An Interactive Digital Platform for Teaching Auditory Physiology using Two Classes of Electronic Basilare Membrane Models

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Abstract: Teaching and understanding the principles of physiology is one of the most important and complex fields in medical education. This article describes the development of a digital learning platform for hearing physiology with computer experiments demonstrating the perceptual masking properties of the human ear. The basis for the development of this platform were two different hearing models: the sequential electronic model of the inner ear described by David in 1972 and the parallel Gammatone model by Patterson from 1988. The platform was evaluated from 44 undergraduate students of audiology. On a Likert Scale from 1= absolutely agree to 5=do not agree at all, students found the learning platform helpful for understanding “audiological physics” (2.10 ±0.67). After working on the learning module, the physiological hearing processes also became more evident to the students (2.24 ±0.69). They also were able to use the learning platform independently without relevant technical problems (1.93 ±0.80). As a conclusion, the usage of such interactive digital platforms might also lead to more efficient learning pathways which interconnect knowledge acquisition, skill development and life experience at the same time.

1 INTRODUCTION

Teaching and understanding the principles of physiology is one of the most important and complex fields in medical education. Already in 1863 Helmholtz brought out his pathbreaking work “On the Sensations of Tone as a Physiological Basis for the Theory of Music”, which in it’s origin german language was titled “Die Lehre von den Tonempfindungen”, which clearly emphasized the educational aspect (stressed by the word “Lehre”) of his work (Helmholtz and Ellis, 2009).

What can also be seen on this historical example is that, depending on the respective context, physiolgical teaching implies the availability of knowledge of a variety of related medical sciences most of all anatomy, cell biology or biophysics. From that knowledge base, normal physiological processes can be explained, which is necessary to develop students’ knowledge of disordered pathophysiological functioning. Therefore besides of a huge amount of background knowledge, thinking in structural relationships is one of the essentials for understanding physiological working principles.

As pointed out by Beard et al., (2003) the use of electrical engineering and computer science for creating models of physiological pathways has led to a deeper understanding of physiological frameworks in the last decades e. g. in modeling the blood flow (Wong et al., 1991; Mabotuwana et al., 2007) or human motor behavior (Lemos et al. 2004; Tagliabue et al., 2007) to mention some examples. This line of reasoning was taken up and refined by (Modell, 2006) who argues, that a “view from the inside” might also help students to develop model oriented learning strategies focusing on causal relationships in physiology. Thus, integration of such models into computer-based educational strategies offer promising new perspectives. To be efficient for students, models should be integrated into an easy to handle learning platform to manage the underlying mathematical algorithms. Today such e-learning

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applications using physiological models already do exist, e. g. simulation models to teach respiratory mechanics (Kuebler et al., 2007) or integrative mathematical model for circulatory physiology (Abram et al., 2007).

This article describes the development of a special learning platform for hearing physiology with computer experiments demonstrating the perceptual masking properties of the human ear. It gives some examples on human voice processing are how they are described using auditory imaging and presents the results of a student evaluation of this tool. Finally future prospects for this platform are discussed with a special focus on web-based learning strategies.

2 MATERIAL AND METHODS

The basis for the development of our learning platforms were two different hearing models: the mechanico-electronical model of the inner ear described by David (1972) and the Gammatone model by Patterson (1987). Despite of the fact, that these models date back more than 20 years, they both still represent classes of current models which are used in scientific studies. Such is the approach of David one of the first models which used a low pass filterbank to describe the cochlea function. It consists of a series of 64 low pass filters with descending cut-off-frequency with one entrance and two exits in each filter. One exit transmits the oscillations to the next element, while the second exit transmits the signals to the query system and is further processed according to the neural auditory pathway (Figure 1).

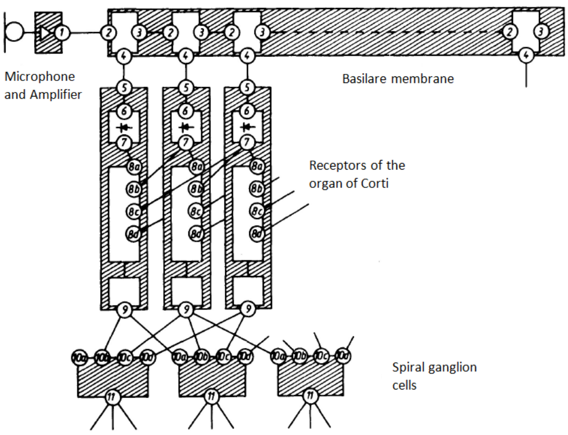

Figure 1: The functional elements of the hearing model of David (from David, 1972).

