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Experimental evaluation of training accelerators for surgical drilling

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Abstract

In some specific maxillo-facial surgeries, like the Epker, the cortical part of the lower maxilla must be drilled with minimum penetration into the spongy bone to avoid the trigeminal nerve. The result of the surgery is highly dependent on the quality of the drill. Drilling must therefore be mastered by students before acting as surgeon.

The study compares the efficiency of two punctual drilling training programs developed on a virtual reality platform with non medical participants. The results show better benefit of training on relevant haptic aspects of the task before introducing multimodal drilling over repeated multimodal simulated drilling exercises.

1. Introduction

During the Epker Osteotomy, the lower mandible is fractured (corticotomy) and reassembled in a better position (osteosynthesis) to correct teeth alignment. It is performed in case of malformation, tumors or trauma. Exercising young residents to this technique is quite challenging as the narrow operative field prevents the trainees to benefit from full direct observation. Moreover, trainers will not let inexperienced trainees practice on patients. The main risk of the surgery is to damage the trigeminal nerve responsible for the sensitivity of the face. Therefore, apprenticeship can be spread out over a long period without much practice of the trainee and expert surgeons expressed the need to overcome the actual training limits.

A user-centered approach was used to point out the critical aspects of the surgery and the main training difficulties. The principle of this surgery is to drill the thickest part of the bone. The difficulty of the drilling part is induced by the risk to impair the nerve with limited visual control in some parts of the task. It is therefore mandatory to master motor control to provide a complete drilling of the cortical without penetrating the spongy bone. When the drill is completed and verified carefully, the bone can be fractured along the weakest part of the inner maxilla, the Epker line. This weakness is due to the presence of the nerve near the surface of the bone. Once properly fractured, the position of the maxilla can be corrected.

During the traditional training curriculum, the trainee is engaged in punctual drillings before performing lines. Drilling entails a combination of multimodal information related to the actions of the surgeon. Sound, vibrating tool, haptic (forces, compliance of the arm) and visual sensations are managed and controlled by the surgeon during this procedure.

A laboratory experiment was designed by the Technion within Skills Project to analyze more precisely the role of multimodal information during compliance management [1]. The experiment was based on a 2AFC compliance discrimination task. The participants either experienced the haptic or bi-modal visuo-haptic sensation first. In the first group the compliance perception was issued from haptic perception only, without any visual information. In the other group, participants could experience bimodal haptic compliance with visual congruence. The results indicated that bimodal information was beneficial to the participants only when haptics was experienced first.

We used these laboratory results as a hypothesis for developing the fundamentals of a drilling training protocol and evaluating new means to enhance training efficiency. Our study investigates if training non expert participants in a unimodal haptic drilling task before experiencing more complex audio and vibratory information and then multimodal interaction favors training efficiency compared to the traditional multimodal training. The experiment is implemented on a force-feedback virtual reality training platform.

2. Training platform

The training platform provides bimanual haptic interaction with two custom-built 6 degrees of freedom (DOFs) haptic devices [2]. For the purpose of the experiment, only one arm is used. Trainers can feel the interaction forces and the weight of the tool (340g). Our system uses a stack piezoelectric actuator in the handle to generate vibration of the tool [3]. Drilling sound is implemented to generate sinusoids as a function of force magnitude.

Visual rendering is obtained with a 3D screen (Samsung 2233RZ) placed between the user's hands and head. The trainee is equipped with NVidia Geforce 3D Vision LCD shutter glasses for a stereoscopic view of the scene. A head motion tracking system adapts the scene to the movements of the user [4].

Figure 1: Training Platform

3. Experimental protocol

3.1 Participants

Twenty participants (5 women and 15 men) contributed to the experiment. All of them were engineers without any experience in surgery.

