Impact of the 2D and 3D Vision on the Learning of Fine Motor Skills According to the Instrumental Dimension: Implications for Training in Minimal Invasive Surgery

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Abstract
New technology in surgery is more and more present and allows to study cognitive processes in complex and natural environment. Comparing to classical minimal access surgery, a new robotic system allows to recover a 3D view and all degrees of freedom for instruments movement. The purpose of this study was to evaluate the perceptual (2D vs 3D view) and instrumental (classical versus robotic) impacts of this new robotic system on learning curves. 40 medical students without any surgical experience were randomized into 4 groups (classical laparoscopy with 3D-direct view or with 2D-indirect view, robotic system in 3D or in 2D) and repeated a surgical task 6 times. After these 6 repetitions, they performed 2 trials with the same technique but in the other viewing condition (perceptive switch). Finally, subjects performed last three trials with the technique they never used (technical switch). We measured the speed, the accuracy and their subjective impressions about their performance (satisfaction, self-confidence and difficulty). Our results showed better performance and improvement in 3D view than in 2D view, whatever the instrumental aspect. In contrast, performance with 2D view was affected by the instrumental aspect. Moreover, participants reported less mastery, familiarity, self-confidence and more difficulty in classical laparoscopy with 2D view than in the other conditions. In conclusion, robotic surgery improves surgical performance and learning, particularly by 3D view advantage. However, technological interfaces are more and more present and create new barriers between the subject’s perception and his/her actions. The perception comes through screens with 2D or 3D images and thus becomes indirect. Furthermore, 2D and 3D images do not carry the same information and thus do not lead to the same performances (Bingham & Pagano 1998; Jackson, Jones, Newport & Pritchard, 1997). Indeed, 3D image contains more cues, especially in order to accurately and efficiently guide the action (Bruce, Green & Georgeson, 2003). Although monocular cues compensate somewhat for the lack of depth perception in 2D view and are useful for some tasks (providing performances similar to 3D view, e.g. in distance estimation, Falk, Mintz, Grünenfelder, Fann, & Burdon, 2001; Servos 2000), 2D vision has been shown to particularly affect kinematics and pattern human motion. Indeed, in 2D view, subjects tend to underestimate object distance when performing reaching and grasping movements (Greenwald, Knill, & Saunders, 2005; Servos, 2000; Marotta & Goodale, 1998).

Our purpose was to study how 2D and 3D images affect the acquisition of the motor skills in an ecological and complex situation. Our main question was: is the difference between 2D and 3D view constant? How does this difference evolve with training? Depth perception is an important factor determining the utility of many computer- and video-based environment (Westerman & Cribbin, 1998), it has also to play a predominant role in minimal invasive surgery. With the technological evolution, surgery constitutes now a very useful field for studying visual depth perception phenomenon. Our purpose was thus both fundamental (understanding the impact of 2D and 3D images on acquisition of skills) and applied (allowing accurate training for surgeon and safe for the patient).

Keywords: depth perception; 3D-2D images; minimal invasive surgery; learning curves.

Introduction

Depth perception
Depth perception is an essential component of human behaviour that determines the accuracy and the quality of human interaction with the environment in everyday life.
feedback. However, open surgery presents some disadvantages that minimal access surgery removes. This surgical technique is characterized by the introduction of a camera and instruments into the body through very small incisions in the skin. Laparoscopic surgery brings a lot of advantages, particularly for the patient: very small incisions, smaller risks of infections, higher accuracy due to the magnification by the camera and fast recovery. For all these reasons, minimally invasive techniques are now ubiquitous and indispensable in the management of surgical disease (Vassiliou, Feldmann, Andrew, Bergman, Leffondré, Stanbridge & Fried, 2005). However, despite these benefits, significant challenges have been noted: the view of the surgical site is now indirect and restricted, the surgeon has to observe and manipulate tissues and organs through very small incisions with long and rigid instruments, the tactile observation is lost, the feedback of the action is principally visual with a 2D image and finally, the degree of freedom for the instruments movements is restricted at 4. Laparoscopic surgery comprises many precise movements in a confined space. The surgeon often has to maintain his precision through an operation in an ergonomically uncomfortable position hampered by tremor and fatigue (Nio, Bemelman, den Boer, Dunker, Gouma. & van Gulik, 2001; Garcia-Ruiz, Gagner, Miller, Steiner, & Hahn, 1998).

