial tests as the individuals using AR and tablet-based learning, therefore, VR was as effective as AR and tablet-based learning. However, cybersickness from using VR headsets might make students beginning to dislike the tool. Although, the VR headsets caused side effects, the students' scores in the VR group were similar to the scores of the AR group who experienced fewer side effects. Therefore, VR was an effective tool. In addition, the two studies of Moro et al. (2017) was the only study with students experiencing cybersickness. Therefore, the authors should work towards amending their VR technology before testing students again.

In contrast to the positive feedback on VR, one article rated the VR technology not as effective as 3D printing in presenting the structure of the acetabular fractures (Huang et al. 2018). However, these "against studies" were a minority of the results.

5.4.5 VR for Training

There was an unequal split of the VR articles between training and education. This amounted to 42 (75%) articles related to VR training. Of the 42 articles, 36 (85.7%) articles were concluded as pro, four (9.5%) articles were considered as neutral and two (4.8%) articles were described as against the VR technology. There were more articles in the quantitative and the qualitative group. The results show a strong number of articles classified as pro than neutral or against and shows support for VR as an effective tool for training.

VR has had a positive impact on otolaryngology residents as it raised the confidence levels of the users (Locketz et al. 2017; Fang et al. 2014) resulting in 87.5% agreeing on their increase in confidence levels (Locketz et al. 2017). In addition, VR simulation also helped residents complete a procedure called mastoidectomy (Wijewickrema et al. 2015). Mastoidectomy scores were higher as they did less injury to the nerves nearby. This was an essential skill to learn as resident progresses onto a surgeon the resident should have mastered the mastoidectomy skill or else if nerve injury occurs in patients it can be detrimental to the patients as patients might lose muscle movement. Moreover, the immediate feedback from the simulation was useful for the residents.

Bronchoscopy training was provided to 47 medical students using a VR bronchoscopy simulator, which was quite popular. The simulator allowed the students to increase their bronchoscopy navigational skills and to improve their bronchial anatomy knowledge (Gopal et al. 2018; Latif et al. 2015). This was a skill learned but to see how long the knowledge will last after training was experimented by Latif (2015). Latif (2015) tested on retention levels of their positive bronchoscopy training. After two months, Latif's prediction of losing or decreasing of the learned skill was correct. Furthermore, retraining the same individuals took less time as they were much faster at learning it the second time. This was important as understanding that the simulators have to be used regularly to see retention being stronger. It does however have its limitations. If students stop using the stimulator for a period of time they begin to forget the knowledge acquired. This information was essential for educators so that they know students should use the VR simulators frequently and flexibly.

Conversely, VR was ineffective for residents as the residents test marks were not improved after the VR simulation; however 87% of the students found VR enhanced their learning (Ellington et al. 2018). In addition to this study, Camp (2016) presented that cadaveric dissection was more beneficial to students as it raised residents scores compared to VR simulation which did not improve scores. The results of the simulator being lower may highlight that the simulator was challenging to operate for the residents.

5.4.6 Crucial Factors to Consider

One of the crucial factors to consider was that different individuals have different levels of visuo-spatial ability (Jang et al. 2017). The high visuo-spatial ability of individuals allowed them to create a mental map and navigate using the map through the virtual environment. However, the low spatial ability of individuals did not use an approach like the high visuo-spatial ability (Dünser et al. 2006). In addition, the visuo-spatial ability also determines the choice of technology the individuals will use to study. Low spatial ability individuals benefit more from a desktop VR system to study anatomy; however, individuals with high spatial ability could not use that technology (Jang et al. 2017). In addition, gender differences were also observed in some of the articles, with males performing better than females (Astur et al. 2004) with more females more susceptible to cybersickness than males (Larson et al. 1999). However, in more recent cases gender difference was not observed and now the gender difference topic has been widley disregarded (Thomas et al. 2010; Dünser et al. 2006). In contrast, the technology should support and focus more on enhancing all the students' spatial understanding instead of a specific set of students (Thomas et al. 2010; Ellington et al. 2018).

The technology containing information made available and accessible for students would not be enough to facilitate learning. The technology design should follow the cognitive load theory (CLT). In addition, the designers and educators should understand the CLT in order for technology to be an effective tool for students. Cognitive load theory was the required mental effort to acquire knowledge (Van Nuland and Rogers 2017). There are three types of cognitive load: intrinsic, extraneous and germane. The intrinsic cognitive load was the difficulty of the information presented to the learner. The extraneous cognitive load was referred to the irrelevant extra material in the content. The germane cognitive load was the crucial part for students as this refers to the necessary information that should be transferred from the working memory to the long-term memory (Küçük et al. 2016). In addition, all three types of load was necessary for the learning process as the germane load should be maximised, intrinsic and extraneous loads should be reduced to facilitate learning. Küçük et al. study (2016) demonstrated the mobile augmented reality (mAR), which tested anatomical knowledge and cognitive load of students. The cognitive load scores were lower for mAR group than the control group (using textbooks). As the cognitive scores were lower, the retention of students was higher, therefore the student scores improved. Therefore, if the cognitive load was lower for any technologies then the tool demonstrates effective for learning.

Another crucial factor for technology was many individuals using VR, experience negative side effects (headaches, blurred vision and dizziness) called cybersickness. Cybersickness was caused by either by sensory conflict or postural instability (Rebenitsch and Owen, 2016). In Moro et al. study (2017) also states that the majority of students experienced cybersickness when using VR than the students who learned through AR and tablet-based group. However, cybersickness did not affect the students' scores; however, in the long term there could be a possibility of VR cybersickness hindering the student's ability to learn anatomy. Therefore, if the negative side-effects of cybersickness were prevented or minimised this could provide a better VR experience. Current researches in the field are trying to tackle the side-effects of cybersickness through various ways.

5.5 Conclusions

Many individuals find learning anatomy quite challenging using 2D images and human cadaveric dissection. The modern technological advancement brings more resources such as AR and VR to aid studying anatomy and the use of these technologies provides another educational resource for our students and users. It is also important to consider published literature and what type of activities or statistics are being measured, and why. Educators should be also aware that technology is not always perfect. Educators and designers of the technology should understand and be aware of the crucial considerations for the users to sustain a positive experience and also to aid in studying anatomy. This will lead to educators making an accurate decision on which AR and VR technology to invest on for students to secure a positive experience.

As the majority of the literature examined was pro for the technology, the next step will be to implement both AR and VR into anatomical education on a wider scale. AR and VR should not substitute human cadaveric dissection, but technologies can complement the resources available to students. Therefore, multiple resources would cover a wider range of student's learning styles – the greater number of resources available to the user, hopefully the better engagement of a wider population.

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Interdimensional Travel: Visualisation of 3D-2D Transitions in Anatomy Learning

6

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Abstract

Clinical image interpretation is one of the most challenging activities for students when they first arrive at medical school. Interpretation of clinical images concerns the identification of three-dimensional anatomical features in two-dimensional cross-sectional computed tomography (CT) and magnetic resonance imaging (MRI) images in axial, sagittal and coronal planes, and the recognition of structures in ultrasound and plain radiographs. We propose that a cognitive transition occurs when initially attempting to interpret clinical images, which requires reconciling known 3D structures with previously unknown 2D visual information. Additionally, we propose that this 3D-2D transition is required when integrating an understanding of superficial 2D surface landmarks with an appreciation of underlying 3D anatomical structures during clinical examinations.

Based on educational theory and research findings, we recommend that 3D and 2D approaches should be simultaneously combined within radiological and surface anatomy education. With a view to this, we have developed and utilised digital and art-based methods to support the 3D-2D transition. We outline our observations and evaluations, and describe our practical implementation of these approaches within medical curricula to serve as a guide for anatomy educators. Furthermore, we define the theoretical underpinnings and evidence supporting the integration of 3D-2D approaches and the value of our specific activities for enhancing the clinical image interpretation and surface anatomy learning of medical students.

Keywords

Clinical image interpretation · Surface anatomy · 3D-2D transition · Artistic and art-based learning · Digital visualisation · Technology-enhanced learning

6.1 Curricular Integration of Clinical Imaging and Surface Anatomy

6.1.1 Clinical Image Interpretation

Identifying clinically relevant anatomical features in radiological images is an essential skill required by doctors (General Medical Council 2009; Royal College of Radiologists 2019;

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World Health Organization 2019), as practicing clinicians are often exposed to human anatomy in the context of clinical imaging (Gunderman and Stephens 2009; Smith-Bindman et al. 2008). As such, the interpretation of diagnostic images is recommended for all anatomical regions in the Anatomical Society regional anatomy syllabus for undergraduate medicine in Great Britain and Ireland (Smith et al. 2016). Early integration of radiology within medical curricula can also be valuable for the student experience of imaging (Kraft et al. 2018). However, we recommended that clinical imaging should be incorporated into undergraduate medical curricula in order to support an understanding of anatomical concepts rather than to prepare students to become radiologists (Keenan and Ben Awadh 2019). In our experience, clinical image interpretation is one of the most troublesome anatomy learning challenges experienced by students when beginning medical school (Ben Awadh et al. 2019). This is likely to be due to the cognitive demands of adjusting to applying mental constructs of 3D anatomy in order to decipher information in 2D cross-sectional slices. For example, visualisation of the anatomical positioning of the heart in 3D will inform interpretation of the arrangement of the atria and ventricles in a CT scan. Medical student understanding of anatomy can be enhanced through exposure to radiology (de Barros et al. 2001; Dettmer et al. 2010; May et al. 2013; Slon et al. 2014) and there is support for the integration of clinical imaging into medical curricula (Nyhsen et al. 2011, 2013) and within anatomy learning (Al Qahtani and Abdelaziz 2014; McLachlan 2004; Miles 2005; Nyhsen et al. 2013).

6.1.2 Interpretation of Internal Living Anatomy Based on Surface Markings

An effective knowledge of surface anatomy and the ability to interpret internal living anatomy based on external surface markings during physical examinations is likely to be frequently applied during the practice of the majority of clinicians. Surface anatomy is consequently regularly delivered and practically utilised during medical school in the context of clinical skills classes and clinical placements. Accordingly, surface anatomy is also a key element of the Anatomical Society core syllabus (Smith et al. 2016). A variety of approaches have been introduced into medical curricula in order to specifically deliver this area of anatomy learning (Azer 2011, 2013; Collins 2008; Sugand et al. 2010). The benefits of constructive, collaborative, contextual, and self-directed surface anatomy learning have been described (Bergman et al. 2013), virtual and digital technologies have been introduced (Kerr et al. 2000; Patten 2007), and positive student experiences and knowledge gains have been identified through the painting of underlying anatomical structures directly on to the skin (Bennett 2014; Finn 2010; Finn and McLachlan 2010; McMenamin 2008).

In a similar challenge to clinical image interpretation, surface anatomy requires the mental visualisation of anatomical structures that are not being simultaneously observed, knowledge that is likely to be cognitively accessed based on a prior understanding of internal 3D anatomy. For example, identifying the auscultation points for the heart valves not only requires identification of the correct position within an intercostal space through palpation, it also requires an understanding of the spatial positioning and internal anatomy of the heart relative to the ribs and sternum. We therefore propose that the processes involved in interpreting 2D and 3D features during surface anatomy learning are likely to be similar to those applied in the context of clinical image interpretation. As such, similar learning activities can be introduced to enhance progression through this 3D-2D transition in both clinical imaging and surface anatomy.

6.2 3D-2D Transition in Clinical Image Interpretation and Surface Anatomy

6.2.1 Theoretical Underpinnings

Becoming accustomed to unfamiliar cross-sectional anatomical views presented within clinical images is seemingly an important initial step in the 3D-2D transition that is likely to occur during the early stages of medical school. This process initially involves developing an appreciation of the orientation of the patient and the coloration of specific anatomical structures presented in each type of clinical image (e.g. the darkest areas on a CT scan indicating air). Once these basic concepts are understood, the identification of increasingly complex features can be achieved through an understanding of anatomical relationships (e.g. the position of the mediastinum between the lungs), and based on notable and readily identifiable landmarks and their expected vertebral levels within cross-sectional images (e.g. bifurcation of the trachea into the right and left bronchi at approximately T4). The progressive increases in complexity of this activity suggests that building on prior knowledge (Ausubel 2012) and scaffolding (Vygotsky 1978; Wood et al. 1976) are important concepts to consider. Evidently, students should understand the underlying principles of clinical imaging before they attempt to identify the anatomy they are observing in cross-sections, and in our experience, preparation appears to be a key factor influencing image interpretation ability (Keenan and Powell, unpublished observations). The importance of prior knowledge is further supported by findings from a recent study investigating the value of a digital 3D micro-CT model for anatomy learning (O'Rourke et al. 2019). We therefore recommend that preparatory anatomical study on the region, system or structures to be visualised should be completed prior to engagement in the basics of clinical image interpretation, rather than gross anatomy and radiology being first introduced to students within the same teaching event. This can be achieved through lecture-based teaching, self-directed workbooks and online tutorials, or a strategic flipped approach (Moffett 2015) to encourage students to become accustomed with fundamental gross anatomy knowledge prior to practical study alongside image interpretation.

Constructivist theory (Kolb 1984; Vygotsky 1978), cognitivist theory (Ausubel 2012), cognitive load theory (CLT) (Huk 2006; Khalil et al. 2005; Sweller 1988) and threshold concepts theory (Meyer and Land 2003) can all inform 2D-3D anatomy learning activities. More specifically, taught and self-directed 3D radiology visualisation activities have been successfully integrated based on the principles of constructivist (Chau et al. 2013; Dalgarno 2002; Huang et al. 2010) and problem-based learning theory (Silén et al. 2008). Considering objects in 3D can increase cognitive load, while reductions can be achieved through multimodality and integration of learning resources (Van Merriënboer and Sweller 2010). This may be accomplished through providing a range of both 3D and 2D learning activities and using both virtual and physical resources. Furthermore, utilising a variety of resources can intrinsically enhance learning (Eagleton 2015; Ward and Walker 2008). While challenging, the process of clinical image interpretation itself is unlikely to be defined as a threshold concept, as it is improbable that the development of this ability can transform an overall understanding of the discipline of anatomy, which is a key requirement underpinning this theory (Land et al. 2005; Meyer and Land 2003, 2005; Meyer et al. 2010). Nonetheless, the processes of critical observation, visualisation and reflection that are required during image interpretation may themselves be threshold concepts for students in the context of anatomical and medical education. These abilities should therefore be supported by any educational intervention seeking to enhance radiology teaching.

A conceptual framework for providing insights into how medical students interpret internal 3D anatomical features based on surface markings and in clinical images can be considered in terms of cognitivism and empiricist learning theories (Dennick 2008), which include the concepts of building upon prior knowledge (Ausubel 2012) and Kolb's experiential learning cycle (KLC) (Kolb 1984), which is itself based on three previous models (Dewey 1938; Lewin 1942; Piaget 1970). Our previous work has shown that that our *Observe-Reflect-Draw-Edit-Repeat* (ORDER) cycle of experiential learning, which is based around the concepts of knowledge transformation through observation and reflection described in KLC, can enhance acquisition of surface anatomy and gross anatomy knowledge (Backhouse et al. 2017). We propose that implicitly integrating ORDER into clinical imaging activities can also improve student abilities in identifying anatomical features in cross-sectional images. The modality appropriateness concept (Lodge et al. 2016), which we have previously outlined as an effective model to describe student learning approaches (Keenan and Ben Awadh 2019) suggests that visual 3D and 2D resources should be used to support learning of 3D and 2D concepts in anatomy and clinical imaging. Furthermore, a study comparing the value and limitations of 3D and 2D imaging in medicine has concluded that due to their differing qualities, both 3D and 2D approaches should be combined (Ballantyne 2011). Based on these principles, we have introduced digital and art-based approaches incorporating physical and virtual resources in both 3D and 2D modalities, and the requirement to complete preparatory work before engaging in these activities. Time on task is an important consideration for learning (Chickering and Gamson 1987; Fasel et al. 2005; Gibbs 2010) and is likely to influence performance in clinical image interpretation and surface anatomy. Widespread integration of these activities into anatomy learning is therefore likely to be necessary within medical curricula in order to optimise learning gains from such approaches.

6.2.2 Spatial Ability

Factors which have previously been identified that could influence anatomy learning include gender (Foster 2011; Kelly and Dennick 2009), learning preferences (O'Mahony et al. 2016; Svirko and Mellanby 2008), artistic background characteristics (Backhouse et al. 2017) and spatial ability (Fernandez et al. 2011; Garg et al. 2001; Guillot et al. 2007; Lufler et al. 2012; Nguyen et al. 2014; Sweeney et al. 2014). All of these aspects should therefore be considered when designing clinical imaging and surface anatomy learning activities. However, a recent systematic review has emphasised the importance of spatial ability in anatomy learning (Langlois et al. 2017) indicating that addressing this element should be a priority. The authors of the review identified studies in which positive relationships had been found in terms of student spatial ability and their performance in understanding cross-sections (Provo et al. 2002) and synthesising 3D representations from 2D images (Luursema et al. 2008; 2006; Nguyen et al. 2014; Provo et al. 2002).

While the mechanisms involved in spatial learning are not fully understood, spatial ability can be described as mental manipulation of objects achieved primarily through visual observation. As we have previously described (Keenan and Ben Awadh 2019), spatial ability consists of several related processes (Carroll 1993). View-based (Lawson et al. 1994; Tarr and Bülthoff 1998) and structure-based (Marr and Vision 1982) approaches have been proposed to describe how the brain mentally constructs 3D images from 2D information. Evidence appears to support the view-based approach (Garg et al. 2001; Wu et al. 2010, 2012), which suggests that 3D constructs are cognitively built from the various 2D views of an object that the eyes observe, and is therefore relevant to the 3D-2D transition.

Although the ability to transfer learning between 2D images and 3D objects arises during early infancy (Barr 2010), the mental manipulation and switching between visualising in three versus two-dimensions when attempting to identify 3D anatomical structures in 2D clinical images (Fernandez et al. 2011; Marks 2000) is challenging for adults and is likely to be where obstacles to understanding arise (Ben Awadh et al. 2019). Due to the likelihood that spatial ability is key to undergoing the 3D-2D transition in clinical image interpretation, it is important to note that this may be a task that students with a higher level of spatial ability will find less troublesome. While engagement in anatomy learning can enhance spatial ability, consideration of training and assistance for students with lower levels of spatial ability and limited prior exposure to anatomy is likely to be necessary (Lufler et al. 2012). We propose that the elements of pre-work, interactive collaboration and peer-peer encouragement within our specific 3D-2D activities, in addition to the simultaneous usage of 3D and 2D resources, can support the learning of students of all spatial abilities.

6.2.3 Student Partner Perspectives

As previously described (Backhouse et al. 2017), we have utilised a student partner approach (Healey et al. 2014) for the creation, evaluation and implementation of innovative learning approaches within anatomy curricula. Author MP contributed to this work as a student partner pursuing a project exploring the development of learning resources to support clinical imaging interpretation. As MP is currently a medical student, she is in a unique position to be able to offer her own insights into the learning challenges involved in clinical image interpretation:

> With many medical schools integrating early clinical experiences into their curricula, exposure to clinical imaging can begin alongside or even before formal anatomy teaching. In my experience, this would not give students sufficient opportunity to orientate themselves around the internal map of the human body and be able to interpret it from 2D and 3D views. Having completed my scholarship project on 3D-2D anatomy learning before commencing medical school, I had already orientated myself to the basics of a CT scan image through the time spent developing learning resources. However, I witnessed many of my fellow medical students twisting and turning their heads on their first exposure to clinical imaging in order to orientate themselves. After a few minutes, some would let out a sigh of relief as they could finally visualise the anatomy in front of them, but for many it took repeated exposure throughout the year for the orientation to ‘click’. This has shown me how challenging this process can be and therefore how important it is that appropriate support is provided to students.
>
> My experience of interactive lecture-based clinical image interpretation has involved being presented with a variety of X-rays, CT scans and MRI images relevant to particular specialties, e.g. trauma, neurology and oncology. Students were taken through key structures and then tested when labels were removed. This approach encouraged rapid identification of structures when presented with the same X-ray, CT or MRI view as those taught. In this context however, image interpretation becomes more challenging when students are presented with unfamiliar views. It is therefore important to supplement this method through encouraging 3D understanding and appreciation of anatomical structures within 2D images in the practical environment.
>
> Repeated exposure to the same cadaveric donor body through dissection has helped me to develop a 3D blueprint of human anatomy that is now engrained in my mind. I often use this blueprint, manipulating it in my head while trying to interpret clinical images. Learning radiology alongside cadaver teaching could therefore be very helpful for all students in terms of the 3D-2D transition through having access to 3D anatomy and 2D images at the same time. It is also important to explicitly communicate image interpretation to students as a potential area of difficulty so that they can address this directly within their own learning strategies. Following evaluation, 3D and 2D methods should be widely implemented to encourage learning and reinforce the 3D-2D transition for students.

6.3 Learning Approaches to 2D-3D Transition in Clinical Imaging and Surface Anatomy

6.3.1 Digital Approaches to 2D-3D Transition

Standard approaches to integrated anatomy and radiology teaching can include dynamic 2D clinical images or practical modalities such as ultrasound (Knudsen et al. 2018) alongside text book illustrations and cadavers. Traditional learning activities that support the 3D-2D transition may include 3D prosections and plastic models for exploration of the 3D arrangement of anatomical structures while simultaneously viewing 2D cross-sectional images. More recently, technology-enhanced learning (TEL) approaches, which possess specific educational advantages (Keenan and Ben Awadh 2019) have become readily available for supporting clinical image interpretation. Visualisation tables, autostereoscopy screens and 3D printed (3Dp) models can be valuable TEL resources in anatomy education (Keenan and Ben Awadh 2019). A wide variety of 3D digital anatomy resources are available, but can be of varying quality and impacts on learning (Zilverschoon et al. 2019). In addition to the visualisation approaches described above, we have delivered teaching of cross-sectional images within the interactive Virtual Human (VH) Dissector software (Donnelly et al. 2009; Fogg 2007; Touch of Life Technologies 2019) and presented X-ray and CT images on tablets within the dissecting room. However, despite being valued by students and increasing in popularity and usage, (Davis et al. 2014; Evgeniou and Loizou 2012; Khan et al. 2009; Link and Marz 2006) many TEL anatomy resources can be limited to 2D images, and 3D digital models may not always be as effective as physical anatomical models for learning (Preece et al. 2013; Wainman et al. 2018). It is therefore likely to be important to include physical anatomy resources alongside digital representations, and to support the 3D-2D transition through combining actual and virtual models.

For example, 3Dp models of the heart can be given to students to hold, view, rotate and manipulate while they simultaneously view cross-sectional images through the heart on a visualisation table or VH Dissector. The 3D aspects of this approach can be replicated through combined use of 3Dp models and an autostereoscopy screen. In this way, 3Dp models and 3D autostereoscopic representations produced from the same image files can be handled and viewed on screen simultaneously, alongside the original cross-sectional images. Combinations of any or all of these 2D-3D approaches may also be effective and may include images showing pathologies as well as normal anatomy.

6.3.2 Art-Based Approaches to 2D-3D Transition

We propose that the development of observational and cognitive skills that are required for clinical image interpretation are likely to be enhanced through engagement in art-based learning approaches. We have shown that there is limited influence of artistic background on learning anatomy using an art-based approach, suggesting that even 'non-artistic' students can benefit from such approaches (Backhouse et al. 2017). Further to our recommendations (Keenan et al. 2017), an additional consideration when planning implementation of art-based learning approaches in anatomy education is described by MP:

> From my experience, medical students are very rigid in their studying and learning methods and can be very unreceptive to change unless there is good evidence that this change will improve their performance. For example, if I had not been exposed to using artistic methods to help learn 2D-3D anatomy through my project before medical school, it would have been very difficult to convince me that this method would be of benefit. I had never used artistic methods of learning before and very much considered myself 'artistically challenged'. However, I have found artistic methods particularly useful when studying at home outside of the dissecting room, reinforcing what I have learnt and using it to help with visualisation in different dimensions.

