The Hurst Exponent – A Novel Approach for Assessing Focus During Trauma Resuscitation

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Abstract— Current assessment of resuscitation team performance is often based on evaluations using checklists that evaluate verbal communication. However, highly efficient teams may function with several non-verbal cues that may not be measured by current assessment methods. Previous work assessing these non-verbal cues has been accomplished by tracking head movements in providers which however have not been attempted in trauma teams. We sought to perform a preliminary, proof-of-concept study to assess the ability to perform head tracking during a simulated trauma scenario. We enrolled a convenience sample of two simulated trauma teams utilizing undergraduate health professional students from four disciplines available at our institution: second year Radiologic Science (RS), fourth year Physician Assistant (PA), second year Respiratory Care (RC), and fourth year Registered Nurse (RN) students. Each team performed a simulated trauma resuscitation two times while wearing Xsens® MTw motion trackers to track head movements during the resuscitation. These motions were analyzed using a standard measure of discriminating movement patterns known as the Hurst exponent (*H*). Pre and Post communication training movement patterns were compared to establish reliability of *H* in trainees learning trauma resuscitation. There was no difference between the pre and post communication training *H* values for either roll or yaw for any of the four disciplines indicating that non-verbal communications was avoided. The Hurst exponent reliably measures the direction of focus of the participants during some simulated trauma resuscitation scenarios. Future research will be needed to evaluate this analytic technique across providers and in the clinical setting.

I. INTRODUCTION

Medical errors occur in over 60% of patients in the outpatient setting and with nearly 1/3 of all patients admitted to healthcare facilities [1, 2]. Many of these errors, and their resultant adverse effects, may be related to poor communication and poor teamwork. Post-graduate team-based training has been shown to improve outcomes; however, there are few pre-graduate team-based training initiatives [3, 4].

Successful critical procedures, including the resuscitation of trauma patients, are the result of effective teamwork incorporating 3 key components: 1) efficient movements, 2) effective communication, and 3) focused assessment. Previous work has shown that highly performing individuals complete critical maneuvers rapidly and with limited variability [5, 6]. Current assessment of resuscitation team performance is often based on evaluations using checklists that evaluate verbal communication. However, highly efficient teams may function with several non-verbal cues that may not be measured by current assessment methods. To perceive these non-verbal cues, individuals are required to divert their visual attention from the patient point of focus to their peers.

Despite the advances in our understanding of how movement patterns influence communication, there is limited data on how providers focus on various aspects of the scene. Although a moving visual cue can be tracked only with eye gaze, a strong correlation exists between head movements and eye saccades [8]. While other fields have assessed non-verbal cues by tracking head movements [9] and used fractal statistics to assess motor skills [10] the use of these techniques in trauma teams are limited. We sought to perform a preliminary, proof-of-concept study to assess the ability to perform head tracking during a simulated trauma scenario. The major contributions of this paper are: (1) the quantitative determination of change in focus/attention during a team-based healthcare intervention activity between the patient/task and team members, (2) the observation that verbal instructions on team-based processes/activities has no direct influence on changing the point of focus of the providers, (3) the result of the *H* exponent is profession-independent, hence can be applied to the pre- and post-training scenarios irrespective of the training received by the healthcare providers.

II. METHODS

A. Hurst Exponent (H)

In complexity theory, the trajectories of a system in state space may be constrained within an identifiable region and easily identified by a set of numerical values (an attractor). Different types of dynamics lead to different attractor geometries, including points, cycles and fractal structures (chaotic systems). In general, Hurst exponents can be used to estimate system attractors from time series data. These exponents quantify both the strength of attraction exerted by the attractor on nearby points and the degree to which neighboring points within the attractor diverge from one another, and thus provide useful characterizations of the system.

Starting from the series $s(t) = [s_1, s_2, \dots, s_n]$ the attractor of the underlying dynamics is reconstructed in a phase space by applying the time-delay vector method. The reconstructed trajectory X can be expressed as a matrix where each row is a phase space vector:

$$X = [x_1, x_2, \dots, s_m]^T \tag{1}$$

where $x_i = [s_1, s_{i+\tau}, \dots, s_{i+(D_E-1)\tau}]$, $m = n - (D_E - 1)\tau$, D_E is the embedding dimension and τ is the delay time.
The Hurst algorithm for obtaining this exponent from a time series is as follows:

$$H(\tau) = \log\left(\frac{R(\tau)}{S(\tau)c}\right) \Big/ \log(\tau) \tag{2}$$

where

$$S(\tau) = \sqrt{\frac{1}{\tau}\sum_{i=1}^{\tau}\left(x_i - \bar{x}(\tau)\right)^2} \tag{3}$$

$$R(\tau) = \max_{1 \le t \le \tau} X(t,\tau) - \min_{1 \le t \le \tau} X(t,\tau) \tag{4}$$

The constant c is typically set to 1.0. A value H in the range of $0.5 < H < 1$ indicates a time series with long-term positive autocorrelation, whereas a value in the range of $0 < H < 0.5$ indicates a time series with long-term switching between high and low values in adjacent pairs. A value of $H = 0.5$ can indicate a completely uncorrelated series.

