DOES IT EXIST A LINK BETWEEN PERFORMANCE AND PARIETAL CORTEX ACTIVITY IN SURGICAL TASKS?

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Keywords: Functional near infrared spectroscopy (fNIRS), Depth perception, Hand-eye coordination, da Vinci surgical system, Posterior parietal cortex.

Abstract: This pilot study would to explore the ideas of a possible correlation between the goodness of surgical performance in robotic assisted minimally invasive surgery (MIS) and posterior parietal cortex (PPC) activity. This cortical area is known to be involved in stereoscopic vision (Sakata et al., 1997), visual control of eye movements and hand-eye co-ordination (Shikata et al., 1996). This issue is of great interest because robotic assisted surgery provides the surgeon with a stereoscopic view of the operative field combined with aligned motor-visual axes and mechatronically controlled instruments. In this contribution, we conduct an exploratory experiment aiming at investigating the hypothesis of a correlation between the performance in reached in a surgically relevant task and the activation of PPC channels as revealed by the fNIRS measurements. First results are very promising and suggest the occurrence of a link between performance and channel activation.

1 INTRODUCTION

The posterior parietal cortex (PPC) is known to be involved in stereoscopic vision (Sakata et al., 1997; Shikata et al., 1996), visual control of eye movements and hand-eye co-ordination (Ferraina et al., 2009; Kim and James, 2010). This brain region may play an important role in robotic assisted intervention which provides the surgeon with a stereoscopic view of the operative field combined with aligned motor-visual axes and mechatronically controlled instruments. Theoretically, performers with superior technical ability may demonstrate enhanced neuronal efficiency compared to those who struggle in robotic environments. This pilot study explores the link between technical ability and PPC activation during depth perception and a hand-eye coordination task in a robotic surgical environment. The PPC activation was investigate both by a group analysis and by a subject by subject analysis. Early results are promising and may suggest a link between technical performance and PPC excitation.

2 MATERIALS AND METHODS

Four, right-handed, healthy subjects participated in this study. Optical topography (OT) assessment was conducted for two experiments involving monoscopic and stereoscopic object depth perception and hand-eye coordination tasks in a robotic surgical environment. The experiment was conducted using the da Vinci Surgical System (Intuitive Surgical, Inc., USA). In the first experiment (object depth perception) subjects were shown a platform of nine numbered spheres of random size, positioned at different depths and were asked to vocally indicate the nearest and farthest sphere. In the second experiment (hand-eye-coordination) subjects were required to manipulate the robotic arms to move elastic bands between predefined locations (cones) in the operative field. Both experiments were conducted using a block design paradigm consisting of self paced stimuli and intertrial visuomotor rest (30s). Five blocks of trials were performed using 2D visual stimulus rendering and five using 3D. In each condition, randomization was used to eliminate ordering effects. PPC activity was indexed by changes in cortical haemodynamics mea-

