COMPUTATIONAL ERGONOMICS – A POSSIBLE EXTENSION OF COMPUTATIONAL NEUROSCIENCE? DEFINITIONS, POTENTIAL BENEFITS, AND A CASE STUDY ON CYBERSICKNESS

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This paper proposes a sub-discipline called 'Computational Ergonomics' and explains how it will support the ultimate goal of 'studying human by building a human through quantitative modeling'. This idea is not new and has been successfully implemented in the sub-discipline of Computational Neuro-Sciences (CNS) for more than 20 years. In fact, quantitative models developed by CNS researchers are becoming comprehensive enough to explain simple voluntary human behavior already. We believe the timing is right for ergonomics researchers to make use of the many open-source quantitative CNS modeling algorithms as fundamental building blocks of quantitative human performance models. This move is also consistent with the new sub-discipline of 'neuroergonomics' (Spring 2003 issue of Theoretical Issues in Ergonomics Sciences) and the call for more quantitative formal models of human performance (Spring 2003 issue of Human Factors). In addition to explaining the essential elements of the proposed 'Computational Ergonomics', this paper presents a case study to illustrate the benefits of the proposed changes. In particular, how the authors' research on simulator sickness with virtual reality systems has benefited from the proposed changes. This paper intends to raise stimulating and controversial arguments to be discussed during the conference presentation.

Introduction

After more than 5 decades of collecting human performance data through empirical experiments, most current ergonomics research is still focused on running empirical experiments rather than developing quantitative models based on previously collected data. This, to a large extent, might have been due to the habit of not publishing the raw data. The lack of published well-documented raw data prohibits the existence of 'pure' model developers. In other words, ergonomics researchers must collect a lot of empirical data by themselves before they can start developing a model and this posts a very high entry barrier

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for most researchers and will certainly drive away those computational scientists and mathematicians whose only interests are in data modeling. A second reason for the lack of quantitative human performance models is that most ergonomics problems are very complicated and in the absence of open-source smaller scaled models as building blocks, the task of developing a large scaled quantitative human performance model is too difficult for most researchers. The third reason is that even if we pool all the developed quantitative human performance models together, they may not be compatible with each other. This paper explains how the essential elements within the proposed sub-discipline can address each of the three reasons. Examples of elements include (i) a suggested requirement of publishing open-copyrighted raw ergonomics data for third-party model developers to work on; (ii) a suggested requirement for model developers to define the structures of their models according to the known anatomical fact of human biology – an important element behind the success of Computational Neuro-Sciences (CNS); and (iii) a suggested requirement for model developers to publish their models in the form of open-source computational code library for others to use. The significance of above elements and others are explained in the following sections.

Challenges on developing ergonomics models

Figure 1 illustrates the common modeling approaches in ergonomics. In the following subsections, the challenges related to these modeling approaches will be discussed using the authors' own research on cybersickness.

High entry barriers

Cybersickness is defined as the sickness generated after a user is exposed to a virtual reality (VR) simulation. The authors have reviewed that there have been at least 63 empirical studies on cybersickness examining the effects of 17 independent variables such as types of scene background and scene movement, exposure duration, types of VR display, display's field-of-view, image delays, use of stereoscopic, inter-pupillary-distance mismatch, method of navigation, postures during simulation, amounts of head movement during simulation, age, gender, pre-exposure posture stability, habituation, menstrual phase, and drug treatment. With so many published empirical studies, there should be plenty of raw data that can support the development of empirical regression models, operator control models, or even production-rule models on cybersickness (Figure 1). However, the reality is that although results of statistical analyses on the effects of 17 independent variables are well documented, the raw data collected in the 63 studies were not published. This makes it difficult for any "outsider" to develop quantitative models to predict levels of cybersickness and prohibits researchers of other disciplines such as computer sciences and computational neuroscuences to contribute their expertise. The authors were able to develop models to predict levels of cybersickness (So *et al.*, 2001; Yeun *et al.*, 2002; So *et al.*, 2004) because the authors have themselves conducted many empirical experiments on cybersickness (e.g., So, 1994; So and Lo, 1998; So *et al.*, 2000; Lo and So, 2001; So *et al.*, 2002). A review of literature indicates that the habit of not publishing the raw data is fairly common in the field of ergonomics.

The compatibility challenges and the absence of model building blocks

Because of the high entry barrier discussed in the last sub-section, it is not surprising to find that there are very few attempts to model the cybersickness generation process. As a good ergonomics practice, it is always worth reviewing related studies. A review of literature on quantitative models on opto-kinetic induced motion sickness, seasickness, and space sickness

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has proven to be productive because there have been published biological conceptual models on vection-induced motion sickness (work by Prof. Robert Stern, Pennsylvania State University and Prof. Ebenholtz at Schnurmacher Institute for Vision Research), empirical modeling to predict seasickness (work by Prof. M.J. Griffin, Institute of Sound and Vibration Research), and operator control models to explain space and motion sickness (work by Prof. Charles M. Oman, MIT, Prof. Telban, State University of New York). However, the three clusters of research used very different approaches (empirical regression: Griffin, 1990; Kalman filter model: Oman, 1982; adaptive filter: Telban *et al.*, 2001, and biological conceptual model: Stern *et al.*, 1995, Ebenholtz *et al.*, 1994) and shared little common building blocks. Although the authors have benefited a lot from their research methodologies, approaches of modeling, and concepts on vomit generation, reusable model building blocks could not be found. The main reason is that these models have different structures.

