DEVELOPING BASIC HAND-EYE COORDINATION SKILLS FOR LAPAROSCOPIC SURGERY USING GAZE TRAINING

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INTRODUCTION

With laparoscopic techniques being used for more urology surgical procedures, consideration needs to be given to the effective training of basic technical skills [1]. Virtual reality-training simulators have been proposed to offer an effective way to train technical skills through repetitive practice in a safe, unthreatening environment. Indeed, recent systematic reviews have shown that such training can translate to improved outcomes in the operating room [2]. However, the most effective way to use these expensive training tools is still not clear, and there has been limited attention on the development of theoretically driven training curricula [3,4].

Recent theoretical frameworks and developments in the motor learning literature may provide educators with some important guidelines for developing surgical training curricula [5]. For example, research examining the skilful performance of visually guided movements from other motor domains (e.g. driving and sport) has implicated the importance of gaze control in optimizing subsequent motor control [6,7]. In contrast, there has been little research focus on the strategic gaze behaviours of surgeons performing visuomotor, laparoscopic tasks. Indeed, the process measures examined tend to be from the 'surgeon–tool' interface (tool movement metrics) as opposed to the 'surgeon–monitor' interface (gaze metrics) [8].

Accordingly, researchers and curriculum developers are only considering half of the 'hand-eye coordination' relationship, and are ignoring potentially important information related to the visual cues used to guide and control instrument movements. By ignoring the strategic role of the gaze system in optimizing fine motor skill control, technical training programmes may not be as effective as they could be. The following sections provide theoretical support for an increased understanding of gaze strategies, and outline some concerns with simply focusing on the 'hand' component of hand-eye coordination.

VISUOMOTOR CONTROL

Research in cognitive neuroscience suggests that when performing goal-directed eye and hand movements, both the time and location at which eye and hand land on the object need to be harmonized [9]. Generally, the eyes are positioned at a point that is not simply the most visually salient, but is the best for the spatio-temporal demands of the job that needs to be done [10]. Secondly, eye movements tend to precede motor actions, so that visually acquired goal position information can be passed to the motor system to coordinate the hands and arms. Indeed, it has been shown that the neural mechanisms regulating goal-directed movements profit from the accurate and timely spatial information of the fixated target [11]. Put simply; 'we move where we look'.

It is evident that eye movements and the gaze system that controls their location play a key role in coordinating precision motor actions; research of several real-life visuomotor tasks shows that each task has a unique eye movement pattern that matches the specific demands of the task. Furthermore, as vision is a scarce resource (we can only fixate on one object at a time), very few 'wasted' fixations are made to objects not related to task completion. For example, in tasks involving the grasping and manipulation of various objects, the hands are never fixated, and once an object has been acquired by the hands it is not fixated either [12]. Implicit in these findings is the conclusion that these eye movement patterns must be learned [10] and are made more efficient and effective through practice [13].

The key point to take from the neuroscience research is that this learning could be optimized by having novices replicate the gaze patterns of expert performers. Instead of simply waiting for learners to develop optimal visuomotor control through hours of (unstructured) practice, we may be able to 'cheat' experience by providing an insight into the underlying gaze control patterns of experts. By teaching novice surgeons to fixate on the correct areas of a display at the correct times, their motor actions will also be more coordinated and optimally guided. However, it could be argued that training could simply focus on providing learners with feedback related to the instrument movements they are making. The following section outlines some reasons why this emphasis might be limited and potentially self-defeating.

AN EMPHASIS ON MOVEMENT FEEDBACK

Currently, virtual reality-laparoscopic trainers provide learners with feedback on their performance based on metrics such as the number of tool movements they made or the economy of these movements (related to an ideal movement path). While this information may be useful in the development of criteria-based proficiency assessment [3,4], it is not very useful for learning. How should a trainee surgeon use this feedback to guide subsequent learning? How does one train to improve 'economy of movement' based on a percentage score? Performance will (likely) improve over time with continued experience of the training tasks, and the learner will be able to chart their improvement with this feedback. However, given the training pressures created by duty hour, and fiscal restrictions, more attention needs to be applied to understanding how technical laparoscopy skills should *optimally* be learned through effective training curricula.

The second concern with a focus on tool movement measures during learning relates to the extensive research findings examining explicit vs implicit motor learning [14]. Explicit motor learning refers to the acquisition of a skill in a highly verbal manner, with conscious awareness of how the skill is executed. A trainee who is provided with movement-related feedback and thus pays considerable attention to the mechanics of performing a skill will learn explicitly. As well as taking up attentional resources that could be applied to other aspects of surgery (monitoring, reflecting, decision-making) the accrual of explicit rules during learning has been implicated in skill breakdown under stress [15,16].