3.2 Description of the protocol

Each participant fills up an informed consent form and is introduced briefly with the project. Preliminary observations showed that the users must be familiar with the training platform [5]. New users tend to exert small amounts of forces or torques not to impair the haptic arms. The user can train the system as long as five minutes to take the tool in hand, explore the working plane with the "passive" tool (i.e. the passive drill), and exert forces. When the user feels comfortable with the device, the experiment can start.

Training value can be acquired through proficiency in which performance is assessed before the training (pre-test) and compared to the performance after the training session (post-test) [6], [7].

At pre-test, participants are invited to perform 5 consecutive multimodal punctual drillings, on a 3mm thick plate figuring a cortical and a spongy layer. No feedback is given to the participants. Drilling performance is assessed through the measure of the penetration depth of the drill into the spongy bone. Each participant is then invited to rate his confidence in his drilling performance on a 10 points scale (0 indicating very a low confidence to 10 a very high self confidence rating).

After this pre-test, participants are equally randomized into two groups. In one group ("Skills group"), trainees are introduced progressively to multimodal drilling. During the first exercise, the participants can locate their drill visually but can only rely on the haptic component of the task as the drill vanishes when drilling begins. Each of the three sessions is composed of 100 repetitions (300 trials in total). In the second Group ("Multimodal group"), exclusively multimodal training is proposed through the whole session. Audio, vibration, compliance, force and visual feedbacks are provided during the 300 trials performed.

For both groups, the training consists in mono-cortical punctual drilling on different plates, each plate being a homogeneous surface composed of two layers. The superficial layer (the cortical) is 5 mm thick. The value of the drilling speed relative to the applied force is varied between the superficial and lower layer to provide 10 different materials from hard to soft bones. Participants are instructed to proceed to successive punctual drills while feedback on the penetration depth of the drill is systematically provided to the participants of both groups after each 20 drills. At the end of both training, each participant has performed the same number of drills.

Post-test performance was assessed after the whole training according to the same protocol as during pre-test. Multimodal drills at pre-test and post-test used different materials than for the training not to favor the multimodal group.

4. Main results

4.1 Pre-test plunge depth

The instructions given to the participants clearly put the stress on the minimization of the penetration into the spongy bone. As the depth of the cortical is 3mm and the diameter of the drill 2mm, a perfect theoretical drill is performed around 5mm. The results show different strategies. Some participants tend to over drill (penetration over 15mm), some tend to proceed to uncompleted drills (penetration<5mm), and other participants show respectable performances (5<<15mm).

Participants were randomly allocated to the two training groups, but Pre-test performance indicates that the two groups are heterogeneous. Participants affected to the multimodal group are more inclined to proceed to uncompleted drills (42% vs 8% for Skills group). Participants from the Skills'group are more inclined to over drill (34% vs 4%) (Figure 2).

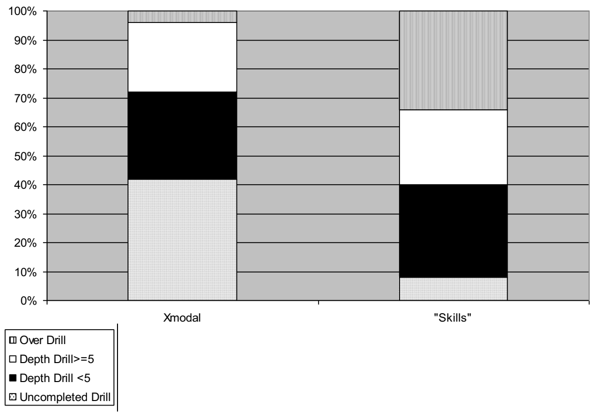

Figure 2: Repartition of penetration depth at Pre-test between "Skills" and "Multimodal" Group.