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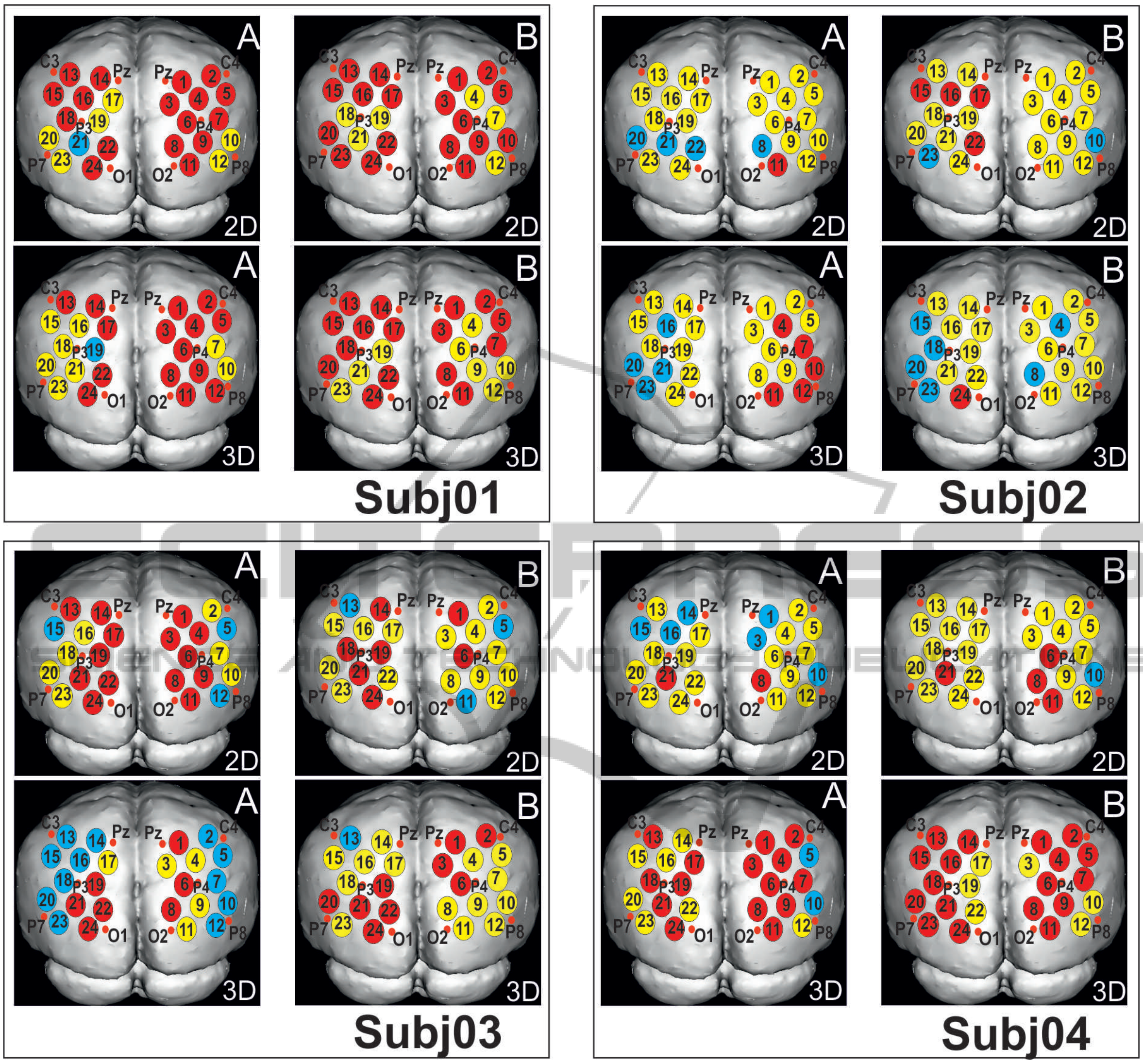

Figure 1: Illustration of the patterns of task-evoked changes in oxyhaemoglobin (HbO_2), and deoxyhaemoglobin (HHb) across depth perception (A) and hand-eye coordination (B) trials. HbO_2 increment and HHb decrement indicating activations (red circles). HbO_2 decrement and HHb increment indicating deactivations (blue circles). Both Hb species increasing or decreasing (yellow circles).

ured using Functional Near Infrared Spectroscopy (fNIRS) based OT equipment (ETG-4000, Hitachi Medical Corp, Japan). OT enables repeated non-invasive assessments of oxygenated haemoglobin (HbO_2) and deoxygenated haemoglobin (HHb) inferring brain function (increase in HbO_2 coupled to decrease in HHb) during complex tasks in realistic environments (Leff et al., 2008). This system was used to acquire functional haemodynamic data from 24 locations (channels) across bilateral posterior parietal lobes simultaneously. All trials were videotaped to enable performance analysis. Performance in the object depth perception experiment was assessed as the percentage of correct depth identification for each sphere-set (%). Blinded error ratings by two independent observers against operation specific checklists resulted in objective scores of technical skill in the hand-eye coordination experiment. For each channel, haemodynamic data were block averaged. Then, mean change (increase/ decrease) from baseline rest in HbO_2 and HHb was calculated on a subject by subject basis. Changes in oxyhaemoglobin (HbO_2), and deoxyhaemoglobin (HHb) from rest were statistically analysed using Wilcoxon Sign Rank Test ($p<0.05$) to determine the location of activated channels (stimulus evoked increase in HbO_2 coupled to a decrease in HHb) in the group analysis. Additionally, the magnitude of ΔHb values (Hb Stimulation Hb Rest) were