In contrast to this approach, the gammatone model represents the basilar membrane as a chain of parallel switched band pass filters. The band pass filters allow to pass sound within a certain frequency band and so influences the spectrum of the input signal. Thus, in contrast to the low-pass-model of David which is a nonlinear serial appoach, sound in this class of models is processed linear and parallely through the filters and then processed further (Figure 2).

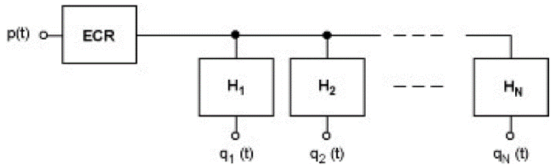

Figure 2: The canal model of the sound transference in the peripheral auditive system. p(t):Input signal; ECR: Ear Canal Resonances; H1-H2: Transference functions of the single auditive filters; N: Number of the parallel filters; $q_1(t)$-q_N (t): Source signals.

To create a basis for the development of learning platforms based on these two hearing models, both model classes were realized with MatLAB Version 6.5.1. On that basis the model of David and the gammatone model were implemented as independent PC-programs. To show the performance of the models the technique of auditory imaging of the basilar membrane movement over time was used for both models.

Finally, evaluation of the didactic qualities of this platform was carried out by a questionnaire survey of 29 undergraduate students of medical engeneering. Following the evaluation program of the Coordination Center Homburg eLearning in medicine (Graf et al., 2007), we gave the students six statements about the learning platform which had to be judged on a five-point Likert scale from 1= absolutely agree to 5=do not agree at all.

3 RESULTS

To show the validity of the implemented models we first carried out simulations with pure sinus tones of 2ms and a pitch level of 500, 1000, 2000 and 5000 Hz. As can be seen in the model of David (1972), high frequencies are presented in the upper channels representing the region of the round window and low frequencies can be associated with the region of the Helicotrema. Both models also showed a very good correspondence in their auditory images of basilar membran movement in conjunction with the applied signal (e.g. spoken vocal e).

Next, to introduce normal and pathological hearing to medical students, we showed how acoustic

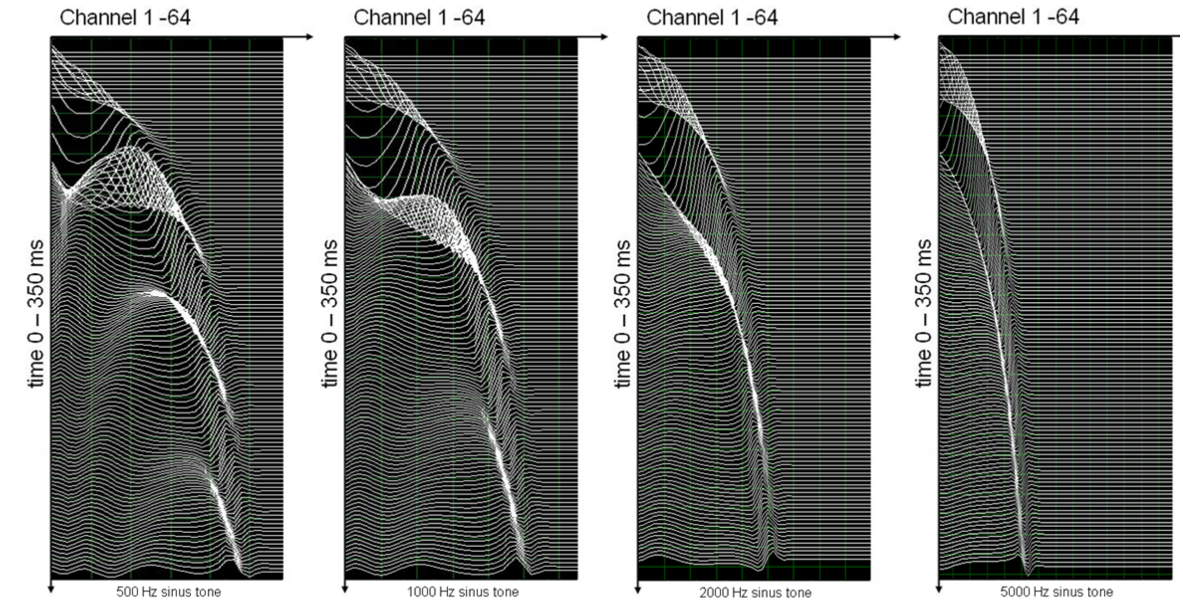

Figure 3: Basilar membrane of hearing model of David (with a 0.5 kHz to 5 kHz sinus tone).

