Eurographics Workshop on Visual Computing for Biology and Medicine (2020)
K. Nieselt and R. G. Raidou (Editors)

Short Paper

Learning Hand Anatomy with Sense of Embodiment

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Abstract

We present a VR-based prototype for learning the hand anatomy. The prototype is designed to support embodied cognition, i.e., a learning process based on movements. The learner employs the prototype in VR by moving their own hand and fingers and observing how the virtual anatomical hand model mirrors this movement. The display of anatomical systems and their names can be adjusted. The prototype is deployed on the Oculus Quest and uses its native hand tracking capabilities to obtain the hand posture of the user. The potential of the prototype is shown with a small user study.

CCS Concepts

• ***Human-centered computing*** → ***Interaction devices; Visualization;*** • ***Computing methodologies*** → ***Virtual reality;***

1. Introduction

Virtual reality is a promising and affordable technology to explore complex spatial relations, such as the human body. The human hand with its high density of bones, joints and other structures is one of the most complex regions of the human body. To fully understand the morphology of the involved structures and their spatial relations is challenging and benefits from interactive 3D visualizations. The imagination of the complex anatomy can be supported particularly well with immersive VR. We aim to combine the potential of immersive VR with embodied learning, which is explained by Lindgren and Johnson-Glenberg [LJG13] as follows: "body activity can be an important catalyst for generating learning, and new technologies are being developed that use natural human physicality and gesture as input." We describe the design and development of a VR prototype, based on the bachelor thesis of Albrecht [Alb19], that supports the sense of embodiment (SoE) and, thus, embodied cognition and learning.

2. Related Work

Since more than two decades, interactive 3D visualizations are generated to support the exploration of the human anatomy and to facilitate active types of learning. Geometric models were created, e.g., based on the Visible Human dataset and used for exploration with clipping planes, clipping boxes or virtual scalpels [PRS97]. The VoxelMan was the pioneering work in this area [SFP*00]. A prominent example for virtual anatomy is also the work from Petersson et al. [PSWS09] who provided a web-based system and presented a comprehensive evaluation with 137 users. While desktop solutions dominated first, more recently VR-based solutions were employed to use the improved immersion for a sustainable knowledge gain [MWS17, SSC*17, PPS19]. VR-based anatomy education is typically focused on a complex anatomical region, such as the inner ear or neuroanatomy. However, few systems are tailored to hand anatomy.

Hand Anatomy Education Computer-assisted hand anatomy education requires a faithful geometric and bio-mechanical model of the human hand. Several groups contributed to this type of modeling, either based on medical image data [KM04] or photos of a human hand [RNL06]. Finite element modelling is typically applied to represent the soft tissue deformations that occur when joints are moved.

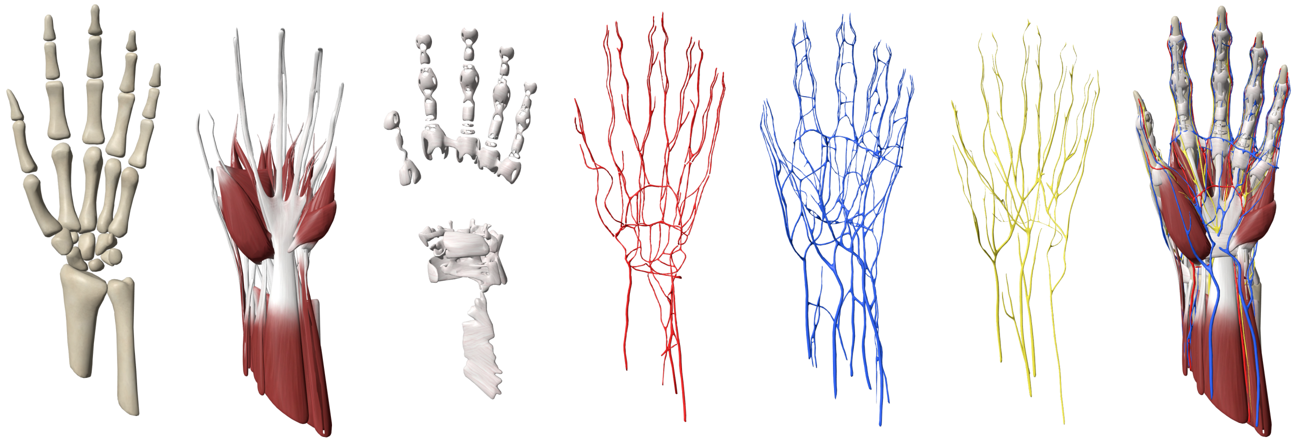
For exploration of a given hand model, Viega et al. [VCWP96] used a magic lens. The lens is used as a clipping plane to remove the skin surface and underlying tissue to reveal the inner bone structure. Jariyapong et al. [JPBK16] describe how learning the hand anatomy is supported by encouraging students to draw bones and joints on the hand (*body painting*). This is related to our approach since embodiment is a central concept there as well.