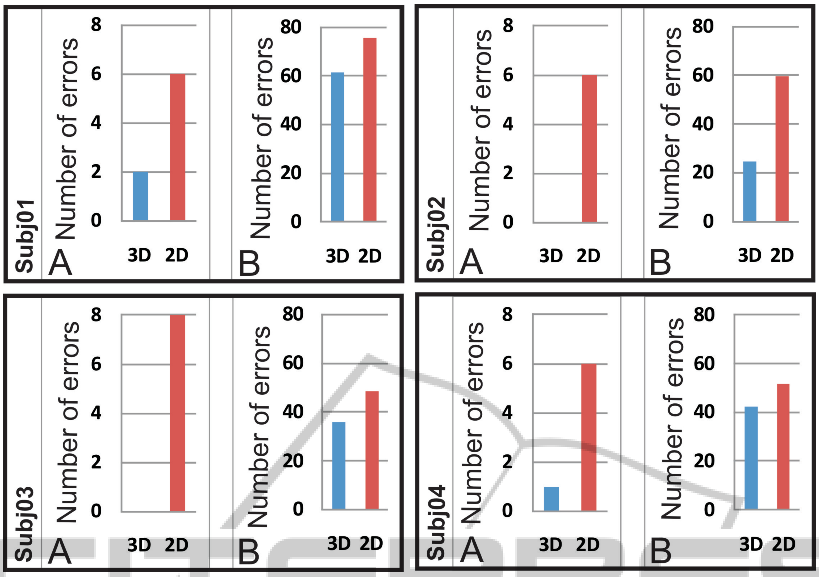

Figure 2: Illustration of subject performance during depth perception (A) and hand-eye coordination tasks (B).

compared between 2D and 3D trials for each channel to determine whether parietal activation was significantly greater during 3D trials versus 2D (Wilcoxon Sign Rank Test, $p<0.05$). .

3 RESULTS

3.1 Group Analysis

Depth perception accuracy was significantly better during 3D versus 2D performance (% of spheres correctly identified). Hand eye-coordination was significantly better during 3D performance, with more technical errors being committed in 2D. The location of activated channels was observed to be function of task domain. Right PPC recruitment was required during object depth perception without movement and during visually guided manipulation of the robotic arms. In contrast, left PPC activation occurred only during the hand-eye coordination task and was not recruited during object depth perception alone. The difference in functional brain responses between 2D and 3D trials was not manifested by a variation in the location of activated channels but instead by the magnitude of parietal excitation. The magnitude of ΔHbO_2 and ΔHHb was found to be greater during 3D versus 2D trials in many parietal channels, for both experiments.

3.2 Subject by Subject Analysis

The results suggest that a link may exist between technical performance, depth perception capability and PPC activation. As illustrated in Figures 1 and 2, Subjects (e.g. Subj01) with poorer technical and depth perception capability and appear to activate the bilateral PPC more broadly than subjects (e.g. Subj02) with superior visuospatial ability and technical skill. Moreover, subjects reaching an intermediate level of performance in both tasks demonstrate intermediate levels of bi-parietal activation.(e.g. Subj03 and Subj04).

Additionally we measured the signal quality using the negative correlation (Cui et al., 2010) which shows neurovascular coupling for each subject. Pair t-test shows that for Subj03 ($p < .001$) and Subj04 ($p < .001$) there is significant PPC activation in 2D visual condition respect to 3D visual condition during the hand-eye coordination task. Moreover, this test shows that for Subj01 ($p < .001$), Subj02 ($p < .05$) and Subj03 ($p < .001$) there is a statistically significant different activation between 3D and 2D visual condition during depth perception task. The PPC activation is statistically different between hand-eye coordination and depth perception task for all the subjects (two-sample t-test, $p < .001$). In general, the concentration of oxyhemoglobin (HbO_2) and total hemoglobin (HbT) is increased and the deoxyhemoglobin (HbR) is decreased in bilateral PPC parietal cortex during both the tasks (depth perception and hand-eye coordination) with respect to the resting state.

4 DISCUSSION

This paper raises interesting questions regarding the possibility of a link between hand-eye coordination and depth perception capability during surgical robotics. (i) May the right PPC function to visually assess and judge an objects depth in space? (ii) May the left PPC help to guide goal- directed complex visuomotor behaviors? (iii) Are more skilled performers operating using enhanced PPC neuronal resources compared to those with poorer technical ability and error prone performance. (iv) Is the performance improvement from 2D (traditional laparoscopy) versus 3D (stereoscopic robotics) secondary to improved depth perception mediated cortically by the PPC at the visual/parietal level? A far larger study cohort and a more detailed analysis would be required to clarify these findings.

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