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Experimental Comparison of Force Feedback vs Tactile Sensory Substitution for Suture Tension Perception

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Experimental Comparison of Force Feedback vs Tactile Sensory Substitution for Suture Tension Perception

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INTRODUCTION
Suturing is an essential part of surgical procedures, yet tension regulation is difficult when using tele-operator systems [1]. Incorrect tension application can lead to various complications. It has been suggested that the use of haptic feedback to allow tension perception would reduce such errors [1]. Many groups have highlighted the benefit of haptic feedback in robot assisted minimally invasive surgery (RMIS) and bi-lateral, kinesthetic ‘force feedback’ solutions have been proposed. However, instability issues have prevented such solutions from reaching clinical implementation [2]. An alternative to bi-lateral force feedback is the use of sensory substitution to represent haptic information to the surgeon without influencing system stability [1][2]. Examples of sensory substitution include visual and vibrotactile feedback, though it has been suggested that such techniques, which do not represent forces by natural methods and/or channels, may lead to higher cognitive loading [2]. In our work, the use of fingertip surface deformation (also known as tactile skin stretch) is considered as a method of representing tangential (shear) and normal (indenting) interaction forces through a natural haptic feedback method. Skin stretch feedback avoids the controller instability issues of bi-lateral force feedback and may be achieved via relatively simple, compact and low cost technology [2].

In this work we investigate the capability of tactile skin stretch feedback (SSF) to aid novice participants in perceiving the tension of simulated sutures during a ‘grasp and pull’ task. The experiment is also conducted with force feedback (FF) and combinations of FF and SSF to permit comparative evaluation between feedback modalities and changes in perceptual capability.

MATERIALS AND METHODS
To investigate user ‘tension perception capability’ related to the SSF and FF haptic modalities under investigation, a novel multi-modal haptic interface (Fig. 1) was combined with classic experimental methods of psychophysics. In the study, participants used the haptic interface to ‘grab and pull’ virtual suture threads, as if they were performing the last stages of tying a knot or pulling the thread through tissue. The study method was based on the classic psychophysics ‘Method of Limits’ protocol [3] and had ethical approval from the University of Bristol (application 4201).
on an actuated ‘lateral stage’ to permit the generation of skin stretch sensations both normal and lateral to the user’s finger pad. In this work lateral deformation is proportional to the suture pulling reaction force $F_{PR}$, while the height of the pins, which are actuated as a whole in this study, are proportional to the grasping reaction force $F_{GR}$ (both via a 0.32mm/N ratio). Such indenting and shearing finger pad deformations are present in natural, every day interactions with real world objects in proportion to exerted forces [2]. Details of the tactile display are shown in Fig. 2, with more information available in [4]. $F_{PR}$ and $F_{GR}$ can also be represented, directly as kinesthetic forces, by the Novint Falcon haptic device. The tactile display is attached to the end effector of the Falcon (Fig. 1). To maintain constant position between the user’s finger pad and tactile stimulus, the second phalanx of the user’s dominant index finger is strapped to a finger rest with the distal phalanx held in place by a finger guide, available in various sizes. To keep the system lightweight and easy to move, the tactile display is remotely actuated via Bowden cables (Fig. 1). In order to compare the effect of different stimulus rendering, four feedback modalities (A-D) were presented to users:

<table>
<thead>
<tr>
<th>FF</th>
<th>SSF</th>
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<tbody>
<tr>
<td>A – Force $F_{PR}$ &amp; $F_{GR}$</td>
<td>$F_{PR}$ &amp; $F_{GR}$</td>
</tr>
<tr>
<td>B – Tactile $F_{GR}$</td>
<td>$F_{PR}$ &amp; $F_{GR}$</td>
</tr>
<tr>
<td>C – Combined $F_{PR}$ &amp; $F_{GR}$</td>
<td>$F_{PR}$ &amp; $F_{GR}$</td>
</tr>
<tr>
<td>D – Hybrid $F_{GR}$</td>
<td>$F_{PR}$</td>
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For each feedback modality, 8 (random and balanced) sequences of comparison stimuli (trials) were completed per participant. Familiarisation with comparison tensions of 0N and 8N was completed before the study.

RESULTS

11 participants (9 male, ages 23-45) took part in the study and completed several feedback modalities each. Modes A and C both had 7 completed trials while modes B and D had 6. Combined psychometric functions [3] were generated for each modality by combining the results of all individual trials for that modality. These combined functions are presented in Fig. 3. In this figure, steeper gradients around 4N (the reference stimulus) indicate a greater sensitivity of

DISCUSSION

The results indicated superior tension perception for force feedback (A) compared to skin stretch feedback (B). However, FF stability is presently too unreliable for commercial RMIS, despite considerable research efforts [2]. Combining SSF with FF (C) had little effect on FF only (A) results. SSF alone (B) led to relatively poor perception but the hybrid mode (D) significantly improved perception over B ($p<0.02$). In D, $F_{PR}$, which related to tension, was displayed by SSF, while FF represented only the grasping force, $F_{GR}$. More reliable grasping via FF improved SSF tension perception. Although our study used an abstracted component of suturing, it seems that SSF has potential, especially when compared to the current clinical standard of no haptics in RMIS.

REFERENCES