B. *Experimental Protocol*

Under an institutional review board (IRB) approved protocol, we enrolled a convenience sample of two simulated trauma teams utilizing undergraduate health professional students from four disciplines available at our institution: second year Radiologic Science (RS), fourth year Physician Assistant (PA), two-year Respiratory Care (RC), and fourth year Registered Nurse (RN) students. Each team consisted of one member from each discipline, randomly assigned, and the PA students were the team leads for the resuscitations. All participants completed a customized 30-minute online trauma resuscitation course, designed by the investigators, prior to the simulation. None had other formal trauma training (e.g. Advanced Trauma Life Support); however, all were certified in healthcare provider cardiopulmonary resuscitation. On the day of data collection, each team completed a simulated trauma resuscitation followed by a customized 30-minute trauma teamwork education module designed by the authors and described previously [11]. This module incorporated the tenets as defined by the Agency for Healthcare Research and Quality (AHRQ) TeamSTEPPS material [12] which is aimed at optimizing patient outcomes by improving communication and teamwork skills. The teams then completed a second simulated trauma/resuscitation exercise, identical to the first scenario. The details of the scenario have been published previously [11]. All data were collected on a single day at Gannon university's Patient Simulation Center and all simulations were video recorded for offline review and analysis.

C. *Measure of Head Movements*

Head motion and orientation of the participants was measured using Xsens® MTw motion trackers (Xsens North America Inc.) affixed using color-coded headbands to the position of the external occipital protuberance. The reference frame of the motion sensor is defined as a right-hand orthogonal coordinate system. The origin is positioned at the head's center of rotation which is assumed to coincide with the atlas. With the head parallel to the sagittal plane, the y-axis of the reference frame is negative in the rostral direction while the positive z-axis points upwards and the positive x-axis points laterally towards the left ear (Figure 1). Rotations of the head about the x-, y-, and z-axis were defined as the roll, pitch, and yaw respectively.

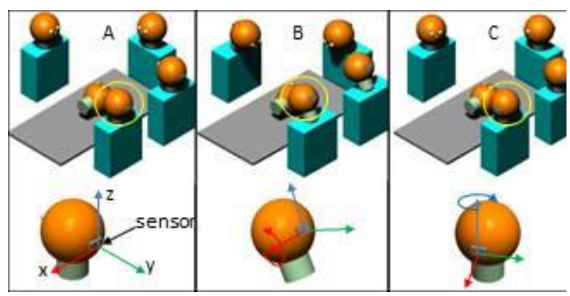

Figure 1. Spatial positioning and head orientation of providers during the simulated trauma/resuscitation exercise. A) zeros of sensors; B) focusing on patient, with a rotation of the sensor around the x-axis (roll); C) focusing on the colleagues with a rotation of the sensor around the z-axis (yaw)

Given that in the simulated trauma scenario, each of the participants in a team stood in a circle around the mannequin representing the patient (Figure 1, 2), a movement of the head up and down (rotation around the x-axis of the sensor and thus change in *roll* angle) is assumed to be representative of a transition of focus from the patient to other team participants, and vice versa. Rotations of the head to look left and right (rotation around the z-axis of the sensor and thus change in *yaw* angle) is indicative of change in focus toward the team members on either side of a participant.

It is important to know where these 4 teams need to stay for better patient's care. We positioned the RT close to the head of the patient since this provider need to do the intubation. The RN need to have access to the thorax for the use of the defibrillator. RS intervene only if needed and therefore is generally toward the leg of the patient.

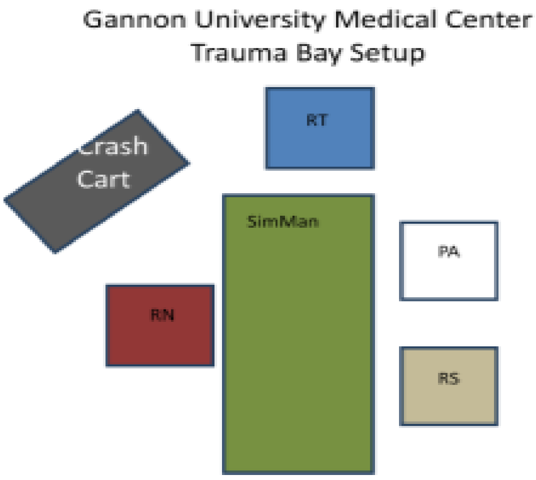

Figure 2. Spatial positioning of providers during the simulated trauma/resuscitation exercise. RT = respiratory therapy student, RN = registered nursing student, PA = physician assistant student, RS = radiologic science student.

