Feasibility of Healthcare Providers' Autonomic Activation Recognition in Real-Life Cardiac Surgery Using Noninvasive Sensors

Lauren R. Kennedy-Metz[1](✉), Andrea Bizzego[2], Roger D. Dias[3], Cesare Furlanello[4], Gianluca Esposito[2,5], and Marco A. Zenati[1]

[1] Medical Robotics and Computer-Assisted Surgery Lab, Harvard Medical School and VA Boston Healthcare System, Boston, MA, USA
lauren.kennedy-metz@va.gov, marco_zenati@hms.harvard.edu
[2] University of Trento, Trento, Italy
{andrea.bizzego,gianluca.esposito}@unitn.it
[3] Human Factors and Cognitive Engineering Lab and STRATUS Center for Medical Simulation, Brigham and Women's Hospital, Boston, MA, USA
rdias@bwh.harvard.edu
[4] HK3 Lab and Bruno Kessler Foundation, Trento, Italy
cesare.furlanello@hk3lab.ai
[5] Nanyang Technological University, Singapore, Singapore

Abstract. Cardiac surgery is one of the most complex specialties in medicine, akin to a complex sociotechnical system. Patient outcomes are vulnerable to surgical flow disruptions (SFDs), a source of preventable harm. Healthcare providers' (HCPs) sympathetic activation secondary to emotional states represent an underappreciated source of SFDs. This study's objective was to demonstrate the feasibility of detecting elevated sympathetic nervous system (SNS) activity as a proxy for emotional distress associated with a medication error using heart rate variability (HRV) analysis. After obtaining informed consent, audio/video and HRV data were captured intraoperatively during cardiac surgery from multiple HCPs. Following a critical medication administration error by the anesthesiologist in-training, the attending anesthesiologists' recorded HRV data was analyzed using *pyphysio*, an open-source signal analysis package, to identify events precipitating this near-miss event. We considered elevated low-frequency/high-frequency (LF/HF) HRV ratio (normal value <2) as a primary indicator of SNS activity and emotional distress. A heightened SNS response by the attending anesthesiologist, observed as an LF/HF ratio value of 3.39, was detected prior to the near-miss event. The attending anesthesiologist confirmed a state of significant SNS activity/distress induced by task-irrelevant environmental factors, which led to a temporarily ineffective mental model. Qualitative analysis of audio/video recordings revealed that SNS activation coincided with an argument over operating room management causing SFD. This preliminary study confirms the feasibility of recognizing potentially detrimental psychophysiological states during cardiac surgery in the wild using HRV analysis. To our knowledge, this is the first case demonstrating SNS activation coinciding with self-reported and observable emotional distress during live surgery using HRV. Irrespective of the HCP's expertise, transient but intense emotional changes may disrupt attention processes leading to SFDs and preventable

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errors. This work supports the possibility to detect real-time SNS activation, which could enable interventions to proactively mitigate errors. Additional studies on our large database of surgical cases are underway to confirm this observation.

Keywords: Cardiac surgery · Cognitive engineering · Neuroergonomics · Emotion recognition · Heart rate variability

1 Introduction

Cardiac surgery represents a complex sociotechnical environment relying on a combination of technical and non-technical expertise in a team-based setting. Surgical flow disruptions (SFDs) to standard operating procedures may be influenced by a variety of sources, including but not limited to patient factors (e.g. unexpected anatomy), provider expertise (e.g. novice vs. expert clinicians) or factors (e.g. fatigue), social factors (e.g. low team familiarity), environmental factors (e.g. operating room [OR] scheduling conflicts), and emotional factors (e.g. anger/frustration) [1]. Many of these sources and their impacts can be observed in healthcare providers (HCPs) through ethnographic approaches. One underappreciated yet critical source of SFDs is the influence of emotional factors, which cannot be observed without the use of either subjective self-report or objective sensors capturing underlying physiological activity.

Emotion recognition and resolution is especially important in HCPs given the known effect emotion can have on processes such as perception, memory, attention, decision-making and reasoning [2]. By identifying emotional states that have the potential to disrupt cognitive processes (e.g. distress), HCPs may be better equipped to anticipate and cope with these changes. Further, the analysis of underlying physiology may provide insight into autonomic processes indicative of intense emotional changes.

Autonomic nervous system (ANS) activity represents the interplay between the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS). Activation of the SNS and withdrawal of the PNS reflects states of elevated distress, which is detectable through heart rate capture and heart rate variability (HRV) analysis. The OR, and the cardiovascular OR in particular, represents a setting with additional pressures such as temporal demands that could exacerbate the negative effect emotions can have on the aforementioned cognitive processes, as well as decision-making capacities [3].

