Performance index for virtual reality phacoemulsification surgery

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ABSTRACT

We have developed a virtual reality (VR) simulator for phacoemulsification (phaco) surgery. The current work aimed at developing a performance index that characterizes the performance of an individual trainee. We recorded measurements of 28 response variables during three iterated surgical sessions in 9 subjects naive to cataract surgery and 6 experienced cataract surgeons, separately for the sculpting phase and the evacuation phase of phacoemulsification surgery. We further defined a specific *performance index* for a specific measurement variable and a *total performance index* for a specific trainee. The distribution function for the total performance index was relatively evenly distributed both for the sculpting and the evacuation phase indicating that parametric statistics can be used for comparison of total average performance indices for different groups in the future. The current total performance index for an individual considers all measurement variables included with the same weight. It is possible that a future development of the system will indicate that a better characterization of a trainee can be obtained if the various measurements variables are given specific weights. The currently developed total performance index for a trainee is statistically an independent observation of that particular trainee.

Keywords: cataract surgery, phacoemulsification, simulator, specific performance index, total performance index

1. INTRODUCTION

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

Phacoemulsification cataract surgery (phaco) is the most common surgical procedure in modern societies with an incidence approaching 1/100 inhabitants/yr. Due to a quickly increasing population age in countries in development, the incidence of cataract surgery is expected to increase substantially in the world.

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 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 [1-4] despite extensive teacher intensive training. These figures are similar for experienced surgeons [5, 6]. For experienced surgeons the number of complications decreased exponentially reaching the asymptote after 400 [7] to 1000 cases respectively [8].

There are increasing demands for rigorous monitoring of surgical skills [9]. Recent development of personal computers have made it possible to simulate virtual reality with relatively inexpensive computers. Virtual reality models have been developed for various surgical procedures and evaluation of the performance with these has been attempted [10-12]. It has been demonstrated that virtual reality training leads to faster adaptation to the psychomotor restrictions encountered by laparoscopic surgeons [13].

We have developed a virtual reality phacoemulsification simulator, PhacoVision® [14-17]. The simulator consists a personal computer, simulation software and a surgeon interface. A preliminary clinical evaluation indicated that the

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simulator authentically simulates cataract surgery [18]. 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 [19]. It was found that the variabilities 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 [19].

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.

The aim of the current study was to develop a performance index that can be used to monitor skill in virtual reality phacoemulsification surgery.

1 METHODS

1.1 Subjects

Two populations were identified. One was individuals naive to cataract surgery but with a good knowledge of the anatomy and physiology of the eye. The other was experienced phacoemulsification cataract surgeons. A sample of subjects from the population *naive* to cataract surgery was obtained by consecutively recruiting students that accepted to participate in the study from medical and optometry undergraduate students. A sample of the subjects from the population of experienced cataract surgeons was obtained by recruiting cataract surgeons in Sweden with at least five years experience that accepted to participate in the study. Both samples were recruited during 2005 and 2006.

All naive subjects primarily included took a tutorial course consisting of; watching a standard edited video of a regular phacoemulsification cataract surgery, watching an instruction video for PhacoVision®, demonstration of PhacoVision® by an experienced administrator, watching a demonstration operation by the experienced administrator, and performing five learning sessions. If at least one of the learning sessions was completed without breakage of the posterior capsule, the subject was kept included in the study, else excluded.

All experienced subjects took a tutorial course consisting of watching an instruction video for PhacoVision®, demonstration of PhacoVision® by an experienced administrator, watching a demonstration operation by the experienced administrator, and performing five learning sessions.

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.

The hardware interfaces provide input from the trainee to the software and feed back visual output from the software to the trainee. The trainee input interface consists of a phacoemulsification hand piece and a nuclear manipulator hand piece, both mounted with four degrees of freedom (three space dimensions and rotation), a microscope foot pedal controlling x and y-direction and focusing in the field and zoom, and a one dimensional phacoemulsification pedal that controls irrigation, aspiration and phaco-power depending on the pedal position. The trainee receives three dimensional visual feed back of the surgical field in real time presented on two organic light-emitting diode (OLED) displays.

During the measurement session the patient case was adjusted as indicated in 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 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 split into a first sculpting phase and a second 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).

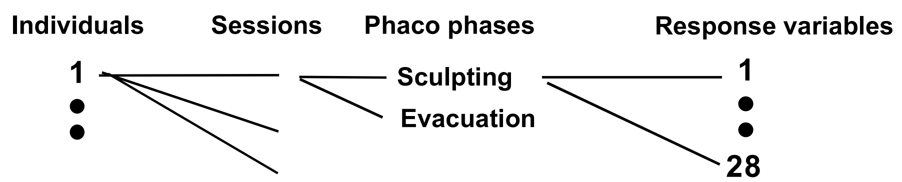

Figure 1 Experimental design. Totally, 9 naive and 6 experienced subjects were included.

