ABSTRACT

Team cognition is an important factor in evaluating and determining team performance. Forming a team with good shared cognition is even more crucial for laparoscopic surgery applications. In this study, we analyzed the eye tracking data of two surgeons during a laparoscopic simulation operation, then performed Cross Recurrence Analysis (CRA) on the recorded data to study the delay behaviour for good performer and poor performer teams. Dual eye tracking data for twenty two dyad teams were recorded during a laparoscopic task and then the teams were divided into good performer and poor performer teams based on the task times. Eventually we studied the delay between two team members for good and poor performer teams. The results indicated that the good performer teams show a smaller delay comparing to poor performer teams. This study is compatible with gaze overlap analysis between team members and therefore it is a good evidence of shared cognition between team members.

1. INTRODUCTION

Eye tracking technique, as an objective assessment of surgical skill has been well documented in the literature [1]. Gaze patterns have been shown to differentiate poor and elite surgeons in several studies [2, 3, 4]. Also eye tracking can be used to examine the workload and vigilance of surgeons [5, 6]. Video analysis of an endoscopic cutting task performed by one vs. two operators indicates that good team collaboration results in superior team performance [7], and higher frequency of anticipatory movement was noticed in dyad teams [8]. Later on, Khan and Zheng [3] used dual eye-tracking to examine the spatial similarity in eye-tracking between two surgeons. Reporting level of gaze overlap is an innovative step in the study of shared cognition between two surgeons in a laparoscopic team. However, people may gaze on the same spot at different time slots. To further analyze the similarity of eye tracking, we need to take temporal features into consideration in addition to spatial ones.

In 2005, Richardson and Dale first used CRP to analyze gaze similarity recorded from two different persons [9]. They studied the relationship between a speaker and a listener based on their eye movements, and found that the coupling between a speakers and a listeners eye movements indicate if the listener was engaged to the speaker or not. While the gaze movement of the speaker was recorded, he watched a television show and at the same time talked about it. Later, the listener watched the same show as he was listening to the previously recorded monologues and his gaze movements was recorded too. Finally CRA was used to detect the matching behavior between speaker and listeners gaze movement. Marwan et al. presented a comprehensive review on different CRP and CRA approaches [10]. One can find an excellent MATLAB toolbox or an R package [11] to perform CRP analysis. CRP can be used to study the differences between two processes or for the alignment and search for the matching sequences of the two data series even when the cross correlation fails or if the system is dynamic. It is a major task to find relations or interrelations between the time series. Linear data analysis is not suitable to analyze the short, non-stationary and complex data series. An appropriate method to analyze this type of data is Recurrence Plots (RP). It has been proven that recurrence is a fundamental property of dynamic systems, which means that after some time the system will reach the state that is arbitrary close to the former states and pass through a similar evolution. RP can visualize the recurrence behavior of dynamic systems. Also, one can perform the Recurrence Analysis (RA) based on the RP. CRP is an extension of RP. It can help in investigating the time dependent behavior of the two processes. The basic idea is to compare the phase space trajectories of two processes in the same phase space. CRP is used to study the similarity of the two different phase space trajectories.

2. BACKGROUND

Cross Recurrence Plots (CRP) can be used to study the difference between two processes or for the alignment and search for the matching sequences of the two data series even when the cross correlation fails or if the system is dynamic. It is a major task to find relations or interrelations between the
time series. Linear data analysis is not suitable to analyze the short, non-stationary and complex data series. An appropriate method to analyze this type of data is Recurrence Plots (RP). It is proved that recurrence is a fundamental property of dynamic systems, which means after some time the system will reach the state that is arbitrary close to the former states and pass through the similar evolution. RP can visualize the recurrence behavior of the dynamic systems. Also one can perform the quantification analysis based on the recurrence plots. CRP is an extension to RP. It can help to investigate the time dependent behavior of the two processes. The basic idea is to compare the phase space trajectories of the two processes in the same phase space. CRP is used to study the similarity of the two different phase space trajectories [10]. Recurrence rate (RR) is an important feature of CRP which can be used to study the time delay between the two systems. Eq. 1 explain the formulation for RR as it has been described in [12].

\[
RR = \frac{1}{N^2} \sum_{i,j=1}^{N} R_{i,j}
\]  

(1)

where \( N \) is the number of points on the phase space trajectory, \( i \) and \( j \) belongs to the two different data series that we are studying and eventually \( R_{i,j} \) is the RP as defined by 2.

\[
R_{i,j} = \Theta(\epsilon_i - \| x_i^j - x_j^i \|)
\]  

(2)

where \( x_i^j \) and \( x_j^i \) are the phase space trajectory of time series \( i \) and time series \( j \) respectively.

3. EXPERIMENTAL SETUP

In this section we describe the setup of the experiment and the proposed method for data analysis. 22 dyad teams have been formed by 17 participant including surgery students and non surgery students. Consent was obtained from the participants before entering the study. Methods for this experiment were subjected to Health Research Ethics Board of University of Alberta.

