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# Human error identification for laparoscopic surgery: Development of a motion economy perspective

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ABSTRACT

This study postulates that traditional human error identification techniques fail to consider motion economy principles and, accordingly, their applicability in operating theatres may be limited. This study addresses this gap in the literature with a dual aim. First, it identifies the principles of motion economy that suit the operative environment and second, it develops a new error mode taxonomy for human error identification techniques which recognises motion economy deficiencies affecting the performance of surgeons and predisposing them to errors. A total of 30 principles of motion economy were developed and categorised into five areas. A hierarchical task analysis was used to break down main tasks of a urological laparoscopic surgery (hand-assisted laparoscopic nephrectomy) to their elements and the new taxonomy was used to identify errors and their root causes resulting from violation of motion economy principles. The approach was prospectively tested in 12 observed laparoscopic surgeries performed by 5 experienced surgeons. A total of 86 errors were identified and linked to the motion economy deficiencies. Results indicate the developed methodology is promising. Our methodology allows error prevention in surgery and the developed set of motion economy principles could be useful for training surgeons on motion economy principles.



## 1. Introduction

Extirpative and reconstructive laparoscopic techniques have become part of the standard approach in most urological surgeries (Pareek et al., 2005; Rane and Wolf, 2005). Manoeuvring laparoscopic instruments requires advanced skills (Pareek et al., 2005), increases fatigue and discomfort (Berguer, 1998) and, as a result, predisposes the surgical team to a wider range of potential errors (Etchells et al., 2003; Wiegmann et al., 2007). Literature in laparoscopy points to a variety of non-technical factors that affect the performance of and create fatigue and discomfort to surgical team during laparoscopic surgeries. These factors include, but are not limited to, posture, height of operating table, location and place of the display, level of instrument handles, level of surgical area and design of instruments. These factors fall within the scope of a ergonomics and human factors area, traditionally known as 'motion economy' (Barnes, 1980). Motion economy deals with the interaction of human operators with their workplace. In this study we use the terms 'human factors', 'ergonomics' and 'motion economy' interchangeably.

### 1.1. Motion economy

The literature refers to motion economy principles as ergonomics principles or guidelines (Wauben et al., 2006). Motion economy has been emphasised in the surgical literature (Philips, 2004). However, in a study conducted jointly with the European Association for Endoscopic Surgery, 89% of the 284 surgeons surveyed were unaware of ergonomics principles, though all of them stated they find ergonomics important (Wauben et al., 2006). Barnes (1980) suggested 22 principles of motion economy categorised across three areas of analysis. These are 'use of human

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body'; 'arrangement of workplace'; and 'design of tools and equipment'.

The first area of motion economy is related to the 'use of human body'. This area comprises 9 principles orienting operators on efficient movement of the hands and other body parts. Examples include the preference of smooth continuous curved motions of the hand to straight-line motions involving sudden and sharp changes in direction; and having the two hands of the operator beginning and completing their motion simultaneously.

The 'arrangement of workplace' is the second motion economy area. It includes 8 principles necessary to organise the workstation and arrange the location of tools and instruments relative to the operator's position. Examples include the requirement to have defined and fixed places for tools and materials; and the importance of arranging tools and materials in a way that permits the best sequence of an operator's hand movements.

The third area of motion economy is the 'design of tools and equipment', which includes 5further principles that take into consideration tool and equipment handling and other design issues related to human factors. Notwithstanding its importance, this area requires extensive research and investigation and is beyond the scope of this study.

Examining the traditional principles of motion economy reveals that they were designed to facilitate the performance of a single worker implementing repetitive, mechanical work with definite steps. Accordingly, not all of these principles are applicable to the surgical environment. For instance, the principle requiring gravity feed to be used to deliver material close to the point of use is not applicable to deliver sterile material and surgical instruments. Further, some motion economy principles may require adaptation to become applicable and suitable for the operative environment. For example, the principle that the motion of the arms should be symmetrical and in opposite directions requires adaptation to include diverse directions (e.g., in opposite directions for each one of the operator's hands), (see Table 1 for a list of motion economy principles and their surgical application). In addition, surgery requires team effort, specific procedures for handling sterile material and instruments, updated and accurate information and is performed on the human body as a working object. Therefore, there may be a need to add new areas to the traditional three areas of motion economy as we will discuss later.

