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The role of stereopsis in virtual anatomical learning

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ABSTRACT

The use of virtual learning environments in the medical field is on the rise. An earlier experiment [Luursema, J.-M., Verwey, W.B., Kommers, P.A.M., Geelkerken, R.H., Vos, H.J., 2006. Optimizing conditions for computer-assisted anatomical learning. Interacting with Computers, 18, 1123–1138.] found that a combination of computer-implemented *stereopsis* (visual depth through seeing with both eyes) and *dynamic exploration* (being able to continuously change one's viewpoint with respect to the objects studied in real-time) is beneficial to anatomical learning, especially for subjects of low *visuo-spatial ability* (the ability to form, retrieve and manipulate mental representations of a visuo-spatial nature). The present experiment investigated the contribution of computer-implemented stereopsis alone to anatomical learning. Two groups with a similar distribution of visuo-spatial ability were formed; one group studied a 3D computer model of the human abdominal anatomy in a stereoptic condition, the other group studied the same anatomy in a *biocular* condition (both eyes exposed to the same image). Although visuo-spatial ability was the most important variable predicting anatomical learning, computer implemented stereopsis provided a significant benefit for one of the post-tasks assessing this learning.

1. Introduction

1.1. Background

The use of Virtual Learning Environments (VLEs) in the medical curriculum is on the rise. Over the last decade, many dedicated medical VLEs have been developed. High end, stand-alone examples include laparoscopic simulators (e.g., Immersion's LapSim, or the Xitact series) and electronically enhanced manikins (e.g., Laerdal's product series). E-learning examples include electronic patient simulations (see Le Beux and Fieschi, 2007 for a recent survey) and anatomical learning environments (Jastrow and Vollrath, 2003 give an overview of such learning environments based on *the visible human project*, a high profile project that included the creation of computerized 3D models of human anatomy based on anatomical cross-sections). Acquiring accurate mental representations of human anatomy is a sine-qua-non for the medical practitioner, the human body being the frame of reference for all other medical knowledge and skills. In earlier research, we reported on the beneficial effects of a combination of computer-implemented stereopsis and dynamic exploration on virtual anatomical learning, especially for participants of low visuo-spatial ability (Luursema et al., 2006). The experiment reported here continues this line of research by taking a closer look at the effects of computer-implemented stereopsis on anatomical learning, without dynamic exploration.

1.2. Media for anatomical learning

Traditionally, human anatomy is taught by means of dissection, complemented by anatomical atlases and manikins. Three self-evident features of dissection will be made explicit here, as they bear on the discussion of anatomical VLEs below. A first important feature of dissection is the availability of *haptic information*: even though a living body provides a very different haptic experience compared to a dead body that has been chemically treated to prevent decay, haptic cues still provide relevant information as to qualities such as weight, flexibility, surface structure, size, and shape. Since the technical implementation of haptic feedback in other media, including VLEs, is still far from satisfactory, haptic information can be considered a unique and irreplaceable feature of dissection.

Second, a number of visual depth cues that are available in dissection usually lack in other media. Prime amongst those is *stereopsis* which is the visual sense of depth that is based on differences in patterns of light projected on both retinae. Stereopsis is one of the most important visual depth cues in one's *personal space*, which can be defined as "the zone immediately surrounding the observer's head, generally within arm's reach and slightly beyond" (Cutting and Vishton, 1995). The perception of stereop-

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tic depth is available in dissection, as well as in studying manikins.

The third feature of dissection is *dynamic exploration* (the possibility to actively and continuously change one's view towards objects of study). This is a given in dissection and manikins, and can be implemented in VLEs too.

In contrast to these advantages of dissection, anatomical atlases and VLEs provide the possibility to contextualize the presented anatomy within a medical knowledge frame. In this sense, both anatomical atlases and VLEs make a great companion to dissection, helping students to create a mental representation of the studied anatomy where topological knowledge of this anatomy is integrated with medical concepts not provided by dissection.

Another advantage of anatomical atlases, manikins and VLEs over dissection is the convenience of use of the former: a dissection room is arduous and expensive to maintain, and not as flexible in its deployment as atlases, manikins, and VLEs are.

Obviously, it is necessary to indicate that, in contrast to dissection, *mediated* anatomical learning (e.g., through atlases, manikins, VLEs) filters out much of the richness of the original anatomy, presenting students a representation that merely retains the conceptual model of its makers instead. This can lead to a situation where students discover only what they are supposed to discover, preventing them to enrich their knowledge beyond the provided model. The training of medical skills is likely to be facilitated if in an earlier (anatomical learning) stage students had the opportunity to test provided conceptual models against the reality of first hand dissection experience. Additionally, keenness to incidental anatomical exceptions and the uniqueness of patients' morphologies as provided by dissection is likely to be crucial to medical competence.