The objective of this study was to assess the feasibility of detecting a high intensity arousal state (through ANS activity) as a proxy for emotional distress associated with a known near-miss event through physiological analysis of HRV signals. By triangulating additional data sources, we sought to identify a specific emotional state represented by this heightened arousal.

2 Methods

2.1 Data Collection

As part of a larger NIH-funded project, video, audio, and heart rate data were captured from the surgical team during a routine coronary artery bypass graft procedure. Two

GoPro cameras captured a wide view of the OR and a narrow view of the surgical field, while microphones equipped to the senior team members (attending anesthesiologist, attending surgeon, and primary perfusionist) captured relevant communications inside and outside of the OR.

Team members were also each equipped with a wearable, wireless heart rate monitor (Polar H10 sensors) and a corresponding signal receiver (Polar V800). HRV was collected given the noninvasive, continuous nature of data collection afforded, as well as its prior utility in the surgical setting [4].

2.2 Case Description

Following the observation of a serious medication administration error by the resident anesthesiologist (new trainee), which should have been prevented with oversight from the senior anesthesiologist, multiple data sources were consulted to identify the events precipitating this near-miss event.

A routine root cause analysis was carried out by hospital administrators [5], which uncovered a self-reported incidence of transient anger/frustration experienced by the senior anesthesiologist. This was induced by task-irrelevant environmental factors concerning OR management, requiring the anesthesiologist to leave the OR and negotiate a departmental argument, all occurring prior to the near-miss event. Video analysis confirms that at the time of the medication administration error, the attending anesthesiologist was in the OR and resuming task-relevant teaching and patient care duties.

2.3 Data Analysis

Using *pyphysio*, an open-source physiological signal processing Python package [6], we analyzed the attending anesthesiologists' HRV to detect the influence of ANS activity via SNS activation and PNS withdrawal, and thereby emotional distress, contributing to the lack of situation awareness and expected oversight during the resident's improper medication administration. Data were analyzed from the time of first incision through sternal closure by calculating all HRV values for all consecutive one-minute, nonoverlapping time windows.

The low frequency/ high frequency (LF/HF) ratio was selected as the primary HRV component of interest in this analysis. The LF/HF ratio reflects the proportion of both sympathetic and parasympathetic innervation [7] such that higher values indicate sympathetic predominance and arousal, while lower values indicate sympathetic withdrawal. LF/HF ratio has been previously associated with mental workload states on short time scales [8]. Based on short-term HRV data collected from a sample of over 1,200 healthy individuals aged 45–54, an average expected LF/HF ratio under resting conditions is around 2.01 units [9]. This value is our frame of reference for the subsequent analysis, given that the attending anesthesiologists' age at the time of data collection was 47.

Additional analysis considered the root mean square of the successive differences (RMSSD), a time-domain HRV associated with cognitive load [10]. Given the primarily parasympathetic nervous system (PNS) tone reflected by RMSSD, lower values indicate parasympathetic predominance and lower arousal states.

Reports given during root cause analysis procedures and audio data during the case were consulted to provide additional contextual information as necessary.

3 Results

Heightened SNS activation, reflecting an extreme elevation in the attending anesthesiologists' physiological arousal and represented by an LF/HF ratio value of 3.39 units, was detected in one sample, representing one minute, prior to the near-miss event (Fig. 1). This is in direct contrast to substantially lower values presenting in five consecutive samples prior to and five consecutive samples after the elevated sample. Specifically, the value of each of the ten minutes on either side of this sample range from 151% to 290% lower than the elevated sample comparatively.

