Virtual Reality as Knowledge Enhancement Tool for Musculoskeletal Pathology

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Abstract. Contemporary requirements of medical explanatory resources have sparked the initiative of developing a unique pilot application which could use real-time 3D visualisation in order to inform General Practitioners (GPs) and allied health professionals as well as educate patients on musculoskeletal issues and particularly lower back pain. The proposed application offers a selection of 3D spinal anatomical and pathological models with embedded information. The interface elements adhered to previous studies' suggestions that the knowledge acquisition and ultimately the understanding of such motley three-dimensional subjects typically entails a strong grasp of the 3D anatomy to which it relates. The Human-Computer Interaction is simplified in order to empower the user to explore the healthy and pathogenic anatomy of the spine without the typical real-life constrains. The paper presents the design philosophy of the interface and the evaluation results from twenty user trials. Finally the paper discusses the results and offers a future plan of action.

Keywords: VR, 3D, HCI, Musculoskeletal, Medical Education, visual interface, Low Back Pain.

1 Introduction

Musculoskeletal (MSK) pathology and particularly lower back pain is an area of common interest for a large segment of medical practitioners including orthopedic surgeons, radiologists, general practitioners (GPs), physiotherapists and podiatrists amongst others [1]. Yet it is evident that the complexity of structures in the spine and the various pathologies that may appear are hindering significantly the learning process for all the aforementioned groups. The contemporary training and continuous professional development methods are unable to cover fully the intricate details of the pathologies occurring [2]. In particular the two-dimensional depictions or pseudo-3D images do not convey the appropriate information to the medical practitioners. To this end, previous studies demonstrated that the knowledge acquisition and ultimately the understanding of such motley three-dimensional subjects typically entail a strong grasp of the 3D anatomy to which it relates [3, 4].

Adhering to these requirements, we developed a pilot application, which uses a simplified interface in order to inform and further educate the interested parties. In particular the novel application offers a selection of real-time, stereoscopic, 3D spinal anatomical and pathological models with embedded information which can be accessed through the interaction with the 3D models. The development of the models preceded an exhaustive collection and analysis of CT scans, MRI scans and high-definition photographic data which informed the virtual reality characteristics of the model. The modeling process was further improved by constant consultation from the medical doctors which provided crucial clinical information. The complete highly detailed 3D models entail photo-realistic structures of the spinal vertebrae, the relevant ligaments, muscles, lymphatics, nerves and blood supply of that region.

Aiming for a user-friendly system the Human-Computer Interaction (HCI) is simplified in order to allow doctors of all grades to explore the healthy and pathological anatomy of the spine. The interface interlinks with a number of additional information complementing the real-time 3D data by high-definition (HD) explanatory animations, real-case scenarios, and problem –based learning (PBL) cases which lead the user through the presentation and reasoning of several lower-back pain case scenarios.

In order to evaluate this prototype system we invited twenty clinical users to assess the functionality and the context of the application. Additional information was gathered by sophisticated eye-tracking system which presented clear measurements regarding eye-accommodation, visual stimuli, and gaze-time during the trials. These preliminary user-trials offered constructive feedback and revealed great promise in the system with the derived results indicating better anatomy and pathology understanding. Interestingly the system enabled the doctors to accelerate the diagnostic triage process and create a 3D mental map of the context during the evaluation process. A number of issues, however, should be dealt with in the future stages of development, with particular interest on the Human Computer Interaction (HCI), which requires additional functionalities without spoiling the existing simplified interactivity. As such a simplified and customisable HCI could enable the user to interact with the system without the burden of unusable information or excessive text. To this end we envisage the development of the future version of the application which will enable the medical practitioners to customise their own systems in accordance to their interests and their expertise. Notably this could potentially provide both an aid to the understanding of the detailed regional anatomy for doctors in training as well as a highly interactive platform of training for those interested in surgical interventions. Finally the subjective feedback from the evaluation drew attention to the potential use of an even more simplified system which could form part of educating patients of their condition and obtaining informed consent.

Overall this paper discusses the challenges involved in the development process of the Virtual-Reality learning application and the HCI design developed for this system. Furthermore this work introduces the visual components of the interface and presents the outcome of a preliminary evaluation. The paper concludes with a future plan of of work which aims to expand the context and interactivity of the system so as to enable other types of users (i.e. undergraduate/postgraduate medical trainees and patients) to access meaningful information without the time and physical constrains of laboratories. Finally this prototype application entertains the use of virtual reality for training purposes of General Practitioner doctors and offering the same user-experience through a web-based version of this application.