Art-based methods can incorporate principles of active learning (Freeman et al. 2014; Hake 1998) and in the context of anatomy education may involve 2D cross-sectional drawing and 3D clay modelling (Backhouse et al. 2017; Keenan et al. 2017; Lyon et al. 2013; Naug et al. 2011; Oh et al. 2009), in addition to papercraft modelling (Hiraumi et al. 2017) and the recently introduced TEL approach of screencast drawing (Greene 2018; Pickering 2017). Our appreciation of the importance of haptic learning and the value of utilising of physical models in addition to digital models (Wainman et al. 2018) has been strengthened by our collaboration with *Haptico-visual observation and drawing* (HVOD) creator Leonard Shapiro. The HVOD process has been shown to enhance memorisation and a deep understanding of 3D anatomy (Reid et al. 2018; Shapiro et al. 2019). Furthermore, comparisons of sliced clay anatomical models with clinical images can provide an effective means for demonstrating cross-sectional anatomy (Oh et al. 2009), clay modelling combined with dynamic clinical imaging resources can enhance understanding of MRI and CT scans (Jang et al. 2018) and the value of multi-modal artistic approaches including clay modelling and body painting have been shown to positively impact upon assessment scores (Nicholson et al. 2016).

6.3.2.1 Art-Based Activities Supporting the 3D-2D Transition in Clinical Imaging

We have further developed our ORDER art-based learning process, that was originally designed for surface and gross anatomy education (Backhouse et al. 2017), to be used for clinical image interpretation. Our ORDER imaging process can include 2D cross-sectional drawing from 3D cadavers or models in addition to the reciprocal transition of constructing 3D models from 2D images, while implicitly guiding students through collaborative observation, visualisation, drawing or modelling and reflection. The activity can be run concurrently in the anatomy laboratory, ideally with small groups of around 8–12 students. Pre-work on the topic concerned will have been completed by students before attending the practical class. The students are divided into two teams, with each team then asked to draw a large cross-section through a particular transverse plane of the human body on a marker board. For example, in a class concerning the anatomy of the hepatobiliary system, one team may be asked to draw a cross section through T10 and would be expected to include labelled anatomical features such as the liver, oesophagus, stomach, spleen, thoracic aorta, inferior vena cava and portal vein in their drawing. The other team would be simultaneously asked do the same at T12, and would be expected to identify and label features including the liver, gallbladder, pancreas, duodenum, spleen, left kidney, coeliac trunk and splenic artery.

Before commencing drawing however, students are asked to visually observe, palpate and haptically explore the gross anatomy of the abdomen without being simultaneously or previously exposed to any cross-sectional information. Students are asked to examine and discuss 3D prosections, skeletons and plastic model resources to facilitate their visualisation of how a cross-section through these 3D resources would appear and which structures would be present at specific level they are considering. It is recommended that students begin by creating a large oval shape drawn on the marker board as their cross-section, identify the orientation of their ‘patient’ and add labels for left, right, anterior and posterior. Students are then able to begin adding anatomical structures to their 2D drawings while visiting and revisiting the 3D resources. Students are also permitted to refer to all other available resources provided that no cross-sectional images are viewed.

The purpose of the exercise is that students are encouraged to cognitively manipulate 3D anatomical information to create a mental visualisation of a 2D cross-section, which they then physically transfer into a drawn representation. As such, novices, experienced students and even postgraduate trainees can all find this activity challenging. In our experience, the nature of the cognitive demands of this activity can lead to important insights and understanding of both 2D cross-sections and 3D anatomy. The expectation should not be that students create an exact image of the cross-section or visually appealing drawing (Keenan et al. 2017), but rather that they learn from the experience of progressing through the 3D-2D transition and then reflect on how their drawing compares to an actual cross-section at that level in terms of the size, shape and position of structures.

Having completed their drawings in around 10–15 min, students are taken through the cross-sections at T10 and T12 by their facilitator, using the VH Dissector (Fig. 6.1) shown on a large screen. Students are encouraged to scrutinise their own drawings in comparison with the VH Dissector image, and in addition to determining the accuracy of their labelling of named structures, to identify where they have correctly drawn structures in terms of size, shape and position, and also the areas where they have been unable to accurately represent the anatomy. Effective learning can arise during this reflective process and if time allows, the extent to which students have learned can be demonstrated through their repetition of the process at an alternative vertebral level. This activity can also be performed in other parts of the body and can be particularly effective when considering the muscle compartments of the limbs and their contents including nerves and blood vessels.

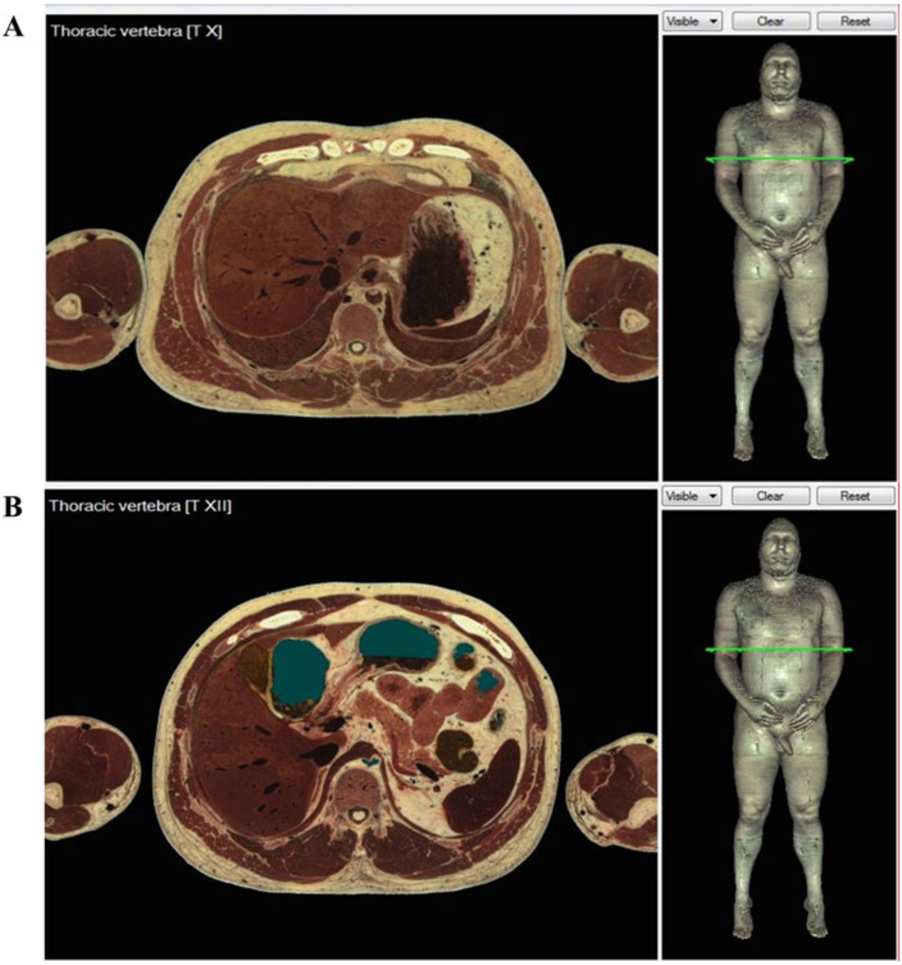

Fig. 6.1 Examples of VH Dissector Pro software (version 5.2.62, Touch of Life Technologies) views when used to show transverse cross-sections through the virtual human at T10 (**a**) or T12 (**b**) as per the described liver cross-sectional drawing activity. When using the software, labels appear when hovering the cursor over features on the cross-sectional image. Specific anatomical features can be selected and highlighted in various colours in the cross-section. Among other features, the VH Dissector software also allows virtual dissection of the 3D virtual human. Images of the VH Dissector software are used with permission courtesy of Touch of Life Technologies www.toltech.net (Touch of Life Technologies 2019)

While drawing a cross-section based on observation of cadaveric specimens and plastic models can support a 3D to 2D transition, the opposite process can be achieved through engaging students in the creation of 3D viscera from modelling clay based on a 2D image. They again follow the ORDER cycle, whereby the ‘draw’ step becomes ‘do’ with respect to the process of model construction. For example, having performed the cross-sectional drawing activity with respect to levels through the heart, students could then asked to observe and reflect upon 2D images of the different surfaces of the heart, or potentially cross-sections at multiple levels through the heart, and then asked to build a 3D clay model showing the chambers, coronary vasculature and relationships with the great vessels. After a first attempt using only the 2D images as reference, students can then be shown 3D plastic models, 3Dp models, or prosections to use as reference to edit their clay models. Once students are satisfied with their models, they repeat observation and reflection of the anatomy by rotating and identifying key anatomical features from different orientations of their models. This activity can also be applied to other relevant viscera in the context of further practical classes. From our observations and evaluations of the ORDER 3D-2D drawing and modelling approach, we have found that many students consider that these activities enhance their knowledge of anatomy and improve their skills in interpreting clinical images. Students also perceive some value in the engaging and interactive design of the learning activities (Keenan and Powell, unpublished observations).

6.3.2.2 Art-Based Activities Supporting the 3D-2D Transition in Surface Anatomy

Surface anatomy can essentially be described as a 2D discipline as it relies upon identification of superficial structures, while simultaneously visualising the position of internal 3D anatomy. The popularity and usage of bodypainting has increased in recent years, likely due to the active nature of this approach, and the enhancement of student engagement in the context of reconciling surface landmarks with gross anatomical knowledge, a concept required for successful clinical examination (Bennett 2014; Finn and McLachlan 2010; Finn et al. 2011; McMenamin 2008). However, it could be considered that bodypainting does not facilitate observation of internal structures in 3D and thereby does not directly support an understanding of the 3D spatial and positional relationships of the underlying anatomy in relation to surface landmarks. Limitations in terms of the practical application of body painting have also been identified (Aggarwal et al. 2006; Sugand et al. 2010).

We have designed a surface anatomy learning activity involving both 2D and 3D modalities in which students create 3D organs from modelling clay including the heart, kidneys and spleen (Fig. 6.2) (Keenan et al. 2017). Students attempt to reproduce viscera at the correct anatomical size and shape based on their prior knowledge of the anatomy, and then seek to place their 3D models within plastic skeletons based on the identification of bony surface landmark which can be considered essentially as 2D when viewed on a living patient. Facilitators are then able to provide feedback on student models and positioning. Evaluation has provided insights into student learning and experience when engaging in this activity (Keenan and Tiri, unpublished observations). Students have found this approach to be engaging and collaborative:

> ‘The modelling session allowed everyone to get involved’; ‘I enjoyed the interactive element, and

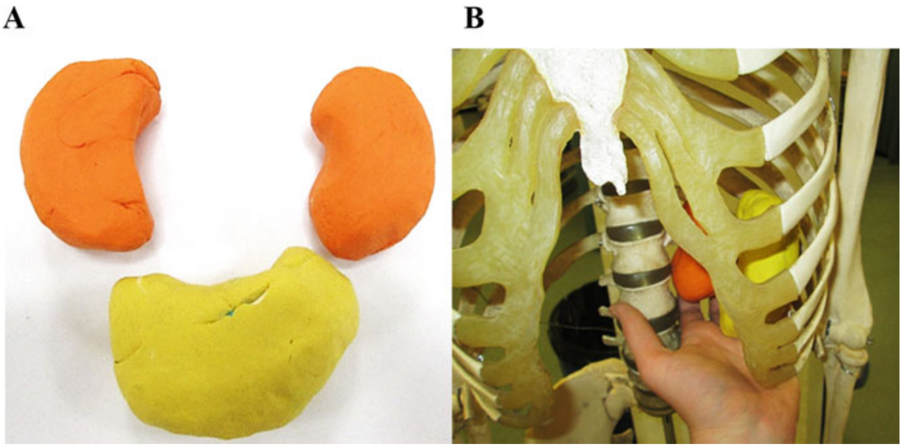

Fig. 6.2 Modelling clay can be used to create visceral organs such as the kidneys and spleen (**a**), which can then be placed within a skeleton (**b**) (Keenan et al. 2017). This process can support an appreciation of surface landmarks simultaneously combined with 3D positional and spatial understanding of internal anatomy. (Images courtesy of Amy Tiri)

> the engaging aspects of the session'; 'I could discuss my ideas with other students'; 'It required more application of knowledge than using cadaveric specimens'.

Students also perceived that this approach enhanced their understanding and appreciation of the 3D nature of abdominal viscera:

> 'Modelling gave me a good idea of the sizes and shapes of different body parts'; 'It was interesting to be able to see and feel how organs were spatially arranged around each other'; 'It was useful when holding the viscera we had made to give a representation of where things are in relation to each other'; 'Modelling gave a better 3D representation of the different structures'; 'It provided a means to visualise anatomy in 3D as it can be difficult to interpret 2D text book images into 3D'.

Furthermore, feedback indicated that the process had supported student appreciation of relationships of internal structures with surface landmarks:

> 'Putting models organs onto the skeleton helps with understanding of surface anatomy'; 'It was helpful to see organs to scale within the skeleton'; 'Holding the organs inside the skeleton helped me to visualise where they should sit'; 'It was useful to find out the size of organs in relation to the skeleton, which is sometimes lost in the isolated specimens in the dissecting room.'

6.4 Summary and Future Directions

Learning approaches which utilise a combination of both 2D and 3D learning resources can support development of student skills, abilities and understanding in observation, visualisation and the interpretation of anatomical features in cross-sectional clinical images and surface anatomy through facilitating a cognitive 3D-2D transition in learning. It is therefore recommended that learning activities which utilise a simultaneous combination of 3D and 2D resources are integrated into anatomy education. Such approaches can incorporate traditional, art-based and digital methods as well as combinations thereof. Our future work will describe our research that has investigated how combined usage of 3Dp models and 2D digital images can enhance the interpretation of anatomical features in cross-sectional clinical images in practical and self-directed learning environments.

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7

Anatomy Visualizations Using Stereopsis: Assessment and Implication of Stereoscopic Virtual Models in Anatomical Education

Edgar R. Meyer and Dongmei Cui

Abstract

Anatomical knowledge, such as gross anatomy, neuroanatomy, histology, and embryology, involve three-dimensional (3D) learning and interpretation. Virtual 3D models especially have been used in the anatomical sciences both as a supplement to traditional anatomical education with cadaveric specimens and as a substitute for cadavers at institutions that do not utilize human donors for educational purposes. This paper discusses the methods used to assess the models' validation and accuracy, as well as suggestions for the models' improvement. This paper also aims to describe students' learning of anatomy using stereoscopic 3D models and provides a summary of the results from the literature concerning students' performance outcomes using virtual stereoscopic models as well as both students' and experts' perceptions of their utilization. There have been mixed results in the literature concerning the effectiveness of virtual 3D anatomical models in general, but there is limited research on stereoscopic anatomical models specifically. Stereoscopic anatomical models have shown to improve the learning of students, particularly for the students with low spatial ability, and they have the potential to enhance students' understanding of 3D relationships.

Keywords

Evaluation · Stereoscopic models · Virtual 3D models · Anatomy · Teaching · Education

7.1 Introduction

7.1.1 Literature Review

When many people think about virtual three-dimensional anatomy, they imagine the viewing of digital anatomical models on a computer screen. Although these models can often be rotated in three dimensions, their rotation is confined to the two-dimensional surface of the flat screen. These types of virtual models are called monoscopic models. Unlike monoscopic models, stereoscopic 3D anatomical models incorporate two digital images which are visualized separately, each with a different eye, so that the brain perceives one image that, in reality, is composed of two images overlain on top of one another.

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In order to visualize stereoscopic models, the viewer must wear glasses with polarized or color anaglyph lenses that allow the viewer to perceive structures as in a 3D movie whereby the anatomical structures appear to "pop out" at the viewer, floating in mid-air in the center of the room.

A recent review article promoted digital technologies in anatomical education overall; however, in almost two thirds of the articles discussed, the digital technologies were not empirically tested (Pringle and Rea 2018). Only about 60% of the remaining third of the studies featuring empirically tested technologies promoted those technologies (Pringle and Rea 2018). Another review article referenced a number of educational studies proposing positive, negative, or neutral outcomes of the use of virtual anatomical models in comparison with other forms of anatomy learning, but it did not specify which studies utilized stereoscopic models (Azer and Azer 2016). In fact, few studies that explore the impact of computerized 3D models on students' learning portray the models in stereoscopic presentation (Luursema et al. 2006, 2008, 2017; Hilbelink 2009; Luursema and Verwey 2011; Brewer et al. 2012; Roach et al. 2014; Cui et al. 2017; Remmele et al. 2018). This paper will focus mainly on the use of stereoscopic models in anatomy learning.

7.1.2 Evaluation of the Effectiveness of Virtual Models

Although 3D models are increasingly used in anatomy education, the images are often limited to online use and monoscopic visualization. The use of stereoscopic 3D anatomical images in a virtual reality environment to teach anatomy and evaluate learning outcomes is still less common (Brown et al. 2012; Anderson et al. 2013; Kockro et al. 2015; Remmele et al. 2015, 2018; Luursema et al. 2017; Cui et al. 2017). One such study addresses the positive impact of a stereoscopic model of cerebral vasculature on first-year medical students' learning of the cerebral arteries (Cui et al. 2017). The study by Kockro and colleagues showed that second-year medical students could learn ventricular anatomy with virtual 3D stereoscopic images just as well as 2D images; however, while the students' mean scores in the 3D group were higher than those in the 2D group, they were not significantly different (Kockro et al. 2015). In another study, medical and dental students learning with static two-dimensional images of the larynx performed better on the written assessment than the students learning with the 3D model of the larynx (Hu et al. 2010), and another study showed no significant difference between the learning outcomes of 2D and 3D groups of junior physicians using this same larynx model (Tan et al. 2012). Nevertheless, in these particular studies, the larynx model was not visualized by the subjects in a stereoscopic format though the Amira software used to construct it has capabilities of displaying the model stereoscopically.

A series of studies conducted by Luursema and colleagues showed the positive effects of stereopsis on anatomy learners (Luursema et al. 2006, 2008; Luursema and Verwey 2011). While these studies offer important insight into the benefits of stereopsis to learning, they do not explore the effects of stereopsis on medical students', residents', or other healthcare students' and practitioners' learning of anatomy. An additional study by Luursema et al. though showed no significant differences in learning outcomes for medical students for the stereoscopic and non-stereoscopic learning conditions for the anatomy of the neck (Luursema et al. 2017). These results suggest more research on the effectiveness of stereopsis in helping medical students learn other regions of anatomy is needed. In addition, more research on the impact of stereopsis in teaching medical trainees is warranted.

7.1.3 Students' Short-Term and Long-Term Retention

While there are mixed results on the effectiveness of 3D anatomy in improving students' learning in general (Azer and Azer 2016; Brazina et al. 2014; Cui et al. 2017; Estai and Bunt 2016; Murgitroyd et al. 2014), studies mention the need for exploring the impact of 3D models on students' long-term retention of anatomical information (Azer and Azer 2016; Van Nuland and Rogers 2016). Studies have been conducted to assess the retention of basic science knowledge, including anatomy, among medical students (Custers 2010; Malau-Aduli et al. 2013). One study showed that team-based learning had a positive impact on the short-term retention of students in a pre-clinical pediatric curriculum, but not on their long-term retention of information (Emke et al. 2016).

The review study by Custers showed that on average, medical students retain approximately half of the information they learn in medical school after a period of 2 years when they are not exposed to the material (called the retention interval) and only about 30% of the information after a similar period of more than 4 years (Custers 2010). Another study by Malau-Aduli et al. on second- through fifth-year undergraduate medical students demonstrated a correlation between students' perception of the clinical relevance of information and their retention of that respective information (Malau-Aduli et al. 2013). These students on average performed lower on the retention tests pertaining to anatomy content compared to other basic sciences such as biochemistry, pathology, pharmacology, and physiology (Malau-Aduli et al. 2013). The fear then is that if the clinical relevance of certain anatomical information is not made clear to students, they will more easily forget the information. A study by Emke and colleagues found that even though a lecture-plus-TBL curriculum for preclinical medical students on pediatrics rotations was better at achieving higher knowledge gains at the end of a course than a lecture-only curriculum, the long-term retention of information was still low (Emke et al. 2016). Thus, ways of improving long-term retention in medical students need to be explored further. Therefore, the development of valid 3D stereoscopic anatomical models and their impact on anatomy learning and retention should be explored further.

7.1.4 Assessment of Virtual Models and Their Validation

Given the mixed results of the effectiveness of 3D anatomical virtual models in improving students' learning of anatomy (Azer and Azer 2016), there is a need for testing the validity of constructed stereoscopic models. Measures have been performed to test the validity of 3D imaging models in various disciplines such as radiology (Zheng et al. 2016), dentistry (Moreira et al. 2014), and kinesiology (Pohl et al. 2010). Therefore, similar measures were implemented in the creation of valid 3D stereoscopic models for anatomy learning.

In order to ensure the creation of valid anatomical models, an assessment instrument for measuring 3D models of anatomical structures can be generated using expert opinions. One of the first steps in acquiring expert opinions involves the Delphi method procedure which involves administering a series of two or more rounds of questionnaires to a team of experts in a particular field or discipline (Dalkey and Helmer 1963; Helmer 1963; Hardy et al. 2004; Okoli and Pawlowski 2004; Hasson and Keeney 2011; Rowe and Wright 2011; Paré et al. 2013).

Secondly, the validity and reliability of the instrument itself must also be considered in the process of gathering information for its construction. Hasson and Keeney cite a number of studies emphasizing the fact that there is controversy over the validity and reliability of the Delphi method (Hasson and Keeney 2011), and according to Hardy et al., the validity and reliability of this method are hampered by the inconsistent characteristics of the Delphi method used in studies, such as its application, design, administration, and analysis (Hardy et al. 2004). In order to improve the validity and reliability of the Delphi method, recommendations can be followed in the form of a series of guidelines (Hasson and Keeney 2011; Rowe and Wright 2011) and a table of validated "attributes" for assessing the reporting of the Delphi procedures (Paré et al. 2013). These measures, in turn, ensure that correct methods for validating models are applied to those like virtual stereoscopic anatomical models.

7.2 Stereopsis and Learning: An Explanation

Stereopsis is a popular topic in research. It has been shown to be important in a number of human activities or abilities, such as depth perception (Bishop 1987; Westheimer 1994; McKee and Taylor 2010), reading (Stifter et al. 2005), observations of 3D visualizations (Wickens et al. 1994; Kim et al. 2013), and visually aided kinesthetic practices (Servos et al. 1992; Fielder and Moseley 1996; Melmoth et al. 2009; O'Connor et al. 2010; Bloch et al. 2015). In addition, stereoscopic visualization has been shown to be significantly better than monoscopic visualization in allowing children and adults between the ages of 18 and 40 to perform multiple-object tracking tasks (MOTs) which are similar to navigating through crowds (Plourde et al. 2017). Very recently, a computer video game improved the stereoacuity of individuals with deficiencies in stereoscopic capacity (Portela-Camino et al. 2018).

Stereopsis is now also relevant to anatomical education. There was no significant difference observed between students learning from monoscopic or stereoscopic models of neck anatomy (Luursema et al. 2017) or between surgical trainees learning with stereoscopic or monoscopic laparoscopic simulations (Roach et al. 2014). However, a study involving a stereoscopic model of head and neck vasculature has shown significant differences in first-year medical students' learning of two-dimensional versus 3D stereoscopic images of head and neck vasculature (Cui et al. 2017). Such examples of varying results in the literature warrant exploration of model validation and assessment.

7.3 Methodology of Model Validation and Assessment

The method of validating anatomical models specifically described in this paper is the Delphi method. The Delphi method has been historically involved in the development of criteria lists based on experts' opinions—these experts being clinicians and basic scientists. Two studies in particular have explored the use of the Delphi method in creating criteria lists for musculoskeletal anatomy (Lisk et al. 2014) and pelvic anatomy (Meyer et al. 2018). In the pelvic study, a four-round Delphi method was used to develop a list of criteria for validating 3D stereoscopic models of the pelvis, and these criteria were organized into seven categories noted in Fig. 7.1 from Meyer et al. (2018).

7.3.1 Importance of Model Accuracy and Validation

In medical education, 3D anatomical models are frequently used to help medical trainees master human anatomy. In the clinical setting, 3D models are used to guide residents and physicians in devising optimal surgical approaches to access specific anatomical regions and treat pathological structures. Since there are variations among 3D models, there is a need for consistent, valid anatomical models. This accuracy and consistency is established through agreement among expert raters of model criteria which are then used by the same experts to review the models constructed according to the validated criteria. Establishing a sufficient level of consistency among experts' opinions ensures that the most important structures necessary for students and trainees to know are included in the models. Table 7.1 from Meyer et al. (2018) provides an example of the experts recruited for the pelvic criteria study. Accuracy is equally important because it ensures that that students and trainees are learning the correct anatomy. One surgeon in his response on his initial Delphi survey admitted that simulations were important training tools because in helping residents practice their surgical skills, they help reduce patient harm (Meyer et al. 2018). Therefore, the accuracy of the relationships of the structures in the models are directly linked to proper surgeon training and indirectly linked to improved patient care.

