Measuring performance in virtual reality phacoemulsification surgery

Per Söderberg*[a,b,F], Carl-Gustaf Laurell[a,F], Wamidh Simawi[a,c,NF], Eva Skarman[d,F], Leif Nordh[d,F], Per Nordqvist[d,F]

[a]St. Erik's Eye Hospital, Karolinska Institutet

[b]Dept. of Biomedical Engineering, University of Miami

[c]Dept of Ophthalmology, Uppsala Akademiska Sjukhus

[d]Melerit AB

ABSTRACT

We have developed a virtual reality (VR) simulator for phacoemulsification surgery. The current work aimed at developing a relative performance index that characterizes the performance of an individual trainee. We recorded measurements of 28 response variables during three iterated surgical sessions in 9 experienced cataract surgeons, separately for the sculpting phase and the evacuation phase of phacoemulsification surgery and compared their outcome to that of a reference group of naive trainees. We defined an individual overall performance index, an individual class specific performance index and an individual variable specific performance index. We found that on an average the experienced surgeons performed at a lower level than a reference group of naive trainees but that this was particularly attributed to a few surgeons. When their overall performance index was further analyzed as class specific performance index and variable specific performance index it was found that the low level performance was attributed to a behavior that is acceptable for an experienced surgeon but not for a naive trainee. It was concluded that relative performance indices should use a reference group that corresponds to the measured individual since the definition of optimal surgery may vary among trainee groups depending on their level of experience.

Keywords: cataract surgery, phacoemulsification, simulator, individual variable specific performance index, individual class specific performance index, individual overall performance index.

1. INTRODUCTION

The present work aimed at developing a performance index for virtual reality phacoemulsification surgery.

Phacoemulsification cataract surgery is the most common surgical procedure in modern societies with an incidence approaching 1/100 inhabitants/yr [1]. Due to a quickly increasing population age in countries in development, it has been estimated that the prevalence of cataract could double by year 2020 [2].

In modern phaco emulsification cataract surgery, a less than 3 mm incision is made into the eye in the periphery of the cornea. The crystalline lens is opened by tearing an operculum in the anterior lens capsule, capsulorhexis. The lens nucleus is then mobilized by liquid dissection along the lens capsule. The lens nucleus is removed by ultrasound emulsification and simultaneous aspiration of the nucleus. Then, the cortical material is removed by aspiration and finally an artificial intraocular lens is implanted into the empty capsule. An important quality factor of the surgical procedure, and technical difficulty for the surgeon, is that the lens capsule remains intact during the operation.

Surgeons in training have reported an incidence of 5-20 % of capsular ruptures during their first 200 cases [3-6] despite extensive teacher intensive training. These figures are similar for experienced surgeons [7, 8]. For experienced surgeons the number of complications decreased exponentially reaching the asymptote after 400 [9] to 1000 cases respectively [10].

There is an increasing demand for rigorous monitoring of surgical skills [11]. The recent increase of computing power in personal computers has made it possible to simulate virtual reality with inexpensive computers. Virtual reality models have been developed for various surgical procedures such as arthroscopy, bronchoscopy, cystoscopy, transurethral prostate resection, gastroscopy, colonoscopy, intravascular procedures, coronary stint or cardiac lead placement and laparoscopic surgery [12].

*per.soderberg@ste.ki.se; +46 8 672 3043; Fax +46 8 672 3352; http://www.ste.ki.se/oph/research_projects/Peso/; St. Erik's Eye Hospital, SE 112 82 STOCKHOLM, SWEDEN. NF: No financial interest. F. financial interest

It is known from extensive research on motor skill learning that the incidence of complications decreases as a function of number of training sessions from a high level as a sigmoid towards an asymptote. Similarly, motor skill or *performance*, increases as a function of number of training sessions from 0 as a sigmoid towards an asymptote. The integral of the performance as function of no. of training sessions is defined as *instructional effectiveness*, IE. The goal of any motor training strategy is to achieve as high as possible instructional effectiveness. In order to measure instructional effectiveness, a relevant performance index must be possible to measure.