2 Contemporary Training Issues

Anatomy training, in the UK in particular, has presented medical educators with a plethora of challenges in recent years as the undergraduate educational focus is shifted away of traditional theoretical pure knowledge acquisition and targeted towards interactive experiential learning. Cadaveric opportunities of anatomical knowledge acquisition are becoming scarce due to a shortage of cadaveric material and limiting practical constrains associated with such endeavours. This situation, in combination with the shortening of the post graduation training years with the introduction of the fast track structured specialty training has limited exposure of trainees to appropriate practical anatomy learning opportunities and has resulted in a large proportion of the current medical and allied health trainees recognising a pressing need for alternative anatomy and pathology experiential based interactive educational packages.

Furthermore, the introduction of the good medical practise guidelines from the GMC and associated publications from the other professional bodies has placed an increased emphasis on continuous education and re-validation [5, 6, 7]. Continuous professional development applications can provide crucial assistance in meeting the clinicians' educational demands. A vast variety of paper based and digital packages have already been developed to this end, however, the end users have expressed concerns regarding their inaccessibility, associated time and space constrains as well as the lack of interactivity.

With particular reference to the anatomy and pathology of back pain, it was found that most of the available educational resources was in either actual 3D plastic model form or in the form of traditional text and 2D illustrations. Large datasets of data capable of 3D reconstruction (such as patient CTs and MRIs) were also available on request for further education, however, these required expert input by a trained specialist. Within a community, rather than hospital, setting, where most of the general practitioners as well as most of the allied professionals involved in the study work, realistically, the only educational avenues available were either in the form of traditional paper based educational material or material available through alternative digital avenues which could potentially be transferable through the world wide web.

Back pain was chosen as the pilot study case as it is one of the most common complaints expressed by patients in GP consultations in the UK. It makes up 30% of out-patient physiotherapy work in Scotland, translating to about 12000 new referrals per annum [8]. Although most of this work (~85%) relates to chronic back pain, however, there are a few pathologies disguising as back pain, which are far more serious and should not be missed. A national physiotherapy low back pain audit[8] identified a gap in stuff education and recommended the development of a web based easily accessible package that would raise awareness and understanding of acute back pain and its management [8].

3 Visualisation Methods

A plethora of digital applications and visualisation methods have been recently developed in order to educate different professionals and especially the medical practitioners, aiming to decrease the learning curve and act as a knowledge enhancement tool. Noticeably a number of aesthetically pleasing visualisations have been produced in a compulsive and fractious manner.

Two dimensional representations and alphanumeric diagrams of complex anatomical data have failed evidently in the past to convey knowledge, mainly due to the fact that the human body itself and the environment that surrounds it, are by definition three-dimensional. As such it is impossible to depict the three-dimensional complexity of multiple layers of the human body through two-dimensional illustrations [9].

In turn the digital formats appeared largely through the pseudo-3D visual representations which offered a different learning avenue than the traditional methods. Although this concurrent approach is considered a breakthrough, the limitations of such systems are constraining the user from developing their own learning pattern. The pseudo-3D models are merely a collection of still images produced from an object through a 360 degrees rotation. The pre-set nature of these models forces the user to add or remove layers of a model in an un-involving rotational manner which does not encourage the investigation of the object from different angles or the non-uniformly application of cross-sections.

Real-time 3D visualisation unlocks this interactivity as it allows the user to investigate the 3D model and interact with it in an infinite number of ways. The manipulation of the presented data is not constrained by pre-set factors but only from the user's motivation to interact with the system. Furthermore, the interaction tools that could be developed for such application can be customised depending on the learning outcome and extend users' experience beyond the typical axis rotation of images or the aloof viewing of multiple animations.

3 VR Interface

Recent studies have advocated that 3D and particularly Virtual Reality (VR) training methods abbreviate significantly the learning curve [10]. Our previous experimentation with different VR and Augmented Reality (AR) systems offered very similar results to the aforementioned [3, 4, 11]. Based on our prior experience we aimed to develop an interface that could accommodate the different visual and auditory information that the particular group requested (GPs).

Yet being aware of the potential system limitations as well as the different levels of computer literacy amongst users we strived towards a simple interface which could compliment the real-time 3D application with a variety of specialised still images, explanatory animations and related documentation that could assist and enhance the knowledge of the specific users [12, 13].

The interface design followed an organic method for distributing information which were interlinked though different connections. As such a single level of the interface could be approached by a number of different points inside the system without constraining the user to follow a specific root. The focus point of the system was evidently the real-time 3D models which can be viewed either on mono or stereo depending the user's equipment as presented in Figure 1.