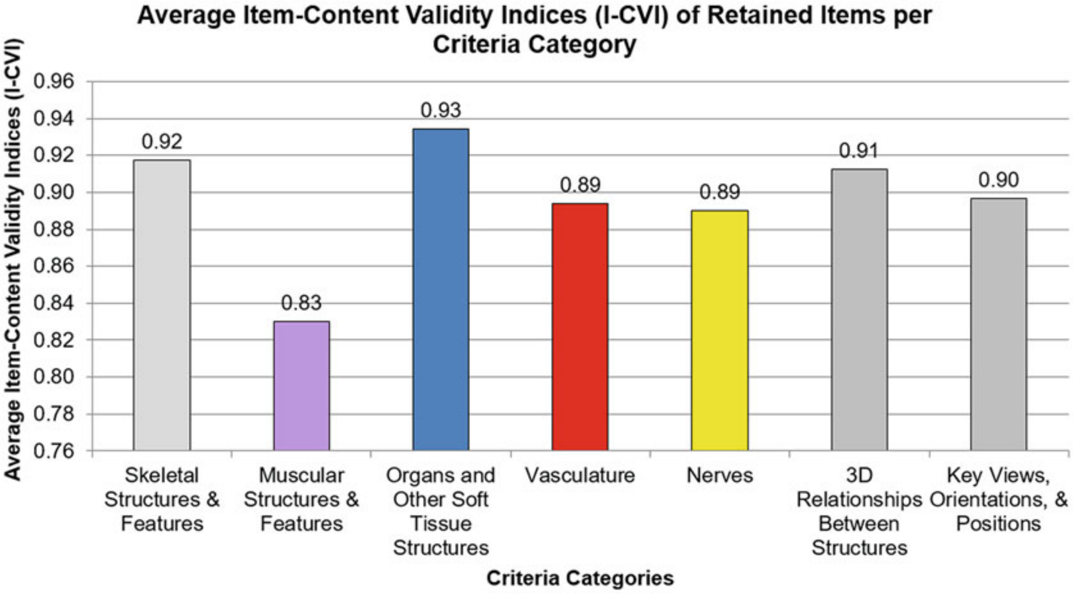

Fig. 7.1 Average Item-Content Validity Index (I-CVI) Values for the retained items in the final criteria list. These average I-CVI values were calculated from the average of all I-CVI values for items within each category in the final criteria list. (Photo credit: Reproduced with permission from HAPS Educator 22:105–118 (2018))

Table 7.1 The number of experts solicited and recruited for the Delphi method

Selection of experts				
Expert category	Expert discipline	# Solicited (n)	# Recruited (n)	# Dropped (n)
Basic scientists	Anatomy	5	3	0
Clinicians	Obstetrics and gynecology	11	1	0
	Pediatric urology	2	1	
	Urogynecology	1	1	0
	Urology	4	1	1 (after round 2)
Total		**23**	**7**	**1**

This table displays the number of clinical and basic science experts who were solicited to participate in the study and the number of experts who submitted responses. Experts were solicited and recruited from faculty members in the anatomical sciences and from clinicians in the specialties or subspecialties of obstetrics and gynecology, pediatric urology, urogynecology, and urology. The urologist dropped out of the study, leaving a total of six experts to complete the study in full

Photo credit: Reproduced with permission from HAPS Educator 22:105–118 (2018)

7.3.2 Experts' Opinions on Anatomical Models

A number of studies have shown that the Delphi method is more optimal than collaborative discussions and other engagements among individuals and groups in predicting criteria for instruments (Dalkey and Helmer 1963; Helmer 1963; Riggs 1983). For the study involving the criteria list for pelvic anatomy (Meyer et al. 2018), the Delphi method was used to gather expert opinions. The particular Delphi procedure used was a classical method that incorporated more than three rounds of administrations beginning with an open-ended, qualitative session (Hasson and Keeney 2011). However, similar to the modified Delphi design, the expert responses were collected using a variety of methods (Hasson and

Keeney 2011), including in-person interviews, online communications, and paper-based surveys, in the subsequent rounds collectively. Experts included faculty (physicians and scientists) who have proficiency pertaining to the pelvis and to the middle and inner ear, respectively, and who are involved in educating medical trainees on these anatomical regions. These experts were selected, following guidelines provided by Okoli and Pawlowski (2004), and they remained anonymous to one another in order to prevent experts from influencing the responses of one another, thus helping to maintain the criterion-related validity (Hasson and Keeney 2011).

7.3.3 Developing Validated Lists of Structures

The development of valid criteria lists can be accomplished through multi-round Delphi method procedures. The study pertaining to the development of musculoskeletal criteria included three rounds (Lisk et al. 2014) while the study pertaining to pelvic anatomy (Meyer et al. 2018) incorporated four rounds. The first round in both studies incorporated open-ended questions. The second round, for the pelvic criteria study only, was reserved for allowing experts to confirm the transcribed responses to their questions, but only if they provided their responses in personal interviews rather than written communication (Meyer et al. 2018).

The remaining two rounds in both studies employed the experts in rating the anatomical items within the lists created from the experts' responses in the first round. In both cases, the experts completed two iterations of rating the items to maintain test-retest reliability. For the musculoskeletal criteria, these items were rated using a five-point Likert scale while for the pelvic and middle and inner ear criteria, the items were rated using a four-point Likert-type scale. In both studies, experts were asked to rate the importance of items, but the four-point Likert scale was used in the latter study to force experts to make a resolute decision on each item's importance to ensure agreement for the retention and removal of items (Lynn 1986). Those items with an agreement, or content validity, greater than or equal to 0.80, a value known as the item-level content validity index (I-CVI), were retained in the final criteria lists while those below were removed (Davis 1992; Polit and Beck 2006). The content validity for each of the criteria lists overall was greater than 0.90, a value that is rigorously valid (Waltz et al. 2005; Polit and Beck 2006). These steps toward establishing content validity can be applied to the development of criteria for any anatomical model.

7.3.4 Assessment and Improvement of Virtual Models

After the lists of validated structures were developed, responses of experts were incorporated into a final survey for analyzing and rating these structures. The content validity of the final list was determined by calculating the average of all items' I-CVIs, or the average scale-level content validity index (S-CVI/Ave) and removing items with a low rank (Polit and Beck 2006; Meyer et al. 2018). Table 7.2 from Meyer et al. (2018) provides the number of items excluded and validated by each expert along with the internal consistency of their ratings between the third and fourth rounds of the Delphi method in the pelvic criteria study. The final list has already been used to make additions and improvements to the 3D stereoscopic pelvic model in our lab. The pelvis criteria were consulted to add missing structures to the existing pelvis model before its implementation in the student learning session of pelvis anatomy. The expert opinions were incorporated into the improvement of the accuracy of structures and to enhance the interpretation of the spatial 3D relationships of structures within the model. Results of quality improvement surveys administered to experts using the criteria list as a guide will help further improve the quality of the 3D models in anatomical education.

Table 7.2 Internal consistency between experts' ratings for rounds 3 and 4

Expert	Total number of items (n)	Number of items excluded	Number of valid items	Overall Cronbach's alpha values
Expert 1	159	22	137	0.917
Expert 2	159	4	155	**0.666**
Expert 3	159	18	141	0.832
Expert 4	159	3	156	0.740
Expert 5	159	4	155	**0.672**
Expert 6	159	26	133	0.856

Coefficient Alpha values have the following reliability considerations: >0.9 = excellent, >0.8 = good, >0.7 = acceptable, >0.6 = questionable, >0.5 = poor (George and Mallery 2003). Coefficient Alpha values in **bold** are considerably inconsistent with the other values. Experts 1 through 3 include clinicians while experts 4 through 6 include basic scientists

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7.4 Implementation of Stereoscopic Models in Teaching and Learning

This paper has already referenced several studies featuring virtual stereoscopic anatomical models used for student learning, so this section will focus on the educational studies published in our lab as well as other educational studies in the literature. Our lab is currently working on studies regarding the implementation of pelvis and middle and inner ear models which have not yet been published. While all of the studies in our lab are voluntary, the protocols for these studies were approved by the Institutional Review Board (IRB) at the University of Mississippi Medical Center.

7.4.1 Used as Supplemental Learning Materials Outside of the Curricula

Stereoscopic virtual anatomical models can be implemented as supplemental learning materials outside of the curricula through programs such as the 3D-Navigator by Voxel-Man, BodyViz, and Vesalius3D. Several studies explore the implementation of virtual stereoscopic models in individual experiments that incorporate student volunteers (Luursema et al. 2006, 2008, 2017; Hilbelink 2009; Hopkins et al. 2011; Luursema and Verwey 2011; Brewer et al. 2012; Roach et al. 2014; de Faria et al. 2016; Cui et al. 2017). Although these studies were conducted during ongoing courses, they were not officially integrated into the curricula.

The limited integration is probably due to the expense of the projection system as well as other equipment necessary for stereoscopic presentation (Read 2015; Hackett and Proctor 2016), including the provision of vast institutional networks with large bandwidths (Temkin et al. 2002). Using large files like DICOM files readable by Amira (Martin et al. 2013) on a device such as a laptop or tablet would require massive storage space in order for the files to be opened quickly. For this reason, learning with stereoscopic models in an institutional virtual laboratory setting with access to adequate network bandwidth, a high-speed computer, and a stereoscopic projection system (Cui et al. 2017) is more feasible for learning. Although stereoscopic models are being developed and incorporated in student learning for discrete educational research studies, more health science centers could take the initiative in fully incorporating stereoscopic virtual models into their anatomy curricula.

7.4.2 Used Inside of the Classroom as Part of the Curricula

Stereoscopic virtual anatomical models can also be implemented as part of the curricula. The web-based three-dimensional Virtual Body Structures (W3D-VBS) system using Visible Human Project data (Ackerman 1998) specifically allows for stereoscopic presentation of models and for incorporation into anatomical curricula (Temkin et al. 2002). Linköping University in Sweden developed a Center for Medical Image Science and Visualization (CMIV) which allowed CT anatomical images to be viewed stereoscopically using a Barco Infitec projection system (Silén et al. 2008). Yet, there is limited mention in the literature of full integration of stereoscopic virtual anatomical models into anatomical curricula. However, the Anatomic Visualize R system originally developed by the University of California at San Diego uses VR and allows instructors to create lesson plans with anatomical model content (Hoffman and Murray 1999; Hoffman et al. 2001). More recently, the brand new Las Vegas School of Medicine at the University of Nevada uses Sectra virtual dissection tables rather than cadavers in their gross anatomy curriculum as the virtual lab was more cost effective (Newman 2018). In addition, in the summer of 2019, Case Western Reserve University (CWRU) and Cleveland Clinic partnered to establish a health sciences complex featuring multiple digital anatomical programs instead of cadavers (Newman 2018). Many undergraduate and health sciences institutions, however, are also purchasing digital dissection and other computerized tools for anatomical education.

7.4.3 Format of 3D Learning

The format of 3D learning includes monoscopic 3D learning and stereoscopic virtual learning. In the monoscopic 3D learning format, models can be rotated on a flat screen or monitor of the computer. Stereoscopic models can also be incorporated into video clips, which allow students to access the learning session in and out of the laboratory or classroom. Stereoscopic virtual learning requires that students study in the laboratory or in the virtual classroom environment due to the complicated projector system or portable projector system setting (Cui et al. 2017). In the stereoscopic virtual learning session, students need to wear glasses with linear polarizing filters in order to view the 3D models that appear to float in the center of the room. The learning session can also be given in an instructional or a self-exploration format with both monoscopic and stereoscopic learning. In the instructional format, instructors can follow a script or give a lecture to students, and students can ask questions during the learning session. In the self-exploration format, students can freely rotate the models and engage in self-directed learning without the instructor's interruption.

In the head and neck vasculature model study (Cui et al. 2017) which followed an instructional format, knowledge pre-tests were administered to the participating students before either the 3D learning session or the 2D learning session while knowledge post-tests were administered after these sessions. In addition, mental rotation tests (MRTs) were administered to the students both before and after their learning experiences to measure their spatial ability both before and after their learning experiences, respectively. The session concluded with the dissemination of surveys assessing students' perceptions of 3D learning.

7.5 Evaluation and Assessment of the Effectiveness of 3D Virtual Learning

Evaluation and assessment are important components of model development as they ensure model viability for learning purposes. Ways of evaluating and assessing models include analyzing student performance outcomes, student perceptions, faculty and expert perceptions, and students' short- and long-term retention.

7.5.1 Student Performance Outcomes

The studies performed by Luursema and colleagues showed the beneficial impact of a stereoscopic model of abdominal and pelvic anatomy on learners' identification and localization tasks (Luursema et al. 2006, 2008; Luursema and Verwey 2011). Another study with medical students showed that those learning with stereoscopic interactive images of the brain performed significantly higher on learning assessments than those learning with traditional 2D images of the brain, but not significantly higher than those learning with monoscopic interactive images of the brain (de Faria et al. 2016). In a study on the impact of virtual middle and inner ear models on teacher trainees, participants learning in a stereoscopic format performed significantly better than those learning in a monoscopic format, and participants specifically learning with the static stereoscopic format had the highest performance scores both for visual attention and determination of spatial relationships (Remmele et al. 2018).

A more recent study by Luursema et al. (2017) showed no significant difference between medical students' performance outcomes from learning with a monoscopic or stereoscopic model of neck anatomy. Similarly, a study exploring the effectiveness of a stereoscopic neuroanatomy (3D group) model on health science students' learning compared to 2D and control groups showed no significant difference between the three groups (Brewer et al. 2012). Nevertheless, in a second experiment of the same study, second year medical students exposed first to virtual stereoscopic neuroanatomy outperformed students exposed to a gross anatomy laboratory experience followed by a virtual stereoscopic experience even though the former students self-reported lower spatial abilities (Brewer et al. 2012). Another study on novice students learning laparoscopic skills showed no significant difference between learners of different spatial visualization abilities who performed laparoscopic tasks with either stereoscopic or monoscopic viewing formats, yet the stereoscopic format seemed to improve task scores for students with lower spatial visualization abilities (Roach et al. 2014).

In a head and neck vasculature model study, knowledge pre-tests were administered to participating first-year medical students before either the 3D learning session or the 2D learning session while knowledge post-tests were administered after these sessions. In addition, mental rotation tests (MRTs) were administered to the students both before and after their learning experiences to measure their spatial ability both before and after their learning experiences. The study results indicated that stereoscopic learning of 3D vascular structures has a statistically significant difference compared to the flat-screen (2D) learning group (Cui et al. 2017). Most importantly, for students with low spatial ability, their knowledge test scores improved to a level comparable to students with high spatial ability

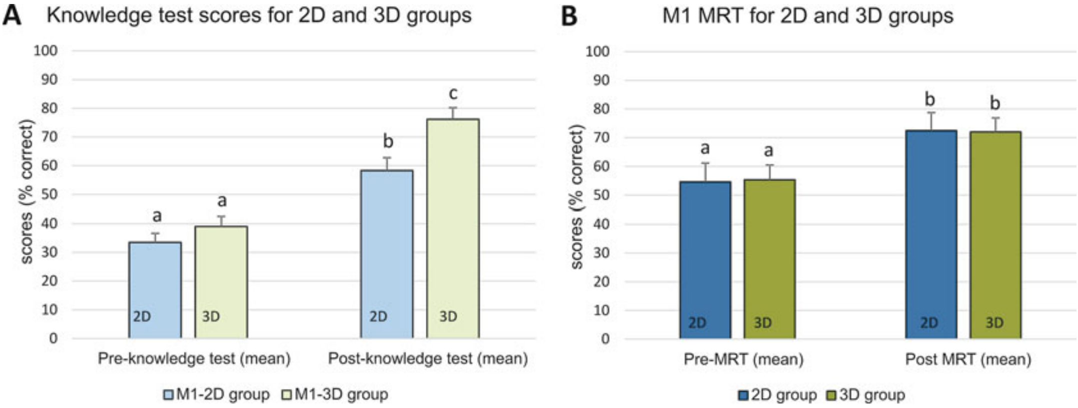

Fig. 7.2 Comparison of the first year medical students' pre-knowledge test scores and post-knowledge test scores between the 2D and the 3D groups (**a**). Comparison of first year medical students' pre-MRT scores and post-MRT scores between 2D and 3D groups (**b**). The statistical relationship between groups is indicated by lower-case letters. Groups that share a common letter do not differ at the $p < 0.05$ level. (Photo credit: Reproduced with permission from Anat Sci Educ 10:34–45 (2017))

after 3D learning sessions (Fig. 7.2. From Cui et al. 2017).

7.5.2 Student Perceptions

In our previous study on head and neck vasculature, students rated the 3D virtual models highly favorably as 97% of students either strongly agreed or agreed with the statement, "The 3D model was interesting, and engaged me in learning the materials." Furthermore, 100% of students either strongly agreed or agreed with the statement, "The 3D model showed orientation of the materials better than the flat screen image." In addition, 100% of students either strongly agreed or agreed with the statement, "The 3D model is helpful to relate the material that I have learned from the book and the material learned in the laboratory." Specific student comments included: "I thought the 3D models were amazing. I would love to study using these models." "They were very helpful in learning the spatial relationships." "Really cool, especially when the CT was incorporated" (Cui et al. 2017). Overall, the survey results showed a high degree of interest and enthusiasm by the students for these 3D virtual models.

In our recent study in an abstract publication regarding the evaluation of a pelvis model, students overall felt that a pelvis model was beneficial to their learning (Meyer et al. 2017). Additional unpublished studies explore students' perceptions of how this model and other models improved their retention of the material.

7.5.3 Faculty and Expert Perceptions

Basic science and clinical experts had differing views on the learning cohorts impacted positively by general 3D anatomy. While most of the basic science faculty in the pelvis criteria study viewed general 3D anatomy as being more important for medical students and residents than pre-health students, half of the clinicians viewed general 3D anatomy as being more important for pre-health and medical students than residents (Meyer et al. 2018). All of the other basic science and clinical experts felt that general 3D anatomy was important for all three learning cohorts (Meyer et al. 2018). Moreover, all of the experts overall felt that the Delphi method was an efficient way to gather their opinions on 3D model criteria for validation purposes, especially since most were unaware of any more efficient methods (Meyer et al. 2018).

While the student and faculty views of virtual 3D anatomy are positive overall, the impact of the models on student learning includes mixed results. In fact, a complete evaluation of virtual 3D learning settings is critical for instructors to understand how to measure students' performance outcomes (Cassard and Sloboda 2016). Another important topic of exploration is how virtual 3D learning, especially for stereoscopic models, affects students' long-term retention.

7.5.4 Students' Short-Term and Long-Term Retention

There is limited research in the literature concerning the effect of stereoscopic virtual anatomical models on students' short- and long-term retention. A review article on educational studies involving 3D anatomical models by Azer and Azer (2016) along with another study on the effectiveness of e-learning tools on undergraduate anatomy students' learning (Van Nuland and Rogers 2016) suggest the need for more studies on these models' impact on students' long-term learning. As a result, studies regarding the impact of virtual stereoscopic pelvis and middle and inner models on medical students' short- and long-term retention will be published soon from our lab.

The real question, though, becomes what anatomical information is actually necessary for students' to remember for a long period of time. Since medical students appear to retain approximately half of the information they learn in medical school after 2 years and only about 30% after more than 4 years (Custers 2010), there is also a need to determine which anatomical content should be retained by medical graduates when they enter their residency programs. Given the correlation between medical students' perceptions of clinically relevant information and their retention of the corresponding information (Malau-Aduli et al. 2013), perhaps the clinically relevant content should be emphasized as being important for long-term learning in anatomy curricula. Moreover, virtual stereoscopic models potentially might be especially useful in improving medical students' long-term retention when they are designed for clinical applications or presented to teach clinical or surgical concepts.

7.6 Discussion of Stereoscopic Model Implications in Anatomy

7.6.1 The Benefits

The added effects of stereopsis have the potential to provide the viewer with depth cues that are not tangible when models are simply viewed and rotated on a two-dimensional computer screen in a monoscopic format. In fact, the virtual stereoscopic head and neck vasculature model improved the learning of first-year medical students, especially those students with low spatial ability (Cui et al. 2017). Other benefits of stereoscopic imaging include more expedient comprehension of complex visual objects (Wickens et al. 1994; Kim et al. 2013) and more adept execution of activities requiring hand-eye coordination (Servos et al. 1992; Fielder and Moseley 1996; Melmoth et al. 2009; O'Connor et al. 2010; Bloch et al. 2015). When applied to virtual stereoscopic anatomical models, all of these benefits can potentially improve students' understanding of complex anatomical regions.

7.6.2 The Limitations

Although the Delphi method was useful for collecting experts' opinions about anatomy in general, receiving responses back from experts on time was more difficult (Meyer et al. 2018). Securing adequate numbers of experts in these two specialized content areas proved to be a challenge, given the varied locations of experts, their varying time availability to commit to participation, and their potential need for incentives (Meyer et al. 2018). Moreover, high costs are associated with stereoscopic effects (Read 2015; Hackett and Proctor 2016). The virtual environments and stereoscopic projection systems are required for learning sessions. Furthermore, when using the multiple rounds of the Delphi method, randomly assigned experimental design, and long-term retention tests, keeping good sample sizes of participants during the studies is very challenging. However, despite small sample sizes, educational studies involving virtual stereoscopic anatomical models are important to determine their efficacy in students' learning.

7.6.3 The Future of Virtual Learning in Anatomy

According to the baseline projections of global investment research analysts of the Goldman Sachs Group, Inc., there is an estimated $80 billion in revenue by 2025 (Bellini et al. 2016). In the healthcare field, specifically, these estimated numbers include the base case assumptions of $5.1 billion in revenue generated from a target population of eight million physicians and emergency medical technicians (EMTs) (800 thousand physicians and 240 thousand EMTs within the United States alone) (Bellini et al. 2016). Plus, these numbers do not include the revenue generated by healthcare professional student and faculty customers. While these monetary approximations are enticingly high for investors, the educational researcher in the anatomical sciences is compelled to ask whether these popular and somewhat novel forms of technology and their applications to computer models and simulations are indeed effective in improving student learning, especially since two review articles describing mixed results on the effectiveness of 3D applications to anatomy learning suggest more research on the impact of 3D technology on anatomy learning should be conducted (Azer and Azer 2016; Hackett and Proctor 2016).

7.7 Conclusions

The experts' ratings collected from the Delphi method and the validity and reliability measures produced a valid and reliable instrument that can be used to evaluate the accuracy and utility of virtual 3D models in anatomy education. By consulting experts and receiving their suggestions for improvements to the models, these virtual 3D models were refined for use in anatomy learning. Although some studies' results indicated student benefits from stereoscopic anatomy learning, there have been mixed results in the literature concerning the effectiveness of virtual 3D anatomical models in general.

More research studies are needed to determine whether virtual stereoscopic models of other complex anatomical regions are effective for medical students and other health professional students whose programs require anatomy learning. However, stereoscopic studies conducted with models of head and neck structures (Hilbelink 2009; Brewer et al. 2012; Kockro et al. 2015; Cui et al. 2017; Luursema and Verwey 2011) and laparoscopic simulations (Roach et al. 2014) are necessary initial steps in establishing the effectiveness of these models as supplements to traditional anatomical education and surgical training.

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Storyboarding in Medical Animation

8

Stefanie Joelle Okemow

Abstract

Storyboards are a series of thumbnail images that act as a planning document for your overall animation project. Each thumbnail image is part of what is known as a shot, and shots are strung together to create scenes, which in turn create a whole animation. Medical animations, compared to film or animated movies, have rigid and specific requirements; however, by utilizing storyboards as a planning document we can infuse our medical animations with emotion, life, and beauty. This chapter will review common storyboarding fundamentals, like camera moves and editing techniques, and how they may be applied to the medical world. Camera moves are important to string shots together and can help add emphasis to specific sections. Zooms and pans are used extensively within medical animation and it is important to note which circumstance might call for either one. Zooms are great for moving to a drastically different microscopic magnification. Pans create visual interest for a stepwise reaction. Techniques such as lighting, depth, and insets and labels create a more balanced composition and save time in the production phase. Storyboards are ultimately about problem solving early to save time and money during the production phase. [M1].