There are several attempts to measure performance with VR simulators [13-15]. It has been demonstrated that virtual reality training leads to faster adaptation to the psychomotor restrictions encountered by laparoscopic surgeons [16].

We have developed a virtual reality phacoemulsification simulator, PhacoVision® [17-20]. The simulator consists a personal computer, simulation software and a surgeon interface. A preliminary clinical evaluation indicated that the simulator authentically simulates cataract surgery [21]. In a recent study of 8 medical or optometry students, 31 response variables were identified and the variability of measurements of theses variables was analyzed [22]. It was found that the variability's in the measurements were larger for the sculpting phase than for the evacuation phase, resulting in a need for larger sample size to measure changes during the sculpting phase than during the evacuation phase [22].

The aim of the current study was to develop indices that measured performance in virtual reality phacoemulsification surgery.

1 METHODS

1.1 Subjects

Altogether, 9 experienced cataract surgeons with at least five years experience that accepted to participate in the study were included. Each subject took a tutorial course including an instruction video for PhacoVision®, a demonstration of PhacoVision® by an experienced administrator, watching a demonstration operation by an experienced administrator, and performing five learning sessions. The subjects were recruited during 2005-2008.

1.2 The simulator

The simulator (PhacoVision®, Melerit AB, Sweden) consists of a personal computer, simulation software and hardware interfaces.

The simulation software is based on a generalized simulation software (M-base®, Melerit AB, Sweden) working on top of Cosmo 3D/Optimizer (Silicon Graphics Inc., USA). M-base has been used to write the phacoemulsification procedure.

In the trainee input interface, the trainee provide input to the software through a manipulator hand piece, a phacoemulsification hand piece, a commercial microscope foot pedal controlling x and y direction of the field, focusing and zoom., and a phacoemulsification foot pedal triggering irrigation in step one, and adding aspiration in step two and ultrasound energy in step three. The trainee simultaneously, in real time, receives 3-D feed-back of the alterations provoked in the surgical field through two organic light-emitting diode (OLED) displays observed through two eye-pieces.

In the administrator interface, the patient characteristics are defined in fourteen parameters (Table 1).

Table 1 VR parameters

Parameter	Setting
1 Patient movement	
1.1 Average frequency of x-y patient field drift calculated for no drift period	1 Hz
1.2 Maximum velocity for x-y patient field drift	2 mm/s
1.3 Maximum x-y patient field drift, 4 mm	4 mm
2 Pupillary parameters	
2.1 Pupillary diameter	7 mm
3 Lens Parameters	
3.1 Maximum allowed horisonatal transitional stretching of the zonuale before lost lens	1.5 mm
3.2 Maximum allowed zonular load	1 rel
3.3 Nucleus hardness	0.5 rel.
3.4 Nuclear angular speed when dialled	1 deg/s
3.5 Force required to produce cracking	1 rel.
4 Phacoemulsification instrument related	
In frontal plane counter-clockwise angle between 12 a' clock and phacoemulsification handle axis	10 deg
In frontal plane counter-clockwise angle between 12 a' clock and manipulator handle axis	290 deg
Distance tip-irrigation port center	2 mm
Average incidence of occurrence of bubbles	1 Hz
Average number of bubbles per group	4 /group

1.3 Procedure

The virtual reality phaocoemulsification procedure was divided into an initial sculpting phase and a subsequent evacuation phase. During the sculpting phase, a cross is sculpted in the lens nucleus. During the evacuation phase, the lens nucleus is cracked into four sectors and thereafter each sector is evacuated by simultaneous ultrasound emulsification and vacuum aspiration.

1.4 Experimental design

The experimental design is outlined in (Figure 1).