### 1.2. Hierarchical task analysis and human error identification techniques

Specific approaches have been designed for reducing human errors known as Human Error Identification (HEI) techniques (Stanton et al., 2009). HEI uses a predefined error mode taxonomy to detect errors and requires breaking down the human–machine interaction into a series of actions. Hierarchical task analysis (HTA) is usually used for this purpose. Here we refer to the technique comprising both HTA and HEI as 'HTA/HEI'.

HTA describes a work system in terms of its goals. It begins with a main task defined by its intended goal and breaks down the main task into its sub-tasks. Each sub-task has a sub-goal contributing towards achievement of the main task goal (Stanton, 2006). These sub-tasks may be further analysed to their constituent tasks and so on. The level of analysis depends on complexity and required description of the tasks or their goals (Lane et al., 2006; Phipps et al., 2008). Rules guide the sequence in which sub-goals are attained to achieve the 'higher' goals (Phipps et al., 2008) and, accordingly, higher levels in the hierarchy influence the manner in which lower levels behave (Shepherd, 2010). Task analysis is a useful way of looking at how people interact with a system in terms of work processes, technology (machines and instruments) and environment (Rose and Bearman, 2012). The error mode taxonomy of HEI is used to highlight potentially unforseen errors in the lowest level tasks of a HTA (Phipps et al., 2008; Shorrock and Kirwan, 2002; Stanton et al., 2009). Once the potential error or disruption is predicted, an error reduction strategy can be implemented (Shorrock and Kirwan, 2002).

HTA/HEI has been used to detect potential human errors across industries (Rose and Bearman, 2012; Shorrock and Kirwan, 2002; Stanton, 2006; Stanton et al., 2009). Recently, HTA/HEI techniques have been applied to predict potential errors in healthcare services, including medication administration (Lane et al., 2006), anaesthesia (Phipps et al., 2008), endoscopic surgery (Joice et al., 1998) and patient positioning for spinal surgery (Al-Hakim et al., 2014). However, HTA/HEI techniques fail to consider explicitly the principle of motion economy and, accordingly, this may limit their applicability in operating theatres. This study aims to address this gap in the application of HTA/HEI techniques.

### 1.3. Why do we need to integrate principles of motion economy with HTA/HEI error taxonomy?

HTA/HEI techniques are used to examine low-level sub-tasks of a task (e.g., surgery) (Stanton, 2006; Stanton et al., 2009). The HTA part is proposed as a means to describing a task (surgery) in terms of its goal and comprises a sub-goal hierarch linked by plans (Stanton, 2006). HEI includes the error taxonomy that detects errors during the execution of sub-goals or related plans. Error occurs where there is a failure to achieve the sub-goal of a planned subtask (i.e., error of execution) or the use of a wrong plan to achieve a sub-goal (i.e., error of planning) (Etchells et al., 2003; Kohn et al., 2000). In order to use an HTA/HEI technique, the analyst or observer applies HTA in order to identify what the operator should do to perform sub-tasks, and uses HEI error taxonomy to identify what could go wrong (Kirwan, 1998; Shorrock and Kirwan, 2002; Stanton, 2006). Kirwan (1998) identifies 3 interrelated components of HEI error taxonomies. These are as follows:

1. External Error mode (EEM): The EEM taxonomy forms the 'external' manifestation of errors as observed by the analyst (e.g., using excessive force, omitting a critical check). EEM is a reference to 'error mode' as stated in some HTA/HEI techniques such as SHERPA (Embrey, 1989).
2. Performance Shaping Factors (PSP): This taxonomy refers to factors shaping the ability and capacity of the operators (e.g., surgeons) to perform specific tasks (e.g., their experience or training).
3. Psychological Error Mechanism (PEM): This taxonomy represents the 'internal' manifestation of errors in psychologically meaningful terms (e.g., lack of confidence, memory failure).

It is logical that PSP and PEM components have direct effect on the number of errors detected via the EEM component – such that one would hypothesise that errors are triggered by lack of expertise and associated lack of confidence, or erroneous omissions during a case. However, the literature reveals that errors also commonly occur in surgical procedures performed by experienced surgeons and operative teams (Al-Hakim, 2011; Joice et al., 1998; Sevdalis et al., 2008; Wiegmann et al., 2007). EEM identifies and describes errors (e.g., using wrong instrument) but does not provide the root cause or actual circumstance that drives or forces a surgeon to act erroneously. Accordingly, we argue that there are factors other than those covered in PSP and PEM that can affect the performance of experienced, highly trained surgeons and their wider teams.

This study, therefore, hypotheses that motion economy contributes to the causes of senior surgical errors. However, the