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Evaluation of four cursor control devices during a target acquisition task for laparoscopic tool control

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ABSTRACT

Current laparoscopic surgery instruments create awkward postures which produce fatigue and pressure points in surgeons. In order to alleviate some of this discomfort a new laparoscopic tool had been developed with the inclusion of an articulating end-effector manipulated by a trackball. The current study was developed to access the performance of four input devices which could replace the manual trackball in a powered laparoscopic tool. A simple Fitts' law task was conducted and the devices' performance was evaluated with both subjective and objective measures. This article makes three main contributions to the scientific community. First, it provides a comparison of four control devices (TouchPad, Mouse Button Module, MiniJoystick Module and MicroJoystick) for use in a powered laparoscopic tool. Second, it provides an understanding of how the non-traditional measure of target re-entry can be utilized to compare control devices and how this relates to the more traditional measures of throughput and error rate. Finally, it contributes to the understanding of how a user's familiarity with a control device could affect the subjective and objective performance of the device. The main results indicate that the TouchPad and MicroJoystick are the best candidate-devices for use in a powered laparoscopic tool. The article also provides support for utilizing the new measure target re-entry when comparing control performance. Although studied in the application of laparoscopic surgery, the results can be generalized for the design of any hand-held device in which the speed and accuracy of the control device is critical.

1. Introduction

Minimally-invasive surgery (MIS) or laparoscopic surgery is an advanced surgical technique that is performed with the assistance of a video (endoscopic) camera and several thin tools that resemble children's scissors attached to a long thin shaft. During MIS procedures, small incisions (up to half an inch) are made in the body and plastic tubes (ports or trocars) are placed in these incisions to allow tools to be inserted into the abdomen (Berguer, 1998). Since MIS requires only small incisions, it reduces trauma to the body, shortens recovery time and reduces the risk of infection (Cuschieri, 1995). Although MIS has revolutionized the medical field, surgeons are limited by the abilities of their instruments since they cannot directly touch or see the target inside of the body.

Surgeons are required to perform a variety of tasks in MIS procedures such as grasping, dissecting, cauterizing, and suturing with various hand tools which greatly influences the finger, hand, wrist and arm posture adopted during surgery (Trejo et al., 2007) (Fig. 1A). In fact, one of the leading causes of surgeon post-operation pain or numbness is the non-neutral postures adopted during MIS procedures (Graves et al., 1994; Crombie and Graves, 1996; Berguer et al., 1998; Berguer et al., 1999; van Veelan and Meijer, 1999; Emam et al., 2001; Doné et al., 2004a; van Veelan et al., 2004) (Fig. 2C). In addition, the current scissor-like handle design (Figs. 1A and 2) has also been shown to increase surgeon fatigue, discomfort and paresthesias in the fingers (Berguer, 1998; DiMartino et al., 2004).

In an effort to remedy the deficiency of current non-powered laparoscopic instruments, a new tool was developed using user-centered design principles (DiMartino et al., 2004; Doné et al., 2004b; Judkins et al., 2004; Trejo et al., 2005; Hallbeck and Oleynikov, 2006) (Fig. 1B). The Intuitool™ includes an ergonomically designed handle and a redesigned grasper actuation mechanism in order to create a more comfortable and intuitive handle/tool interface. In addition, an articulating end-effector (controlled by a trackball) was also added allowing surgeons to comfortably articulate the device by manipulating the end-effector with a trackball (Fig. 1B). This addition allows surgeons to make fine

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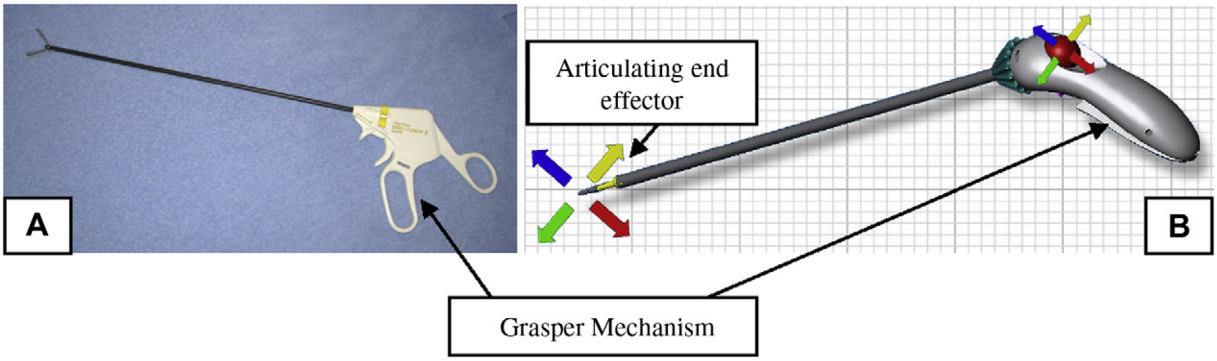

Fig. 1. (A) The current laparoscopic tool. (B) The Intuitool™ prototype with articulating end-effector.

motor movements with the tool without altering their posture (DiMartino et al., 2004).