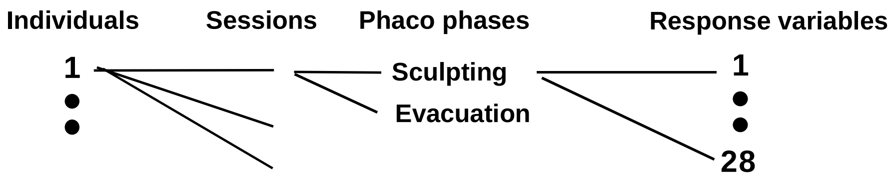

Figure 1 Experimental design. Totally, 9 experienced subjects were included.

Altogether, 9 experienced subjects were recruited. Each subject performed 3 phacoemulsification sessions including the sculpting and the evacuation phase. For both the sculpting phase and the evacuation phase, 28 response variables (Table 2) were measured.

Table 2 Response variables

Variables description	Number within cathegory
1 Overall procedure	
1.1 Procedure time consumption	2
1.2 Energy deposited	1
2 Microscope foot pedal technique	5
3 Phacoemulsification technique	
3.1 Phaco tip movement	4
3.2 Manipulator tip movement	4
4 Erroneous manipulation	4
5 Damage to ocular structures	8
Σ	28

2 RESULTS

2.1 Performance index

Individual variable specific performance index

For each individual *i*, the performance, P_{ij}, for a specific variable, j, was the outcome of the three iterations averaged for the j:th variable. *The individual variable specific performance index, $IVPI_{ij}$.* was defined as the average of the three iterations compared to the database reference value for the j:th variable, RP_j, (Equation 1).

Equation 1 Individual variable specific performance index

$$IVPI_{ij} = \frac{P_{ij}}{RP_j}$$

The database reference value for the j:th variable, RP_j,, was an average for the j:th variable as measured in a reference population of naive trainees.

Individual class specific performance index

The individual class specific performance index, $ICPI_{ic}$, was defined as the average individual performance index within a class of variables (Equation 2).

Equation 2 Individual class specific performance index

$$ICPI_{ic} = \frac{IVPI_{ia} + IVPI_{ib} ... IVPI_{im}}{m}$$

When a, b...m are the m variable indices belonging to a specific class of variables, c.

Individual overall performance index

The individual overall performance index, $IOPI_i$, was defined as the average individual performance index for all variables measured.

Equation 3 Individual overall performance index

$$ICPI_{ic} = \frac{IVPI_{ia} + IVPI_{ib} ... IVPI_{in}}{n}$$

When a, b,…n are all indices for the *n* variables measured.

2.2 Individual overall performance

A scatter plot of the overall performance during the sculpting phase for all subjects (Figure 2)

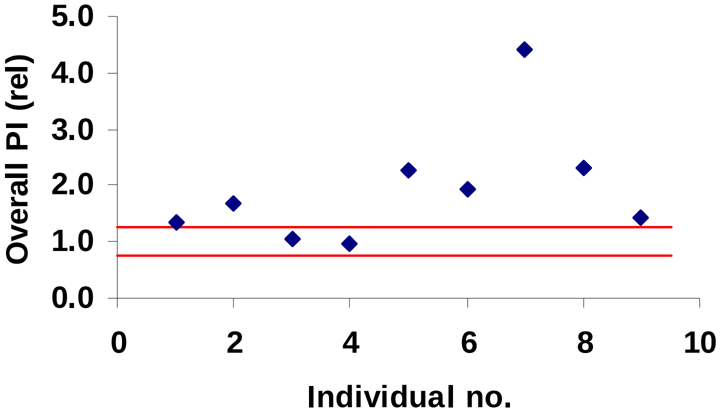

Figure 2 Individual overall performance of experienced surgeons during the sculpting phase. Red lines are 95 % confidence intervals for performance of the reference population of naïve trainees.

demonstrated that on an average the experienced surgeons performed less good than the naive trainees. This was however most expressed for experienced surgeon no. 7.