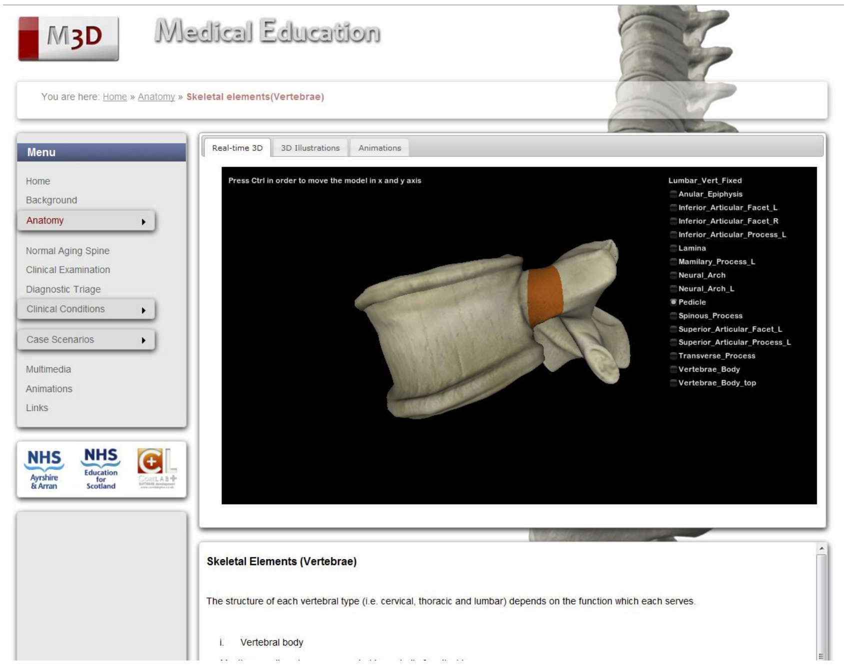


Figure 1–Screenshot of the main application interface.

Yet adhering to the simplistic approach of information conveyance the stereo to mono alteration can be achieved automatically as soon as the system recognises the specific equipment.

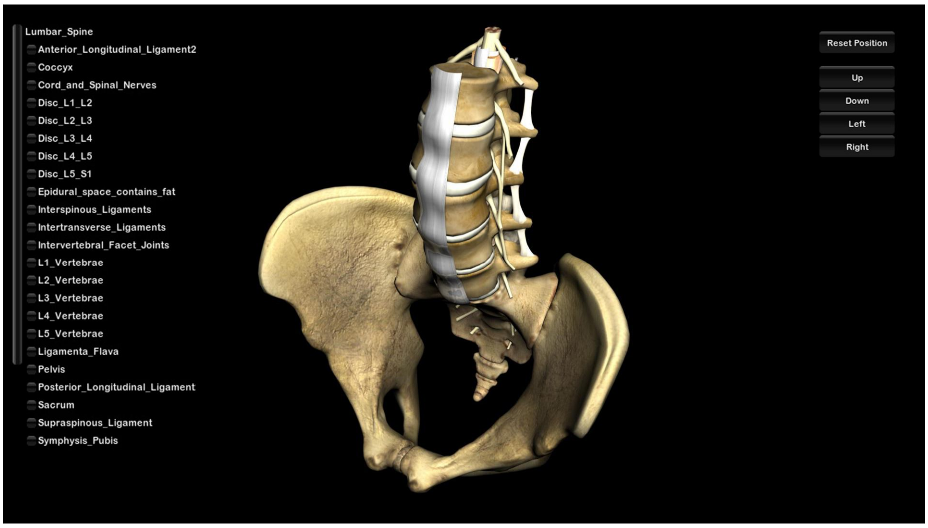


Figure 2–Screenshot of the real-time 3D model of the lumbar spine and pelvis in full-screen.

The interactivity for each model was kept to a minimum at this stage offering to the user the flexibility to rotate, zoom, and pan the model. Additionally all the requested sections of each model could be identified and the relevant terminology is presented on the side of the screen in a semi-transparent layer which aims to avoid any unesseccery visual conflict between the main visual information (i.e. 3D model) and the supplementary information (i.e. alphanumeric data).

The system also enables the user to maximise in full-screen the real-time 3D model and maintain only the related terminology (Figure 2). Currently we are in process of developing a new range of interaction tools which will improve significantly the user experience and learning process. This group of tools will empower the user to dissect in non-uniformly manner the model, intersect CTs and MRIs related to the model, apply selective transparency, move individual parts and compare one or more models in the same window. The latter could be beneficial for training regarding identification of similar conditions, yet in different stages (i.e. malignant cord compression).