Altogether, 9 naive and 6 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 Development of performance index

Only response variables for which a high value intuitively indicates a lower performance was selected.

A *specific performance index* for the j:th specific naive trainee, $PI_{i,j}$ was defined as the mean value for all the experienced trainees for that particular response variable, i, $\overline{E}_{i,\cdot}$, divided by the performance value for the j:th individual, for the i:th variable $N_{i,j}$ (Equation 1).

Equation 1 $$PI_{i,j} = \frac{\overline{E}_{i,\cdot}}{N_{i,j}}$$

Only variables for which the mean specific performance index for naive trainees was less than one (Equation 2)

Equation 2 $$\overline{\overline{PI}}_{i,\cdot} < 1$$

were considered valid variables.

Then, the individual *total performance index*, for the j:th individual, $\overline{\overline{PI}}_{\cdot,j}$, was defined as the sum of specific performance indices for that individual, $PI(Valid)_{\cdot,j}$, divided by the number of valid performance indices, n, (Equation 3).

Equation 3 $$\overline{\overline{PI}}_{\cdot,j} = \frac{PI(Valid)_{\cdot,j}}{n}$$

2.2 The sculpting phase

For the sculpting phase, TotalProcedureTime, SculptingTime, PhacoEnergyUsed, ManipulatorBehindIrisTime, PhacoRhexisDamageTime and ManipulatorBeyondPosteriorCapsuleTime were identified as valid variables (Figure 2).

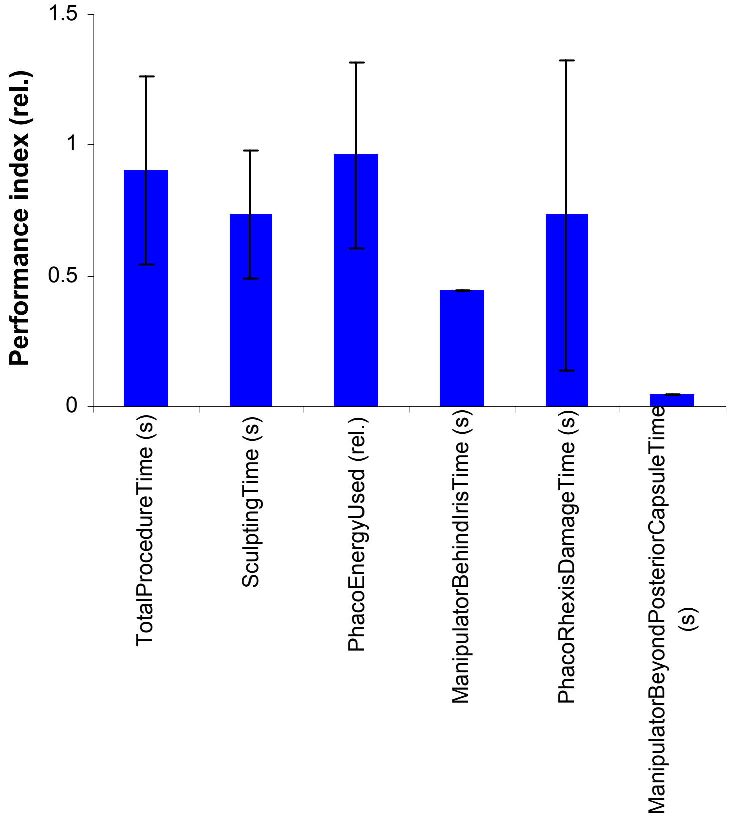

Figure 2 Valid variables for the sculpting phase.

The distribution function for the individual total performance indices for the sculpting phase was found to be relatively even (Figure 3)

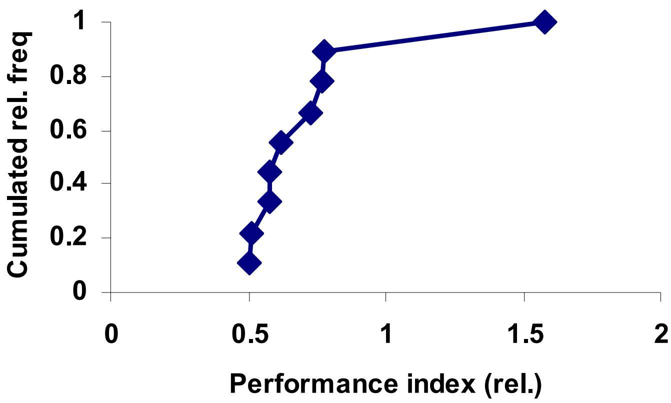

Figure 3 Distribution function for total performance indices for the sculpting phase for naive trainees.

indicating that, for the sculpting phase, parametric statistics can be used in the future for comparison of averages of total performance indices among groups.