Keywords

Medical animation · Storyboarding · Biocommunication · Animation · Digital health literacy · Learning theories · Communication illustration

8.1 Introduction

While some link the origins of the storyboard to Leonardo Da Vinci's intricate notebooks, the technique began to gain prominence for use in film by animators like Walt Disney (Hoffart N et al. 2016; Lottier 1986). It has now found its way into the production flow of many different types of visual media and acts to convey movement and camera angle. Storyboards are primarily used for film, but these principles might equally be applied to still images such as cover art or photography. Functionally, storyboards are an integral tool to incorporate into a workflow, especially when there is a great deal of complex information to be shared. Storyboards provide a way to organize thoughts (Lottier 1986; Walker et al. 2015) facilitate collaboration (Barkman 1985; Farra et al. 2016), and act as the blueprints of an animation. They allow artists to

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solve problems before finalizing the more complicated aspects of the project. Storyboarding engages with both the creative process as well as critical ways of thinking (Lottier 1986; Tweed 2005). Problem solving in the early stages of production is a useful skill to cultivate; it will save you time, money, and headache (Paez and Jew 2013).

The intention or goal behind each individual animation will dictate the artist's every formal decision. Sometimes, in the field of medical animation, basics of animation such as character development or a concern with the look-and-feel of the image can be lost because animators may feel limited by the rigid confines of the scientific world, or the necessity of representing their source material with scientific accuracy. However, a simple shift in perspective can allow us to tell scientific visual stories that are more relatable, captivating, and, ultimately, more educational as a result.

We might begin to conceptualize the storyboard by relating it to its aesthetically similar cousin: the comic strip. Storyboards are similar in visual layout to that of comic strips (Hart 2013) and as such it is important to review the common jargon associated with comics and how those tools can be borrowed for use in storyboards. McCloud (1994) defines comics as "juxtaposed pictorial and other images in deliberate sequence" (9). Where comics and storyboards differ is their artistic intent. Unlike comics, storyboards do not need to be aesthetically pleasing. A storyboard is a series of sketched sequential drawings that are easily modifiable and can move around each other (Walker et al. 2015) with the goal of communicating narrative. Hart (2013) describes the storyboard as a tool designed to "give you a frame-by-frame, shot-by-shot organized program for your shooting sequence for the shooting script" (3).

This chapter will review common storyboarding fundamentals and how they may be applied to the medical world. We will explore different ways to set up a storyboard while covering the common tools that are available. We will cover how different types of shots may be used to the advantage of the learner, as well as consider the typical elements of a medical illustration, such as an "orientation illustration," and its equivalent in the medical animation world: "the establishing shot." We will also discuss other types of shots, including the close up, extreme close up, split screen, and the medium shot; these shots will be described alongside examples. Moving beyond the shot composition of medical animations, we will discuss different camera moves, such as zooms and pans, detailing the circumstances in which one might be more beneficial as opposed to the other; we will also cover common transitions, such as fade-ins, cross dissolves, or cuts. Finally, the chapter will close with a discussion of lighting basics, depth of field, line of action, and issues more specific to medical animation such as size relation, insets, and labels.

8.2 Tools for Storyboarding

Before you can start a storyboard, you have to have the tools to do so. There are so many ways to create a storyboard and a lot of your artistic decisions will depend on your specific needs: Are you working for a client? Are you sending your storyboard to a production team? Are you collaborating with another storyboard artist to finish the project? Each of these situations will dictate how professional and polished a completed storyboard must appear.

8.2.1 Rough Thumbnails

Even in the case of a simple, personal project, any animation will benefit immensely by having a rough thumbnail storyboard mapped out. This can be done on sticky notes so shots can be easily moved around, or simply with pencil on paper. The central goal when setting up a rough storyboard is to sketch out the main elements in each frame even if their position and the camera angle will change slightly before the completion of the final product. As Hart (2013) points out, even Oscar-nominated films such as *Pirates of the Caribbean* and *Lord of the Rings* started out as thumbnail sketches (Hart 2013). Additional written notation can help guide your production later on, especially in cases where a more complex illustration was left out due to time constraints.

8.2.2 Storyboard Pro and Other Computer Software

When sending a storyboard off to a client or another member of the production team, I need the storyboard to be more polished. The fewer questions the production team has the faster they can get the animation out; similarly, a polished storyboard makes the process much smoother from the client's perspective, and limits the potential for surprises when receiving the final animation.

There are a number of different tools that facilitate the process of delivering clear and legible storyboards. Microsoft Word's charts make it possible to add or delete frames seamlessly. This is a useful tool, especially in the context of editing the flow of the story; the charts make it easy to add or subtract frames, as well as shift frames around in the narrative, which is a common occurrence during the storyboarding process. Microsoft has its disadvantages compared to other tools within the Adobe suite, with its lack of design elements and lack of precision for the inclusion of insets, labels, and leader lines. Making your choice of program will depend, in part, on how much of the story flow is already mapped out. Moving shots around in InDesign isn't as seamless as within a Word table. There are also other third party apps specifically for storyboarding such as Boords and Storyboard Pro. Boords is extremely user-friendly, allowing you to drag and drop shots throughout your project; however, it requires a paid subscription in order to export a PDF of your storyboard. Storyboard Pro is another software which allows the user to draw the storyboard directly in the application; however, the cost of the software might be prohibitive if you are not strictly a storyboard artist.

The storyboard acts as a structured communication method to share complex information between inter-professional teams (Farra et al. 2016). The final tool you and your team decide on will impact how successful the storyboard is.

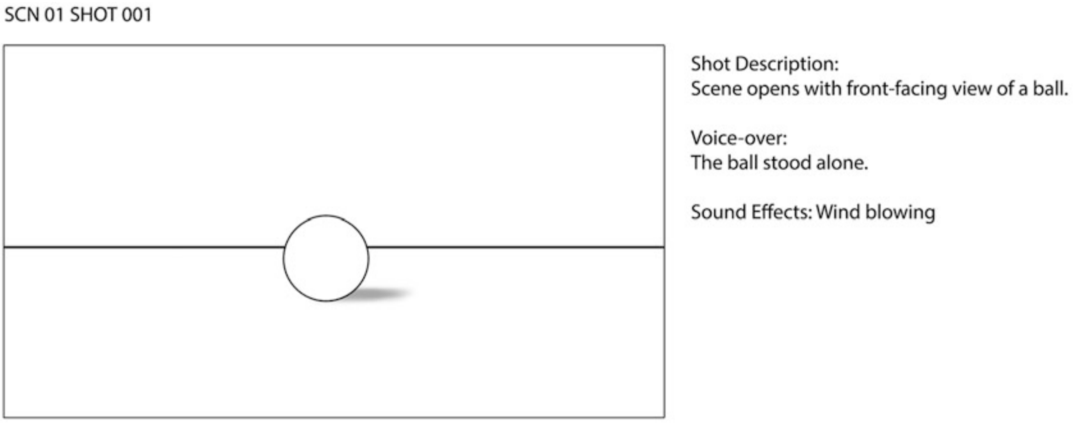
8.3 Medical Animation: What Is the Story?

When planning a medical animation, concepts like character development and story arc are rarely discussed. And yet, I think that is precisely what is missing from a lot of medical animation. Just as other, more traditionally narrative animations, medical animations depend on answering the question: “what story are we trying to tell?” For example, medical animators might ask themselves: Why does a certain surgical product exist? What problems does it solve? Who benefits from a new pharmaceutical on the market? Framing animations by thinking through the stories they tell, that is, going beyond just the physiology and the science of the product, helps draw viewers in and make them see the bigger picture. Isn't that why we got into medical animation in the first place?

8.3.1 Scenes and Shots

Animations are comprised of scenes, and each scene is comprised of shots. Scenes are important events unified by character, location, time, or theme (Paez and Jew 2013; Hart J 2013). If scenes are the chapters of the animation, then shots are the paragraphs; each paragraph has a different way it can be framed. The shots in the storyboards themselves are usually shown as individual rectangles that roughly match the intended final aspect ratio (Walker et al. 2015). To make the animation more visually interesting, these shots usually have different content or present the viewer with different angles. Storyboarding these angles beforehand helps the decision making process when setting up cameras in a 3D program or within After Effects.

The storyboard shots themselves can have a variety of different information (Fig. 8.1) including the scene and shot number, shot descriptions, voice-over, sound effects, and most importantly: the thumbnail. Shot description language can include a variety of information from explaining what assets will appear and the composition of



SCN 01 SHOT 001

Shot Description:
Scene opens with front-facing view of a ball.

Voice-over:
The ball stood alone.

Sound Effects: Wind blowing

Fig. 8.1 Storyboard shot

the frame, to the point of view and the transition style.

Organizing a storyboard with numbered scenes and shots makes editing things easier down the line. There are different ways that these can be organized but (Fig. 8.2) gives a few different examples for various setups depending on how much space is needed for notes or voice-overs.

Some of the most important decisions that are made during the critical thinking phase involve establishing the content for the shot: What are the important *nouns* of the scene (the people, places, or objects)? These nouns are communicated through an establishing shot that sets the tone of your animation (Walker et al. 2015).

8.3.2 Establishing Shot

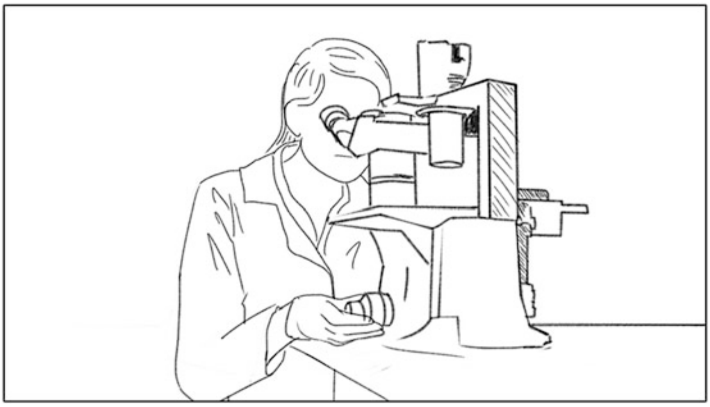
Educational animations need to clearly flow through learning goals and a major tool for constructing this narrative movement is the use of establishing shots that are clear and concise. A typical textbook illustration will often include a legend or an orientation illustration; an establishing shot for medical animation is no different. An establishing shot presents the medical animator with an opportunity to frame the viewer on a specific body part or health concern. Deceptively simple, the establishing shot often does a lot of work in providing the context for the overall animation. Here are some examples of establishing shots that set the scene for the animation to follow: an animation about genetic research might have an establishing shot of a genetics lab, or someone doing bench work (Fig. 8.3); an animation about a surgical device could use an establishing shot of an OR room set up for the specific surgery the device is used for (Fig. 8.4); an animation detailing the lung cancer pathophysiology could have an establishing shot of a person coughing (Fig. 8.5). The importance of giving context in the establishing shot cannot be understated, especially when the details of the animation happen at a microscopic level. Typically, I suggest setting up establishing shots in a macroscopic environment that is very familiar to the viewer.

8.3.3 Close Up

Medical animation often deals with complicated and detailed subject matter and close up framing allows the animation to narrow in on these details. It is important that enough of the subject is visible in the frame so the viewer can tell what it is. One of the challenges of a well-constructed close up is balancing interesting composition with clear, didactic imagery. One tool for approaching this challenge is by changing the viewpoint. The viewpoint of the shot refers to the specific angle of the camera as it pertains to the object of interest

Fig. 8.2 Storyboard template setup samples

Fig. 8.3 Establishing shot microscope



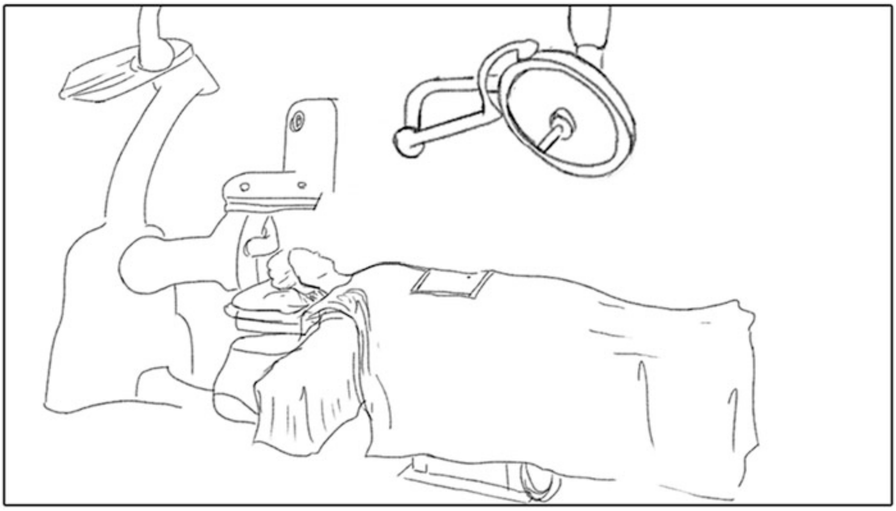


Fig. 8.4 Establishing shot OR

(Walker et al. 2015). The movement between specific camera angles, such as bird's eye view or a worm's eye view, can provide more visual interest to the learner, which in turn facilitates an increase in the potential for knowledge retention (Figs. 8.6 and 8.7).

Fig. 8.5 Establishing shot lung cancer

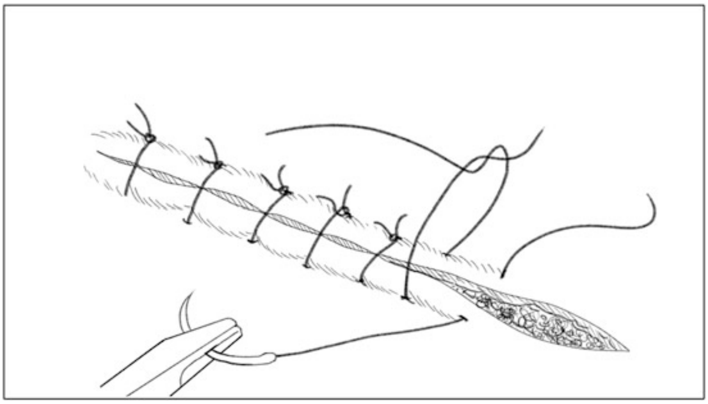


Fig. 8.6 Bird's eye view

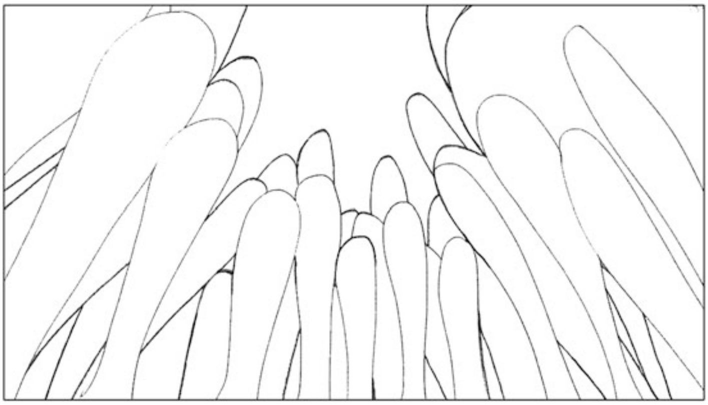


Fig. 8.7 Worm's eye view

8.3.4 Split Screen

Split screen shots are a great device to use towards the end of an animation. They can help define why a product is effective or illuminate a series of steps that lead to a final result comparing the visual states before and after. The split screen is not the greatest for comparing things that are too visually similar, and in some cases might need to be hyperbolized for effect. This shot works best for a presence comparison rather than a simple difference comparison, where it is visually obvious without explanation that one option is preferable to the other. For example, healing states with or without a product that will reduce scarring would be an example of a visual comparison where there

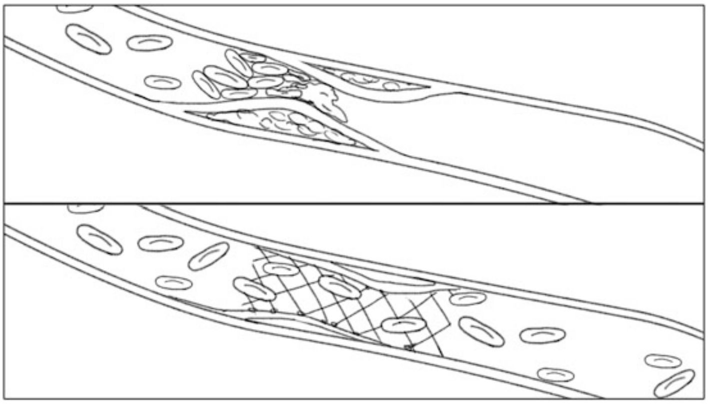


Fig. 8.8 Vertical split screen

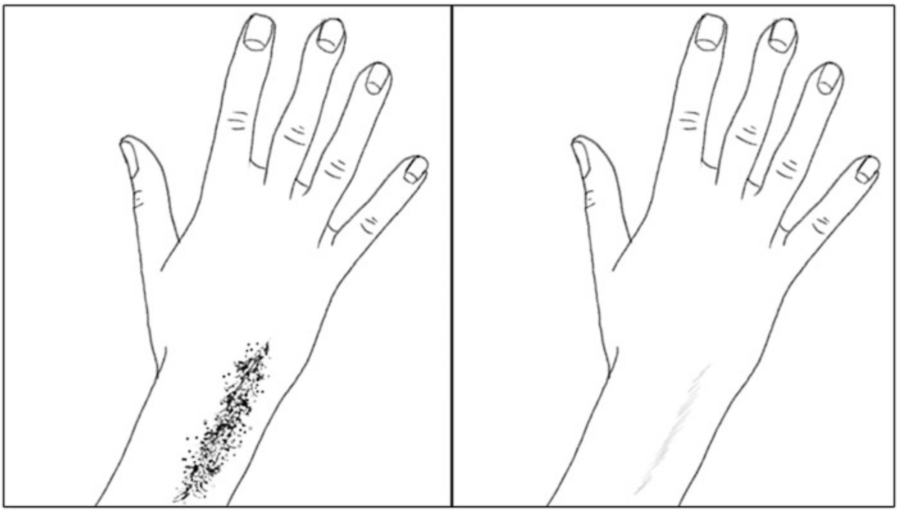


Fig. 8.9 Horizontal split screen

would be a dramatic visual difference between the two, with one clearly favourable. When drawing out a comparison in a storyboard, I have typically already set up one element to be present in the preceding shots. From there, I'll decide whether the split screen of the two elements should be vertical (Fig. 8.8) or horizontal (Fig. 8.9) depending of the ratio of the elements and the overall screen real estate.

8.4 Storyboard Techniques: Camera Moves and Transitions

Camera moves and transitions are what drive an animation forward. There are several different types of these such as zoom, pan, cut, dissolve, and fade and tilt (Walker et al. 2015), some of which will be discussed further below. Ensuring these are well planned can help to tell a story seamlessly. Certain transitions may be more favourable in comparison to others, particularly in the ways that they draw emphasis to certain elements for the learner. One of the primary concerns for the animator planning camera movements is an effect experienced by the viewer named "eye trace" (when the eye follows the natural flow of movement of a main element). Eye trace is especially important when thinking about camera movements and transitions because too many opposing movements can distract the viewer and disrupt their overall learning experience. Camera movement is usually depicted with arrows that overlap the frame, as well as through shot description annotations (Walker et al. 2015). Beyond the use of arrows, we can also borrow comic book strategies for transitions, such as moment-to-moment, action-to-action, or aspect-to-aspect (McCloud 1994).

8.4.1 Zoom

Zooms are powerful tools for medical animators. In recent years, zooms have become so pervasive within the industry that they have almost achieved the status of cliché. I would argue that their educational usefulness far outweighs their potential drawbacks. Zooms are perfect for transitioning out of a macroscopic establishing shot and into a microscopic close-up shot. When drawing a zoom in (Fig. 8.10), I will draw a rough bounding box of the new framing with arrows coming from each corner of the current frame to the corner of the new framing, showing a representational camera movement. A zoom out (Fig. 8.11) is shown with arrows present at each corner of the frame pointing outwards, implying that the camera will be pulled back.

8.4.2 Pan Across

Camera pans are excellent tools for increasing visual interest during a scene that has multiple steps, and which would otherwise be presented through the use of a stagnant or stable camera. Even adding a subtle camera motion can give the illusion of realism. When planning a camera pan, it is equally important to consider the possibility of eye trace. For example, if the camera is panning to the right and a protein enters the shot from the left, the eyes will naturally follow it as it moves across the frame to the right; the next element might seamlessly enter from the right to prevent the eyes of the viewer from jumping back and forth. Leveraging multiple camera movement techniques will elevate the overall feel of your animation.

8.5 Storyboard Techniques: Continuity

Continuity is defined as uninterrupted sequences without significant change (Rousseau and Phillips 2013). Continuity is a key concern in animation storyboards; it keeps production staff from making critical mistakes and it represents the largest component of problem solving that a storyboard artist must undertake. A central issue in the production of a successful animation is ensuring the learner has a frame of reference, and that the information they are meant to take away is presented in a manner that builds sequentially. Medical animation relies primarily on linear storytelling and continuity between shots is key for learning.

8.5.1 Line of Action: 180° Rule

The line of action refers to an imaginary line that is drawn from one character to the character they are interacting with (Paez and Jew 2013). This is a rule developed in cinema, but is useful to adapt for medical animation. The viewer of a film often has a difficult time keeping track of narratives between multiple characters when the camera shifts more than 180° degrees (Fig. 8.12). This will cause the characters on the screen to flip their right/left relationship to camera (Figs. 8.13 and 8.14).

Violating this rule is called “crossing the line” (Rousseau and Phillips 2013). “Crossing the line” is a great rule of thumb that can be applied to specific situations in medical animation; for example, we can think of molecules as characters, or the surgical field and the placement of surgical instruments within that field. When showing a surgery, I always try to storyboard from the surgeon’s perspective. Generally, I recommend never crossing the line of action, unless such a movement is absolutely necessary to reveal a specific detail. If this were the case, I would also consider alternative ways to represent the detail, such as using an inset.