A scatter plot of the overall performance during the evacuation phase for all subjects (Figure 3)

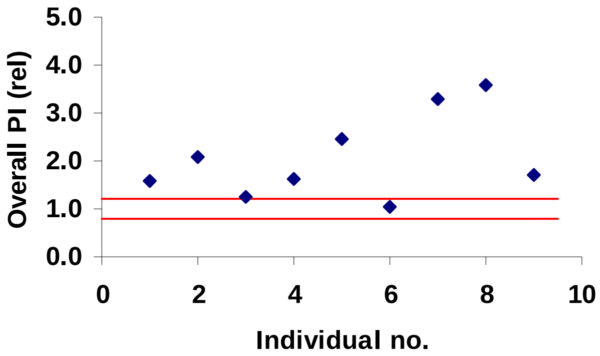

Figure 3 Individual overall performance of experienced surgeons during the evacuation phase. Red lines are 95 % confidence intervals for performance of the reference population of naïve trainees.

similarly showed that the experienced surgeons on an average performed less good than the naive surgeons. This was however most expressed for experienced surgeon no. 7 and 8.

2.3 Individual class specific performance

To understand why experienced surgeon no. 7 performed less good than the naive surgeons during the sculpting phase, the individual class specific performance indices for experienced surgeon no. 7 for the sculpting phase were plotted (Figure 4).

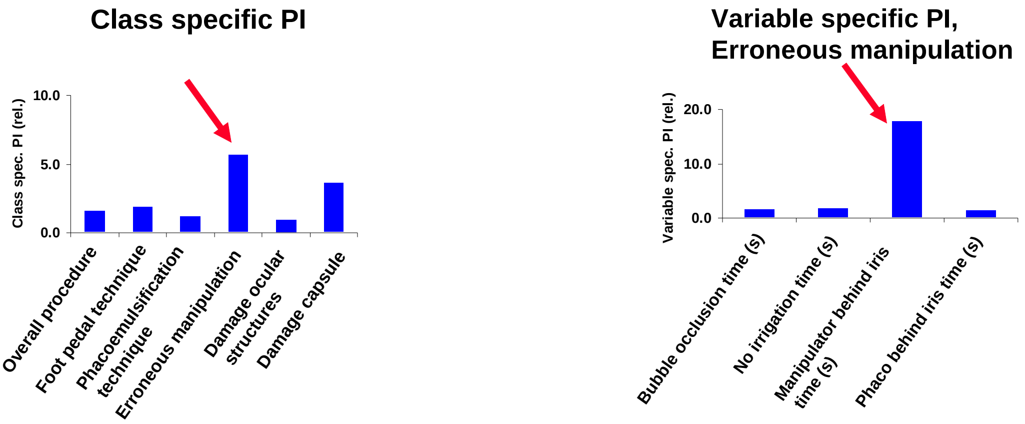

Figure 4 Performance of experienced surgeon no. 7 during the sculpting phase. Left: Individual class specific performance. Right Individual variable specific performance.

it was seen that most of the low level performance during the sculpting phase was related to the *Erroneous manipulation* class of variables. When the individual variable specific performance indices for the *Erroneous manipulation* class were plotted for experienced surgeon no. 7 (Figure 4) it was seen that most of the erroneous manipulation was related to the fact that the manipulator tip was positioned behind the iris.

When the individual class specific performance indices for the evacuation phase were plotted for the experienced surgeon no. 7 (Figure 5)