Head movement during gaze can have several levels of complexity. If the subject's gaze is fixated on a point they are paying visual attention to, the complexity of the head movement is low. The movement of the target and the change in the target's trajectory from predictable (based on an obvious, recognizable pattern) to unpredictable increases the complexity of the subject's head movement. Random movements are observed during visual scanning for a clue when the subject is not paying attention to a single event.

D. *Application of Hurst Exponent to head movements.*

The decrease in head movement complexity, and therefore increase of attention on a well-defined task can be quantified using Hurst exponent (*H*). This study evaluated the *H* values of Euler coordinates of head motions as an indicator of focus and attention to the patient (roll) and to the teammates (yaw), during a simulated trauma resuscitation using a unique team of interdisciplinary trainees.

The *H* algorithm is a statistical measure used for analyzing nonlinear time series data. It provides an estimate of the persistence of data over time. Persistent data denotes information that does not change frequently (fixating a point). Anti-persistent data indicates that if a value in the time series had been up in the previous period, it is more likely that it will be down in the next period and vice versa. With values lying between 0 and 1, a *H* value between 0 and 0.5 indicates anti-persistence. This means that the activity from which the time series data was collected goes through a switching sequence between high and low values. A *H* value of 0.5 is indicative of a purely random motion, while a H value lying between 0.5 and 1 indicates persistent data. The *H* estimate was applied in the study to determine if there is a change in the direction of focus of the participants during trauma resuscitation scenarios occurring after online training and TeamSTEPPS.

Repetitive changes of the head's Euler's angles, irrespective of the complexity of the motions is made evident by *H* values, which was computed from motion data collected during the trauma resuscitation scenarios. The computation of *H* estimates was done using a Microsoft Excel add-on (NumXL 1.59 by Spider Financial) applying the corrected Hurst exponent algorithm [13, 14]. We used the paired, two-sided t-test to compare pre and post values by provider discipline and considered a $p<0.05$ to be significant.

III. Results and Discussion

The result of the *H* estimates in the Pre- and Post - TeamSTEPPS training scenarios are summarized in Table 1. There was no statistically significant difference between the pre- and post-TeamSTEPPS *H* values for either roll or yaw while comparing data of all of the healthcare disciplines involved in the study. pre- and post-TeamSTEPP scenarios show high persistence (subjects mostly focusing on a specific scene) with *H* values ranging between 0.8 and 1(Figure 3, 4). An example of raw data is presented in Figure 5.

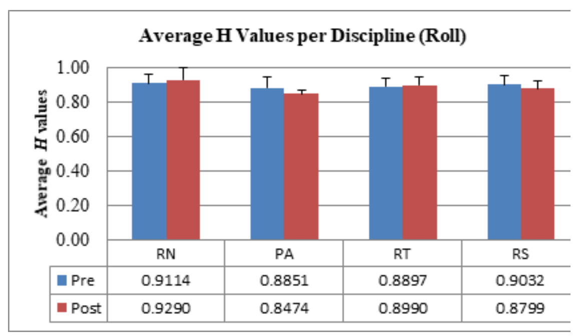

Figure 3. Clustered column charts of H estimates of roll head motions (looking up and down)

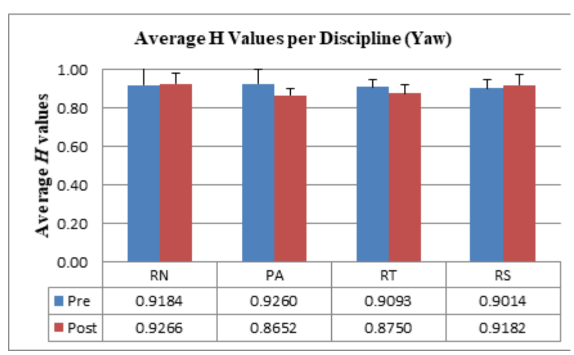

Figure 4. Clustered column charts of *H* estimates of yaw head motions (looking left and right)

Table 1. Mean *H* estimate values

	ROLL				
	Pre		Post		p-value
	Mean	St. Dev.	Mean	St. Dev.	
RN	0.9114	0.05	0.9290	0.07	0.55
PA	0.8851	0.06	0.8474	0.02	0.35
RT	0.8897	0.05	0.8990	0.05	0.54
RS	0.9032	0.05	0.8799	0.04	0.20