4 Context Development

A photorealistic, real-time 3D model of the spine was constructed drawing on data from traditional illustrations, large CT and MRI datasets and under guidance by specialist medical practitioners. This was realistically textured and annotated via an interactive system whereby selecting a label would indicate on the model the exact position of the labelled structure and vice versa. Detailed, but not exhaustive anatomy labelling was included in the 3D model. Structures trivial to general medical anatomy and pathology were deliberately omitted. On the other hand, structures commonly affected by pathology were highlighted in case studies. The visual input of information was further enriched by greatly detailed still images and high-definition animations.

Five different aetiologies of acute lower back pain were illustrated using the 3D models, animations, photorealistic still images and correlating with medical diagnostic imaging. Thus mechanical back pain, cauda equina syndrome, spinal stenosis, ankylosing spondylitis and malignant infiltration of the spinal cord were presented as medical case studies with subsequent questions on diagnosis and management.

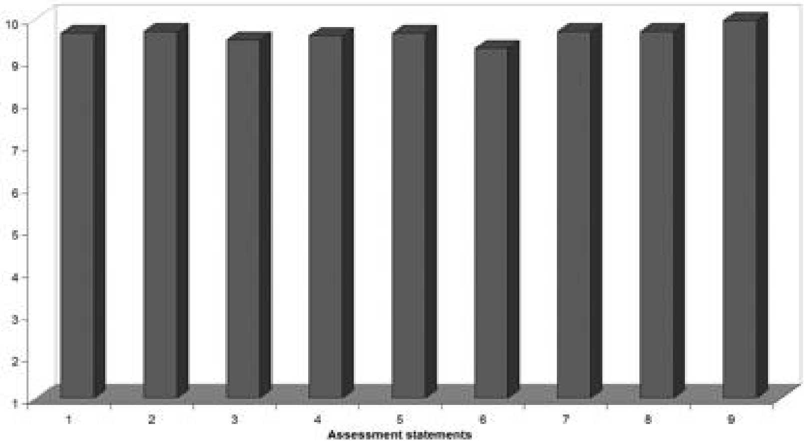
An extended optimisation of the 3D models was further applied in order to improve their refresh rate when presented in a 3D stereoscopic format. Notably the optimisation process was applied in a two fold approach, firstly to the actual geometry and in turn to the textures and shaders. The final optimisation outcome enabled the models to be viewed by minimum specification computers and handheld mobile devices.

5 Evaluation

Preliminary evaluation of the system was undertaken through interactive sessions of the end users with the 3D real-time environment and subsequent anonymised scoring of the user experience and the medical context. Comments relating to the educational value of the associated factual information of the proposed application are beyond the scope of this paper and will not be further analysed here.

Evaluation of the interface was two fold: Subjective user evaluations were gathered regarding the usability, interactivity and usefulness of the interface and the use of the real time 3D models, as scores on a Likert scale. Objective evaluation was also performed by a neutral observer on the usability of the system as evidenced by the user/3D model interaction, time to retrieval of information and overall willingness to explore the application. Eye tracking equipment also monitored the user's focusing points and indicated whether the interface augmented or hindered the learning process.

Quantitative and qualitative analysis of the Likert questionnaire and of free text comments and suggestions was performed (Table 1). Twenty users, 60% general practitioners and 40% physiotherapists accessed and evaluated the application. Their prior familiarity with 3D technology ranged from none to moderate with only 5% having prior exposure to 3D within the context of educational material. The users' IT competence also ranged significantly with the majority (80%) subjectively and objectively scoring average IT competence. 10% subjectively scored themselves as proficient, but objectively only 5% was. 5% (User 8) scored themselves as moderately competent but on objective assessment was of very limited IT competence, a factor that affected the user's interaction with the application and the subsequent user's assessment. Despite of this limitation of this user, the scores were included in the analysis. Overall, end users were overwhelmingly satisfied with the interactivity provided by the 3D model and found information portrayed sufficient and easy to access. It is interesting to note that 95% of the users strongly agreed that the application can be used as an educational tool for both practitioner and patient and that they would use it as an aid to teaching. Even the user who found interaction with the system difficult scored it relatively high for conveying information for teaching purposes.



1	The 3D real time models are useful for understanding MSK anatomy
2	The 3D real time models are useful for understanding MSK pathology
3	The 3D real time models are useful for explaining to the patient MSK anatomy
4	The 3D real time models are useful for explaining to the patient MSK pathology
5	I can manipulate easily the 3Dreal time models and interact with them
6	I can easily correlate the 3Dmodel sections to their names in the list provided
7	The 3D models provide sufficient structural detail
8	The 3D models are realistically textured
9	I would use the real time 3D models for teaching purposes

Table 1 – Likert scores, 3D model evaluation
(1-10 scale, 1=Strongly disagree, 10=Strongly agree).