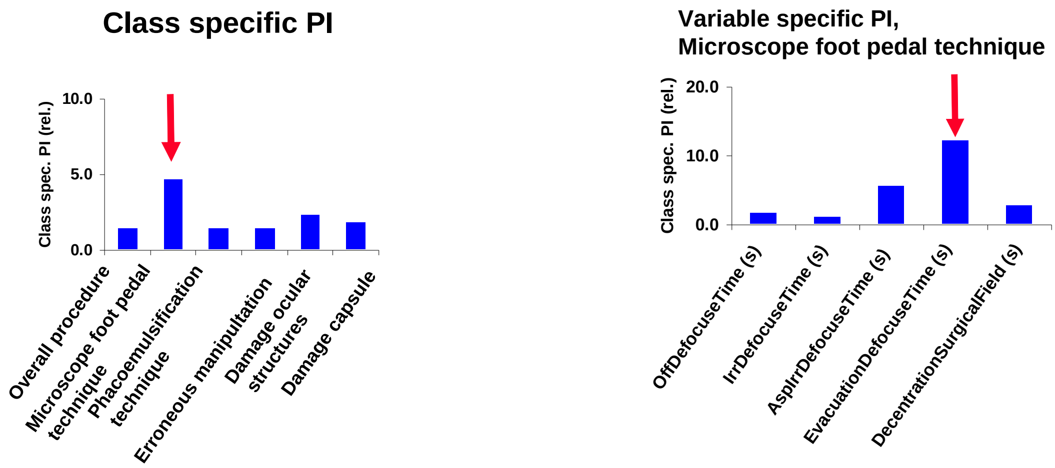

Figure 5 Performance of experienced surgeon no. 7 during the evacuation phase. Left: Individual class specific performance. Right: Individual variable specific performance.

it was seen that most of the low level performance during the evacuation phase was related to the *Microscope foot pedal technique* class of variables. When the individual variable specific performance indices for the class *Microscope foot pedal technique* were plotted for experienced surgeon no. 7 (Figure 5), it was seen that most of the erroneous microscope foot pedal technique was related to the fact that the phacoemulsification tip was defocused during the evacuation phase.

3 DISCUSSION

The purpose of the current study was to develop relative indices that measure performance in virtual reality phacoemulsification surgery.

The currently developed *Individual overall performance index* provides a measure of an individual trainee as related to a reference population of naive trainees. The overall performance can be broken down into an *Individual class specific performance* indicating which type of behavior of the trainee that was faulty. Further, the specific problem within the *Individual class specific performance* can be analyzed as an *Individual variable specific performance index*.

It should be considered that the size of the reference population of naive trainees is still relatively limited. Therefore, the precision of the relative performance indices here presented is limited.

The outcome however indicates that performance of experienced surgeons may not representatively indicate the authenticity of a simulator designed for training of naive trainees. This is due to the fact that an experienced surgeon can without risk handle several maneuvers that are considered very dangerous and not desirable for a naive trainee. Thus, if such maneuvers are tagged as not desirable in the performance index, the experienced surgeon will perform at a lower level. E.g. in the current study, the experienced surgeon no. 7 got a high overall performance score (indicating low level performance) for sculpting (Figure 2) that could be attributed to erroneous manipulation (Figure 4) because the manipulator tip was positioned behind the iris a considerable amount of time (Figure 4). This is a behavior that an experienced surgeon may manage without risk, but that is not desirable for a naive trainee due to increased risk for capsular rupture.

Similarly, it was presently found that experienced surgeon no. 7 performed at a an overall low level during the sculpting phase (Figure 3) that could be attributed to low microscope foot pedal performance (Figure 5), because the phacoemulsification tip was not in focus during evacuation (Figure 5). Again, for the experienced surgeon it may be advantageous to focus the interest on for him more important variables than focusing while the naive surgeon should focus the instrument tips in order to avoid damage during the procedure.

In the currently proposed performance indices, all measured variables are given the same weight. It is most possible that when more experience on the significance of various variables is accumulated, the performance indices will gain relevance if different variables are given specific weights.

We have developed a VR phaco emulsification cataract surgery simulator [17-23].

The current study has proven that performance during VR phacoemulsification cataract surgery can be summarized in an overall measure that can be broken down into various main components of the surgery, which can finally be analyzed in detail. The study further indicates that relative performance indices should use a reference group that corresponds to the measured individual since the definition of optimal surgery may vary among trainee groups depending on their level of experience.

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