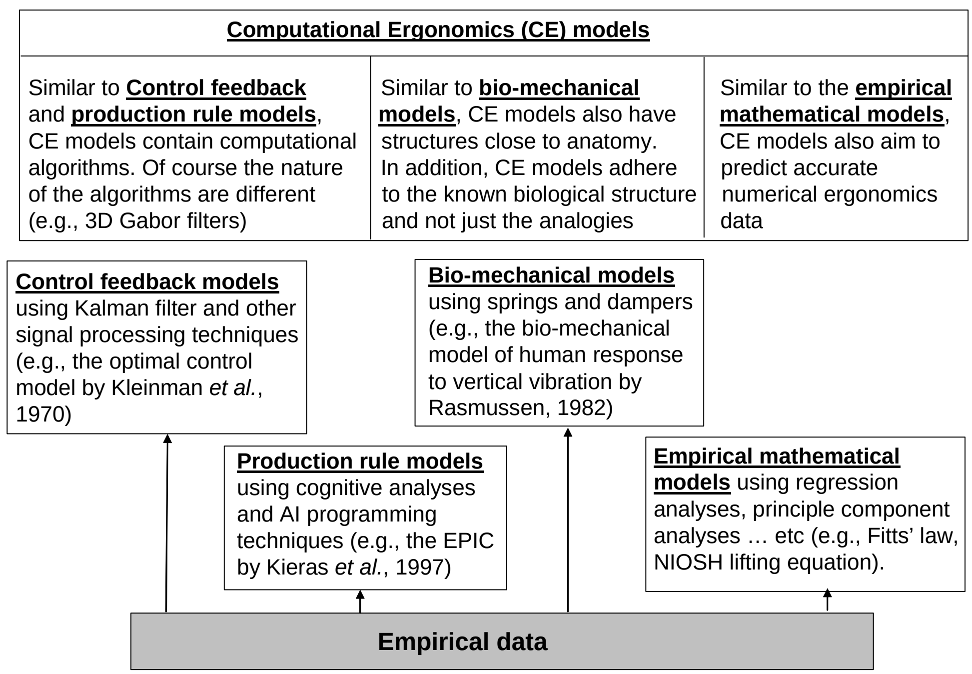

Figure 1 An illustration of the common quantitative model approaches used in the field of ergonomics and their similarity with 'Computational Ergonomics (CE)' models. The differences and the uniqueness of CE models are explained in the text.

Potential Benefits of Computational Ergonomics Approach of Modeling

The authors humbly admit that the use of computational algorithms to model and predict ergonomics behavior is not new. An example related to motion sickness is the motion sickness dose value (MSDV, Griffin, 1990) which takes in the time histories of vertical ship motion accelerations and output the predicted percentages of passengers that would vomit. Another example is the herristic mathematical model to predict levels of motion sickness by Oman (1982). The proposed 'Computational Ergonomics (CE)' approach to modeling is not just the application of computational models, it consists of four essential elements: (i) a CE

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model structure must adhere to the human anatomical structure, (ii) the willingness to share the source codes of CE model building-blocks, (iii) the use of computational algorithms, consistent to the true biological process, to construct the model building-blocks, and (iv) the sharing of raw data. In short, these four elements are referred to the "A,B,C,D" (**A**natomical structure, open-source **B**uilding-blocks, **C**omputational algorithms, and sharing of raw **D**ata) of Computational Ergonomics.

Anatomical structure

To solve the compatibility challenges of different ergonomics models, it is proposed that all computational ergonomics models should be based upon the known biological structures. Applying this requirement to the study of cybersickness, a biological plausible model to predict individual vection (illusion of self-motion) ratings while exposed to a VR simulation is developed (Figure 2). From the extensive study of anatomical fact of human biology together with the finding of a biomechanical pathway of vection, a sensation of vection is suggested to be generated at the parieto-insular vestibular cortex (PIVC) (Brandt, 1999). Our eyes first capture a sequence of motion pictures. Then visual signals are transferred via optic nerves to the visual cortex. At the region of primary visual cortex (V1), the spatial frequency of motion pictures is extracted. Efferent signals from V1 are received by the middle temporal cortex (V5). Inside this region, local optical flow vectors are evaluated. On the vestibular signal pathway, physical head movement is measured by semi-circular canals. The head movement stimuli are then fed into vestibular nuclei (VN) and are routed to PIVC where visual and vestibular signals are integrated and hence generate vection. Because this model involves the essential biological process in vection generation, it can be used as a model building block for future models related to vection.