Some of the collated comments that predominated in our qualitative analysis:
90% of users – Realistic, accurate, interactive 3D facilitate learning.
85% of users – Easy to use/navigate
80% of users – Excellent integration of visual stimuli (3D model) and factual information (text/labels)
95% of users – Asked for expansion of the application to cover other body areas/pathologies
60% of users **-** Suggested reduction in the volume of the associated factual information and indicated that the 3D models and animations conveyed the required information more effectively.
Extracts from individual users' comments:
"User friendly – things are in common sense areas"
"Use of 3D is intuitive. Super imposed pathologies and medical scans on 3D models facilitate learning by demonstrating real life pathology and engaging the user"

“Could easily be tailored to patient education, facilitating patient enablement”
The aforementioned feedback and observations were further verified by the preliminary analysis of the eye-tracking generated data which demonstrated an approximately 90% concentration of eye gaze on the 3D models at in any given page of the interface as illustrated in the Figure 3 below.

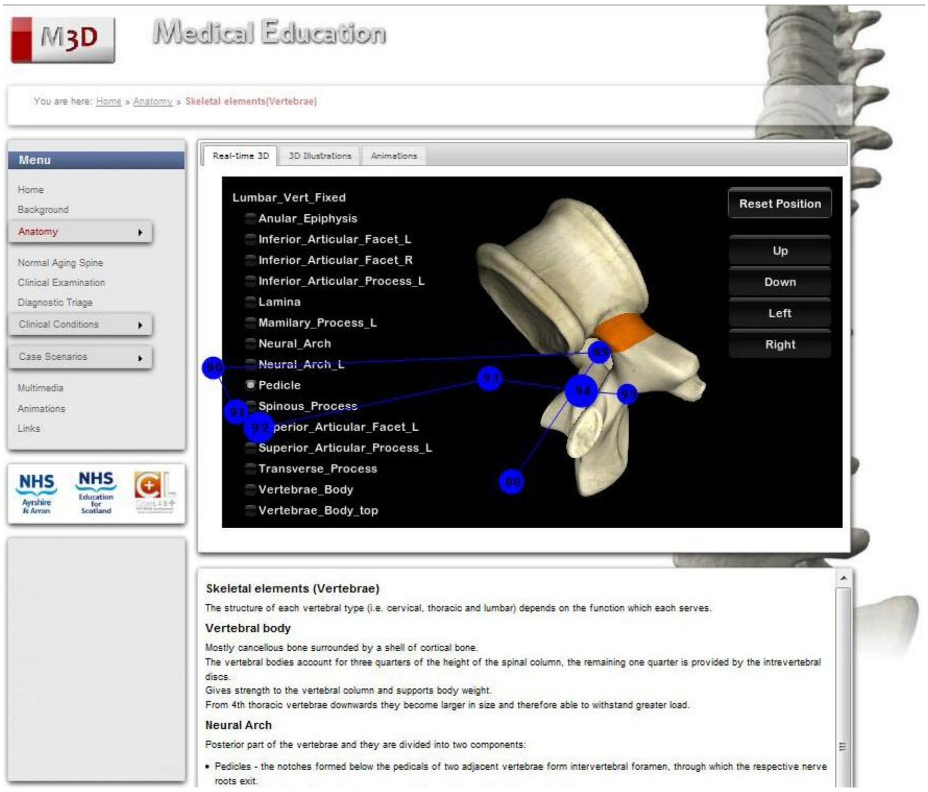


Figure 3- Screen capture of the recorded video footage presented the eye-tracking results.

6 Conclusions

Overall this paper discusses the challenges involved in the development process of the Virtual-Reality learning application and the HCI design developed for this system. Furthermore this work introduces the visual components of the interface and presents the outcome of a preliminary evaluation. The proposed interface has been evaluated with the use of both quantitative and qualitative methodologies. The derived results are promising as the vast majority of the users enjoyed the experience and refreshed or accumulated the indented material by exploring the 3D real-time data in a simplified, timely manner.

Our tentative plan of future work aims to expand the context and interactivity of the system so as to enable other types of users (i.e. undergraduate/postgraduate medical trainees and patients) to access meaningful information without the time and physical constrains of laboratories. Additionally aspiring to increase the accessibility of the system the prototype VR application entertains the use of virtual reality for training purposes of General Practitioner doctors and offering the same user-experience through a web-based version of this application which currently can be visited on the www.3dmedicaleducation.co.uk. Consequently we plan a second series of system trials which will further inform our thinking and design of interface tools.

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