A new robotic system (da Vinci robotic system) allows to restore three-dimensional visualization of the operative field and the degrees of freedom lost in classical laparoscopy. This system consists of two primary components: the surgeon’s viewing and control console and, a moveable cart with three articulated robot arms: two arms contain instruments and the third carries an endoscope with dual optical channels. The surgeon is seated in front of the console, looking at an enlarged three-dimensional binocular display on the operative field while manipulating handles that are similar to “joy-sticks”. Manipulation of the handles transmits the electronic signals to the computer that transfers the exact same motions to the robotic arms. The computer interface has the capacity to control and modify the movements of the instrument tips by downscaling deflections at the handles by a factor between (5:1 to 2:1). It can eliminate physiologic tremor, and can adjust grip strength applied to the tools.

As the tactile and force feedbacks are lost in minimal-access surgery, the video image plays the most crucial role in giving the surgeon information about the performance of the operation. Compensation for the lack of depth perception in a 2D environment invokes the use of monocular depth cues such as light and shade, relative size of objects, object interposition, texture gradient, aerial perspective and motion parallax. Using these cues, all laparoscopic operations can be accomplished; however, time and accuracy may be lost as these techniques do not completely compensate for stereoscopic depth perception. Moreover, representation of depth perception in 2D vision is difficult and resource intensive (Westerman & Cribbin, 1998). Finally, effective development and application of such systems relies, at least in part, on understanding the manner in which depth cues are employed by users.

In order to precisely identify the role of the 3D view, we differentiated and independently studied the influence of the three-dimensional view (afferent component) comparing 2D and 3D view and the influence of movement freedom restoration (efferent component) comparing classical laparoscopy with robotic system. This allowed us to study how performance evolves according to the 2D and 3D images but also to evaluate the influence of the instrumental component (dexterity of instruments) on this performance. Finally, we also studied the impact of the use of the 3D view on subject’s self-confidence, satisfaction and facility during the learning, knowing that these factors influence performance, motivation and new technology acceptance (Chiss основное количество, Pace, Schlachta, Mazonza & Poulin, 2003; Rattner, Apelgren & Eubanks, 2001). To avoid any bias from earlier laparoscopic experience in our comparison between classical and robotic laparoscopic techniques, we only selected medical students without any experience in open, minimally invasive or robotically assisted surgery.

Materiel and method
Subjects As shown in table 1, 40 medical students were randomized into four groups: the first using classical laparoscopy with indirect view (2D screen), the second using classical laparoscopy with direct (3D) view, the third using the robotic system in 3D and the fourth using the robotic system in 2D. Subjects were unaware of the existence of 2D and 3D options of the robotic system, and then unaware of the advantages or difficulties related to their experimental condition. Our four experimental conditions allowed us to differentiate two dimensions (see Table 1): one we called “perceptive”, afferent component, where the type of vision (binocular versus monocular) was the main within-technique difference (between 2D and 3D viewing conditions with the same technique) and another we called “instrumental”, efferent component, where the freedom degree for instrument movement was the main between-technique difference (between robotic system and classical laparoscopy). This experimental plan allowed us to more precisely study the influence of the 3D view on learning curves and particularly to answer the question: is the major part of performance explained by the benefit of 3D view (in this case, we should observe a predominant effect of perceptive dimension and thus a difference between 2D and 3D, irrespective of the instrumental dimension) or by the recovery of movement freedom (in this case, we should observe a predominant effect of instrumental dimension and thus a difference between classical and robotic system, irrespective of the perceptive dimension)?
Procedure Experiment consisted of three successive phases: (1) Learning curves: subjects repeated 6 times the task in one of the 4 experimental conditions (2) Perceptive switch: subjects performed 2 trials with the same technique as in the first phase but in the other viewing condition (2D vs 3D) (3) Technical switch: subjects performed 3 trials with the other technique (classical vs robotic system).

These two switches allowed us to study how participants adapted their strategy to the change in depth perception (loss or gain of binocular depth perception) and to the change in technique. Evaluating performance after a technical switch is highly relevant to understand the risk associated to a change in procedure (for example, a conversion procedure when the surgeon has to revert to a classical method) and to determinate an adequate surgical training with the different technologies (Blavier, Gaudissart, Cadière & Nyssen, 2007).

Task The task involved passing in succession a needle, with a thread attached, through rings placed in different heights and depths. This task required depth perception and wrist articulation skills (Scott, Bergen, Rege, Laycock, Tesfay, Valentine, Euhus, Jeyarajah, Thompson & Jones, 2000). It also developed skills at needle transfer and ambidexterity. Rings route resumed a lot of useful and usual fine movements required in minimal invasive surgery (grasping needle, curving and introducing it...) and notably reproduced all the complexity of the suture gesture (except the knot). By all these aspects, this task is a very efficient and accurate way to evaluate minimal invasive systems (Blavier et al., 2007).