Open-source building-blocks and computational algorithms

The bottom part of Figure 2 illustrates the flow of the computational quantitative model with respect to the biological structured model on vection. Visual and vestibular stimuli are major factors generating vection. Our current model consists of two modules to calculate the spatial frequency and perceived velocity of visual stimuli. Fourier analyzer acts as V1 to extract spatial frequency. Similar to V5, scene velocity detector employs optical flow to estimate the perceived velocity. For vestibular stimuli, we use a head-tracking device as a physical motion detector to measure the head movement. Integrating these three inputs together, we can determine how much vection is generated. Based on this simple biological plausible computational model with the analysis of ergonomics data, we invented a metric called Cybersickness Dose Value (CSDV) that can accurately predict levels of cybersickness (So et al, 2000). Currently, the Fourier analyzer building-block has been made available on www.cybersickness.org. User can upload a snapshot of a VR simulation to the website and the server will automatically calculate its spatial frequency.

In the future, other open-source libraries of useful neuro-computing algorithms in our site will be included in the site. With the recent advances of computational neuroscience in understanding higher brain functions (Dayan and Abbott, 2001), there will be many open-source computational building blocks that are freely available to ergonomics researchers.

Sharing of raw data

In order to solve the high entry barrier challenges, it is proposed for all computational ergonomics researchers to share their raw empirical data in a standard format so that other ergonomics researchers can analyze the data with their own methods. These raw data can be open-copyrighted and require all users to acknowledge the original data owners in their

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work. Applying this to our study of cybersickness, a sharing platform has been set-up on www.cybersickness.org for other researchers to download our open-copyrighted raw data collected from two of our recent experiments. We hope that this approach would encourage third-party model developers such as computational scientists and mathematicians to analyze our data.

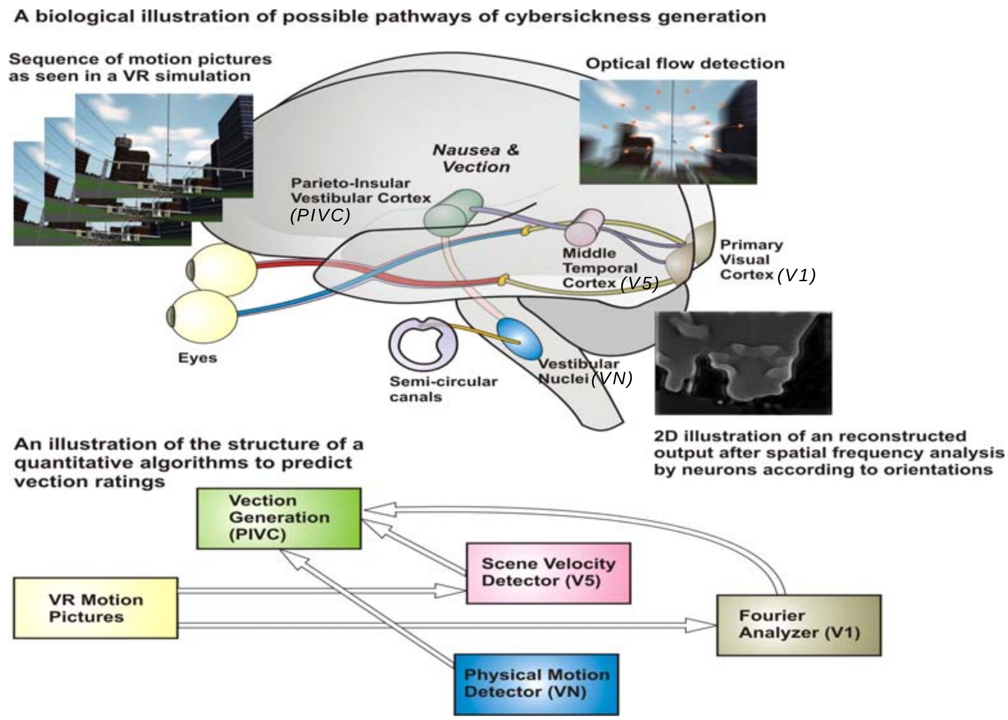

Figure 2 An illustration of a possible biological pathway of vection generation at PIVC region using inputs from V5 and V1 regions. The bottom part illustrates the structure of a quantitative model to predict vection levels.

Conclusions and Future Research Directions

Computational Ergonomics is a new paradigm to link physical and neuro-ergonomics with the help of computational neuroscience. Figure 1 illustrates its relationship with the existing common modeling approaches in the field of ergonomics. This emerging field can encourage researchers with different disciplines to develop quantitative ergonomics models. A well-developed biological computational model with open-source codes can form fundamental building blocks for others to use and the sharing of raw empirical experimental data with a standard format can allow theorists to easily study ergonomics problems. We strongly believe computational ergonomics will be one of the focus areas leading towards the total elucidation of complicated human behaviors.

Acknowledgement and References

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