3. VR Hand Anatomy Education

The requirements were acquired based on an interview with an anatomy educator (12 years of professional experience) and an analysis of the anatomy curriculum and learning material (anatomy atlas, textbooks) of medical students.

- RQ 1: The geometric model needs to be complete, with respect to bones, muscles, tendons, ligaments, vessels and nerves.
- RQ 2: The virtual hands should mirror the physical hand posture of the student as exact as possible.
- RQ 3: Labeling should be provided that shows the names of the corresponding structures.

DOI: 10.2312/vcbm.20201170



(a) *Bones* **(b)** *Muscles* **(c)** *Ligaments* **(d)** *Arteries* **(e)** *Veins* **(f)** *Nerves* **(g)** *All combined*

Figure 1: *All anatomical systems of the 3D hand model that can be controlled by the student.*

- RQ 4: An overview over all structures as well as the ability to selectively display anatomical systems, such as nerves, is essential.
- RQ 5: The VR environment should be accessible regarding setup complexity and costs.

3.1. 3D Hand Model

The curriculum of the hand anatomy relates to two aspects of anatomy education: regional anatomy and systemic anatomy. In regional anatomy, the students learn about specific body regions, and systemic anatomy teaches about biological systems [PS18].

With respect to RQ 1 129 structures are essential according to the anatomy atlas of Netter [Net14], including:

- locomotor system (29 bones, 39 muscles, 8 tendons, 21 ligaments),
- cardiovascular system (14 arteries, 7 veins), and
- nervous system (11 nerves).

For the visualization of the hand model, two approaches can be pursued: Either a realistic rendering or an abstract one. Inspired by anatomy atlases we chose an abstract visualization with illustrative colors for each system (e.g. arteries are red, nerves are yellow). For the display of muscles, the orientation of fibers is important to convey the direction from their origin to their insertion. This will be achieved with textures on the 3D model. The 3D model that contains all structures and textures was obtained by an external vendor [cde].

The chosen hand model consists of 817 K vertices. In the application, it is possible that four virtual hands are visible at the same time (two representations of the user's own hands, two large overview hands in front of the user). This would result in over 3200 K vertices. With empirical performance tests, we determined the Oculus Quest's vertex budget at around 200 K vertices. Therefore, the resolution of the hand models has to be reduced substantially. This was realized in Blender (v2.8.2, `https://www.blender.org/`) with different decimation operators. After this process, 97 K vertices remained for one hand, which resulted in real-time performance (>60 FPS). Figure 1 shows the final hand model.

3.2. Animating Virtual Hands

To create an animated movement of the hand model, *skeletal animation* is used [BP07]. Here, the 3D model needs to be rigged, i.e. provided with an invisible skeletal structure. This process was carried out with Blender. We oriented ourselves on the natural skeleton of the human hand in this process. After rigging, the anatomical 3D structures need to be connected with the rig (skinning). Each vertex of the 3D model is connected to the rig with a weight factor. Depending on this factor, the vertices move along with the rig. This was done for the right hand model and mirrored for the left hand model.

3.3. Inducing Sense of Embodiment in the User

Our motivation is to improve the learning experience through SoE. Therefore, the three sub-aspects *Sense of Self-Location*, *Sense of Body Ownership* and *Sense of Agency* need to be considered [KGS12]. The perspective has a high-influence on the feeling of self-location, i.e., the feeling of being in another body. In our application, the user sees their hands from the ego-perspective, since this increases the sense of self-location compared to, e.g. a third-person view perspective [SSSVB10, PKE11]. The virtual hands have the same position and orientation as the real hands, which provides a feeling of body ownership [CH07, HMMW11].

The sense of agency is induced by giving the user a feeling of control over the virtual hands by mirroring the movements and postures of the real hands as accurate as possible (RQ 2). This is realized by tracking the posture of the user's real hand continuously. We used the built-in hand tracking capabilities of the Oculus Quest.