The experimental set up includes four main components. The first one is a laparoscopic training box measuring at 30 x 30 x 20cm (Fig. 1). Inside the box, the distance of home plate to different pins is labeled (Fig. 1a). The training box has ports of entry for a laparoscope and laparoscopic graspers. The second component is two 17 video monitors (Tobii 1750 LCD Monitor, Tobii Technology, Stockholm, Sweden), which displays the image captured by a laparoscope and a webcam. We also used a standard laparoscopic imaging system, including laparoscope, camera, light source and video monitor (Stryker Endoscopy, San Jose, California, USA). Finally, two high-resolution remote eye-trackers (Tobii 1750 and X50, Tobii Technology, Stockholm, Sweden) were set in an orthogonal arrangement (Fig. 1). Each eye-tracker can remotely track one operators eye motions unobtrusively within a comfortable viewing distance. Gazes of two operators in a dyad team were recorded separately by the two eye-trackers and the data fed into the Labview software to synchronize the gazes in time on top of the surgical video streams.

Each dyad team performed a set of laparoscopic simulation task, where the camera driver conducted a laparoscope to locate different colored pins for the primary performer. Then the performer grasped and transported a plastic cylinder (2 cm long, 1.5 cm wide) among the pins. The task contains four different subtasks including loading the cylinder into the pin, transfer the grasper into the home plate, return the grasper to the pin and pick up the object from the pin. The pins, which were 2 cm in length and protruding out of the center, were mounted on two interior sidewalls of the wooden box (Fig. 1(a)). Totally, there were five different colored pins (blue, red, orange, pink, and yellow). The experimenter randomly assigned the sequence of selecting the colored pins. The camera driver needed to manipulate the laparoscope forward and backward to locate pins, the object and the home position. He was also required to rotate the light cord clockwise and counterclockwise to keep the object and the instrument at the center of the view. For this study we analyzed the second and third subtasks and called them the transportation period. Therefore, we would like to find out the delay between team members during the transportation period.

4. DATA ANALYSIS AND RESULTS

We analyzed the good performer and the poor performer teams based on the team members delay behaviour. To make sure that it is a good indication of team cognition we also compared the results with gaze overlap percentage for good performer and poor performer teams. To get a distinctive category of elite and poor performer teams, we chose the top and bottom 25% of the teams based on the overall completion time, which is shown as two selected regions in Fig. 2(a). As discussed earlier, we mainly focused on the tool transportation period for analysis purposes. We specifically considered the period that tool transports from the orange pin to home and from home to the orange pin. The orange pin has been chosen because of its greater distance to home plate and
In order to calculate the delay between team members we used RR as described in Eq. 1 and [9]. We calculated RR for different gap between the two signals and the gap that generated the highest RR is selected as the delay between the two team members. The orange dots in Fig. 2(a) shows the corresponding delay for good performer and poor performer teams. As it is expected, good performer teams show smaller delay comparing to poor performer teams.

We also calculated the pixel overlap of the camera driver and the performer, to make sure that it is compatible with delay analysis. People have previously discussed that gaze overlap can define the level of expertise [3]. In this paper we set the threshold to 50 pixels, which indicates a gaze separation of almost 5 visual angle for our setup. As [3, 4] suggested a visual angle of at least 3 identify the eye-gaze mismatch. This implies that both team members are roughly looking at the same spot if the Euclidean distance between their eye-gaze locations is less than 50 pixels. The red horizontal line in Fig. 2(b) shows 50 pixels separation threshold on the difference between two gaze signals (blue curve).

Fig. 3 shows the relationship between delay analysis and overlap analysis. As you can see in Fig. 3(a) the good performer teams show smaller delay behaviour and higher gaze overlap between team members while the poor performer teams have higher delay and lower gaze overlap. Fig. 3(b) shows the linear relationship between delay and gaze overlap, as the gaze overlap increases the delay decreases.

Eventually Fig. 4(a,c) shows the CRP for two good performer teams and Fig. 4(b,d) shows the CRP for two bad performer teams. As you can see the average length of the marked diagonal line for the good performer teams are larger comparing to the poor performer team. This indicates a higher recurrence rate (RR) and eventually a smaller delay.

5. CONCLUSION

Table 1 shows the gaze overlap percentage for good performer and poor performer teams during the orange-pin tool transportation periods. The gaze overlap between two team members in the good performer teams is significantly higher than the poor performer team (good performer: 56.17 ± 7.47%; poor performer: 29.60 ± 13.04%).

The average delay for good performer and poor performer teams is presented in Table 1. Delay analysis showed that two team members in poor performer teams displayed a 2.25 ± 2.54 sec gaze delay; whereas the delay dropped to 0.26 ± 0.11 sec for Good performer teams.

In future work we will also investigate the role of foveation [13, 14, 15, 16, 17, 18] in team cognition.
Fig. 4: Cross Recurrence Plots for a good performer team (a,c) and a poor performer team (b,d) with the main diagonal line shown in black.

Table 1: Comparison of different features for elite and poor performer teams

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<thead>
<tr>
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<th>Gaze Overlap (%)</th>
<th>Delay (sec)</th>
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<tbody>
<tr>
<td>Good Performer Teams</td>
<td>56.17 ± 7.47</td>
<td>0.26 ± 0.11</td>
</tr>
<tr>
<td>Poor Performer Teams</td>
<td>29.60 ± 13.04</td>
<td>2.25 ± 2.54</td>
</tr>
</tbody>
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6. REFERENCES