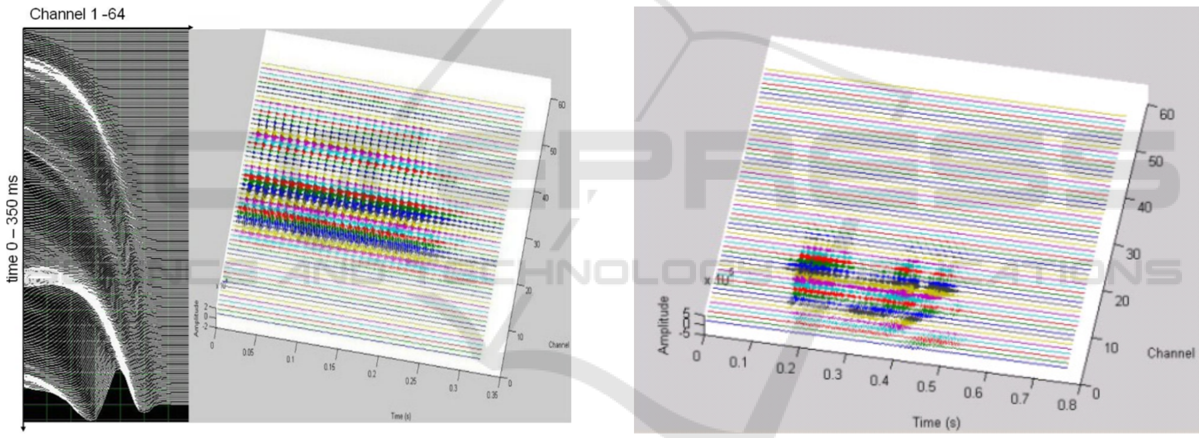

Figure 4: Comparison hearing model of David vs. Gammatone model for the vocal 'e'.

signals (e.g. spoken words) are processed by hearing impaired person. First with the gammatone model. According to the impairments we adapted the filters to the pathological situation and compared the results of the basilar membran movement with a conventional threshold audiogram (Figure 5).

Due to the more physiological approach we therefore used the David-model for auditory imaging of hearing impairments. (Figure 6).

For evaluation purposes, we offered our learning platform to 29 undergraduate students of audiology. They tested the benefit of this digital platform in their learning process. The following statements were judged on a five-point Likert scale from 1= absolutely agree to 5 =do not agree at all:

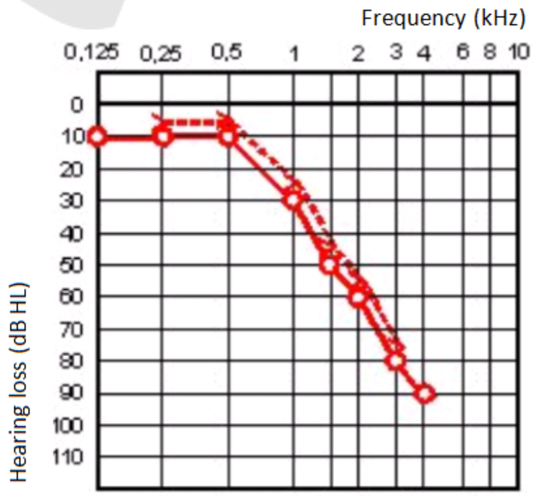

Figure 5: Comparison of the Gammatone model with a threshold audiogram.