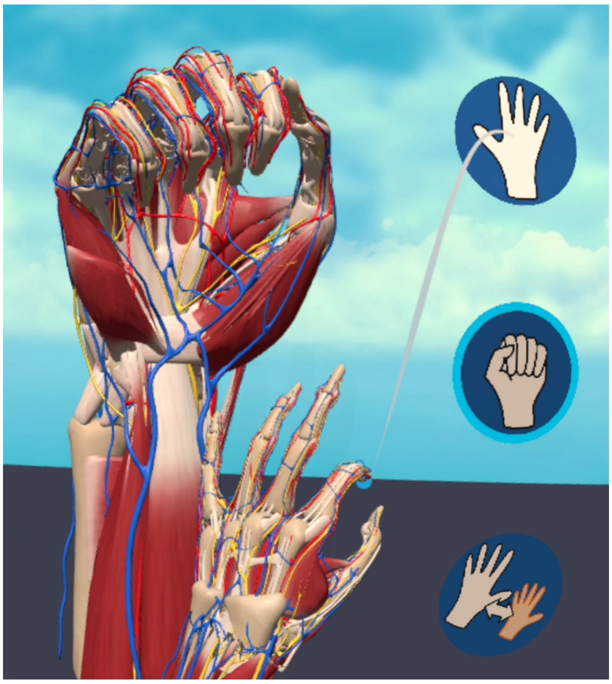


Figure 2: *An enlarged hand is shown in front of the user that can be set to three states via ray-based interaction: (1) open hand, (2) closed hand, and (3) mirroring the user's hand. To select a different mode, the user has to roughly point in the button direction and pinch their index finger and thumb.*

3.4. Additional Features, Interaction and Menus

For interactions, we provide two types of menus that take into account the limitations of hand-based interaction, i.e. imprecision due to optical tracking and hand tremble. These menus are described in the following along with additional features that support learning.

Large Copies of Hands. Visualizing the virtual hands only on the positions of the real hands restricts the user to freely inspect hands from all perspectives. Therefore, we added two enlarged hands in front of the user that can be explored by physically walking around them. It is essential to employ a good initial viewing direction for reducing the learner's mental load [SHM09]. Stull et al. [SHM09] recommend a canonical view. We follow this recommendation and employ an anterior view. The large hands can be set to three states: (1) open hand, (2) closed hand, and (3) following the posture of the user's hand.

Changing this state is a context-specific operation. Therefore, a context menu is attached to the large hands (see Figure 2). Here, it is possible that the user cannot reach the menu. Therefore, a ray-based interaction technique is chosen, where a ray is sent out from the user's hand in the direction of their palm. To support the user with inaccurate pointing, an invisible sphere is used for casting. If a menu item is hit by the sphere, the ray is bent to this menu item (see Figure 2).

Labels. To allow the student to learn the anatomical terminology and to fulfill RQ 3, labels are used (see Figure 3). We chose external labels, as elongated and thin structures, such as arteries, would not allow readable internal labels (see Oeltze-Jafra et al. [OJP14] for a discussion of internal and external labels in medicine). We positioned the labels and anchor points manually for the initial anterior view and recreated the layout used in the Netter anatomy atlas [Net14]. The labels were placed on an invisible plane. If the user rotates their hand, this plane is still facing the user, which ensures that labels are always visible.

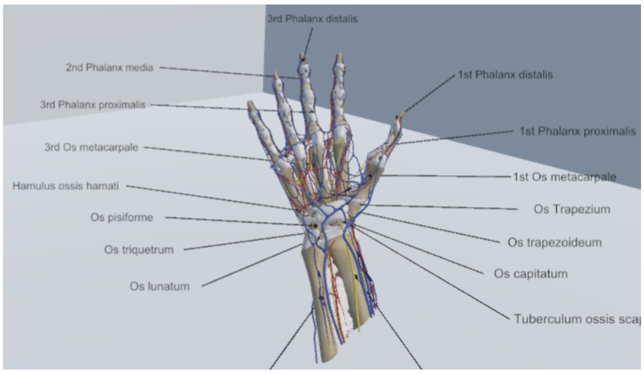


Figure 3: *Labels for the bones are shown on the user's virtual hand.*

Figure 4: *By pressing buttons with the virtual hand, anatomical systems can be shown or hidden.*

Showing and Hiding Anatomical Systems. With respect to RQ 4, the possibility to show all structures or only specific systems is essential to support systemic anatomy. This will allow to investigate structures that would otherwise be occluded by others. Therefore, we allow the user to show and hide structures by anatomical systems. The user can do this for bones, muscles, ligaments, arteries, veins and nerves.