In contrast, implicit motor learning refers to the acquisition of a skill in a nonverbal manner, with little conscious awareness of what is learned. By generating movement control that makes less demands on the already taxed cognitive resources of the surgeon, implicit motor learning develops skills that are more stable in conditions of psychological stress, fatigue, multitasking and over time [14–16]. However, in reality it is difficult to limit the extent to which the learner tries to attend to the control of movement patterns. Motor learning researchers have therefore used various manipulations to limit the accrual of explicit rules, including engaging working memory on another task, preventing errors, and analogy and observational learning instructions [14].

A NEW DIRECTION – GAZE TRAINING

The crux of the argument being presented here is that providing instructions about novice surgeons' gaze strategy can overcome both the limitations identified with movement-centred feedback. First, compared to abstract information related to instrument movements, gaze location feedback provides concrete information to guide performance (i.e. where to look). Learners can use this information to guide subsequent learning attempts, whereas information about the number or economy of their instrument movements is harder to translate into practical guidance for task completion. Second, gaze training may be viewed as a form of implicit motor learning where movements are guided with little conscious control. By focusing on what you are looking at rather than on the movements of the instruments, explicit rules are less likely to be accrued during learning and reinvested in under pressure.

For gaze training to be a practical solution, four conditions need to be met. First, we need to be able to objectively assess the eye movements of surgeons as unobtrusively as possible, as gaze control processes occur at a subconscious level and are not readily available to introspective report. Second, gaze measures need to be able to differentiate between expert and novice performance. If we predict that experts will have more efficient and effective gaze strategies than novices, our measures must be sensitive enough to reflect these differences. Third, we must demonstrate that efficient and effective gaze strategy can be trained and is not simply a bi-product of experience. Finally, we need to demonstrate that there is an advantage to gaze training over more traditional (technical/movement-focused) skill training in terms of either (or both) the speed of learning or the robustness of performance under stress or additional attentional load.

In the sport psychology/motor learning literature, these conditions have already been met. New eye-tracking equipment allows tasks to be performed in their normal environments with few restrictions on the range of movement of head or body. There is also a wide literature base of >50 scientific publications that have supported the perceptual-cognitive advantage of experts as determined through gaze analyses [13]. For training gaze behaviours to improve motor skill performance, positive results have been shown in skills such as basketball free-throw shooting, tennis service return, golf putting and others [17]. Only recently have researchers started to look at how gaze training may provide benefits to novice performers for how robust their skills may be under pressure, but these results also look promising [18].

We are currently extending this research into the laparoscopic surgery domain and hope to demonstrate similar benefits to learning that have been shown for sporting skills. We have verified that gaze behaviour can be easily collected from surgeons performing tasks on both a virtual reality platform and on video training boxes. We have also determined significant differences in gaze location between experienced and novice surgeons for several basic procedural tasks; particularly with reference to 'wasted' fixations by novices. We now hope to use the information we have collected about how expert surgeons use their gaze to guide their motor control on basic laparoscopic tasks, to train a group of novice surgeons. Their speed of skill learning and their performance under pressure will then be compared with a group of surgeons trained in a more explicit, movement-focused manner.

CONCLUSION

Here we have presented a different view to the theoretical frameworks generally adopted for technical skill learning in surgery. We propose that novices should be taught the gaze strategies of expert performers, as opposed to a focus on their hand and tool movements. This strategy is supported by the findings from the neuroscience literature, which identify the critical relationship between accurate gaze and accurate movements. From a practical perspective, expert eye movements and gaze locations are easier to mirror than expert tool or hand movements, and feedback can be more readily converted into meaningful instructions. Finally, concerns with the accrual of explicit rules about movement control early in learning have been supported in a range of domains, including surgery. By drawing attention away from the control of tool movement, gaze training should prevent such conscious accrual and should 'free-up' resources to be applied to other key surgical tasks.

It is acknowledged that effective hand-eye coordination is only a relatively minor part of being an effective surgeon, with knowledge and judgement arguably being more critical [19]. However, it is important that these basic 'technical' skills are learned in as effective and efficient a manner as possible. We have demonstrated that a sport skill learned 'implicitly' through gaze training is more robust to pressure effects and more durable over time than one learned using movement cues [18]. Furthermore, there is the opportunity for future research to also examine the visual information used to underpin the 'higher order' skills of expert surgeons (decision-making and judgement calls). Again, we would expect that experienced surgeons are focusing their attention where it needs to be to make effective judgements, and novices may benefit from being privy to this information. Thus, there are several potential benefits of developing a gaze-focused approach to understanding surgical skill learning and performance and these warrant further research attention.

CONFLICT OF INTEREST

None declared.

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