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Benchmarking of Comfort and Learnability of a New Soft Robotic Tool for Key-hole Surgery*

A. Shafti, Y. Noh, H.A. Wurdemann and K. Althoefer1
A. Aydin, O. Elhage and P. Dasgupta2
1 Centre for Robotics Research, Department of Informatics, King’s College London
2 Department of Urology, Guy’s and St. Thomas’ Hospitals, London, UK
ali.shafti, yohan.noh, helge.wurdemann, abdullatif.aydin, oussama.elhage, prokar.dasgupta, k.althoefer@kcl.ac.uk

Abstract— Laparoscopic surgery requires precise and time consuming procedures to be performed. These procedures involve awkward poses in the upper body as well as the hands and fingers of the surgeons. STIFF-FLOP is an ongoing EU FP7 project that proposes the creation of a stiffness controllable soft robotic manipulator for laparoscopic surgery. The manipulator is proposed to help laparoscopic surgeons and their patients by simplifying the tasks involved and reducing risk of errors. This paper reports on a series of tests performed as part of a study into the new soft manipulator’s ease of use and level of required effort as well as learnability. The study was performed on a limited prototype of the manipulator. Surface EMG of the forearm muscles was used to benchmark effort and comfort and questionnaires were provided for subjective assessment. Participants (n=25) were timed and their muscles activities recorded for comparison. Results show that the average rms EMG levels were 25.9% less with the STIFF-FLOP manipulator when compared with conventional laparoscopic tools. On a second attempt with the STIFF-FLOP manipulator participants spent an average of 32.1% less time, showing the manipulator’s learnability and ease of adaptation. Further details and analysis of results are provided within the paper.

Keywords— minimally invasive surgery, electromyography, comfort, learnability, benchmarking, robotic surgery

I. INTRODUCTION

Surgical methods have advanced in the last few decades, leading to laparoscopic and minimally invasive surgery (MIS). MIS enables the surgeon to perform the intended procedure through small incisions of 5-15mm. Special, long and narrow tools are required to perform this type of surgery. MIS improves upon patient conditions as it reduces exposure of internal organs as well as scars and recovery times [1]. However, the limited access and tough to operate tools cause difficulties and physical stress which in turn lead to errors and discomfort [2].

This has resulted in added interest for engineers to provide better solutions for MIS. Roboticists in particular have been working on this problem for more than two decades [3] in an endeavour to create new tools that increase precision and reduce errors. Efforts include robots to handle the camera for surgeons [4] to complete surgical systems such as the Da Vinci and its master-slave setup. STIFF-FLOP (STIFFness controllable Flexible and Learn-able manipulator for surgical OPerations) is an EU FP7 project aimed at creating a soft robotic manipulator for MIS. The manipulator can squeeze through the small incisions, take the required shape and trajectory and increase its stiffness when needed to perform a task with the tools at its tip.

![Image](image_url)

**Fig. 1** Test set-up. The STIFF-FLOP manipulator is inserted into the 2:1 scaled phantom organ. A zero degree endoscopic camera is used for indirect vision. A conventional laparoscopic is also present for comparison.

While robotic tools are generally assumed to be helpful in MIS, few studies aim to objectively assess and benchmark their effect. Usual comfort and ergonomics studies in a medical context rely on questionnaires and Borg scales in particular which are subjective approaches [2,5-7]. However, improvements in terms of comfort and effort in particular cannot be assessed solely based on subjective data. For STIFF-FLOP, objective assessment of comfort and effort involved with the manipulator’s use are defined as project goals to ensure the best approaches are used for the final device. At this point in the research, spatial motion and targeted movements were tested for learnability, comfort and effort involved. This

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F. Andorno, N. Marchese, S. Arolfo and A. Arezzo
Department of Surgical Sciences, University of Turin
Turin, Italy
federica.andorno@gmail.com, nicola.marchese@hotmail.com, simone.arolfo@tiscali.it, alberto.arezzo@mac.com
paper reports on these tests which included timing, video monitoring, and surface electromyography (SEMG) for objective assessment of the participants’ effort (n=25) as well as questionnaires for subjective assessment.

II. EXPERIMENT SETUP AND PROTOCOL

The tests were designed to look at how fast the participants get used to the new manipulator (i.e. learnability) and how comfortable it is to use. A 3D, 2:1 scaled phantom of the pelvis and inferior abdominal cavity was specifically created for these tests by Fundacja Rozwoju Kardiochirurgii (FRK), one of the STIFF-FLOP partners. The phantom is scaled to match the current STIFF-FLOP manipulator size scaling. Each manipulator model is 30mm long and has a base diameter of 25mm. The manipulator will be scaled down in later stages of development. Figure 1 shows the test setup.

The STIFF-FLOP manipulator was controlled using the two joysticks on an XBOX controller. Each joystick is used to actuate one of the modules. Participants (n=25) were asked to perform a spatial motion test. Three points were marked inside the phantom organ in a circular shape (A, B and C - diameter=20cm) at 120 degree intervals. The participants were asked to start at point A and do a clockwise trajectory (A to B and then to C) followed by a counter clockwise one (A to C and then to B). At each point the participants had to press a button on the controller twice. This same task was then repeated using a conventional laparoscopic tool – following the same trajectories, opening and closing the tip twice at each point.