In order to determine the effectiveness of the newly developed handle/grasper mechanism and end-effector, an evaluation of the Intuitool™ prototype was conducted (Trejo et al., 2005). Fifty-eight percent of responding laparoscopic surgeons believed the Intuitool™ would relieve hand/wrist pain and 53% believed the tool would reduce hand/wrist stiffness, confirming that the redesign using user-centered design principles was successful. In addition, 92% of respondents believed the addition of the articulating tip would be useful. These data show that the ergonomic handle design, the grasper mechanism and the end-effector articulation are all keys to a well-designed non-powered ("cold"), laparoscopic tool.

The next step in the design process is to combine multiple laparoscopic instrument functions, such as grasping and cauterizing, into one unified tool. In order to accomplish this feat, an electrically powered ("hot") tool must be developed. However, since no powered laparoscopic tools are equipped with an articulating end-effector, current control devices on the market must be adequately tested to see how they perform in this particular operation. In particular, we must ensure that the performance of the device used to control the end-effector is not affected by the distance traveled or the width of the target (which can range from an artery to a thin tissue) because the overall utility of the device would be significantly affected. There are many benefits associated with utilizing a powered control device for this operation. Specifically, the use of a powered control device could reduce the pain incurred during surgery by transferring the power source for the end-effector from the thumb or index finger to the powered device. However, before we can draw such a conclusion, we first must compare the performance of the control devices.

The best available instrument for comparing pointing device performance is Fitts' law. Fitts' law is an information processing model of human psychomotor behavior which involves a pointing task in which researchers record the time it takes for a participant to position a cursor and select a target (Fitts', 1954). Card et al. (1978) was the first study to study cursor control devices using Fitts' law. Subsequent studies focused on comparing the performance of different control devices such as a mouse, trackball, isometric joystick, step keys, text keys and TouchPads (ex. MacKenzie et al., 1991). These studies used a discrete task, where participants began with the pointing device at the starting position and moved to a target. This is similar to the skills required for laparoscopic surgery as the cursor movement can be used to simulate the movement of the articulating end-effector in the body (Fig. 3).

The most common evaluation measurements for Fitts'-type tasks are speed (movement time) and accuracy (error rate, the percentage of selections with the pointer outside the target). In fact, the ISO standard (ISO 9241; ISO ISO/TC 159/SC4/WG3, 1998), "Requirements for non-keyboard input devices", proposes only one performance measurement, throughput (in bits per second, bps), that is a composite measure derived from both the speed and accuracy in responses. These measures are typically analyzed over a variety of task or device conditions. More recently, however, researchers have developed new accuracy measures in order to elicit differences among devices in precision pointing tasks (MacKenzie et al., 2001). Unlike the standard measurements (movement time and error rate), which are based on a single measurement per trial, these proposed measurements capture the behavior *during* a trial. A recent exploratory study utilizing these measures found that of the seven measures developed (target re-entry, task axis crossing, movement direction change, orthogonal direction change, movement variability, movement error, and movement offset) only two of them made a significant contribution to the prediction of throughput – target re-entry and movement offset (MacKenzie et al., 2001). Of these two, target re-entry explained about 41% of the variance.

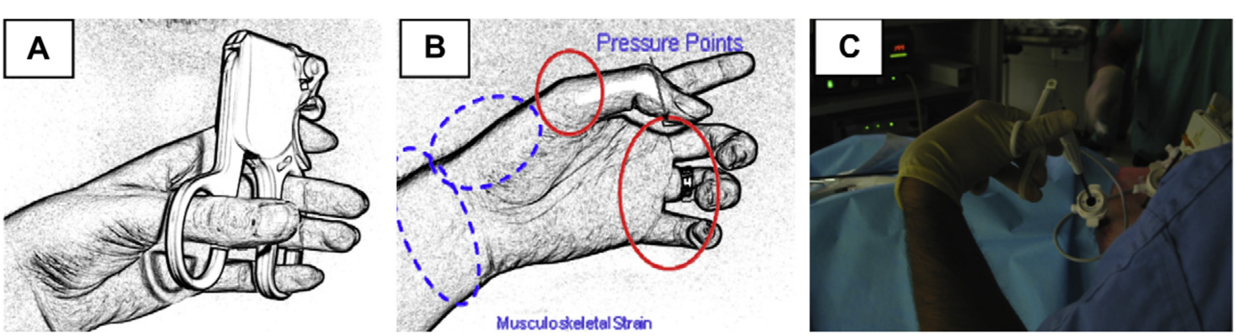

Fig. 2. (A) The hand position incurred using the current laparoscopic tool. (B) The pressure point encountered when using the current laparoscopic tool. (C) The awkward hand postures incurred when using the current tool.