For each trial, we calculated a performance score that was the number of rings in which the subjects went through with the needle in 4 minutes. All procedures were video recorded and accuracy was evaluated by three independent observers: for each trial, an error score was constituted by the total of failures (failure to grasp needle in one attempt, dropping the needle, missing the ring) and an ambidexterity score corresponded to the total number of alternative use of left and right instruments.

Questionnaires After determined trials (1, 2, 6, 7 and 9), participants evaluated their performance and answered a questionnaire about feelings of mastery and familiarity with the technique and their feeling of performance satisfaction, self-confidence and difficulty on a 4-point Likert scale.

Results and discussion

As illustrated in figure 1, our study showed that learning curves were different according to the technique and the viewing condition ($F(15,180)=2.12$, $P<0.005$). Moreover, performance and improvement was significantly better in 3D view than in 2D view, whatever the instrumental aspect may be. In 3D-view conditions, learning curves of robotic and classical laparoscopy followed a similar pattern, with better performance and greater improvement than robotic system in 2D and classical laparoscopy with indirect view. In 2D-view conditions, we observed an improvement during the first three trials with the robotic system while in classical laparoscopy, the improvement was really small and progressive. Moreover, the gap in performance between 3D-view conditions (robotic system in 3D and classical laparoscopy with direct view) and 2D-view conditions (robotic system in 2D and classical laparoscopy with indirect view) increased trial after trial. This finding of best performance with a 3D view whatever the instrumental aspect (classical or robotic), emphasizes the persistent and increasing impact of perceptive advantage brought by binocular vision that overlaps the instrumental difficulty. In contrast, in 2D-view conditions, performances and improvement were better with the robotic system than in classical laparoscopy. This result suggests that unlike the 3D view, instrumental benefit influences and facilitates performance in 2D view. Indeed, the 3D vision appears to be essential and more intuitive, requiring less cognitive elaboration and mental load. Recent cognitive studies have shown that the 2D vision requires a strong training and that the information processing in 2D view is longer and slower than with the 3D vision (Mazin & Lenoir, 2004; Greenwald et al., 2005). The cognitive resources usually involved in the 2D image processing may be involved in other processes when the 3D vision is used, allowing to increase gesture precision and safety. No accuracy progress was observed in any condition during all trials ($F(5,180)=.53$, $P=.75$) but ambidexterity score improved in all conditions particularly in 3D-view conditions, subjects using both hands with more facility ($F(5,180)=9.73$, $P<0.000$, see table 2).

| Procedure | Experiment consisted of three successive phases: (1) Learning curves: subjects repeated 6 times the task in one of the 4 experimental conditions (2) Perceptive switch: subjects performed 2 trials with the same technique as in the first phase but in the other viewing condition (2D vs 3D) (3) Technical switch: subjects performed 3 trials with the other technique (classical vs robotic system). These two switches allowed us to study how participants adapted their strategy to the change in depth perception (loss or gain of binocular depth perception) and to the change in technique. Evaluating performance after a technical switch is highly relevant to understand the risk associated to a change in procedure (for example, a conversion procedure when the surgeon has to revert to a classical method) and to determinate an adequate surgical training with the different technologies (Blavier, Gaudissart, Cadière & Nyssen, 2007). | Task The task involved passing in succession a needle, with a thread attached, through rings placed in different heights and depths. This task required depth perception and wrist articulation skills (Scott, Bergen, Rege, Laycock, Tesfay, Valentine, Euhus, Jeyarajah, Thompson & Jones, 2000). It also developed skills at needle transfer and ambidexterity. Rings route resumed a lot of useful and usual fine movements required in minimal invasive surgery (grasping needle, curving and introducing it...) and notably reproduced all the complexity of the suture gesture (except the knot). By all these aspects, this task is a very efficient and accurate way to evaluate minimal invasive systems (Blavier et al., 2007). For each trial, we calculated a performance score that was the number of rings in which the subjects went through with the needle in 4 minutes. All procedures were video recorded and accuracy was evaluated by three independent observers: for each trial, an error score was constituted by the total of failures (failure to grasp needle in one attempt, dropping the needle, missing the ring) and an ambidexterity score corresponded to the total number of alternative use of left and right instruments. Questionnaires After determined trials (1, 2, 6, 7 and 9), participants evaluated their performance and answered a questionnaire about feelings of mastery and familiarity with the technique and their feeling of performance satisfaction, self-confidence and difficulty on a 4-point Likert scale. | As illustrated in figure 1, our study showed that learning curves were different according to the technique and the viewing condition ($F(15,180)=2.12$, $P<0.005$). Moreover, performance and improvement was significantly better in 3D view than in 2D view, whatever the instrumental aspect may be. In 3D-view conditions, learning curves of robotic and classical laparoscopy followed a similar pattern, with better performance and greater improvement than robotic system in 2D and classical laparoscopy with indirect view. In 2D-view conditions, we observed an improvement during the first three trials with the robotic system while in classical laparoscopy, the improvement was really small and progressive. Moreover, the gap in performance between 3D-view conditions (robotic system in 3D and classical laparoscopy with direct view) and 2D-view conditions (robotic system in 2D and classical laparoscopy with indirect view) increased trial after trial. This finding of best performance with a 3D view whatever the instrumental aspect (classical or robotic), emphasizes the persistent and increasing impact of perceptive advantage brought by binocular vision that overlaps the instrumental difficulty. In contrast, in 2D-view conditions, performances and improvement were better with the robotic system than in classical laparoscopy. This result suggests that unlike the 3D view, instrumental benefit influences and facilitates performance in 2D view. Indeed, the 3D vision appears to be essential and more intuitive, requiring less cognitive elaboration and mental load. Recent cognitive studies have shown that the 2D vision requires a strong training and that the information processing in 2D view is longer and slower than with the 3D vision (Mazin & Lenoir, 2004; Greenwald et al., 2005). The cognitive resources usually involved in the 2D image processing may be involved in other processes when the 3D vision is used, allowing to increase gesture precision and safety. No accuracy progress was observed in any condition during all trials ($F(5,180)=.53$, $P=.75$) but ambidexterity score improved in all conditions particularly in 3D-view conditions, subjects using both hands with more facility ($F(5,180)=9.73$, $P<0.000$, see table 2). |
satisfaction, self-confidence and facility, essential factors of well-being, motivation, accurate performance and new performance but also in the feelings of mastery, familiarity, benefit of the training in the improvement of the situation (F(2,72)=11.61, \(p<0.0005\)). We showed thus a positively evolved in all conditions, indicating an increase with 2D indirect view than in the other conditions self-confidence and more difficulty in classical laparoscopy procedure occurs.