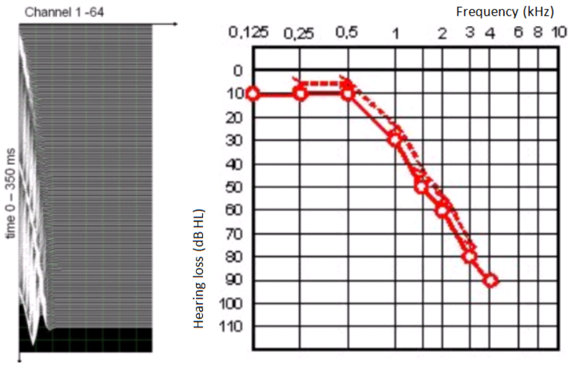

Figure 6: Comparison of the David model with a threshold audiogram.

1. The learning platform was helpful for the understanding of the lesson "audiological physics".
2. I was able to use the learning platform independently without relevant technical problems.
3. After working on the learning module, the physiological hearing processes became evident to me.
4. I would like further instruction for a more intensive use of the platform.
5. Would you prefer to use additional carrying-on learning platforms?
6. Did the learning module also help you to improve your practical competences in audiology?

Figure 7 reports the judgements of the 44 students.

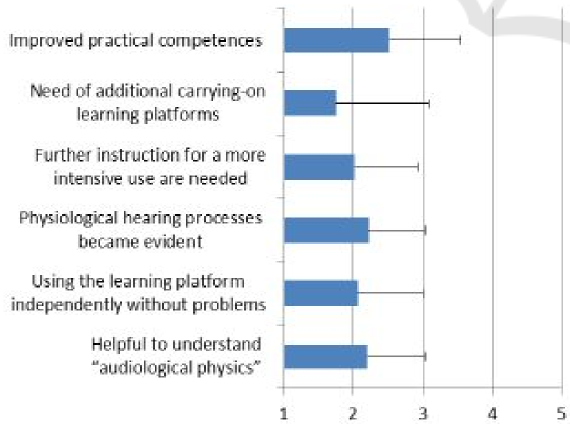

Figure 7: Judgements of 44 students on a five-point Likert scale from 1= absolutely agree to 5 =do not agree at all.

A total of 34 students found that the learning platform was helpful for the understanding of the lesson "audiological physics" (Mean ± StDev: 2.20 ± 0.82). 35 Students were able to use the learning platform independently without relevant technical problems (Mean ± StDev: 2.07 ± 0.93). 32 students reported that after working on the learning module, the physiological hearing processes became evident to them (Mean ± StDev: 2.23 ± 0.80). However, also 34 students claimed that further instruction for a more intensive use of the platform would have been helpful to them (Mean ± StDev: 2.02 ± 0.90). This goes alongside with the fact that 36 students would prefer to use additional carrying-on learning platforms (Mean ± StDev: 1.75 ± 1.33). With respect to practical skills only 22 students reported that this digital platform also helped to improve their practical competences in audiology (Mean ± StDev: 2.52 ± 1.02).

4 CONCLUSIONS

For more than 20 years teaching in the medical program at Witten/Herdecke Private University has followed the goal of introducing students to the reality of patient care by a practical approach (Mitzkat et al., 2007). Therefore several aspects like problem based learning have been introduced into a integrated curriculum. Alongside of these innovative didactical approaches, e-learning is one of the future prospects of medical teaching. As one component in the teaching-framework this article describes a learning platform for hearing physiology based on computational models of the cochlea.

After proving the validity of our model, we showed how our simulation can be used as a e-learning device for undergraduate medical students and used our simulation to demonstrate the relationship between a tone threshold audiogram and the basilar membrane displacement. With this approach, students are enabled to construct a causal relationship between the threshold audiograms and the tone allocation on the basilar membrane. By interfacing of different types of media, students not only get technical informations but also impressions how hearing pathologies restrict the processing of auditory informations in hearing disabled persons.

The usage of such interactive learning programs might also lead to more efficient learning pathways which interconnect knowledge acquisition, skill development and life experience at the same time. Our program therefore can easily be embedded into practical training in physiology or linked to larger e-learning environments e.g. in interactive casebooks on imaging systems in otorhinolaryngology described by Grunewald et al., (2005) or virtual models of the human temporal bone developed by Wang et al., (2006).

Online availability of such a platform might also lead to an indenpendent teaching and learning of audiology from time and place, which can be enriched by direct care of the professional lecturer. Thus, the integration of learning platforms like ours into medical education can catalyze the shift toward applying learning strategies, where teachers will no longer serve mainly as the distributors of content, but will become more involved as facilitators of learning and assessors of competency.

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