Since this operation should be performed for the user's virtual hands and the large copies, it can be considered as a global operation. For this, the user always needs to have access to the menu. Therefore, we realized a menu in close distance to the user. A fixed menu position is inappropriate when the user may move away. Therefore, the menu follows and positions itself in front of the user in the height of their elbows. The user can press buttons by pushing them directly with a finger (see Figure 4).

3.5. VR Design Decisions

The prototype supports room-scale VR, i.e., the user may move in the tracking space. This allows her to freely explore the medical content from all sides, which is a very natural way to investigate an object. However, the medical content has to be arranged in a way that is not distracting.

A seated experience, however, is also provided, since it may be more appropriate for some users and for a longer usage. This makes the prototype more accessible (RQ 5).

Regarding the type of VR headsets, we decided for the Oculus Quest as it is affordable and mobile. Additionally, there is almost no technical setup involved, except for the optional setup of the room-scale tracking space (RQ 5).

3.6. Technical Details

The prototype was realized with Unity v2019.1.3f1 (`https://unity.com/`). The rigged and skinned 3D hand model created with Blender can be directly imported. With 1.600 × 1.440 pixels per eye, a refresh rate of 72 Hz and a horizontal field of view of 90 degrees, Oculus Quest enables a convenient VR experience.

4. Evaluation

We evaluated the prototype with 7 users (4 females, age ranges from 18 to 36). Five participants worked at an advertisement agency with a technical job and two were computer science students. Only two participants had previous experience with VR applications. All participants were right-handed and used a computer for several hours a day.

After an introduction of approximately five minutes, the participants used the VR headset to get familiar with VR. Afterwards, they employed our prototype themselves and we analyzed how the functions were used. Finally, the users filled out three standardized questionnaires regarding usability, presence, and SoE.

Observations. All participants started by inspecting their hands thoroughly from different perspectives. After that, they tried different poses, mainly forming a fist and opening their hands again quickly.

The interaction with the close menu to show and hide anatomical systems and the distant menu to control the large hand copy were used cautious first. After some attempts, the users were confident executing functions with both menus.

Usability. The usability assessment was based on the widely used *Standardized Usability Scale* (SUS) [Bro13]. It contains ten items with Likert scales and is used to provide a high-level assessment of the usability of a product. With an average of 85 (from 100 maximum) the usability was assessed as very good (range: 77.5 to 92.5) (see Figure 5).

Presence. High levels of presence are essential for the imagination of the users and their motivation. Thus, it is generally recommended to assess it in the evaluation of a VR system. Since presence is a subjective impression (it may differ strongly for different users working with the same system), questionnaires are employed

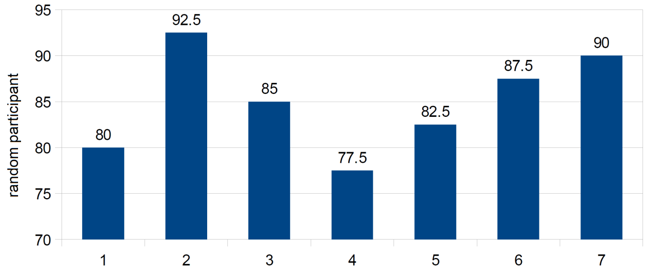


Figure 5: *Standardized Usability Scale (SUS) scores of each participant.*

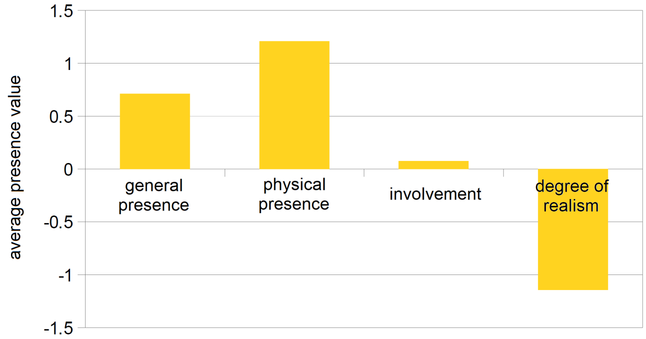


Figure 6: *Average presence scores.*

as well. We compared two questionnaires. The questionnaire from Witmer and Singer [WS98] contains 32 items and was considered as too long. Instead, the *Igroup Presence Questionnaire* (IPQ) from Schubert [Sch03] was used. According to this questionnaire, the presence is assessed with respect to

- general presence,
- physical presence,
- involvement, and
- degree of realism.