Furthermore, participants reported less mastery, familiarity, benefit of the training in the improvement of the situation (F(2,72)=11.61, \(p<0.0005\)). We showed thus a positively evolved in all conditions, indicating an increase with 2D indirect view than in the other conditions self-confidence and more difficulty in classical laparoscopy procedure occurs.

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Table 2: Error scores and ambidexterity scores in trials 1, 2, 6, 7 and 9 (interobserver reliability, Cronbach’s alpha = 0.86)

<table>
<thead>
<tr>
<th></th>
<th>Classical laparoscopy</th>
<th>Classical laparoscopy</th>
<th>Robotic system in 2D</th>
<th>Robotic system in 3D</th>
<th>P value</th>
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<tr>
<td></td>
<td>With indirect view</td>
<td>With direct view</td>
<td></td>
<td></td>
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<tr>
<td>Trial 1</td>
<td>20.12±2.29</td>
<td>9.03±3.14</td>
<td>18.89±5.1</td>
<td>11±4.3</td>
<td>(P&lt;0.0000) (1,2-3,4)</td>
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<tr>
<td>Trial 2</td>
<td>20.87±5.74</td>
<td>10.33±1.53</td>
<td>17.75±6.98</td>
<td>12.67±4.66</td>
<td>(P&lt;0.05) (1,2-3,4)</td>
</tr>
<tr>
<td>Trial 6</td>
<td>20.56±5.66</td>
<td>8.67±1.53</td>
<td>17.29±4.15</td>
<td>8.67±4.87</td>
<td>(P&lt;0.0001) (1,2-3,4)</td>
</tr>
<tr>
<td>Trial 7</td>
<td>22.67±4.73</td>
<td>11±8.66</td>
<td>22.11±5.28</td>
<td>11.63±7.25</td>
<td>(P&lt;0.01) (1,2-3,4)</td>
</tr>
<tr>
<td>Trial 9</td>
<td>30.43±9.55</td>
<td>13.08±4.58</td>
<td>23.67±8</td>
<td>10.5±4.37</td>
<td>(P&lt;0.0005) (1,2-3,4)</td>
</tr>
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**Error score**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Error score</th>
<th>Ambidexterity score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>3.02±2.33</td>
<td>15.67±10.21</td>
</tr>
<tr>
<td>Trial 2</td>
<td>4.62±2.44</td>
<td>17.54±2.64</td>
</tr>
<tr>
<td>Trial 6</td>
<td>7.06±2.5</td>
<td>23.05±7.23</td>
</tr>
<tr>
<td>Trial 7</td>
<td>9.33±2.08</td>
<td>14.04±7.81</td>
</tr>
<tr>
<td>Trial 9</td>
<td>2.86±2.54</td>
<td>13.07±7.43</td>
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**Figure 2: Learning curves for performance scores after the technical switch (trials 9-11)**