Direct view of the operating field was obstructed to simulate MIS. Participants had indirect view through a monitor using a zero degree WOLF endoscopic camera. The camera position is unchanged throughout all tasks. SEMG signals of the forearm muscles were recorded throughout these experiments using a purpose-built EMG acquisition board. Time spent on each task as well as the camera view were recorded. Figure 2 shows a participant during the test. Once the laparoscopic task was completed, participants were asked to perform the task one more time using the STIFF-FLOP manipulator. This was to assess learnability, enabling comparison of time and effort from a first attempt to a second. Thus the tests are categorised as the 1st STIFF-FLOP test (‘SF1’), Laparoscopic test (‘LAP’) and 2nd STIFF-FLOP test (‘SF2’).

After the above tests, participants were handed a questionnaire including statements on ease of use, mental and physical exhaustion as well as ergonomics to be rated from 1 (i.e. “strongly disagree”) to 5 (i.e. “strongly agree”). These provided a subjective assessment to accompany the previously obtained objective measures. Tests were conducted at the Sherman Education Centre, Guy’s Hospital in London. 25 participants were tested with 8 categorised as experts (i.e. more than 500 laparoscopic and endoscopic procedures) and 17 as novices (i.e. less than 500 laparoscopic and endoscopic procedures). Ethical approval was obtained prior to these experiments (reference number BDM/13/14-123).

III. EXPERIMENT RESULTS AND ANALYSIS

EMG signals were acquired using a custom-built system. The circuit provides 6 channels with a total of 10³ V/V gain per channel and band pass filtering using 4th order Butterworth filters between 20Hz and 450Hz. The circuit output was recorded using the Bitalino microcontroller system with a sampling frequency of 1kHz and transmitted wirelessly through Bluetooth to a nearby computer. Recommendations from SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles – SENIAM.org) were used during system design and use. The recorded raw EMG signal goes through a set of signal processing routines in MATLAB. These routines remove the signal’s dc level, filter out motion artefacts present below 20Hz, rectify the signal and finally apply a sliding root mean square method with a 200ms window to obtain a linear envelope estimation of the signal. Root mean square (rms) is the square root of the mean of the squares of a sampled data and is a measure of the signal’s power.

Fig. 2 View from the endoscopic camera during the STIFF-FLOP task showing the target areas and the soft manipulator moving to each target. Top left shows the starting point. Top right shows the manipulator at point A, bottom left at point B and bottom right at point C.

Fig. 3 Experiment results for all, expert and novice participants – (a) Comparison of average time spent on different tasks with standard error marked (b) Comparison of average rms EMG levels for the flexor muscle group during different tasks with standard error marked.
Figure 3 summarises the main objective results of the study categorised by task and participant experience. Figure 3(a) describes the average time results for participants during the different tasks. In average, SF1 takes a longer time than other tasks, i.e. 36.4% more than LAP (p=0.0071). On a second trial with the STIFF-FLOP manipulator however elapsed time is reduced by 32.1% (p=0.0232). Similar trend in results is seen when looking at experts or novices alone. Elapsed time is generally longer for experts.

Figure 3(b) presents the EMG amplitude analysis results. In average, LAP shows a higher muscle activity and recruitment for all types of participants. SF2 shows a 25.9% less average muscle activity compared to LAP (p=0.0128). There is a similar trend when looking at particular expertise groups. Novices show a 33.6% reduction of muscle activity from LAP to SF2 (p=0.0193). EMG data of one expert participant were discarded as the recording was corrupted (i.e. n=24 for results in Figure 3(b)). P-values were obtained through t-tests.

The questionnaire results show that most participants experienced no mental or physical exhaustion. 80% strongly disagreed with the new manipulator having caused them mental exhaustion and 84% strongly disagreed with the occurrence of physical exhaustion. Figure 4 shows the results for the questions involving comfort and ergonomics. As figures 4(a) and 4(d) show however, the participants are divided on the manipulator’s ease of use and ergonomics. Still a large portion of participants found it ergonomical and easy to use.

Younger and thus less experienced participants reported more familiarity with the XBOX interface. This interface was not so easy to use for older participants based on comments made by a few of the participants (which covers most of the experts groups). Also, experts tend to choose slower movements to retain precision. This explains differences in elapsed time and muscle recruitment levels between the two groups of participants.

It is important to note that the particular STIFF-FLOP prototype used for this study was limited and only capable of general spatial motion and targeted movements – more complex tasks were not possible. Targeted movement is an easy task to perform with a conventional laparoscopic tool particularly due to the 2:1 scaling of the phantom organ which favours the laparoscopic tool. New STIFF-FLOP prototypes are capable of complex movements going as far as bending around organs with control and reduction of user errors through movement scaling. Such tasks are difficult to perform with a laparoscopic tool. Future studies will focus on these new prototypes and involve more complex surgical tasks which are expected to provide a better comparison and higher improvement margin on conventional methods. Comparison with other teleoperated tools is also desirable.

IV. CONCLUSION

This paper reports on a study of comfort and learnability for a new soft robotic manipulator designed for minimally invasive surgery. Participants were all of clinical background with different experience levels, categorised as novices and experts. The task performed by participants consisted of targeted movements performed with the new STIFF-FLOP manipulator for 2 trials and a conventional laparoscopic tool for 1 trial to compare. Elapsed time and muscle activity were looked at for objective assessment and questionnaires were used for subjective results. Results showed that the average muscle recruitment required to use the new manipulator is significantly less than the laparoscopic tool. However, as results are close, it can be deduced that there is room for improvement for the new manipulator. Elapsed time was 32.1% less when operating the new manipulator for a second time which shows the device’s learnability. Questionnaire results showed that while a majority of participants reported no mental or physical exhaustion during use of the new manipulator, opinions were divided with regards to ease of use and ergonomics. The results have to be further analysed, particularly looking at the video recordings for task accuracy as well as correlations between the EMG signal and movements.

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