On a scale ranging from -3 to +3 , the best rate was achieved for physical presence (1.2), whereas the degree of realism was negatively assessed (-1.2) (see Figure 6). The limited realism was explained mainly by the fact that it is not realistic to see the inner structures of the own hands. Additionally, some deformations of muscles were not perceived as sufficiently plausible. Thus, for widespread use in medical education, an improved procedure for animation has to be incorporated.

Sense of Embodiement. Finally, the SoE was assessed with selected questions from Gonzalez-Franco and Peck [GFP18] according to its three components: (1) sense of ownership, (2) sense of agency, and (3) sense of location. Questions that did not apply to our prototype were removed, e.g. questions regarding haptic feedback.

On a scale ranging from 0 to 2.5, the assessments are quite similar, ranging from 1.5 (sense of agency) to 1.9 (sense of ownership). A sense of agency of 1.5 means that users had the impression to be able to control the virtual hand with their own hand. The 1.9 rating of sense of ownership is in line with current research that correlates high ownership with high realism of the hand model [LKRI20]. For the sense of location, the average rating was 1.7.

5. Conclusion & Future Work

We presented a VR-based prototype for learning the hand anatomy that is designed to induce SoE. The user learns anatomy, primarily by moving the hand joints. This type of learning is *active* and thus more promising than passive types of learning, such as watching a predefined video sequence. Features were added to show and hide structures by their anatomical system, to investigate large copies of the user's hand and to learn the terminology with labels. The potential of the prototype is shown with a user study with a high score on the SUS scale, as well as a presence and SoE questionnaire.

To validate the system in its learning context, a user study with medial students has to be performed in the future. Here, two groups of students should learn hand anatomy in a traditional way and with the VR prototype in a between subject design study. After that, an assessment of their knowledge gain can be used to rate the two approaches.

For future work, we envision that students can include a clipping plane or magic lens to filter parts of anatomical structures locally, which would allow to explore parts of the hand in context. It would also be desirable to show the corresponding 2D image data (cross-sectional anatomy) in combination with a clipping plane. A possibility to select labels could be used to display further textual information related to a particular structure. Hand anatomy is certainly the major application of the presented concepts. Exploring foot anatomy would be an interesting extension. Since feet are anatomically similar to hands, it would be possible to map the hand movement to feet. This, of course, would corrupt the sense of embodiment to some degree.

References

[Alb19] ALBRECHT A.: Learning hand anatomy with sense of embodiment, 2019. Bachelor Thesis; Otto-von-Guericke University Magdeburg, Germany, Dept. of Computer Science. 1

[BP07] BARAN I., POPOVIĆ J.: Automatic rigging and animation of 3D characters. *ACM Transactions on Graphics 26*, 3 (2007), 72–es. 2

[Bro13] BROOKE J.: SUS: a retrospective. *Journal of usability studies 8*, 2 (2013), 29–40. 4

[cde] CDEROLIN: 3D hand model. `https://sketchfab.com/cderolin/collections/hand-anatomy`, last accessed on 21.08.2020. 2

[CH07] COSTANTINI M., HAGGARD P.: The rubber hand illusion: sensitivity and reference frame for body ownership. *Conscious Cogn 16*, 2 (2007), 229–240. 2

[GFP18] GONZALEZ-FRANCO M., PECK T. C.: Avatar embodiment: towards a standardized questionnaire. *Frontiers in Robotics and AI 5* (2018), 74–83. 4

[HMMW11] HOLLE H., MCLATCHIE N., MAURER S., WARD J.: Proprioceptive drift without illusions of ownership for rotated hands in the "rubber hand illusion" paradigm. *Cogn Neurosci 2*, 3-4 (2011), 171–78. 2

[JPBK16] JARIYAPONG P., PUNSAWAD C., BUNRATSAMI S., KONGTHONG P.: Body painting to promote self-active learning of hand anatomy for preclinical medical students. *Medical education online 21*, 1 (2016), 30833. 1

[KGS12] KILTENI K., GROTEN R., SLATER M.: The Sense of Embodiment in Virtual Reality. *Presence: Teleoper. Virtual Environ. 21*, 4 (2012), 373—-87. 2