Summing up, traditional anatomical learning methods involved direct and mediated methods, each having their unique qualities. Direct methods (i.e., dissection) offer haptic information, 3D visual information, and dynamic exploration, while mediated methods (i.e., anatomical atlases and manikins), provide conceptual knowledge, and convenience of use. For the development of detailed anatomical knowledge, these methods should be seen as supplementary rather than supernumerary. Nowadays, VLEs offer the possibility to implement two features traditionally associated with dissection and not with mediated medical learning, namely stereopsis and dynamic exploration. However, little is currently known as to the effectiveness of these two features for anatomical learning.

1.3. Human factors

Stereopsis is one of the most important visual depth cues in personal space, especially for prehension (Servos et al., 1992; Bradshaw et al., 2004). One could say that stereopsis and prehension are functionally coupled with respect to goal-directed motor behavior in personal space (dynamic exploration being the goal-directed motor behavior under study here). Endoscopic surgery, where practitioners generally get visual feedback on their actions by means of a two-dimensional video display, has over the years provided an important applied field to test the ecological validity of this coupling.

Initially, inconclusive results were reported, mostly due to technical limitations; e.g., a combination of shutter glasses and a relatively low monitor refresh rate will lead to noticeable flicker (as in Wentink et al., 2002), which is very likely to influence test results. Other studies implemented stereoptic feedback and biocular feedback on different systems, without controlling for image resolution and other relevant system differences. The reader is referred to Huber et al. (2003) for a more detailed discussion of this older work. A recent, better controlled study has confirmed the expected superiority of endoscopic performance under three-dimensional (stereoptic) imaging, compared to two-dimensional (biocular) imaging (Byrn et al., 2007).

In contrast, we do not know whether the coupling of stereopsis and dynamic exploration contributes also to visuo-spatial learning (of which anatomical learning is but one example). However, Luursema et al. (2006) recently showed that a virtual anatomical study phase that combines stereopsis and dynamic exploration, led to better learning than a study phase that involved only exploration of standard anatomical views (top, side, and front). Whether this can be ascribed to stereopsis, dynamic exploration, or its combination is as yet unclear.

Successful learning depends on the formation of mental representations of the information to be learned. For anatomical learning, where the information to be learned is visual and spatial in nature, *visuo-spatial ability* is a cognitive ability that needs to be taken into account. Visuo-spatial ability refers to the ability to form, retrieve and manipulate visuo-spatial mental representations (Carroll, 1993; Hegarty and Waller, 2005). The relevance of visuo-spatial ability for medical practitioners was demonstrated in several studies that found visuo-spatial ability to correlate highly with success as an endoscopic surgeon (e.g., Risucci, 2002; Wanzel et al., 2002). Additionally, Rochford (1985) found a significant positive correlation between spatial learning disabilities and underachievement in an anatomy course for second-year medical students at Cape Town University. A comprehensive review of the important role of spatial cognition in medicine, with special attention to its practical implications, can be found in Hegarty et al. (2007). Luursema et al. (2006) found that participants of low visuo-spatial ability benefited more from the condition that included both stereopsis and dynamic exploration than participants of high visuo-spatial ability. This finding could potentially impact anatomical instruction by suggesting a way to support students of low visuo-spatial ability.

To assess the contribution of stereopsis to the benefit of combined stereopsis and dynamic exploration for anatomical learning, we compared two groups of participants, which were subjected to different anatomical study phases after which they were tested for their amount of anatomical learning. For both groups, the study phase showed an auto rotating 3D model of human abdominal anatomy. Participants in the stereoptic study phase wore shutter glasses by means of which they experienced the presented models stereoptically. Participants in the biocular study phase did not wear any specific headgear, and consequently experienced the model *biocularly* (both eyes were exposed to identical images). Anatomical learning was assessed by two tests, an identification task and a localization task. Visuospatial ability was measured by the Vandenberg and Kuse mental rotation test (Vandenberg and Kuse, 1978; Peters et al., 1995).

Having established a learning benefit for the combination of stereopsis and dynamic exploration, we were interested to assess the learning benefit of stereopsis alone. Similar to our earlier study, we expected participants of low visuo-spatial ability to benefit more from computer-implemented stereopsis than participants of high visuo-spatial ability because they are probably less able to construct a 3D mental representation from a biocular presentation.

Also, although stereopsis can be easily implemented across the whole range of virtual learning environments, its potential for learning has been largely unexplored. If computer-implemented stereopsis proves to be beneficial to visuo-spatial learning, this would be of consequence to the implementation of educational practices in virtual environments where this type of learning is critical.