	YAW				
	Pre		Post		p-value
	Mean	St. Dev.	Mean	St. Dev.	
RN	0.9184	0.10	0.9266	0.05	0.87
PA	0.926	0.07	0.8652	0.04	0.34
RT	0.9093	0.04	0.8750	0.05	0.17
RS	0.9014	0.05	0.9182	0.06	0.64

Previous works suggested that ocular tracking can identify eye movement patterns that differ between providers of different proficiency [15]–[18]. Resuscitation of critically ill patients, including trauma patient, can often be chaotic making ocular filtering through this chaos challenging for providers. Problems with scene perception during critical procedures and trauma resuscitations, as measured by visual tracking, have been linked to cognitive deficiencies [15, 16]. Proficient providers have longer fixation times on fewer aspects of the scene during trauma resuscitation scenarios while less proficient providers have short fixation times, often haphazardly scanning the entire scene [15]. Identifying visual centers of attention may be one objective way to identify cognitive deficiencies in providers and allow impactful, focused feedback to trainees. Our preliminary work suggests that the *H* exponent may reliably measure how providers focus on the scene. Identifying areas where healthcare providers divert their focus from the patient could potentially lead to focused interventions to help improve performance.

The limitation of this work lies in the small number of subject available for the analysis and limited healthcare disciplines. Also, this was performed in a simulated setting and future work will be needed to evaluate these techniques in the clinical setting. This work represents a stepping-stone for the use of fractal statistical analysis in the characterization of visual attention and non-verbal communication in emergency medicine scenarios. As a follow-up to this study, further analysis will be needed to determine the probability of the recurrence of positive autocorrelation in both the Pre and Post scenarios, and the predictability of H estimates in either scenario. While the H values deduced from this study indicate persistence focus of the providers in a specific direction, more insight can be got on the specific subject of the persistent focus if the *H* results are compared with visual head orientation observations.

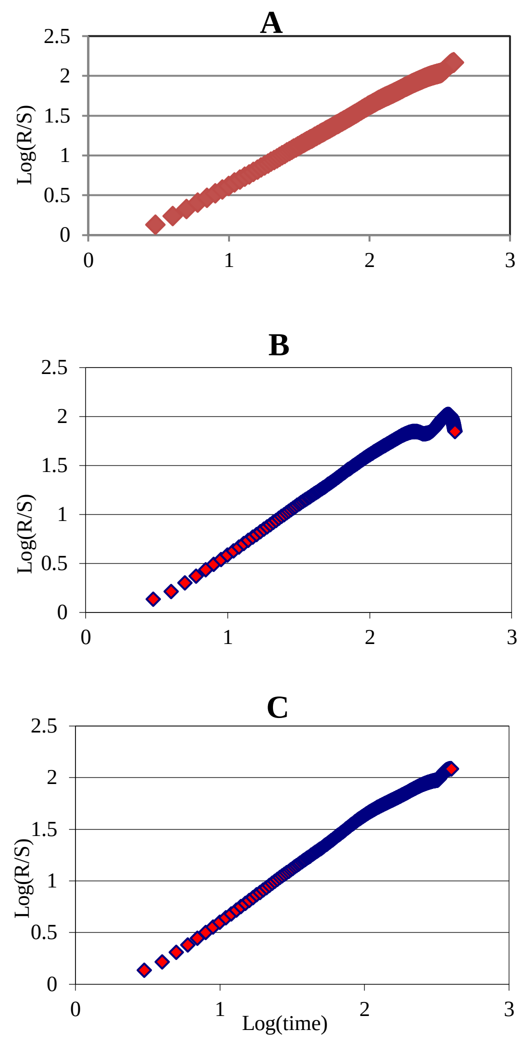

Figure 5. Rescaled Range (R/S) plots of roll (A), pitch (B) , yaw (C) with Hurst Exponent *(H)* values of 0.9392, 0.8457, and 0.8940 respectively, from a 10-second sample data of a provider's head movement. Motion data was collected at a sampling frequency of 40Hz. *H* is the slope of an R/S plot.

IV. Conclusion

We used head movement to infer the focus of healthcare providers in a simulated trauma resuscitation activity. By positioning the laying simulated patient a waist height of the provider they were forced to rotate their head on the sagittal plane to look down. By positioning the team members around the bed and not in direct line of sight, the provider where forced to move the head left and right rotating it around the coronal plane. We recorded and analyzed these two signals as a figure of merit of the focus of the provider either on the task or on the teammates. The Hurst exponent applied to the signals, reliably measures the direction of focus of the participants during a simulated trauma resuscitation scenario. Future research will be needed to evaluate this analytic technique across providers and in the clinical setting. Application of H to the determination of orientation independently of either direct *in situ* visual observations or review of recorded videos, presents opportunities for markerless, and non-video dependent deduction of team efficiencies in various work and non-work scenarios, and real-time analysis of same in low-light conditions.

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