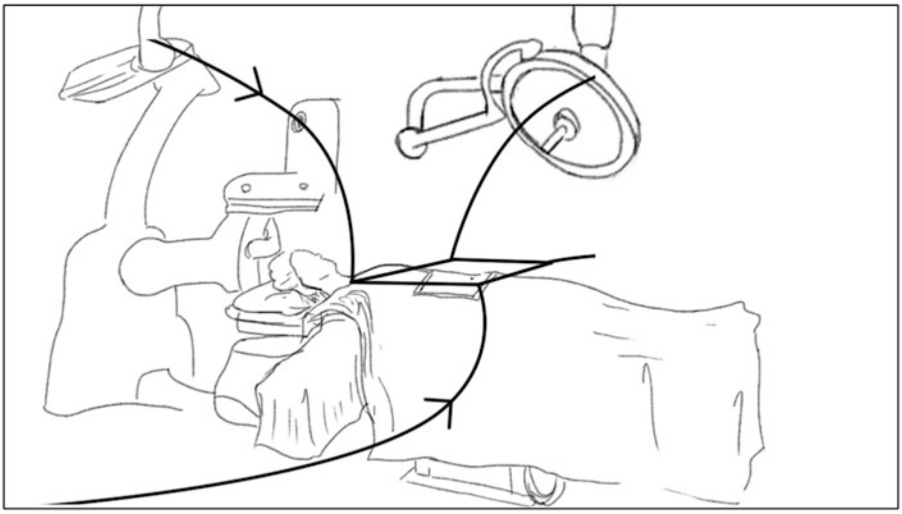


Fig. 8.10 Zoom in

Fig. 8.11 Zoom out

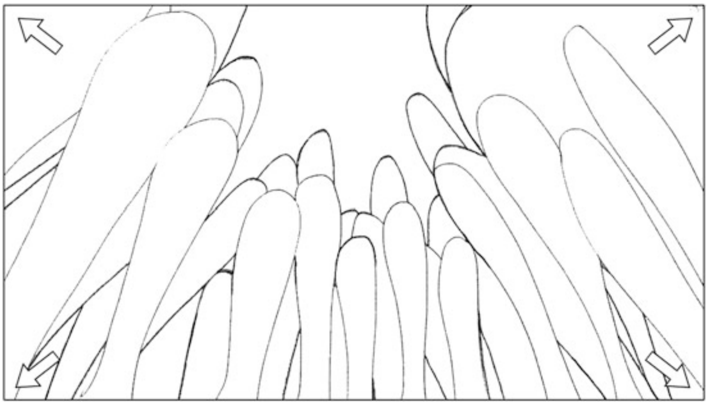
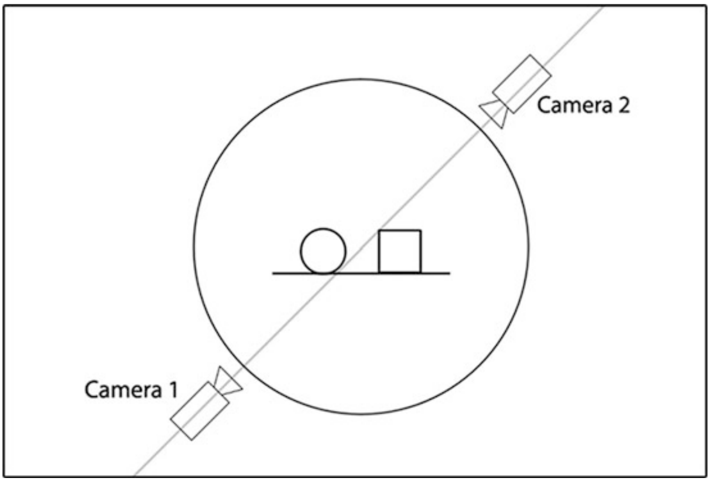


Fig. 8.12 Line of action



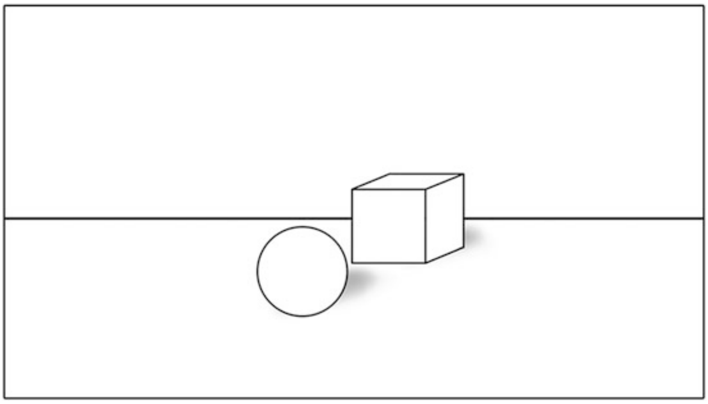


Fig. 8.13 View from camera 1

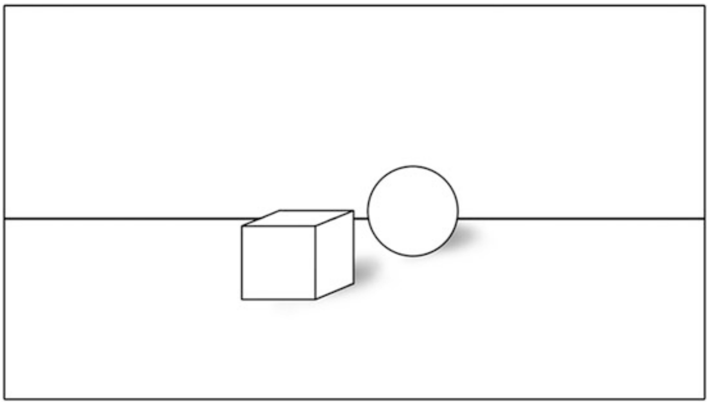


Fig. 8.14 View from camera 2

8.5.2 Jump Cuts

When providing a different angle onto an element, it is crucial that the angle change by a minimum of 30° degrees, while still abiding by the 180° rule. This is especially important when storyboarding moment-to-moment and action-to-action shots (McCloud 1994). Adhering to this minimum change ensures that the angle will be different enough that the viewer isn't jarred.

8.5.3 Sizing Proportions

Sizing and proportion are important because you don't want to give the impression you've done a zoom or a camera rotation when that wasn't your intention. Mapping out the scale of cellular elements early will help dictate the overall composition of the frame.

8.6 Storyboard Techniques: Editing

Additional components to consider in the storyboard production process are special effects that might be added later in postproduction. These may not have a huge impact on the overall flow of a story, but they can drastically change the way a viewer experiences the animation. Including these components in your thumbnails, or as notes for your production team, is important particularly if the animation is an inter-professional collaborative production (Farra et al. 2016).

8.6.1 Lighting

Lighting has the ability to change the entire mood of a piece. Lighting isn't used exclusively to shift the brightness of a scene, but can shift the hue of a shot as well. Lighting becomes especially impor-

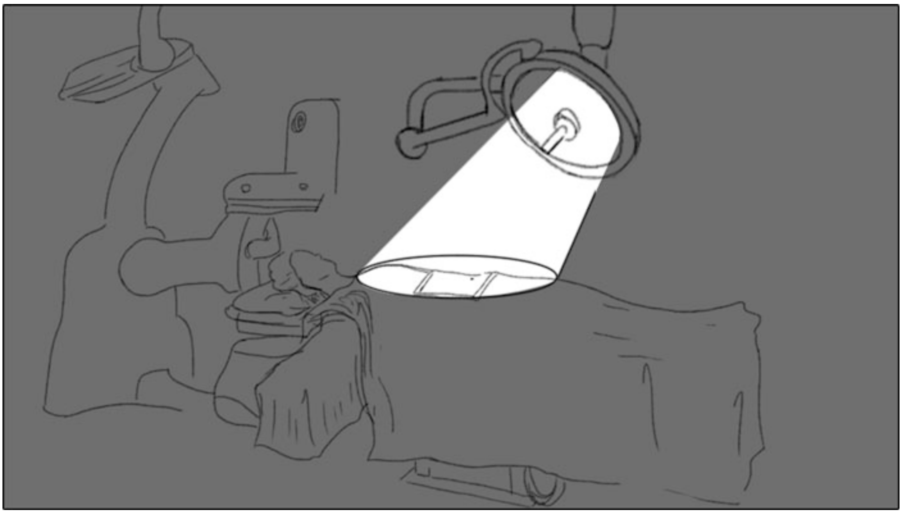
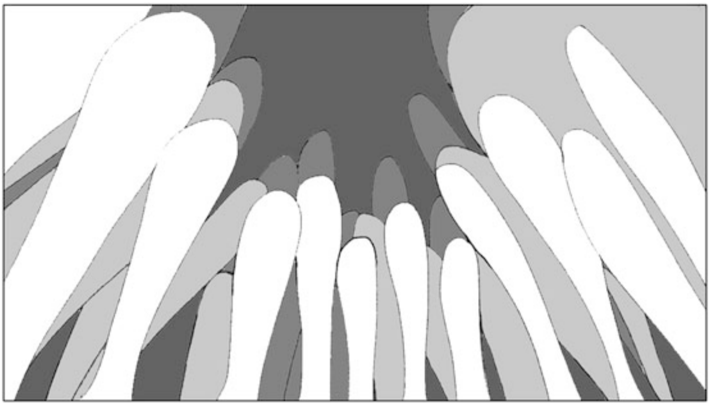


Fig. 8.15 Spotlight

Fig. 8.16 Depth lighting



tant to think about in molecular animation. There is no light at the molecular level, so everything we add in terms of color is representational and with that we can let our artistic license "shine" a bit. Backlighting visual elements can be a great way to play with more translucent cellular objects. I represent backlighting in a storyboard by having background elements darker and adding a slight glow to foregrounded focal elements. Spotlighting (Fig. 8.15) draws attention to a specific area or event; for example, in an OR, spotlighting can be a great way to set the scene while focusing the viewers' eye on the surgical field. I storyboard this by actually drawing a conical shape that represents my spotlight and darkening everything outside of it. Three-point studio lighting is great for replicating real-life product shots. Having a strong front focal light is a good way to create depth in a shot (Fig. 8.16). There are a variety of lighting techniques that might be adapted to the field of medical animation; I recommend thinking critically with the high-quality and professional photographic images you consume, to consider how the techniques being used can be incorporated into your storyboarding and animation projects.

8.6.2 Depth of Field

Another tool that can be used to enhance the visuals of your animation is depth. A scene with

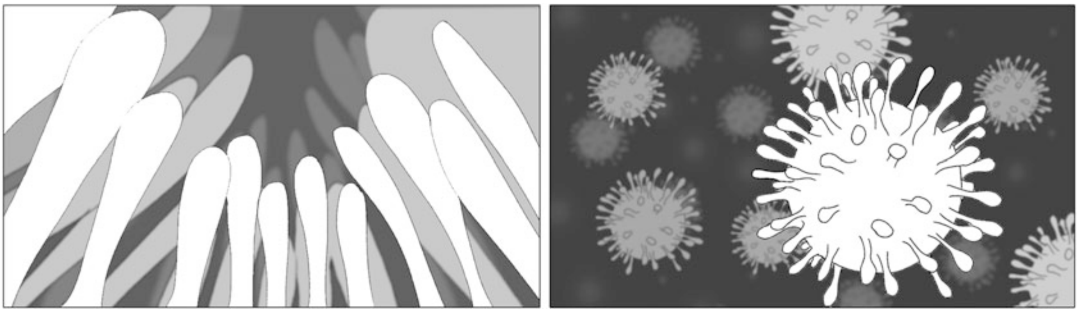
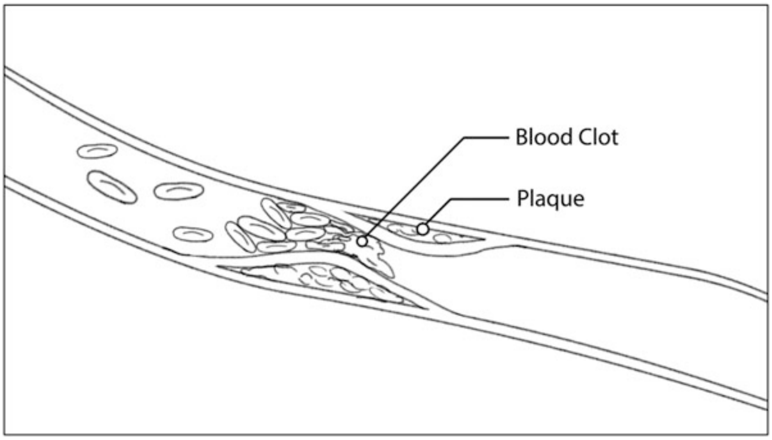


Fig. 8.17 Using blurs to create depth

Fig. 8.18 Leader lines and labels



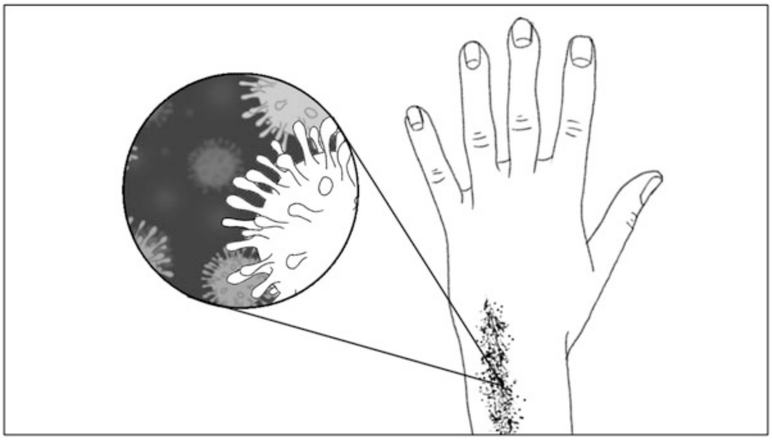
a clear and expansive sense of space draws the viewer in and adds a level of realism to your animations. Setting up depth in a thumbnail can be achieved simply through a number of different methods. Perspective drawing is a great way to add the illusion of depth to your images (Paez and Jew 2013). In addition to perspective, blurs can be a good tool for mimicking focal lenses. When the two layers are blurred relative to their distance from the focal layer, it gives the illustration depth (Fig. 8.17). At minimum, two layers are needed, but three layers are ideal to give a better sense of perspective and position in space. Dividing your image into foreground, middle ground, and background, will force you to break the tendency to create flattened images that exist on a single plane (Paez and Jew 2013). Finally, another means to provide depth to your storyboard images is through the use of rack focus, which can be particularly effective in molecular scenes when a reaction is happening in the foreground, causing a subsequent reaction to take place in the background, without having to pan or shift the camera angle.

Storyboarding the depth of the shot provides your production team an idea of the camera focus as well as a sense of the type of lens to use.

8.6.3 Insets and Labels

Something common to almost all didactic medical animations is the need to label content. Labels are sometimes seen as an afterthought, but their placement as well as their timing in the animation enhances the learner experience. In thinking about insets and labels, we can recall our earlier discussion about eye trace. Labels should follow along the same flow of movement and remain onscreen long enough for the viewer to read them and absorb the information. In storyboards, I like to give a rough placement of leader lines and inset shape to block out the composition (Figs. 8.18 and 8.19). Inset and label style is typically developed

Fig. 8.19 Inset



along with style frames and color compositions, so I often use a standard, simple leader line/label template throughout my storyboard so as not to overcomplicate the board.

8.7 Summary

The key to a great medical storyboard lies in understanding that the importance should be placed on overall communication and not the illustrations themselves. Sometimes a great storyboard can be a rough sketch on a napkin—as long as it communicates the goal of the story. Like any story, medical animations also follow a narrative; the only difference is that our characters are cells instead of people.

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9

The Hidden Curriculum of Utilisation of Imaging and Unregulated Digital Resources within Clinical Education

Joanna Matthan and Gabrielle M. Finn

Abstract

Clinical education has changed dramatically over the last 30 years. The increasing use of imaging and visualisation technologies within medical, dental and other healthcare sciences education curricula is taken for granted, with little consideration given to the agenda behind the colonisation of the basic sciences curricula with these technologies or their ultimate utility with regards to patient care. Sufficient critique is rarely given prior to the incorporation of imaging modalities into teaching and learning, and the hidden curriculum remains deeply buried under the impetus to 'move with the times'. Coupled with increasingly easily accessible but unregulated streamed digital teaching resources widely utilised in healthcare professions' curricula, there remains a danger that future generations of clinicians may be exposed to erroneous information that could ultimately impact on the safety of their patients. Educators must develop a reflective approach, and together with institutions develop a collective responsibility to integrate and map evidence-based and clinically-relevant approaches within the respective curricula, rather than bombard undergraduates with the latest technology and never-ending (and sometimes unreliable and unregulated) information without awareness of the potential dangers lurking within their preferred teaching methods and ideologies. Healthcare professionals must subject teaching resources utilised within their curricula to the same scrutiny that textbooks undergo, with content accuracy and endorsement via reputable sources, preferably peer reviewed and traceable, taking precedence.

Keywords

Hidden curriculum · Social media · Teaching resources · Unregulated resources · Pedagogy · Education · Students · Learners · Medical education · Healthcare education · Technology-enhanced learning

9.1 Uncovering the Digital Hidden Curriculum

The mantra that healthcare provision must be evidence-based or, at the very least, based on the best available evidence out there seemingly does

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not always extend to medical or clinical education. A quick review of the variety of teaching delivery and curricular types across medical and healthcare institutions reveals disparity and diversity that is not easily reconcilable with a clear evidence base. Institutions prefer to maintain a degree of independence and do things in their own way and, particularly, to have the freedom to deliver teaching in methods which best fit in with their own strategy and agenda. And, as such, this is understandable. Despite the vocational nature of many of the healthcare professions, many are delivered at higher education institutions, where the delivery and scope of educational attainment is required to be wider and, more necessarily, not limited to delivery of specific learning outcomes within a narrow frame of delivery methodology. Even the regulatory bodies' (General Medical Council – GMC, General Dental Council – GDC, Nursing and Midwifery Council – NMC, etc.) refrain from providing prescriptive guidance for attaining graduate-level achievements across a wide spectrum of desired outcomes, indicating by their absence of clear guidance that institutional independence and variation in educational delivery is acceptable.

Educators rarely stop to explore the reasons behind the slow but determined steer towards the incorporation of newer pedagogical methods in higher education institutions (Finn and Matthan 2019). Within healthcare education, two phenomena have risen seemingly out of nowhere over the past 20 years, namely the voluminous use of imaging within healthcare professions -related curricula and the more recent trend to utilise virtually any resources available on the World Wide Web (WWW or internet), without due consideration to the reasoning for the seemingly irresistible move in this direction. It may be time for educators to take a step back and look at the wider view behind these popular trends. Educators need to ask themselves whether their institutions persist in reforming clinical education without *actual* change, an idea postulated by Bloom (1988). Several simultaneous winds of change within the healthcare educational sector have contributed to a change in stance. These are the cultures of commercialism and professionalism, and a loss of autonomy and discretion for physicians in the clinical decision-making process. Focusing on the need to reform has at times shifted educators' gaze away from the learning that occurs in curricula outside that what is offered by the formal course, i.e., the hidden curriculum.

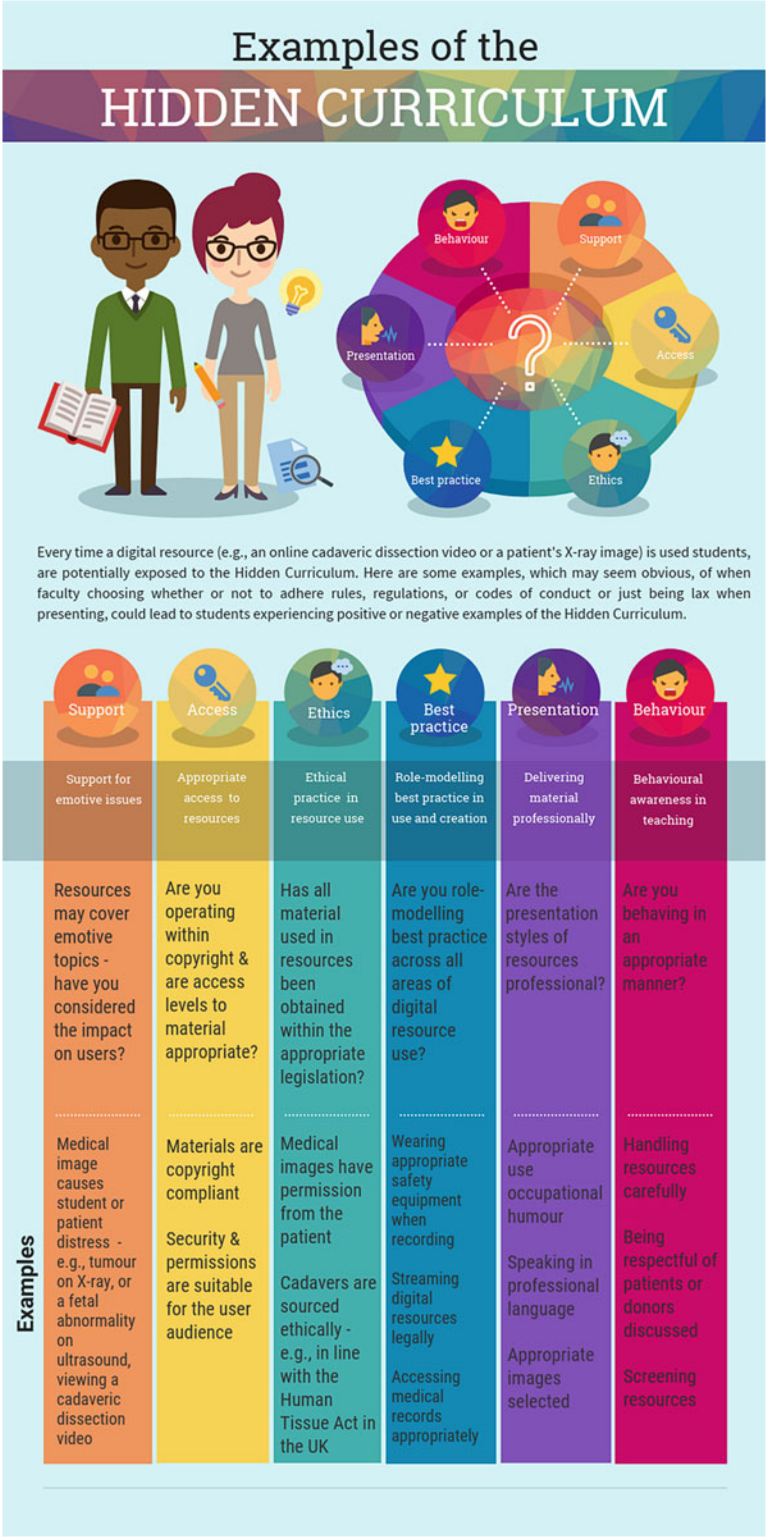
Definition
The hidden curriculum refers to the tacit, implied, unwritten, unofficial, and often unintended behaviours, lessons, values, and perspectives that students learn during their education.

As early as 1930s, John Dewey (1938) remarked that "*Perhaps the greatest of all pedagogical fallacies is the notion that a person learns only the particular thing he is studying at the time. Collateral learning in the way of formation of enduring attitudes, of likes and dislikes, may be and often is much more important than the spelling lesson or lesson in geography or history that is learned*"; this idea has taken hold and been developed within the education community since the 1970s. Today, it is acknowledged that there is a clear and fundamental distinction evident between the taught curriculum delivered to students, and that which they learn. Three types of curriculum have been identified: (1) that which is explicit (or the stated curriculum), (2) that which is hidden (or the unofficial curriculum), and (3) that which is absent or null (or the excluded curriculum). It is important to clarify the use of the term 'hidden' curriculum in the context of this article (Lawrence et al. 2018). Within the first few years that the term was used in relation to medical education (Hafferty and Franks 1994; Hafferty 1998; Hafferty and O'Donnell 2015), it was distinguished by Hafferty (1998) from 'informal curriculum' (which is "*unscripted, predominantly ad hoc, and highly interpersonal* *form of teaching and learning that takes place among and between faculty and students*"). Hafferty (1998) clarified the 'hidden curriculum' to specifically incorporate "*the commonly held 'understandings,' customs, rituals, and taken-for-granted aspects of what goes on in the life-space we call medical education.*" According to these definitions, the terms are not synonymous but overlap (Lawrence et al. 2018). In this article, there is some overlap with 'hidden' and 'informal' curriculum (although Lawrence and colleagues do caution against it) and by hidden curriculum is meant the predominantly unacknowledged and unintended learning that occurs within the learning process. Usually this relates to absorption of values and perspectives within the routine environment, the attitudinal and social relationship interplay that occur unintentionally within the learning and teaching environment. These serve to inadvertently reinforce norms prevalent in the environment, norms that are often unquestioned and avoid scrutiny. While these usually refer to social norms, such as those that may influence a student's character and convey a moral message to them, institutional choices and curricular models can also reinforce other messages, not necessarily evident. Hafferty (1998) recommended uncovering four areas of institutional hidden curricula to help understand the flow of current 'pedagogical winds'. These areas are (1) institutional policies, (2) evaluation activities, (3) resource-allocation decisions, and (4) institutional "slang". In lay terms, the hidden curriculum is sometimes regarded as learning 'they way we do it around here' (Hafferty and Finn 2015).

Within education, the hidden curriculum has long been discussed (Snyder 1971), primarily as critique of implicit reproduction of inequalities, unequal opportunities and use of power in educational institutions (Edwards 2015). It is understood primarily as those things selected and enacted as part of a formal curriculum that provide hidden messages to certain groups and types of students to 'keep them in their place', maintain social hierarchies and power position, primarily as a form of inadvertent reinforcement of social injustice. From its inception in education, the hidden curriculum has evolved within medical education to mean that there is a significant difference in what is being *taught* and what is actually being *learned*; in effect, the hidden curriculum is that which creates the difference between these two. The hidden curriculum, however, may not have solely negative effects (although most use it with underlying negative connotations; Lawrence et al. 2018), and can be used to promote social change (Edwards 2015; Cotton et al. 2013).

There will always be hidden aspects of curricula and the issue is more a question of the legitimacy of what actually remains hidden (Edwards 2015). Educators should aim to bring these to the forefront so the full implications of educational choices made by them and/or their institutions are appreciated. The digitalisation of modern education must be scrutinised in the same manner as other educational interventions. With the move into a digital era, the future projections of which show no signs of abating, it should be noted that every encounter with a digital resource exposes the learner to a hidden curriculum. As depicted in Fig. 9.1, potential sources of the hidden curriculum are observed in, for instance, (1) behaviour, (2) presentation, (3) support, (4) access, (5) best practice, and (6) ethics.

Let's consider a worked example utilising Fig. 9.1, that of streaming an openly available Youtube anatomy video which contains cadaveric dissection. For context, you are a teacher and select this video to demonstrate a concept within a lecture theatre. There are many potential sources of tacit messages that are at play in this situation, these could be considered under the headings presented in Fig. 9.1. Firstly, in this example, the source is openly available, but that is not an explicit pass to play the video for an audience. Is this a copyright violation? Where did the cadaver in the video originate from? Was it legally obtained? Is filming cadaveric permitted in that country? Did the donor consent? Has the donor's anonymity been preserved? Does the dissection



Examples of the
HIDDEN CURRICULUM

Every time a digital resource (e.g., an online cadaveric dissection video or a patient's X-ray image) is used students, are potentially exposed to the Hidden Curriculum. Here are some examples, which may seem obvious, of when faculty choosing whether or not to adhere rules, regulations, or codes of conduct or just being lax when presenting, could lead to students experiencing positive or negative examples of the Hidden Curriculum.