Furthermore, our findings emphasized the need to adapt the training tasks to the technique used. Indeed, as shown in figures 1 and 2, the bad performances after the perceptive (F(3,36)=35.06, \(p<0.0000\)) and technical switches (F(3,36)=18.21, \(p<0.00005\)) suggested that the two techniques (robotic and classical laparoscopy) involved or trained less than identical skills. This stresses the necessity to adapt and to pursue training with the different techniques (and thus traditional techniques) in order to prevent gap in performance and thus the operating risk if a conversion procedure occurs.

Finally, participants reported less mastery, familiarity, self-confidence and more difficulty in classical laparoscopy with 2D indirect view than in the other conditions (F(3,36)=4.39, \(p<0.05\)). However, these impressions positively evolved in all conditions, indicating an increase in the satisfaction and in the control sensation of the situation (F(2,72)=11.61, \(p<0.0005\)). We showed thus a benefit of the training in the improvement of the performance but also in the feelings of mastery, familiarity, satisfaction, self-confidence and facility, essential factors of well-being, motivation, accurate performance and new technology acceptance in operating room (Marshall, Smith, Gorman, Krummel, Haluck & Conney, 2001; Jones & Cale, 1997). By all these characteristics, this study encourages the use of bench models in training of surgical skills in parallel to traditional learning.

**Conclusions: Implications for learning**

The development of technical skill is fundamental to the process of becoming a surgeon. The fundamental change, produced by new technology, in how surgeons perform operations has educational implications related to learning curves and patient safety (Sidhu, Tompa, Jang, Grober, Johnston, Reznick & Hamstra, 2004). Moreover, educational issues have proved to be a significant hurdle to the widespread dispersion of minimal access surgery techniques (Sidhu et al., 2004).

Traditionally, surgeons have honed their skills in the operating rooms through hands-on experience with veteran mentors (Hamilton, Scott, Fleming, Rege, Laycock, Bergen, Tesfay & Jones, 2001). This manner of teaching effectively trains surgeons in traditional open surgical techniques, but is costly in terms of time, resources and patient morbidity (Bridges & Diamond, 1999). Over the past decade, minimally access surgery has revolutionized general surgery, posing new obstacles for experienced surgeons attempting to acquire laparoscopic skills (Jones, Brewer & Soper, 1996). Indeed, laparoscopic surgery requires specialized training and practice in order to acquire new skills to operate, to manipulate tissues with long instruments and a new knowledge of anatomy and spatial orientation (Gallagher, Ritter & Satava, 2003; Cadière & Leroy, 1999).

Classical laparoscopic surgery is generally a two-dimensional surgery. The loss of depth perception and spatial orientation are the main drawbacks for the novice to overcome when facing the television monitor (Chan, Chung, Yim, Lau, Ng & Li, 1997). Advanced complicated laparoscopic surgery requires precise manipulation of the...
Mastery of technical skill is thus crucial to surgical training. However, a survey in 2003 revealed that 82% of Canadian surgical residents considered their training in minimally invasive surgery inadequate (Chiasson et al., 2003) and 65% of American residents surveyed would pursue extra training in laparoscopy if it were available (Rattner et al., 2001). With the growing complexity encountered in performing minimally invasive surgery, training in the operating room alone may be inefficient and impractical (Hamilton et al., 2001). Moreover, some studies have shown that practice using inanimate models increases psychomotor skills and translates into improved performance in the operating room (Scott et al., 2000).

In this context, our paper suggests some issues and emphasizes some important aspects to take into account in the surgeon’s training settings. The first finding is that the 3D view led to better performance and greater improvement than 2D view, whatever the instrumental advantage may be. However, if robotic surgery improves surgical performance and learning, particularly by 3D view advantage, there is no transfer of skills between classical and robotic surgery in novice performance (this transfer exists in expert surgeons performance, Blavier & Nyssen, submitted). The difficult skill transfer after the technical switch suggests that the two techniques involved or trained not exactly identical skills, and lays stress on the necessity to pursue training with the different techniques. Another point our study emphasized is the benefit of the training in the improvement of the performance but also in the feelings of mastery, familiarity, satisfaction, self-confidence and facility. By all these characteristics, this study shows the utility of simulations sessions for the training of surgical skills but also for the development of an accurate self-evaluation and self-confidence, and thus encourages the use of bench models in training of surgical skills in parallel to traditional learning.

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References


