Design of a Multimodal VR Training Platform for Maxillo-Facial Surgery

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Introduction

- The aim of the Maxillo-Facial Surgery Platform is to provide a VR pedagogical training system allowing to ease the transfer of skills from senior operators to novices for some of the basic skills that underlie a very delicate operation in the field of facial surgery called the Epker osteotomy.
Introduction

- Introduction to « skills » in the MFS simulator
- The Epker Osteotomy - Why this surgery?
- Why a simulation?
- Design of a Virtual Trainer
- Overview of the platform
Surgical Skills

Skill is defined as the ability to perform a specific task

“Surgical competence entails a combination of knowledge, technical skills, decision making, communication skills, and leadership skills”

(Moorthy and al, 2003)
Objectives and Conceptual framework

Focus on low levels sensori-motor skills

Enaction

“The principle idea of enaction is that a cognitive system develops its own understanding of the world around it through interactions with the environment” (Vernon, 2010)

“Research specific to medical education has shown that adults learn faster and have greater retention of knowledge when they participate in an interactive setting («Knowles, 1980»).
The Epker Osteotomy

Surgical Principles: Osteotomy of the Maxilla
Drilling the Maxilla while preserving the inferior alveolar nerve
Why this surgery?

- Difficult to teach as only one operator at a time can see the small operative field
  
  Difficult access and limited vision of the operating field

- Rely on very fine sensations
  
  Surgeons rely on multisensory information

- Young learners practice very progressively with few experience
  
  Stressful procedures due to the complex, delicate and intricate structures of the human face

- Limits of traditional companionship:
  
  Teaching rely mostly on observation and real practice on patients whose availability and variability cannot be controlled
Why a simulation?

- Safe for the patient
- Control of the educational content
- More repetitions in the same time period
- More focused exercises on the critical step
- Full monitoring of the student performance
- Opportunity to give Feedbacks to the learner
  - Summative Feedback: summary of learner progress
  - Formative Feedback: providing the learner with possible explanation (Manches and al, 2010)
- « Supports reflection IN action and ON action » (A. Tesniere)

Ethical: “Never the first time on a patient”
Design of a virtual trainer

Task Analysis

Identification of:
- relevant sub-skills
- task model
- expert/novice differences

Data acquisition campaign in Anatomy laboratory

Measurement of:
- quantitative data
- specification needed
- skills signature

Definition and design of a multimodal VR training platform.
User centered approach

- Starting point: Constitution of a working group

- Explicitation interviews with 3 expert surgeons
  - Procedural knowledge
  - Reflection on practice (references, sensations, postures, ...)
  - Reflection on teaching practice

- First Task Model
Task analysis

- Identification of the critical steps and main strategies
- Major differences between novices and experts

- Importance of haptic interaction for anatomic reference (Spine of Spix)
- Strong use of haptic sensation for drilling
- Importance of posture to stabilize movements
Expert vs Novice

- Novices tend to localize the Spine of Spix using visual indices. Expert surgeons rely more on haptic information.

- Novices tend to proceed to a superficial and incomplete drilling (Fear of impairing the nerve inside the spongy bone).

- Novices tend to use an insufficiently firm grasp of the instruments leading to unstable movement.
Task analysis and identification: the Epker osteotomy

Three main sub-tasks

1) Localisation of the Spine of Spyx
2) Drilling the fraction lines
3) Distraction
Considering these results we decided to focus on a pedagogical training system for the transfer of the basic skills involved in the Epker surgery.

The training protocol is focused on the transfer of the following needed sub-skills:

- **Relevant sensori-motor sub-skills**
  Perception-by-touch, Fine Control (in movement and force), Multimodal feedback management, Bi-manual coordination, postural control.

- **Relevant cognitive sub-skills**
  Perceptual-Observational, Memory organization, Procedural
Data acquisition campaign in Anatomy laboratory

- Experimental investigation of Epker surgery (MFS)
- Main goal was to help defining hardware specification
- Further analysis helps define Skills signature and compare expert surgeons performance between reality and simulation

Results of the analysis:

- Working space 200x200x200mm
- Peak Force and Torque 25 N
- Continuous Force and Torque 12 N
- Stiffness 13,000 N/m
- Max Speed of the tip 1 m/s
- Angular orientation

Technically: Very demanding specification
Quantitative investigation of surgical expertise

Compliance, sound and vibration

- These data are a key element of the definition of the platform training protocol, defining how to implement each modality to guaranty high degree of accuracy of the simulation and enhance the learning process.

- These data will be used to evaluate the quality of the simulation by direct comparison of expert/novice behavior in reality and during simulation.
Quantitative investigation of surgical expertise

- Multimodal analysis of Acquired MFS data gives results on force-position correlations:
  Management of compliance during bone drilling operation:
Quantitative investigation of surgical expertise

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    - Expert surgeons keep constant stiffness while drilling.
Quantitative investigation of surgical expertise

- Multimodal analysis of Acquired MFS data gives results on force-position correlations:
  - Management of compliance during bone drilling operation:
    - Expert surgeons keep constant stiffness while drilling.
    - Change in compliance occurs during drilling procedure.
How to manage all these modalities in a better way than simple simulation?

- Change in vibration
- Change in sound
- Change in compliance

Perception experiments

Multimodality management experiments

Specific erosion software
Training Protocol

A set of basic exercises addressing sub-skills with increasing difficulties
Advance feedbacks are provided to speed up learning process
Access to the next exercise is blocked until successful completion:

- Quality of the drill
- Speed of the procedure
- Specific criteria like penetration depth in the spongy bone.
The Maxillo Facial Surgery Platform: A multimodal approach

- Compact all in one structure
- 3D Screen with head tracking
- Sound rendering
- Force feedback device for left hand
- Tactile prop
- Tangible elements
- Force feedback device for right hand
- Dedicated HMI software
Software development:

Training Protocol exercises HMI

Sound synthesis

Dedicated bone erosion software

Tactile synthesis

Developed in OpenGL environment and XDE real-time simulation framework
Conclusion:

We introduced new multimodal platform for the training of Maxillo Facial Surgery

- Multimodal (Force feedback, sound, vision, vibration)
- Support enactive learning
- Immersive
- Bi-manual
- A trainer, not only a simulator
- A research platform as it allows full monitoring and control of the different modalities

How these new technologies improve Learning?
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