	Support	Access	Ethics	Best practice	Presentation	Behaviour
	Support for emotive issues	Appropriate access to resources	Ethical practice in resource use	Role-modelling best practice in use and creation	Delivering material professionally	Behavioural awareness in teaching
	Resources may cover emotive topics - have you considered the impact on users?	Are you operating within copyright & are access levels to material appropriate?	Has all material used in resources been obtained within the appropriate legislation?	Are you role-modelling best practice across all areas of digital resource use?	Are the presentation styles of resources professional?	Are you behaving in an appropriate manner?
Examples	Medical image causes student or patient distress - e.g., tumour on X-ray, or a fetal abnormality on ultrasound, viewing a cadaveric dissection video	Materials are copyright compliant Security & permissions are suitable for the user audience	Medical images have permission from the patient Cadavers are sourced ethically - e.g., in line with the Human Tissue Act in the UK	Wearing appropriate safety equipment when recording Streaming digital resources legally Accessing medical records appropriately	Appropriate use occupational humour Speaking in professional language Appropriate images selected	Handling resources carefully Being respectful of patients or donors discussed Screening resources

Fig. 9.1 Potential sources of the hidden curriculum associated with the use of digital resources in biomedical teaching

distress the audience? Were the audience given any warning shots and expecting it in this context? Does the procedure uncover a pathology that may cause an audience member distress? Remember, it might not be the video itself but the topic – for example, a tumour may be more emotive if someone has a family member with a recent cancer diagnosis. Have you got appropriate support in place should there be emotional distress evident in your audience? You did not make the video but the instructor featured in it is not wearing appropriate personal protective equipment (gloves, etc.) during the dissection – what does this role-model to students? The video contains an element of macabre humour, everyone laughs but is this really signposting appropriate behaviour or is it appropriate in this setting? How can you role-model what is appropriate behaviour? The video uses all the relevant terminology and achieves the anatomical learning outcome you intended so, just in case the video gets taken down, you export it using online software.

You might ask what is the point of this example? Well, it is to demonstrate that even the seemingly innocent act of watching a Youtube video within a teaching session can expose students to many unintended learning outcomes – both positive and negative. Streaming this video creates an unintended curriculum, one which, for the most part, is hidden. Nonetheless, the subliminal messages are there – donor consent doesn't matter, copyright does not matter, appropriate use of occupational humour does not matter, etc., etc. We may never know if the students picked up on the negative role-modelling in the video, but it is a risk and thus careful consideration is required before educators unleash digital resources. Chen (2015) cautions against turning a blind eye to the hidden curriculum, so we do not perpetuate its messages through our deliberate ignorance; everything cannot be 'unhidden' or remedied by adding in more lectures, coursework, reflective exercises, or evaluations into the formal curriculum but we must closely look at the systems within which we operate. To counter the detrimental effects of the hidden curriculum, educators need to "*use our moral imagination and develop our practical wisdom*", without a "*reactionary swing from one extreme to the other*" and demonstrate courage to students in that we are capable of setting appropriate boundaries and communicating difficult information (Chen 2015).

9.2 Hidden Curriculum in Imaging

With the recent (over)use and expansion of the term hidden curriculum in medical education, some have postulated that its continued utility in medical education is questionable (Lawrence et al. 2018). Still, as it is widely thought that the effects of the 'hidden curriculum' are more influential than the formal curriculum itself (Lawrence et al. 2018), it is worth aiming to expose 'that which is hidden' to attempt to action those practices which might be considered detrimental or reinforcing bias / bad practice. In fact, MacLeod (2014) recommends that the medical community move from aiming to repeatedly identify perceived hidden issues to tackling what can be considered 'now-visible practices' (MacLeod 2014). A broader and perhaps more useful definition in the context of today's overexposed medical education curricula is the definition by Balboni et al. (2015) who have defined the hidden curriculum as "*the process ... which instills behaviors, attitudes, and values among trainees in tension with the ideals of the medical profession*"; it is with this in mind that the hidden curriculum of imaging is examined.

Utilisation of imaging in clinical education is riddled with little acknowledged hidden curricula. Some circumspection and debate has always surrounded the incorporation of imaging into clinical curricula. Little or no national regulatory guidance exists for any of the healthcare professions as to the level of imaging knowledge required at graduation.

The GDC, GMC and NMC all provide only vague recommendations, mainly perhaps because imaging is a specialist skill requiring several years of dedicated training for radiology trainees to acquire competence in. Institutions, programmes of learning and educators continue to experiment and implement sometimes disproportionate amounts of radiology teaching into the curriculum, with no clear idea of how much knowledge a graduate actually requires, how valuable the imaging utilised in teaching potentially is or of the unintended messages silently relayed to the student body through this modality.

It is clear that, in many parts of the world within the healthcare industry, imaging is the bread and butter of clinical medicine and the final word in diagnostics, with an unacknowledged or perhaps unvoiced suggestion that its usage is more reliable than a clinician's acumen. Imaging modalities, it is widely believed, trump those findings revealed by careful observation by the experienced clinician. It is clear that many findings are ultimately and conclusively revealed by imaging technology but an overreliance on visualisation technology to diagnose a patient has its downsides, and a hidden message. The unwritten message not merely to the patient but to the doctor treating patients, and by extension to the entire healthcare team, is that acumen alone is not enough. To prevent litigation, one must have the diagnosis clearly spelled out in shades of gray, which in part legitimises the practice of defensive medicine. This shift from development of solid clinical acumen to that which an expensive machine can reveal in seconds, says much about the state of modern clinical curricula. It reveals an agenda that has wider societal implications, one which has perhaps inadvertently impacted on curriculum development.

The intention at the inception of incorporating imaging into medical education was to exemplify living anatomy and clinical relevance, but the hidden message may be that however much one learns anatomy and clinical skills, one's skills are never going to be as good as the diagnostic imaging tool and that, to avoid litigation, you need to practice defensive medicine and utilise these modalities. Leask (2009) has shown that incidental lessons learned about what and whose knowledge is valued (the imaging modality?) and what and whose knowledge is not valued (the clinician's acumen), as well as power and authority, are some of the incidental lessons reinforced by the hidden curriculum.

To exemplify some of the potential hidden curriculum messages lurking within imaging utilisation in teaching, imagine this scenario referring back to Fig. 9.1: You are an obstetrics consultant and have two medical students shadowing you for the week. Each day is spent doing different tasks and much of your day is interrupted providing expertise to your junior colleagues in clinic or in theatre. On one day, you are doing imaging investigations on pregnant mums, some of which are tricky and require your full attention. The students are sat in the corner of the darkened room as patients come in one after the other. Most patients look at the students and are quickly told who they are and the imaging continues with them on the bed. Sometimes, patients walk in (it is after all a busy clinic and is running late) and the students are not mentioned or introduced. Have you considered issues to do with consent, not just in clinic but when using these patient imaging results in your teaching practice? Are you taking the time to role model good practice in obtaining the images (and consent for having the students shadow) as part of the process? When something worrying or unusual comes up on the screen, do you automatically start discussing it with the students without discussing it with the mum/parents first? Are you looking at the screen when you are talking or at the the mum? If you are looking solely at the screen, what does this role model to the students? Are you role modelling a caring attitude even when there is an image to look at and not treating the image and the parent present as an abstract concept to diagnose? At the end of each consultation, do you assist with wiping off lubricating jelly on the mother's abdomen or do you continue to focus on the image in front of you? If the latter, what does this say about your relationship with the living breathing person in front of you and what do you think your students take away from this scenario? When you are interrupted by your registrar about something they are struggling with in another consultation room, do you give them your full attention or do you explain your role and apologise to the patient in front of your first? Do you take care to cover the patient and the image on screen to protect confidentiality? Do you discuss the imaging findings of the other patient your registrar is discussing with you openly in front of the students and your patient? Have you considered consent issues for your other patient as well as well as your own professional conduct? In the doctor's office, your students are exposed to several images that stay on the screen, as you and your colleagues have not switched them off. They can see the patient details from them, none of which the students have been consented for. Your colleagues are all relating a funny story about a finding on the screen and the 'odd' patient they had. Do you pause to think whether it is okay to discuss other patients and their imaging findings in an open forum and the message it relays to the students present? You also then get an urgent phone call from another colleague in a different specialty who requests that you urgently review their patient (under their care but who is pregnant). They want imaging to be done to get a conclusive diagnosis. You review the patient and your clinical acumen tells you the diagnosis and you do not need to subject your patient and the unborn child to radiation. Do you trust your clinical acumen or do you consent to the imaging request 'just to be on the safe side'?

Much of what you do and the way you react to situations conveys unintended messages to your students. An abstract and distant approach with a focus primarily on getting the image up on screen and then going through it with your full focus may convey a message that you have not intended, namely that the patient in front of you with their array of complexities and messy feelings and questions is not your primary focus. These inadvertent messages may speak louder to the students than anything else they imbibe during shadowing week. It is thus of paramount importance that we realise that a critical step to impacting on the next generation of healthcare professionals in this digital era is for faculty to examine their own behaviours and expectations, constantly reflect and assess their interactions and be willing to avoid taking 'electronic shortcuts' that may compromise security (Mostaghimi et al. 2017; Fuks 2018): "*until the culture of the hospitals and teams within which students function is changed, students will continue to receive conflicting messages on what is "ethical" and "professional.""* (Mostaghimi et al. 2017).

9.3 The Use of Unregulated Internet Resources – Are We Teaching Our Students to Be Discerning?

The temptation to use fast and easy-to-use digital resources is ever-present, and not merely for students. No longer do even the most dedicated researchers use conventional print as their primary sources; an abundance of knowledge has been accumulated and is available on the internet at one's fingertips, a source not for lamentation but delight (Silberg et al. 1997). The internet after all is not all bad; not only has it opened out unlimited possibilities for everyone wanting to utilise its resources, it is user-friendly, graphically pleasing, and hosts a substantial number of high-quality resources, with seemingly endless opportunity to teach, inform, and connect people (Silberg et al. 1997). Much like the new world was portrayed as the land of opportunity to the early pilgrims, the internet lured users with its abundance of opportunity. It does not discriminate against those with little or much wealth, is not interested in backgrounds, privilege (or lack of privilege) or ability, and can be considered quite inclusive and accepting. However, much like with the land of opportunity, a metaphorical ‘Wild West’ soon emerged.

The way in which society interacts changed dramatically since the deregulation of the internet in 1995 (Plant 2004). In this new unregulated and free-for-all world, knowledge, ‘fake-news’, dark webs and dodgy sites abound. In this landscape of plenty, few are able to navigate with ease without encountering some aspects of the ‘Wild West’. For educators and learners, it is difficult to be discerning with regards to freely available sources on the internet, a vast amount of which is unregulated and decentralised. With the demise of so-called antiquated methods of information gathering, the ability to discriminate between reliable and accurate sources, and what makes them thus, is lacking. Salpeter (2008) suggests there is a wider challenge to develop a generation of digital citizens able to operate in the unregulated online world, and it is not enough anymore for educators to demonise, for instance Wikipedia as an unreliable source – its accuracy has been pointed out by some to be comparable to Britannica and Encarta (Salpeter 2008) – instead, what is needed is a programme of education to ensure generations brought up with digital devices are trained to become digitally savvy and able to discriminate between those sources that are not peer-reviewed and those resources that have no basis in evidence-based investigation. This is even more important for those training to become healthcare professionals of the future. Cutting-edge medical information is now available not to a select few but to everyone with access to the internet, from the leisure of their homes, while on the move or from work (Okamura et al. 2002). This has resulted in an explosion of unregulated and unscreened ‘health’ information, which may contain erroneous information, with potentially adverse outcomes for unsuspecting users; there is no shortages of internet scandals involving peddlers of magic potions and lotions. Healthcare professionals, and those training them, must be aware of the risks involved with a lack of engagement with developing the skill to be discerning; these skills may save their students as future healthcare practitioners and their patients. This skill can be developed and honed during higher education as part of a skills set required to function in the ever-digitalised world.

In the case of anatomy education, even a quick internet search on any anatomical subject reveals a plethora of websites, images, videoclips (cadaveric and animated) and 3D material that bombards the knowledge-seeker with its abundance. A google search (done on 23rd May 2019) using the word *‘platysma’* generated 605,000 results, 10,700 of these videoclips alone. A yahoo search revealed 371,000 hits for the same anatomical word. The volume of hits reveals a veritable minefield to the novice learner, and even the seasoned anatomist can become swamped. Using the internet to find accurate sources of information to learn about the platysma muscle resembles a ‘cocktail conversation’, not the effective communication and decision-making tool it could be in the hands of a discerning individual. Already in 1996, prior to the avalanche of information that swamped the internet in the following two decades, Achenbach (1996) identified the problem as not being that of too little information but too much, with vast amounts of the information misleading, inaccurate or incomplete. Silberg’s et al. (1997) prophecy that the internet would have the ‘potential to become the world’s largest vanity press’ has come to pass, with anyone able to publish anything online without accountability and with full anonymity. Technological brilliance, shiny and attractive sites, and the convincing content can lull the naive viewer into placing more value on the content than it necessarily merits (Silberg et al. 1997). For the novice learner then, in this landscape of abundance and plentitude, with all manner of voices clamouring to be heard, to avoid the ‘Tower of Babel’ effect and getting hopelessly lost, the simple solution is often to navigate to the first and most popular site, in both of the browsers utilised it was Wikipedia, which, interestingly, students are time and again told not to use as a credible source, posing a dilemma even for the digitally savvy user.

How then can educators separate the wheat from the chaff, and the useful from the useless? How do we teach our students to be discerning and become discerning ourselves? Chen (2015) cautions against "*prohibiting or actively not engaging in social media and technology*" as this may leave students alone in their struggle with the challenges posed. Educators must remember that the bedrock on which technical tools and internet resources rest is their actual *content* (Silberg et al. 1997); this must, in the healthcare professions arena, have sound educational value that is grounded in the best available evidence. Standards do exist by which to quality-control content, to enable the educator or learner to differentiate science from drivel, to discern advertising or promotion from education, and evidence from opinion (Silberg et al. 1997); these are the tried and tested quality standards followed by peer-reviewed entities in print that should logically and reasonably also apply to the digital world. Accountability for the content accuracy and, consequently, for recommending or utilising sources or resources for the student body, rests not solely on the content providers but on the educator recommending or using them in their educational practice, and institutions which push for educational reform. Silberg and colleagues suggested four core standards of (1) authorship, (2) attribution, (3) disclosure, and (4) currency which are valuable but not automatically good proxies for assessing either quality or accuracy; they do, however, enable assessing validity of the information available with a clear framework, although achieving the rigorous standards prevalent in conventional print might be unattainable (Jadad and Gagliardi 1998). Adherence to and compliance with these standards suggests a completely new role for the educators as monitors of quality and content and information traffic directors (Silberg et al. 1997), a challenging task in the digital world where not everyone plays by the rules and several may be driving their own agendas. It is important to remember that setting benchmarks for reliability is not a guarantee for quality (Silberg et al. 1997), and there is much value to be gleaned from sources that are not the traditional professional sources, i.e., regulatory bodies, government agencies, journals, professional societies, universities and librarie.

Further, there are hidden signals relating to technological access. For example, do streamed resources require a particular internet speed connection, and what does that convey to those that might not have access to that? When are users expected to access it, and does that imply using mobile devices and/or data they're expected to provide themselves? Perhaps these are things that one takes for granted, but these are all things that might have an exclusionary effect. It may seem a bit outdated when the presumption is everyone has device and data, but in an era where widening access and participation into Higher Education is top of the political agenda, it is not something that we can assume. Taking our thoughts back to Fig. 9.1, we are making assumptions about access and there is a potential role-modelling issue to surround the use and display of (expensive) technology, for both students and teachers.

Guidelines-wise, the internet is a somewhat free-for-all space, reminiscent – as previously suggested – of the 'Wild West'. Recommendations are dotted around in the maze that the internet is, in publications, and on websites but there is little clear regulated guidance, and – even more worryingly – no consequences for poor or dangerous practice. There have been attempts to regulate content but these have not been widely adopted. Consequently, several universities, societies, corporations and companies have developed their own internal guidance, an amalgamation of which we present in the textbox below, along with two examples of reputable sources for use in biomedical education (picked at random due to familiarity with content).

Textbox: Two Examples of Good Practice in Biomedical Education Resources

Geeky Medics has a worldwide audience (68 million views and over 300,000 subscribers) for those interested in clinical education. Using a variety of platforms from a website, YouTube channel, blog and a smartphone app, the idea behind this diverse resource is to create accurate and relevant information that is freely available to clinical practitioners and students. Contributors go through a process of applying and being validated for content creation and they can range from medical students to more senior level clinicians. Published content ranges from clinical skills videos, exam guides, exam question bank, student notes and clinically-relevant anatomy content. Accuracy and reliability is paramount, with a process that quickly weeds out any erroneous information mapped into the management of the resource. The content authentication process varies depending on the content type. In the case of a *clinical skills* guide, a senior registrar or consultant in the relevant area is consulted to watch our video and review the written guide, then provide feedback. In these cases, information on who reviewed the guide and their credentials are placed at the end of the guide. At times when the reviewer does not want mentioning, a generic "reviewed by a cardiology (or whichever specialty it relates to) consultant" is placed at the end of the guide. In the case of other *clinical content* (e.g., a piece on a specific condition), the content is reviewed by a registrar and also referenced against guidelines in place nationally (NICE, etc.). In the case of *anatomy*, content is by an experienced anatomist and anatomy educator, who also has a clinical perspective. Content is clearly referenced to peer-reviewed and reputable anatomy texts.

(continued)

To improve reliability: The anatomy review process is in its early stages and developing its robustness. The content gets a considerable amount of views, and the nature of the audience means they regularly flag issues they notice, after which they are checked and fixed rapidly.

AnatomyZone is an internet based resource platform founded on the idea that anatomy is necessarily interactive, three-dimensional and fun. Their vision is one of providing the best anatomy resource on the internet and ensuring it is always free to use, thereby making it a valuable resource for students. The content creators are medical doctors with wider interests in technology, medical education, neuroscience and musculoskeletal anatomy. Content ranges from bite-sized anatomy videos to questions, flashcards and tutorials and boasts over 30 million views and over 300,000 subscribers. The over 190 video tutorials it boasts are well made and predominantly accurate, with a system in place for corresponding with the content creators.

To improve reliability: Sources are difficult to locate on this site, and its credibility would greatly improve if references were available for every resource.

Textbox: Points to Consider When Searching for Reputable Digital Resources

Audience	**Currency**
Is the intended audience clear? Is this aimed at the general public, children, academics?	*Are the dates that the content was posted and/or updated clearly stated and updated regularly?*
Is it addressing the topic sufficiently to satisfy the target audience?	*Is it clear when the information was published?*
Is it relevant to your area of interest?	*Are all links from the page functional?*
Accuracy	**Data protection**
Are there evident typographical errors?	*Is the storage and usage of personal data clearly stated and justifiable?*
Is the text easy to read, clear and concise?	
Has the material presented been through a process of peer review and editing?	
Are the cited sources verifiable?	
Attribution and referencing	**Disclosure**
Is the content referenced at all times?	*Is fully ownership and disclosure (including sponsorship, commercial arrangements, support, conflicts of interest and advertising) explicitly stated?*
Are the sources reputable and peer reviewed?	
Is the name of the publication evident?	
Does it 'appear' professional?	
Has the publication been referred to elsewhere?	

(continued)

Is there a references / bibliography section?	
Authorship and traceability	**Domain**
Is the author identified? If not, why have they remained anonymous?	*Can you tell from the domain name (URL, web address) whether the information published is from a credible source?*
Can the authors be considered experts in their field?	
Is there enough information to establish credibility?	
Are the contributors openly acknowledged?	
Are the contributors' affiliations openly acknowledged?	
Are the qualifications and relevant credentials of the contributors clearly stated?	
Commercial considerations	**Educational value**
Is the source geared at making a profit?	*Does the content accurate meet an accuracy analysis and compare with printed and other peer-reviewed sources?*
Is the source freely available or at a 'reasonable' cost?	*Is there any misleading content evident?*
Are the tools utilised in making the resource paid for or freely sourced?	
Content	**Endorsement**
Is the process for content selection outlined and justified?	*Is the source externally endorsed or ratified by a reputable organisation?*
Are the justifications for suitability of content creators, staff, reviewers, and advisory boards clearly articulated?	*Is there a national regulatory body to whose standards contents must be matched, and is this clearly stated?*

(continued)

Copyright	**Feedback**
Are copyright issues duly considered?	*Is it possible to leave open feedback?*
	Is there a route for contacting the authors?
	Objectivity
	Is the author clear about biased opinions?
	Are arguments objective?
	Are personal opinions expressed and, if yes, stated as such?
	Has the website got a clear agenda – Political, commercial or the like?
	Regulatory bodies
	Is the content in line with that recommended by national / international regulatory bodies?
	Quality assurance
	Does the site have quality protocols that are part of a well-established editorial process?

9.4 Anatomy Education, the Hidden Curriculum and Unregulated Digital Resources

Anatomy education serves as an exemplar to elucidate some lesser discussed themes emerging from the hidden curriculum with increased use of imaging and the use of unregulated digital resources available on the internet. Anatomy education is rife with hidden agendas; these have been dealt with extensively elsewhere (Hafferty and Finn 2015) and thus are not the main focus here. Instead, we propose to, by polarising the more traditional use of cadaveric specimens with the increasing use of imaging in anatomy education, illustrate the oft-missed and little discussed implications evident in the trend to utilise digital resources when teaching about the human body. We acknowledge that polarisation is coarse and the arguments used perhaps provocatory by nature. Educational attainment using cadaveric or imaging or other educations sources is not the scope of this discussion; those too have been tackled elsewhere (Estai and Bunt 2016; McMenamin et al. 2018; Pickering and Swinnerton 2019; Hafferty and Finn 2015; O'Keeffe et al. 2019) The intention here is to utilise the hidden curriculum as a form of 'gap analysis' (Hafferty and Finn 2015) where polarisation is a tool for revealing that which is not evident; after all, in the high stakes environment of clinical education, students are constantly "*on the lookout for message gaps between what faculty formally tell them about course/learning standards versus what students come to learn (also from faculty) about what they "really should be doing" to "pass the course."*" (Hafferty and Finn 2015) It also serves to highlight some of the less considered consequences of widespread utilisation of visualisation in (anatomy) education, with the intention of starting a wider debate on the issue.

Clinicians and educators commonly consider anatomy to be the true foundation of medicine, perhaps even the foundation of all healthcare professions; it is, after all, the most concrete of all the sciences students encounter in their learning journey. Where dissecting the human body was a requirement (and to some extent also a rite of passage) for medical and dental students in earlier times, a move towards integrated curricula, a decrease in pure basic sciences teaching and an increase in clinical skills teaching in the early years, coupled with financial constraints, accessibility to donated bodies, a shortage of highly-qualified teaching staff, the requirement for expensive equipment to embalm and preserve the donated bodies in addition to stringent regulations around body donations has led to a downsizing and devolving of foundational anatomy teaching for healthcare students across the board. The implications have been far-reaching, impacted on anatomy knowledge – and by extension on clinical care.

Johnson et al. (2012) suggest that, through educational reform, the anatomy educator is now required to (1) teach students to understand and visualise the human body utilising a variety of tools available (touch for physical examination to for example imaging modalities, and (2) develop students' clinical reasoning skills. The modern anatomy course, according to him, should include all of the following five of the elements, each of which has a supporting body of evidence; there are dissection/prosection, interactive multimedia (computer-assisted learning), surface anatomy, clinical anatomy, and imaging (Johnson et al. 2012). Even still, with so many elements to incorporate into teaching, the basic anatomical subject matter taught to healthcare students has not changed significantly since earlier times. Competing for time with physiology, pharmacology, pathology, and practical clinical skills in healthcare curricula has, however, led to a drastic change in the tools available for students and educators. To replace full body dissections, prosection based teaching and, increasingly, technology modalities have now become firmly rooted in anatomy learning. In the arsenal of teaching tools are digital and paper anatomy textbooks, dissection atlases, plastic models, plastinated anatomy specimens, virtual reality glasses, 3D printing and social media channels. The internet is rife with anatomy video clips and tutorials (many of which lack clear consent details and for which the ethical process of utilising images is questionable) detailing the secrets of the human body not merely for healthcare professionals, but for anyone with access to the internet. Software applications for smartphones and computers are readily and freely available to enhance anatomical knowledge with both rapid access and ease; a veritable smorgasbord of choice for anyone.