[KM04] KURIHARA T., MIYATA N.: Modeling deformable human hands from medical images. In *Proc. of ACM SIGGRAPH/Eurographics symposium on Computer animation* (2004), pp. 355–63. 1

[LJG13] LINDGREN R., JOHNSON-GLENBERG M.: Emboldened by embodiment: Six precepts for research on embodied learning and mixed reality. *Educational Researcher 42*, 8 (2013), 445–52. 1

[LKRI20] LOUGIAKIS C., KATIFORI A., ROUSSOU M., IOANNIDIS I.-P.: Effects of virtual hand representation on interaction and embodiment in HMD-based virtual environments using controllers. In *Proc. of IEEE VR* (2020), pp. 1–8. 5

[MWS17] MARKS S., WHITE D., SINGH M.: Getting up your nose: a virtual reality education tool for nasal cavity anatomy. In *Proc. of SIGGRAPH Asia 2017 symposium on education* (2017), pp. 1–7. 1

[Net14] NETTER F.: *Atlas of Human Anatomy, 6th Ed.* Saunders/Elsevier, 2014. 2, 3

[OJP14] OELTZE-JAFRA S., PREIM B.: Survey of labeling techniques in medical visualizations. In *Proc. of Eurographics Workshop on Visual Computing for Biology and Medicine* (2014), pp. 199–208. 3

[PKE11] PETKOVA V. I., KHOSHNEVIS M., EHRSSON H. H.: The perspective matters! Multisensory integration in ego-centric reference frames determines full-body ownership. *Front Psychol 2* (2011), 35. 2

[PPS19] POHLANDT D., PREIM B., SAALFELD P.: Supporting Anatomy Education with a 3D Puzzle in a Virtual Reality Environment – Results from a Pilot Study. In *Mensch und Computer* (2019), pp. 91–102. 1

[PRS97] PREIM B., RAAB A., STROTHOTTE T.: Coherent zooming of illustrations with 3d-graphics and text. In *Proc. of Graphics Interface* (1997), pp. 105–113. 1

[PS18] PREIM B., SAALFELD P.: A Survey of Virtual Human Anatomy Education Systems. *Computers & Graphics 71* (2018), 132–53. 2

[PSWS09] PETERSSON H., SINKVIST D., WANG C., SMEDBY Ö.: Web-based interactive 3D visualization as a tool for improved anatomy learning. *Anatomical sciences education 2*, 2 (2009), 61–68. 1

[RNL06] RHEE T., NEUMANN U., LEWIS J. P.: Human hand modeling from surface anatomy. In *Proc. of Interactive 3D graphics and games* (2006), pp. 27–34. 1

[Sch03] SCHUBERT T. W.: The sense of presence in virtual environments: A three-component scale measuring spatial presence, involvement, and realness. *Zeitschrift für Medienpsychologie 15*, 2 (2003), 69–71. 4

[SFP*00] SCHIEMANN T., FREUDENBERG J., PFLESSER B., POMMERT A., PRIESMEYER K., RIEMER M., SCHUBERT R., TIEDE U., HÖHNE K. H.: Exploring the Visible Human using the VOXEL-MAN framework. *Computerized medical imaging and graphics 24*, 3 (2000), 127–32. 1

[SHM09] STULL A. T., HEGARTY M., MAYER R. E.: Getting a handle on learning anatomy with interactive three-dimensional graphics. *Journal of Educational Psychology*, 101 (2009), 803–816. 3

[SSC*17] SEO J. H., SMITH B. M., COOK M., MALONE E., PINE M., LEAL S., BAI Z., SUH J.: Anatomy builder VR: Applying a constructive learning method in the virtual reality canine skeletal system. In *Proc. of International Conference on Applied Human Factors and Ergonomics* (2017), pp. 245–52. 1

[SSSVB10] SLATER M., SPANLANG B., SANCHEZ-VIVES M. V., BLANKE O.: First Person Experience of Body Transfer in Virtual Reality. *PLOS ONE 5*, 5 (2010), 1–9. 2

[VCWP96] VIEGA J., CONWAY M. J., WILLIAMS G., PAUSCH R.: 3D Magic Lenses. In *Proc. of ACM Symposium on User Interface Software and Technology (UIST)* (1996). 1

[WS98] WITMER B. G., SINGER M. J.: Measuring presence in virtual environments: A presence questionnaire. *Presence 7*, 3 (1998), 225–240. 4