Multifractal Analysis of Heart Rate Dynamics as a Predictor of Teammate Trust in Human-Machine Teams

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Overview. Teams are complex systems with many different layers (i.e., physiological, behavioral, technological, and other socio-cognitive constructs, such as trust) that interact with one another to accomplish a common goal or task. Each team member is far more likely to exhibit multifractality in physiological and social measures rather than a single pattern across all scales (Likens et al., 2014). The multifractal structures or multifractality are a form of self-similar systems in which a distribution of scaling parameters (fractal dimensions) can characterize the dynamics. Multifractal analysis is a method of capturing the underlying scaling in physiological behaviors (in our case, heart rate variability) via generalized dimensions (Grassberger, 1983) and $f(\alpha)$ spectra (Halsey et al., 1986). The scaling parameters of a multifractal system can be analyzed in terms of Hölder exponents (h). Values of h are interpreted as follows: $0 \leqslant h < 0.5$ represents antipersistent behavior, $h = 0.5$ represents random behavior, and $h > 0.5$ represents persistent behavior (Bishop et al., 2012). The persistent behavior means that an increase in one time period is more likely to be followed by a further increase in the next period. In this study, we applied multifractal analysis to study the time-dependence of inter-beat interval (IBI) in light of a human-machine team (HMT) task process and examined how the Hölder exponent of IBI changed across individual team members over time. Another layer of an HMT is trust in a teammate, which is dynamic and emerges through the interaction between the team members (Demir et al., 2021); therefore, it needs to be predicted by interaction-based real-time physiological and psychological measures (Huang et al., 2020). A previous study from the same experiment has examined trust using exploratory factor analysis (EFA; see Demir et al. (2021) for full details). In this study, we analyzed the trust data with a focus on one of those EFA factors, i.e., "*trust that human team member put in the AI pilot*," to examine the relationship between the Hölder exponent of IBI and trust.

Scenario and design. In this study, the primary team task was taking photographs of predefined reconnaissance targets in a simulated remotely piloted aircraft (RPA) synthetic task environment. The RPA ground station team was composed of three interdependent roles who communicated via text chat: (1) the *navigator*, who provided information regarding the flight plan as well as speed and altitude restrictions of each waypoint; (2) the *pilot*, whom participants were told was an AI teammate controlled the movement of the RPA and negotiated altitude and airspeed settings with the photographer to meet photo requirements; and (3) the *photographer*, who operated the camera system and sends feedback to the other team members about the status of target photographs. The experiment consisted of ten 40-minute missions in which teams needed to take as many good photos of ground targets as possible while managing the RPA and adjusting to changes in altitude, airspeed, and targeting constraints along the route. The missions were conducted across two sessions (four missions for Session 1 and six for Session 2) with a one to two-week interval between sessions. The primary study manipulation was system failures with limited recovery times, which were applied to pre-selected targets in each mission, including (1) role-level display failures, (2) abnormal behavior of the AI, and (3) a cyber-attack on AI, leading to the AI providing false, detrimental information to the team.

Method. In this experiment, there were 22 teams, composed of two randomly selected participants, randomly assigned to the navigator and photographer roles. The pilot role was assigned to one experimenter who mimicked an "AI" pilot (Wizard of Oz paradigm; Kelley, 1984) by using restricted language via chat script to mimic the computer language capabilities. We considered the measures of IBI (the time between heartbeats in milliseconds) and trust. Trust was measured through a questionnaire administered to the navigator and photographer roles at the end of each session. There is no universally recognized way to measure trust in HMTs, so we adapted our questionnaire to capture both team trust and trust put in an AI adapting questions from Mayer et al. (1995) and Jian et al. (2000).

Results and discussion. The findings show that the Hölder exponent of IBI differentiated across the roles and decreased across the missions. There was also a positive association between the Hölder exponent of IBI and trust in the AI team member. The findings suggest that: (1) the Hölder exponent increased with trust in the AI teammate; (2) Both Hölder and trust decreased over time; (3) the Hölder exponent was predictive of the participant's trust. The Hölder exponent results indicate that antipersistent behavior (i.e., an increase at a one-time interval is more likely to be followed by a decrease) was associated with getting over the missions (i.e., decrement of the Hölder), which is also associated with the decline of trust.

Acknowledgments. This research was partially supported by ONR Award N000141110844 (Program Managers: Marc Steinberg, Paul Bello) and ONR Award N000141712382 (Program Managers: Marc Steinberg, Micah Clark). We also

acknowledge the assistance of Steven M. Shope, Sandia Research Corporation, who developed the testbed.

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