Many healthcare educators disagree as to the best way to teach anatomy (which is increasingly challenging within the constraints mentioned above as well as significant time constraints allocated to anatomy teaching); this is not a debate we intend to elaborate on here as others have dealt with this extensively (McMenamin et al. 2018; Pickering and Swinnerton 2019). However, the widespread use of imaging and visualisation technologies in anatomy education does require some pause for thought. It is not contested that cadaveric anatomy confers numerous benefits to the healthcare student (Gunderman and Wilson 2005): (1) there is a tactile element which is not easily replicated by illustrations and virtual dissection simulations, (2) it encourages active exploration rather than passive observation (Gunderman and Wilson 2005), (3) it allows development of manual dexterity and instrument usage necessary for a significant number in their future careers (Wilson et al. 2018), and it emphasises concretely to students that the human body is the foundation on which all subsequent knowledge rests on (Roach 2003).

Equally important arguments can be made to incorporate radiology in to anatomy education, and it is hardly worth contesting the fact that imaging offers much to the student of gross anatomy. With imaging, gross anatomy can come to life for the student, who through the imaging modality may see its relevance (Guttman et al. 2003; Böckers et al. 2014; Koens et al. 2003) and anatomy within context, although there is some dispute as to how exactly relevance may be utilised in teaching (Bergman et al. 2015). No more are students limited to the two-dimensional cross-sectional images that made their way into the healthcare arena in the 1970s. Today, radiographs, barium investigations, fluoroscopy, PET, CT and MRI imaging provide detailed internal anatomy images for clinicians as well as students. Some institutions have older CT scans for use in teaching and many have incorporated ultrasound into the teaching of anatomy in the undergraduate years (Griksaitis et al. 2014). These allow both real-time, synchronous or asynchronous views of the inside of the human body, and functional PET and MRI scans can show minute metabolic alterations in, e.g., the brain and heart allowing for better prognostication and richer correlation between the structure and function of a organ; cinegraphic techniques enable changes in the structure of an organ, for instance the heart and the cardiac cycle, over time to be viewed (Gunderman and Wilson 2005). Pathology is easily viewed, albeit in shades of grey, through imaging, and in vivo anatomy can be inspected, greatly advantageous over the morbid and static cadaveric tool (Gunderman and Wilson 2005). Despite the wide range of available software and other virtual resources, most are aimed at medical specialties, not for instance nursing or dentistry (McHanwell 2015). Different resources can effectively confer different advantages when teaching anatomy (Sugand et al. 2010; Ward and Walker 2008; Hackett and Proctor 2018), and cadaveric learning can be a effectively combined with technology (Biasutto et al. 2006).

Clunie et al. (2018) have pointed out that technology-enhanced learning studies incorporating anatomy education are often not rigorous enough to draw recommendations and conclusions from; programmatic flaws cannot and must not be plugged with increasing use of technology (Finn and Matthan 2019), and imaging in particular, to try and bridge the gap between sound clinically-relevant teaching and the clamour for the newest gadget out available. The heavy and indiscriminate use of technology, imaging including, can lull both educators and students into complacency that they are learning when they are merely engaged or entertained, and a high level of vigilance is required to protect against the 'magpie effect' where new technology (or at least that which is not considered 'traditional' or out-dated') appears shiny and new and is utilised widely without due respect to the evidence base for its usage. It is widely understood that cadaveric anatomy is not the only means of teaching anatomy (McHanwell 2015). Current evidence suggests that it may be no more or less effective than digital learning (McMenamin et al. 2018; Wilson et al. 2018), and the only logical conclusion one can draw from the diametrically opposite results in the literature are that *variety* could be key to enhancing learning when incorporating technology into anatomy teaching (Finn and Matthan 2019). In some areas of healthcare education (dentistry, notably), radiology may be studied as a separate discipline and not implemented within the anatomy curriculum. As students frequently experience conceptual difficulties when interpreting two-dimensional radiographic images in terms of three-dimensional anatomy, intermediary solutions of three-dimensional reconstruction facilities offered, such as the Visible Man software and newer technologies including augmented reality (Kugelmann et al. 2018) offer solutions with making the leap from 2D to 3D. An array of newer technology has made its way into anatomy education: 3D printing, internet resources, virtual reality glasses and other forms of augmented reality anatomy learning; these provide educators with the educational tools from which to diversify their teaching (McMenamin et al. 2016) but to avoid ill-considered consequences, it is worth adopting a cautious approach to widespread implementation of new technologies (Finn and Matthan 2019; McHanwell 2015) although innovation must remain an essential part of educators' practice.

9.4.1 The Rise of Imaging May Be at the Expense of Expertise in the Anatomical Sciences

Gunderman and Wilson (2005) identified numerous reasons for the rise and appeal of radiological imaging in anatomy education. Numerous institutions have downsized or closed anatomy departments; many anatomy departments have been subsumed into other departments, resulting in a paucity of anatomists available for teaching on the shop floor. Funding streams have moved away from the gross anatomy sphere into those that are have of a more 'sex appeal' with regards to newer biological sciences fields; attracting people to study anatomy is harder than previously, and the far-reaching effects of the funding cuts are predominantly on anatomy departments aiming to procure cadaveric resources and equipment to preserve them and space to utilise them. A hidden message relates to some of the scandalous revelations in the world of anatomy: if there are no anatomy departments, there can also be no scandals relating to the misuse of specimens and accountability issues to regulatory bodies, the negative effects of even one scandal can be devastating for an institution. Rather than invest in trained and competent staff, the lure is to utilise technology that may or may not have a significant impact on learning but at least through the usage of which, 'risky' material such as donated bodies, can be easily replaced and the space used to meet other growing institutional demands. Imaging after all rarely imposes on the wishes of patients' families or the patients themselves, as they are usually obtained through pre-existing clinically utilised pathways where the patient's consent is obtained, confidentiality maintained and their wishes fulfilled. Gunderman and Wilson noted in 2005 that the practical appeal of the rise of imaging as a tool for teaching gross anatomy, in part, '*rests on the decline of the field of anatomy in biology and medicine*', a prophecy arguably come to fruition in the decade following its publication (Gunderman and Wilson 2005). This is reflected in the aforementioned causes for decline but also in the incorporation of anatomy-specific assessment questions in undergraduate exams; increasingly, assessment questions are linked to imaging rather than to their clear relevance in other parts of the discipline (surgery, general practice, orthopaedics, etc.).

As a standalone approach in the teaching of anatomy, radiology has numerous limitations (Gunderman and Wilson 2005), many of which serve to illustrate the underlying message being delivered to students (or some of its hidden curriculum). Where cadaveric encounters are practical and hands-on, and rarely leave the observer or learner 'cold', inspecting radiological images is an abstract endeavour, with no tactile feedback, no engagement of sensory feedback systems and can be completely free of emotions. Learning from prosections and dissections is messy business, preparing students for a career in which bodily fluids are ever-present and no encounter with a patient is completely free of this messiness. Radiological images by contrast are sanitised, dehumanized even, primarily as they are pictorial representations beneath the skin (Gunderman and Wilson 2005). No incisions are made, no fluids are split, no pain is induced or even imagined. The viewer is somewhat god-like. Where the process of dissecting (or even learning from prosections) involves actually touching the cadaver or its parts – a key aspect relevant and necessary to most clinical professions – the viewer of images (or user of technology to learn anatomy) distances themself from this very human and clinical aspect of the profession and simply looks at images. Gunderman and Wilson (2005) suggests that this could render these existential encounters less substantial, and even deny '*the human form some of its natural substantiality*'. Imaging removes every aspect of sensory feedback other than vision: there is no tactile feedback from the images, no smells emanating from the screen, no auditory feedback when, for instance a dissector touches the lungs. In moving from cadavers to images and widespread use of technology, we may be sending our students the hidden message that it is not necessary to be an active explorer and to use all our senses to learn; it is sufficient to distance ourselves from the patient, look at images from a screen, refrain from touching, feeling, smelling – and make a cold clear diagnosis. The images on a screen are as far removed from a person as can be. Through engagement with cadavers, for instance, the natural link between human anatomy and the face of the person that once was lived and breathed (and donated their body) are more clearly observed and the link with our own as well as our patients' mortality is more powerful than with even the best available imaging technology used (Gunderman and Wilson 2005); Magli (1989) suggests that the face marks our humanity more than any other body part. In losing this link with the face (i.e., the patient's humanity), we risk losing, for our students and future practitioners, an immediate and natural connection between anatomy and the human form (Gunderman and Wilson 2005).

A further and deeper exploration into the limitations of using imaging in anatomy education (and by extension any technological or non-technological modality utilised to teach) to replace cadaveric anatomy links to the, for want of a better word, spiritual dimension (Gunderman and Wilson 2005). The dissecting room has long been associated with a closely guarded 'secret' of dead bodies, an area only available to those requiring extensive learning through access to them (dentistry and medical students, primarily).

All the modern day rituals surrounding the secrecy of access and even discussion around encounters in the dissecting room hark back to this earlier time. Access is still limited, with smart cards or specific entry codes, windows are covered or the area is situated at the top floor or basement level where there is no fear of the general public peering in (and being distressed?). Although the reasoning has changed for this continued secrecy (e.g., regulatory bodies, distressing bystanders, respect for the dead, donor dignity, etc.) the primary goal of cordoning off an area for the purposes of dissection and inquiry using dead bodies is evidently to learn from them. A hidden component not so readily evident is the element of professionalism and confidentiality that goes hand in hand with this seemingly exclusive ritualistic and secretive behaviour. Healthcare professionals are required to hold the highest levels of professionalism; confidentiality is sacrosanct. What better way that to practice this skills so relevant in the living population through developing a sensitivity to it via the dead, in the early stages of training, thereby instilling in students the concept of professionalism and confidentiality through role-modelling it in the dissecting room? This is not an area that learning through images ventures near. Linked to this is the evident wonder that having access to donated bodies and dissection awakens is students (Konner 1987), and the respect they develop through seeing professional conduct role-modelled in staff both in the laboratories as well as at the annual memorial services held for donors. This is the hidden curriculum that anatomy teaching with and without cadaveric specimens enacts (see Table 9.1 for a summary); not all is tangible but much of it makes sense in terms of patient care and developing ‘soft skills’ necessary for the profession.

Table 9.1 Hidden curriculum messages using cadaveric dissection and imaging

Examples of hidden elements in the debate between cadaveric dissection versus imaging in anatomy education (modified from Gunderman and Wilson 2005)

Utilising Cadaveric specimens in anatomy	Utilising imaging in anatomy
Encounters are tangible, physical and may evoke emotion	Encounters are distant, cold, emotionless, and abstract
Multiple senses are evoked in all interactions	Only vision is sufficient in interactions
Encounters with patients may be ‘messy’	Encounters with patients are clean and ordered
The encounter is active, requires engagement with multiple modalities	The viewer is god-like and all-seeing, not necessarily needing to see or touch the patient
Active exploration is needed to make a diagnosis	Passive participation (and an image) can reveal a diagnosis
A face links the body with humanity and their previous life	Encounters can be faceless, and occur below the skin
Evokes a sense of professionalism and a code of conduct around death and dying	Encounters may be distant with no opportunity for professionalism and discussions around death and dying
Encounters role model confidentiality	Faceless encounters with all patient details removed, so no need for further confidentiality development
Instill a sense of wonder in the human body, the foundation of practice	Little wonder at the body, technology is supreme

While we recognise that by polarising cadaveric anatomy with imaging modalities in anatomy education we have omitted the spectrum of teaching modalities widely utilised in anatomy education, we hope that it will have some value in developing a sense of some of the hidden curriculum issues that taking a deeper look at educational practice can reveal, as well as the wider implications these may have for the patient at the end of every student’s learning journey; institutional change and educational interventions impact directly on the patient, who has little say in the educational journey of their healthcare providers. We thus caution educators and institutions to pause and reflect on what kind of healthcare professional they aim to nurture before blindly incorporating more unevidenced change into their practice or developing increasing reliance on imaging technologies and technological innovations to replace traditional practice (in this case, physical cadaveric teaching) (Waldby 2000), without fully appreciating the long-term impact on society.

9.5 Can the Hidden Curriculum Be Used as a Mechanism by Which to Teach?

Healthcare students have described several instances of professional misconduct and dehumanizing treatment but they often feel trapped in these situations and feel pressured to be a team player, fearing repercussions of professionalism monitoring. Thus, students keep silent and aim to fit in, despite intuitively knowing the behaviours they have experienced are unprofessional. Within months, they can become assimilated to these hidden cultures and are at risk of propagating these bad practices in future (Liao et al. 2014). By addressing the hidden curriculum, it may be possible to not only change hidden bad practice and rectify poor organisational culture but even harness the knowledge of the unknown to teach. Within the anatomy education literature, there are examples of faculty reporting their deliberate use of the hidden curriculum as teaching tool (Aka et al. 2018). The idea of the deliberate exploitation provides a distorted lens through which both the hidden curriculum and education can be viewed. The context of the Aka et al. study was using anatomical body painting to 'teach students by stealth' required professional skills, such as how to ask someone to undress or for informed consent for a physical examination. This use of the hidden curriculum to achieve explicit learning outcomes without formal teaching demonstrates the hidden curriculum in a peculiar and uncomfortable reframing. Unpicking this framing, one first considers the hidden curriculum by definition, it is both hidden and conveyed tacitly, and there have been studies have remedially suggested initial uncovering the hidden curriculum and subsequent embedding learned insights into the formal curriculum, to date, no one has recast tacit learning as being intentional. Recasting raises a numerous questions but we will consider a few here. How can a learning outcome that is formally un-stated and intentionally invisible to students be evaluated or assessed? Indeed, how would students know if they are meeting these hidden learning outcomes? How would faculty know when their students had met these learning outcomes? Are strategies of intentionally invisible teaching ethical?

What does all of this duplicity mean for the use of digital resources within biomedical fields? The obvious take-home message is that teaching by subterfuge is not an appropriate educational strategy, mostly because it cannot be guaranteed that learning will be achieved, as well as potentially crossing ethical boundaries.

9.6 Conclusions

In the ever-evolving digital landscape within modern-day medical education, addressing the hidden curriculum is no simple feat; by its very definition, the hidden curriculum is difficult to recognise and perhaps even harder to tackle – nor is it always ideal or meaningful to address every emerging revelation. Despite clear evidence of the emergence of 'hidden curriculum fatigue' within medical education research, there remain areas that require deeper investigation with regards to the phenomenon. Use of imaging without due consideration to the underlying messages that make their way across to students and perpetuate pre-existing poor practice from educators and institutions does need reviewing. Where the hidden curriculum still has the ability to reinforce negative institutional and workforce culture and practice (and be deliberately exploited), it must be examined, and considered modifications made. A wider interprofessional and international view is required to tackle flawed educational interventions that emerge over time; this needs to be coupled with a cultural shift involving responsible and reflective implementation of educational interventions, always bearing in mind that what is taught to healthcare students today becomes evident in clinical practice within the space of a few years. Healthcare programmes need to develop clear and unified policies when mapping out educational interventions to ensure that they are meaningful for students, in line with regulatory body recommendations and have minimal negative impact on patient safety in the long run. These include digital interventions, such as imaging, and the indiscriminate use of unregulated digital resources embedded into healthcare education. Armed with greater information, educators need institutional, pedagogical and practical support to develop a reflective approach to, and deeper awareness of, the implications of utilising unreliable and unregulated resources, on the impact this may have on students' learning and on the safety of the patient. Patient care is, after all, the ultimate test of implemented pedagogical interventions, and all meaningful reform must place the patient at its very centre.

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10

Online Distance Learning in Biomedical Sciences: Community, Belonging and Presence

Jenny Crow and Jo-Anne Murray

Abstract

In higher education (HE), distance learning (DL) has increased worldwide. Many educational establishments have embraced online distance learning (ODL), with online courses being delivered by a great number of institutions, ranging from community colleges to major universities world-wide. Distance learning (DL) is not a new concept (Keegan D. Theoretical principles of distance education, London, Routledge, 1993), it dates as far back as the eighteenth century as a means of providing access to those who would otherwise not be able to participate in face-to-face educational courses. Traditional DL courses lacked interactivity and the emergence of computers and the internet provided the opportunity for learners to undertake online distance learning (ODL). Many ODL students are biomedical professionals juggling work and family commitments, and therefore the ability to study at a time and place that suits them allows them to engage in learning that they otherwise would not be able to do without relocating. However, whilst ODL offers greater learning opportunities, the lack of campus time and face-to-face learning contact can result in learners feeling isolated.

Knowledge is constructed in the midst of interactions with others and is shaped by the skills and abilities valued in a particular culture. Thus, the teacher plays a key role in this learning process in shaping the leaning activities and supporting the development of knowledge and understanding. Therefore, it can be said that the role of the ODL instructor differs from that associated with traditional on-campus education. The instructor becomes the facilitator to support student learning, whilst the student actively participates in what and how knowledge is imparted. Consequently, students studying online are often required to take on a greater responsibility for their own learning. They learn more independently than the on-campus students, as they cannot just simply follow what the other students are doing, they must log into the VLE as a solitary initiative and interact with fellow students and their tutor of their own accords, this chapter looks at how presence and belonging can be supported in ODL as well as supporting staff and students to transition to ODL.

Keywords

Online · Distance · Community · Biomedical

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10.1 Introduction

In higher education (HE), distance learning (DL) has increased worldwide. Many educational establishments have embraced online distance learning (ODL), with online courses being delivered by a great number of institutions, ranging from community colleges to major universities world-wide. Distance learning (DL) is not a new concept (Keegan 1993), it dates as far back as the eighteenth century as a means of providing access to those who would otherwise not be able to participate in face-to-face educational courses. Traditionally, distance learning was in a correspondence course format whereby materials were posted to students (Lim et al. 2007), initially in print form and evolving to CD-ROM. Students submitted and received responses by post and consequently rapid communication was not feasible. As such, the distance between students, staff and peers was a barrier (Moore 1989) resulting in distance learning being an isolating experience with slow intermittent communication (Keegan 1993). However, DL has evolved over time with developments in technology enabling distance learning to be delivered entirely online with increased communication, engagement, feedback and collaboration, which offers an interactive student learning experience.

Technology has played a key role in the emergence of ODL by distorting the concept of distance between the learner and instructor; thus, enabling learners to access education at any time and from any place (Beldarrain 2012). The greatest benefit to learners is the flexibility offered by online learning. Individuals can participate in studying while maintaining busy professional and personal commitments as most ODL courses allow students to work at a time that is convenient to them and at a place of their choice; thus, the classroom is essentially wherever the student wants it to be. Thus, ODL has been described as “a process to create and provide access to learning when the source of information and the learners are separated by time and distance, or both” (Honeyman and Miller 1993). Developments in internet speed, internet platforms and communication tools now enable online delivery of learning materials. Commonly, delivery of learning, teaching and assessment is via a virtual learning environment (VLE), which is used for both on-campus and online distance learners. VLEs can host interactive learning materials and communication tools offering a more engaging experience compared to the flat text provided in correspondence distance learning.

Students can now access a wealth of courses from institutions around the world. Leaners are not limited to courses offered in their geographic area (Peacock et al. 2012; Murphy and Farley 2017). This brings freedom for learning to fit in with life commitments (Brown 2001; Bolliger and Inan 2012). Previously, this was not the case, with some students having to relocate or take time out of their bio-science career to study at their preferred institution. Other students would have missed this opportunity or been forced to choose a less ideal option. There are also benefits to institutions, by increasing the pool of potential students and bringing a richer learning experience, through drawing together varied work experience and cultural perspectives. Online distance learners have the flexibility to study anytime, anywhere; however, the approach to studying differs from education in the traditional classroom setting in that learners’ study at a physical distance from each other and their teacher. This lack of face to face interaction with their tutor and other students can impact on the learners’ sense of belonging to a scholarly community (Rovai 2002). Consequently, studying in this manner can result in students feeling isolated and insecure about their learning (Knapper 1988), which is known to be linked to a higher risk of online distance learning (ODL) students dropping out of their studies (Peters 1992). Students in ODL courses can report feelings of social disconnectedness, missing familiar teacher immediacy, and the interpersonal interactions and social cues they more typically have when learning face to face (Slagter van Tron and Bishop 2009). Therefore, whilst interaction is key in any educational setting, interaction in digital education (DE) courses is considered to be the cornerstone of effective DE practices (Fulford and Zhang 1993).

10.2 Communication and Collaboration

Communication plays an integral role in learning. It enables sharing of information, thoughts and ideas, all of which contribute to learning. Communication creates opportunities for learning to occur by clarifying information, promoting enthusiasm in learning, encouraging interaction and building positive relationships between learners. Within the traditional classroom setting social and communicative interactions occur between student and teachers, and student and student (Picciano 2002a). However, this face to face interaction cannot take place in online DE, instead interactions occur via the internet.

Communication media used in DL can reduce the feeling of distance and isolation from peers and tutor, and to provide opportunities for collaborative learning activities (Bates 2005). Such media include asynchronous discussion boards in the VLS, synchronous chat rooms (e.g. Skype), virtual classrooms (e.g. Zoom) and virtual worlds (e.g. Second Life). These tools can facilitate synchronous conversation between staff and students. Staff are now able to be present in the learning experience, which is aligned with the element of "teaching presence" in the community of inquiry framework (Fig. 10.1). Technology can also facilitate rapid feedback on student assessments and in wider choice of formats: for example, audio, text and video. Digital feedback offers the chance to provide more detailed, comprehensive feedback to students in a timelier manner. It can also enhance social presence and instructor immediacy behaviours and allow for nuances to be conveyed through tone of voice and use of language.

Technological advances also create the opportunity for collaborative groups activities, peer feedback and peer support. Students can learn together, collaboratively critique learning materials, and co-create content. Garrison and Arbaugh (2007) propose that these types of activities are necessary to fulfil a "deep and meaningful learning experience". The community of inquiry framework outlines three main areas to create this learning experience (Fig. 10.1). The area of "cognitive presence" suggests that students require discussion and reflection to gain knowledge. The move to include constructivist practices also aligns with the shift from learning

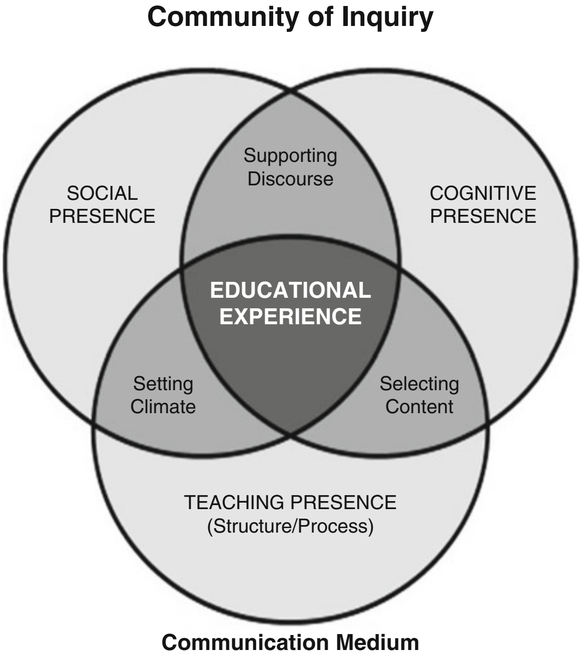

Fig. 10.1 Community of inquiry framework (Reproduced from Garrison and Arbaugh 2007)

being teacher centred to learner centred. In an environment that is teacher centred, the member of staff is the fount of all knowledge and shares this with the students (King 1993). The disadvantage of this approach is that the student is more likely to memorise information and recall it when required. In a learner centred approach the teacher takes the role of curator of resources and inspires students to take responsibility for their own learning. Additionally, students are expected to problem solve and research resources themselves, further promoting independent learning. The aim is that students can consequently apply their learning to various situations (Laurillard 1993). Therefore, in ODL the instructor's role is changing to becoming more of a "partner in learning" than a facilitator (Beldarrain 2012), with the instructor viewing the students as contributors of knowledge, allowing them to participate in the creation of content (Collis and Moonen 2005). This is a change in approach for academic staff who often require time to adjust to this new style of teaching. Equally, students may also need to adjust to becoming independent learners.