2.3 The evacuation phase

For the evacuation phase PhacoEnergyUsed, IrrigationDefocuseTime, IrisDamageTime and PhacoBeyondPosteriorCapsuleTime were identified as valid variables (Figure 4).

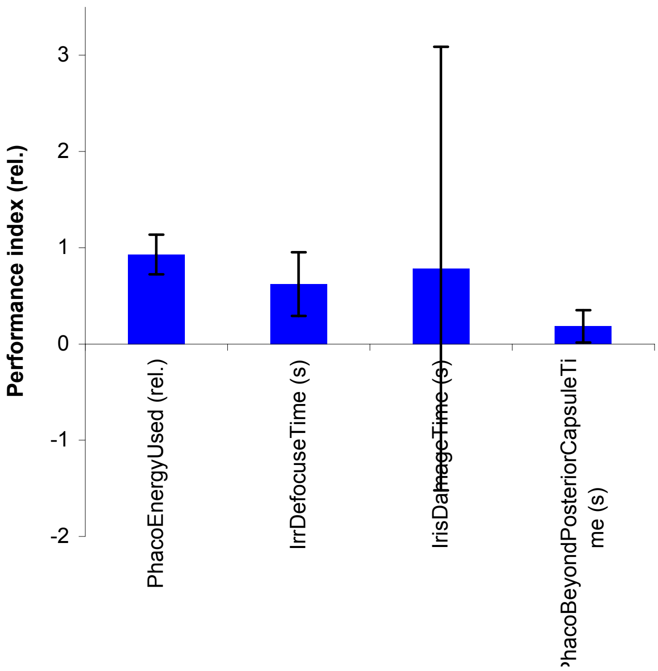

Figure 4 Valid variables for the evacuation phase.

The distribution function for the individual total performance indices for the evacuation phase was also found to relatively even (Figure 5),

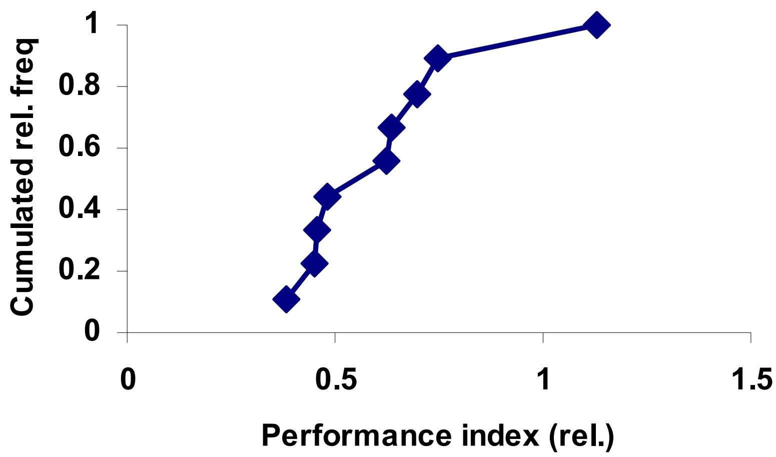

Figure 5 Distribution function for total performance indices for the sculpting phase for naive trainees.

indicating that also for the evacuation phase parametric statistics can be used in the future for comparison of averages of total performance indices among groups.

3 DISCUSSION

The purpose of the current study was to develop a performance index for virtual reality phacoemulsification surgery.

The relatively small sample size in the current preliminary attempt to develop a performance index is a limitation. However, the principle is proven to be feasible. It is possible that with a larger sample size, the response variables presently found to be valid (Figure 2 and Figure 4) may change.

Due to the small sample size, the resolution of the frequency distribution for the sculpting and the evacuation phase (Figure 3 and Figure 5) is limited. It is however important to notice that both are roughly evenly distribution indicating that parametric statistics will be possible to use for comparison of groups with performance indices defined as herein.

In the current first attempt to develop a total performance index for an individual, all variables included are given the same weight. It is possible that future development of the system will show that a trainee will be better characterized by differentiating the weights of different response variables. However, currently we are lacking knowledge for such a weighting.

A great advantage of adding the performance for each specific response variable into a total compound index for that trainee is that the total compound index is statistically an independent observation of that individual which will facilitate comparisons between groups in future studies.

We have developed a VR phaco simulator [14-19].

The current data indicate that it is useful to analyze the performance during VR phaco, separately for the sculpting and the evacuation phase, as a total performance index for a specific trainee.

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