4.2 Final plunge depth at Post test

Training proficiency at post test is training dependant. Precise drills are more frequent in the Skills group (19, 38%) than in the Multimodal group (11, 22%) (Figure 3). The percentage of rough drills is more important for the Multimodal group (35, 70%) than for the Skills group (31, 62%). None uncompleted drills occurred for Skills group participants but still 4 (8%) for the Multimodal group. A correspondence analysis [8] indicates that the Skills group is significantly associated to shorter penetration depth than the Multimodal group (Chi2 =6.37, p*=0.04).

4.3 Effect of training on standard deviation of penetration depth at Post-test

Standard deviation calculated on the 5 drills at Post-Test is lower for the Skills group (m = 1.05) than for the Multimodal group (m = 1.79). The result is not statistically significant (t=1.92, p=0.07) but could indicate that Skills group tend to lead to more stable performances than the Multimodal group.

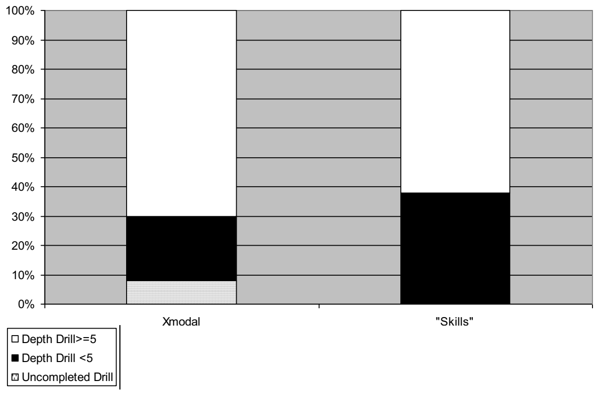

Figure 3: Penetration Depth at Post-test

4.4 Effect of training on self confidence rating

Training impacts positively self confidence. Mean confidence level is statistically higher at post-test 7.85 (SD=0.98) than at pre-test= 4,35 (SD=2,27; t-=6,06; P=0.00008, P<.01). At post-test, both groups of participants have comparable self confidence estimates (mean= 8,15 for unimodal group and 7,6 for Multimodal group (F= 1.609, p=0.22; P>.01).

4.5 Effect of training on the strategy implied in drilling

Interviews performed after the experiment show the impact of training on the strategy implied during drilling. When introduced with drilling through compliance only (Skills group), participants clearly declare relying mainly on compliance discrimination, even when they could use multimodal in the third block of trial. Participants provided with multimodal information during the whole training do follow heterogeneous strategies. Some of them use sound variation (and the accompanying vibrations) of the drill. Others explain that their strategy relied on compliance even if other sensations were at their disposal.

5. Discussion

All participants improve their performance during training on the platform and all of them increase their confidence on their drills. Performance is assessed with the distance penetration depth into the spongy bone but also as mentionned by [9] through the minimisation of variance. Participants who followed progressive training with initial focus on compliance information only before training with vibratory (audio and handle vibrations) and then to multimodal information reach significantly better performance than participants who were trained to drill with multimodal information only. As pacing and performance feedbacks were the same for both groups, we can hypothesize that early focused training on the haptic sensation helps the trainee to focus his attention to this relevant aspect of the task before considering the drilling as a whole multimodal task [10]. The trainee is guided along is learning process strategy rather than discovering on his own the relevant aspects of the task. This result is coherent with the result of the interviews with the participants and matches the results obtained by [11] showing the advantage of early exposure to haptic interaction during laparoscopic training.

6. Conclusion and perspectives

Focused training on the haptic component of drilling before practicing on multimodal exercises leads to short term drilling performance improvement. A future study will be proposed to the same participants to investigate long term effects of the training. On the other side, this experiment was performed with non medical participants. A similar experiment is planned with medical and dental students for further investigation of accelerators in surgical education.

The result of this preliminary experiment is coherent with the data gathered during psychophysical compliance discrimination task [1] and if validated at a larger scale can be used to orient the content of virtual reality-based training for surgical drilling education. Indeed, multimodal virtual reality based training in surgery offers considerable new opportunities to reconsider surgical training, even for open surgeries [12].

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