10.3 Communication Tools

There are two categories of tools, synchronous and asynchronous. Chickering and Ehrmann (1996) have provided seven principles for implementing the use of new technologies in ODL courses, which can be applied to both asynchronous and synchronous communication media:

1. Encourage contact between students and faculty
2. Develop reciprocity and cooperation among students
3. Use active learning techniques
4. Give prompt feedback
5. Emphasise time on task
6. Communicate high expectations
7. Respect diverse talents and ways of learning

Synchronous tools are live or real-time, examples include web chat (e.g. Skype), virtual classroom software (e.g. Zoom) and virtual worlds (e.g. Second Life). Asynchronous tools are not live; therefore, students and staff can participate at a time that suits them (e.g. discussion forums). The benefits of using a synchronous tool include the ability for participants to have a real-time conversation. Students can ask questions and receive an instant reply. Additionally, when participants share web cameras they can also connect visually. Ridings et al. (2002) in their study share about the importance of viewing visual cues and facial reactions in connecting participants together, consequently creating a more personal experience. The disadvantage of live sessions is participant availability. Students could be in diverse time zones, have differing work and other commitments. Thus, resulting in not all students and staff being available at the same time. Recording sessions can mitigate this. However, students who view the recordings miss out in the live interactions.

Virtual Worlds are synchronous and are like multi-user computer games. They differ from computer games in that their aim is communication and not achieving of set objectives or tasks (Wiecha et al. 2010; Kahu 2014). Plus some institutions have created simulations in virtual worlds (Beard et al. 2009). In this chapter we are going to focus on Second Life as it has been widely used in higher education for learning activities (Michels 2008). Similar activities are achievable in alternative platforms. Second Life was created in 2003 by Linden Labs (Wiecha et al. 2010). Participants in Second Life are termed Residents. This links into the idea that Second Life is a community and a place where participants belong. Residents select an avatar to embody their online presence. Participants can customise and swap their avatars at liberty, so creating a personalised experience. Avatars can communicate via voice and text chat (Wiecha et al. 2010; Petrakou 2010) and can gesture (Andreas et al. 2010). Virtual worlds can increased a sense of belonging compared to tools with text-based comments, for example discussion forums (Keskitalo et al. 2011). Additionally, Baker et al. (2009) propose that students can feel more confident in asking questions in a virtual world compared to a face-to-face setting, thus increasing engagement. When students join these sessions they can feel less isolated, in the learning experience, as other participants are visibly present. (De Lucia et al. 2009)

Asynchronous tools (e.g. discussion boards) have the advantage of allowing participation at any time. Discussion forums are popular in ODL, as they offer students and staff the opportunity to fit contributing around their alternative commitments (Hew and Cheung 2008). Students can also take time to consider a response, compared to the pressure of providing an instant response in a live session (Kirkwood and Price 2005). The disadvantage of asynchronous tools is that communication is not instant and participants might have to wait for a response from their peers or staff (Swan 2001). As mentioned before, lack of presence can be an issue in discussion forums. However Delahunty (2012) suggests different writing styles can display different identities of participants, therefore might go some way in creating different presences within the learning environment. Wikis are another example of an asynchronous tool. Wikis can be an individual or group activity. Students can bring together different resources in the same place including text, images, audio and video. Within the group and students can edit co-author comments and resources to create a final piece of work. Therefore linking into the concepts of cognitive presence (Garrison and Arbaugh 2007). Once complete these resources can be shared with the wider class.

Traditionally many bio-science subjects when taught face-to-face offered much time in laboratories. Due to the practical element of these courses it was not possible to replicate this learning for online distance students. Advances in technology have, however, brought laboratory simulations that can be used in both online distance learning and blended learning. Students can practice their skills in a virtual laboratory. Simulations have the additional benefit that students can undertake the experiment many times at no extra cost (Bonde et al. 2014), and diverse outcomes can be explored by changing the variables, practice is undertaken in a low risk environment so consequences of different actions can be explored (Bonde et al. 2014; Weller et al. 2012). Often in a face-to-face setting laboratory time is limited, therefore it is frequently not achievable for students to learn at their own pace and have multiple practices at certain techniques (Makransky et al. 2016). Unique cases that rarely occur can be simulated thus giving students to opportunity to experience these cases. Students can practice a range of scenarios and then hone their skill set (Weller et al. 2012). Whilst laboratory time is essential for developing practical skills simulation enables students to be better prepared for real-life settings and challenges (Makransky et al. 2016).

10.4 Community

The growth in technology has also enabled growth in online communities. Traditionally the term community was used in relation to physical location (Hiltz and Wellman 1997) or personal connection (Gusfield 1975), for instance the connection shared between neighbours. Attributes of communities included shared goals, trust and purpose. For example, clearing of a disused space and for use by the community. Like ODL, technology has enabled groups of people, who also have shared goals or support, to connect via the internet. Key elements of virtual communities are: trust, (Chiu et al. 2006; Ridings et al. 2002) sharing and participation (Ardichvili et al. 2003). In online communities, location is irrelevant, thus bringing the benefit that new people can join diverse communities (Mcmillan and Chavis 1986a, b). Figure 10.2 shares additional aspects of community.

As mentioned previously, in the past, distance learning was an isolating experience. Distance was a barrier in providing support for students. Now that this barrier has been removed a community of learners within a cohort is achievable (Kelly and Stevens 2009). The advantages of building a community within an OLD course are support for students (Brown 2001) and assisting students in formulating information (Murray et al. 2015; Garrison and Arbaugh 2007). Thus, the foregoing suggests an environment that supports

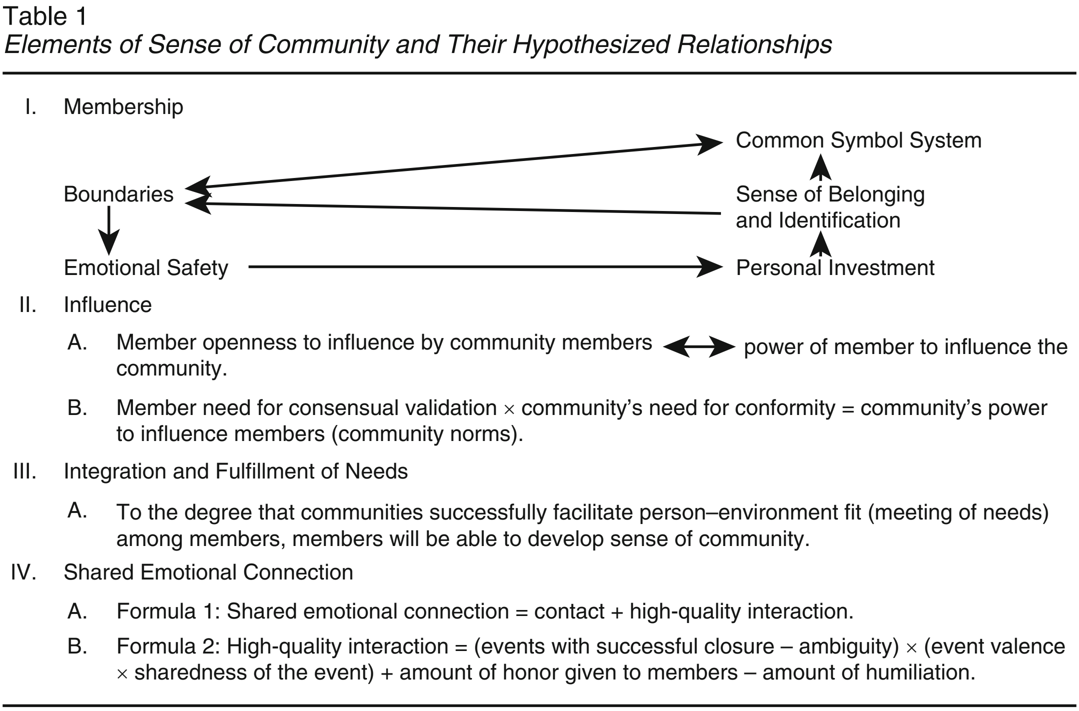

Table 1
Elements of Sense of Community and Their Hypothesized Relationships

I. Membership

II. Influence

A. Member openness to influence by community members ↔ power of member to influence the community.

B. Member need for consensual validation × community's need for conformity = community's power to influence members (community norms).

III. Integration and Fulfillment of Needs

A. To the degree that communities successfully facilitate person–environment fit (meeting of needs) among members, members will be able to develop sense of community.

IV. Shared Emotional Connection

A. Formula 1: Shared emotional connection = contact + high-quality interaction.

B. Formula 2: High-quality interaction = (events with successful closure – ambiguity) × (event valence × sharedness of the event) + amount of honor given to members – amount of humiliation.

Fig. 10.2 Elements of sense of community and their hypothesized relationships. (Reproduced from Mcmillan and Chavis 1986a, b)

a sense of community among learners is a key requirement in HE. In ODL, the concept of an online community for learning is of particular importance, but the consideration is how to build a community. The community of inquiry model (Garrison et al. 2000) framework proposes that a successful community of learners develops as a result of interactions within a community of inquiry that is composed of instructors and students. This social and interactive approach to learning has been described as social-constructivist (Gabelnick et al. 1990) and as a result of this pedagogical philosophy there has been an increased importance placed on implementing educational practices that endeavour to promote the concept of community (Dawson 2006).

Rovai and Wighting (2005) proposed that community is generated and sustained through interactions. A lack of social interaction has been reported as a severe barrier to ODL by students and has been strongly related to online learning enjoyment, effectiveness of learning online and the likelihood of undertaking further studies by online DE (Warburton 2009); further emphasising the importance of interaction and communication between students engaged in ODL programmes. Building a community of inquiry (Garrison et al. 2000) is also important. McMillan and Chavis (1986a, b, p9) define community as:

> a feeling that members have of belonging, a feeling than members matter to one another and to the group, and a shared faith that members' needs will be met though their commitment together

Mcmillan and Chavis (1986a, b) highlight in Fig. 10.2 that belonging is one of the key elements in participants feeling integrated into a community. They also deduce that with effort community can be built in various ways. These include: offering student support, sharing of university values (Cooper 2009), increasing engagement (Ardichvili et al. 2003; Blanchard and Markus 2002; Liu et al. 2007), sharing of facial expressions (videos and live sessions)

(Bullen 1998), sharing expectations (Garrison and Arbaugh 2007), sharing of background (Mcmillan and Chavis 1986a, b) and, increasing digital literacy (staff and students) (Rovai and Jordan 2004). Brown (2001) shares that belonging and community are intertwined.

10.5 Belonging

It is important to consider the concept of belonging and the significance for ODL. Belonging is not a new concept. Maslow (1943) in the hierarchy of needs, describes belonging as the next need to be met, after basic needs (e.g. security and food). In a face-to-face setting, this can happen organically. Students connect with their university on a physical campus. Often the university's values are shared throughout campus as a reminder to student and staff. Students do not have to seek these out. If they wish, face-to-face students have readily available opportunities to engage with their peers, for example in talking with peers in the same lecture space. They would also gain an opportunity to speak staff. Now considering this from an ODL student point of view. ODL students can study at any location and they may never have visited the campus. They miss the opportunities to connect with the university, its values and face-to-face with staff and peers.

There are also different aspects of belonging. Schlossberg (1989) describes belonging as a scale between marginalisation to mattering. Marginalisation meaning the student feeling disconnected and isolated. Mattering meaning feeling they belong. Maslow (2017) outlines that belonging is a "deficit" that can only be filled by other people. Rovai and Wighting (2005) describe "alienation" as lack of belonging or social contact. Wilson et al. (2008) surveyed students in relation to belonging. In the study, they divided belonging into three elements, connection, support and commitment. Support being their needs being met. Commitment being what the students put into the community. Support, commitment and connection are interdependent (Osterman 2000; Williams et al. 2012). As the student feels more supported, they are more likely to contribute to the community. Likewise, the more students support peers (commitment) the more connected they feel. Thus, giving the student a role in the community (Mcmillan and Chavis 1986a, b). Conversely, some students feel connected to others and committed not only to their own learning journey but to their peers also (Brown 2001). Figure 10.3 illustrates this interdependence. None of this is possible without engagement (Wilson et al. 2008; Spanierman et al. 2013).

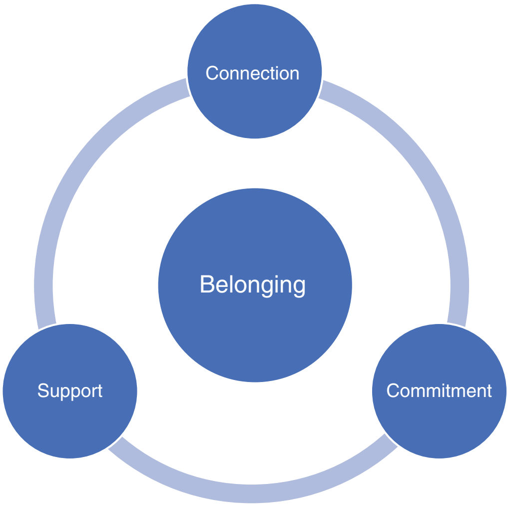

Fig. 10.3 Interdependence of support, connection and connection within belonging. (Derived from Wilson et al. 2008)

Student are diverse and can experience various levels of belonging (Tinto 2006), with certain groups of students feeling an increased lack of belonging. The factors that can affect belonging include: ethnicity, gender, LGBTQ+, disability, (Trujillo and Tanner 2014) and level of income (Tinto 2006). This chapter is not going to go into these into any detail. However, it is important to note that certain students start with deeper feelings of marginalisation, which can take extra effort to overcome. Researchers have suggested there are strategies to encourage belonging. Soria and Stubblefield (2015) demonstrate that building awareness of student strengths can encourage belonging. The study was undertaken in an on-campus cohort; however, it could be applied to ODL. In addition, they found that when students shared their strengths with the cohort, it encouraged friendship, and acted as an initial point of connection to build upon. Friendship in the context of ODL, is defined by Brown (2001) as a person a student “felt comfortable communicating” with. Rovai and Jordan (2004) conclude that staff presence have an impact on students feeling part of a cohort.

10.6 Presence

The lack of physical presence in ODL has prompted investigation of the concept of presence when learning online at distance (Bibeau 2001). In the face to face setting it is assumed that students will develop a sense of belonging due to their physical presence within the group or class. This may take place both within and out with the classroom setting, and whilst there is some debate over whether students may or may not feel part of a group despite being there in the physical sense, there is considerable discussion over the lack of physical presence in ODL.

There is no consensus in the literature regarding the definition of presence. However, in terms of constructing a community of enquiry, Garrison et al. (2000) describe three types of presence: teaching, cognitive and social presence. Teaching presence has been described as the direct and indirect role and influence of the teacher in the design, direction and facilitation to ensure a quality educational experience (Anderson et al. 2001). Cognitive presence has been defined as the extent to which a learner can construct and confirm meaning through discourse in a critical community of inquiry (Garrison et al. 2000). Social presence, in its simplest form can be described as a students’ sense of “being in” and “belonging to” a course and/or group to be able to interact with the other students and the instructor despite being separated by time and location (Mckerlich et al. 2011). Social presence has been cited as a prerequisite to establishing an on-line learning community where students can collaborate as learners (Bibeau 2001; Garrison et al. 2000).

Furthermore, it appears that the degree of social presence can mould the quality or quantity of interaction (Beldarrain 2012). In fact, it is believed that social presence is one of the first components required to initiate learning online (Aragon 2003). The concept of social presence was first described by Short et al. (1976) as “the perception that one is communicating with people rather than inanimate objects, despite being separated by geographical distance”. Others have described it as “feeling intimacy or togetherness in terms of sharing time and place” (Shin 2002, p122); “the degree to which a person is perceived as a “real person” in mediated communication” (Gunawardena and Zittel 1997, p9); and “the ability of learners to project themselves socially and emotionally in a community of inquiry” (Rourke et al. 1999, p3). Perceptions of other participants as real and salient appear to be critical to establishing an environment in which students feel comfortable sharing ideas, raising questions, and collaborating (Rourke et al. 1999). When students do not perceive other individuals in DE courses as realm or salient, it appears they are less likely to respond to their ideas or questions or to seek answers from them (Russo and Campbell 2010). Social presence appears to be closely related to the concepts of immediacy and intimacy (Stodel et al. 2006) and therefore it would appear that frequent contact with peers and timely feedback from a tutor appears necessary for promoting social presence and engagement in ODL.

10.7 Engagement

Osterman (2000) shares that through student engagement sense of belonging can be increased. This next part in the chapter considers engagement. The term engagement is frequently used. Firstly, engagement is a verb (Picciano 2002b) consequently requiring an action. In ODL the term engagement, can be interchanged with the term participation.

From a staff point perspective, engaging students on an ODL course is different from in a face-to-face setting. Ideally, course staff can consider what types of engagement are best suited for their course materials and student cohort at the planning stage. Salmon (n.d.) illustrates that when expectations and goals are defined in advance, this then gives staff the opportunity to communicate these with the student. This can involve providing examples about what participation looks like, whether observing only is acceptable and the level of interacting with peers (Chiu et al. 2006). Within induction, resources can be provided in the area of netiquette, so that students are aware of best practice in online communication. It can be helpful to draw student's attention to different types of communication. For example, monologue, reflection, critical assessment and comments on peer contributions. Pittaway (2012) suggests categories of contributions: academic, intellectual, personal, professional and social. In some cases, students can favour certain types of communication and therefore avoiding the other styles. Staff can encourage students to contribute in various mediums, via text, audio and video. Hew and Cheung 2008, advise that staff take an active role in engagement of students. In their paper they suggest staff actively spur on students and they share that staff could assign students to facilitate group discussions, to boost engagement. Rovai (2001) suggests considering how students engage with their peers as markers for quality forum posts, for instance asking questions of their peers, when sharing a rubric for grading discussion forums. Other suggestions include: "open and friendly" communication from staff (Tu and Mcisaac 2002) and engagement from university support staff (Garrison and Arbaugh 2007). These tie in with the concept of 'Teaching presence' within the Community of Inquiry framework (Garrison and Arbaugh 2007).

In assessing student engagement Moore (1989) talks about three types of interaction: student to content, student to staff and student to student. Student to content is where students engage with the learning themselves. This was possible with traditional distance learning. Hence there is student to staff interactions where staff have the opportunity to encourage students, ask questions which can motivate students into deeper learning. Students also have access to staff to gain insights into their expertise. This is one of the benefits of enrolling on a course rather than the student undertaking self-set learning via an internet search engine (e.g. Google). Additionally, staff can steer the learning if students get off track or make some incorrect assumptions. Finally, there is student to student interactions. Moore (1989) describes that this can assist students with motivation.

Engagement and presence are two contrasting concepts. A portion of students struggle to engage, they are frequently known as lurkers. Students who observe the contributions but do not add to them. Posters are students who contribute. Members of staff are often concerned about the students who lurk. Preece et al. (2004), raises that there a number reason why student chose to lurk. These can include: lack of confidence with the technology, digital literacy or their thinking that no further contributions are required. Concluding that sometimes, in some situations, lurking can be a positive choice, as it keeps the discussion concise. Conversely, when a student posts excessively, it can be off-putting to peers. Therefore, it is optimal that students create a positive presence online. A presence that other students and staff like to engage with showing self-awareness of others' perceptions.

In ODL, staff and students can find engaging more challenging than in a face-to-face setting. One of the reasons is lack of visibility of others in the space (De Lucia et al. 2009), in other words, presence. When posting in a discussion forum, it is not possible to view how many people have viewed the post, if any. Alternatively, if the post has been heard in face-to-face setting, all participants are visible. When a comment is made, it is a reasonable assumption that everyone in the space will have heard. Consequently, having an active presence within a course can encourage others that their posts have been heard. With further evolution of technology, this situation could be improved in the future. However, there are a portion of students who are not interested in engaging with others on the course, also known as "lone-wolves" (Brown et al. 2013). These students wish proceed through the learning as fast possible. To receive the full benefit of the learning students are required exploring the content from varied perspectives, undertaken in partnership with their peers (Garrison and Arbaugh 2007). The challenge for staff in this situation will be drawing them into the learning journey and not just the end goal of certification. Although ODL students have easy access to interactions with their peers they may need encouragement to interact.

10.8 Transitions

Modern ODL programmes are based on based upon constructivist and connectivism pedagogy. Connectivism pedagogy has been described as the process of building networks of information, contacts and resources that are applied to real problems (Downes 2007). In connectivism, learning begins when learners join together in a learning community, whereby the development of networks of both content and person can be applied to authentic problems (Strong and Hutchins 2009). Partlow and Gibbs (2003) state that online DE courses should be relevant, interactive, project-based and collaborative, whilst providing leaners with some choice or control over the learning. Such an approach permits learners to work at their own pace and on authentic, real-world tasks and necessitates the need for collaboration between learners and their instructor. Indeed, this fits with Vygotsky's (1978) theories of learning whereby knowledge is constructed in the midst of interactions with others and is shaped by the skills and abilities valued in a particular culture. Thus, the teacher plays a key role in this learning process in shaping the leaning activities and supporting the development of knowledge and understanding. Therefore, it can be said that the role of the DE instructor differs from that associated with traditional on-campus education. The instructor (often referred to as the tutor) becomes the facilitator to support student learning, whilst the student actively participates in what and how knowledge is imparted. Consequently, students studying online are often required to take on a greater responsibility for their own learning. They learn more independently than the on-campus students, as they cannot just simply follow what the other students are doing, they must log into the VLE as a solitary initiative, and interact with fellow students and their tutor of their own accord (Knowles and Kerkman 2007). Thus a greater level of discipline is needed in ODL. Nevertheless, the flexibility afforded in DE allows learners to come to their learning at a time when they are motivated and ready to learn. Thus, modern distance learning can be described as a collaborative effort between student and teacher, unbounded by the traditional limits of time and location.

Thus the move to ODL can take adjustment for both staff and students. The term transition is often used to describe the student journey to higher education (Araújo et al. 2014). It is widely understood that this shift can be unsettling for students and then requires additional support. In this case, students experience a shift in environment, student cohort and increased academic expectations. Transition is a "process" (Kift et al. 2010; Tett et al. 2017) where the learner engages with the content, receives support, is involved in activities that assist with belong and receives contact from university staff. (Kift et al. 2010). These papers have similar findings to the work of the QAA in Scotland who provide a Student Transitions Map (QAA Scotland, Yahaya et al. 2002) suggesting different support needs at different points in the student's journey. Induction is important especially because if students do not feel connected at the start it is challenging to develop that connection later (Johnson et al. 2007). However, activities encouraging belonging can be added in throughout the course as part of induction (Araújo et al. 2014). Burke et al. (2016) suggest that including activities that build student confidence in their abilities can assist with belonging. Erichsen and Bolliger (2011) propose that when students enrol on a course, they are required to adapt to the culture the university is based in. Despite the course being online the course will be influenced by the cultural values in which the institution is physically located in. Students who transition onto an ODL course might have to adjust to a new medium of study. Many institutions now provide resources for students to assist with this transition, such as resources for study skills and digital literacy (Kubincova et al. 2018).

When staff agree to develop and deliver ODL courses they may also go through a transition.

This transition can involve changes in practice and learning of new technology. There are some benefits. ODL enables staff to teach from any location. However, some staff can be opposed to changing to a different mode of teaching (Michael 2012). Staff feel comfortable with face-to-face teaching and are resistant to change. This can be a barrier in delivering ODL. MacKeogh and Fox (2009) found that staff resistance was linked to perceived lack of time and lack of understanding of the pedagogical benefits of ODL. On the other hand, they discovered that the response from staff was mixed and not all staff were resistant. The move to ODL can be an unsettling process for staff. Academic staff can enjoy the performance of delivering a lecture. Within the face-to-face environment, staff can view the students in the room and also engage with them. Staff also have the opportunity to receive real-time feedback to see if students are engaging. This is familiar to them. It is beneficial if staff are supported in their transition to ODL. Learning Technologists and Senior Management can provide support, which can assist with the transition. Senior management can encourage and share the institutional strategy for ODL. Learning technologist can provide pedagogic advice, staff development and technical support. In some situations learning technologist are also involved in building content. A final point to consider is around the content. Wheeler (2015) advises that where possible it is best to completely redesigning learning materials for ODL rather than re-creating the campus-based learning materials.

10.9 Conclusion

Online distance learning can be an isolating experience for the learner; however, with the use of the appropriate approaches and tools to support communication, presence and belonging it can be an extremely rewarding experience for both students and staff. Care should be taken to build in interaction in ODL courses and programmes and the transition to ODL for both staff and students should be well supported.

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