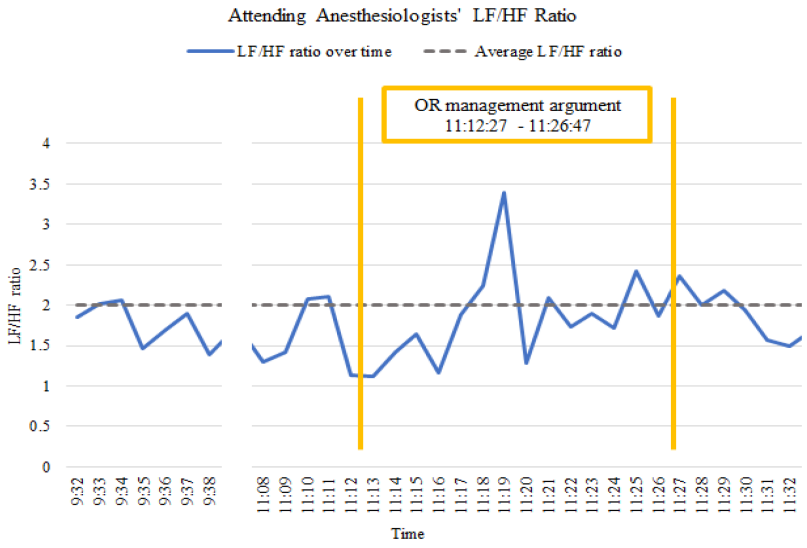

Fig. 1. Visual representation of the attending anesthesiologist's LF/HF ratio over time (blue solid line). For reference, the gray dotted line indicates this individual's average LF/HF ratio value over the course of the entire surgical procedure (2.00). From 11:12:27 through 11:26:47, the anesthesiologist is engaged in a frustrating case-irrelevant conversation. This marked elevation in SNS activity (observed here through an uncharacteristically high LF/HF ratio value) may be an indicator of emotional distress, and possibly of anger. (Color figure online)

Analysis of the parasympathetic tone revealed a sharp decrease in RMSSD amid the same samples reflecting heightened LF/HF ratio values (Fig. 2). The pattern of change does not mimic the LF/HF ratio observation precisely, but complements the finding of sympathetic activation by illustrating parasympathetic withdrawal during the same timeframe.

During standard root cause analysis procedure, the attending anesthesiologist confirmed a state of high emotional distress (specifically, frustration and anger) induced by

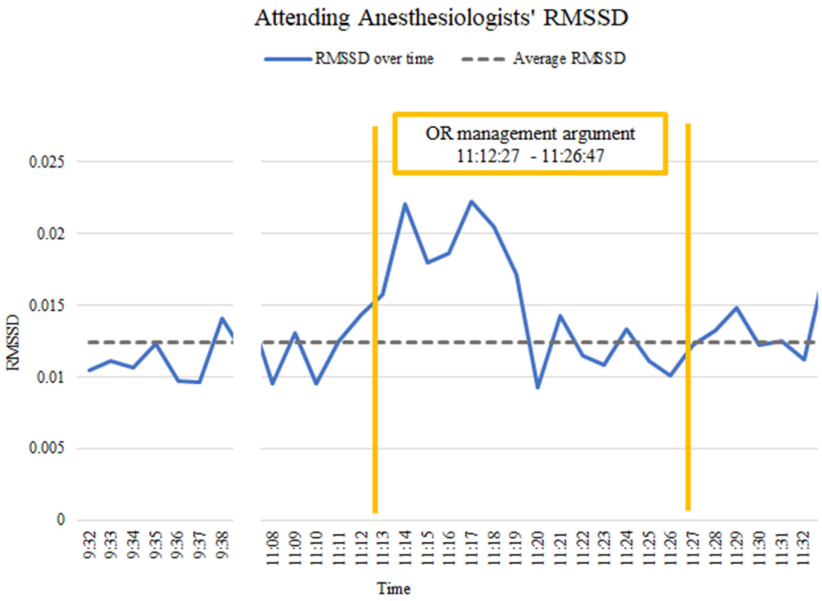

Fig. 2. Visual representation of the attending anesthesiologist's RMSSD over time (blue solid line). The gray dotted line indicates the average RMSSD value recorded over the course of the entire surgery. Corresponding to the time of the self-reported frustrating case-irrelevant conversation, we can observe a decrease in PNS activity (a sharp decline in RMSSD), complementing LF/HF ratio results. (Color figure online)

task-irrelevant environmental factors. Meanwhile, the trainee who committed the medication administration error confirmed lack of procedural knowledge and had no prior experience in the cardiovascular OR. In combination, it could be argued that the trainee's inexperience coincided with the senior anesthesiologists' lapse in attention/judgment, ultimately resulting in the preventable near-miss event that occurred.

The anesthesiologists' self-reported state of distress was further confirmed by audio recordings capturing an argument over OR management occurring at the same time as the LF/HF ratio elevation and RMSSD decline. This involved conflicting demands stemming from a discussion surrounding OR management and flow. The nature of the discussion required staff to compromise on OR flow and created tension among staff given the limited resources available (OR rooms currently in use and scheduled for use), patient concerns (delaying surgeries for patients who were already prepared and waiting for surgery), timing (operating late into the night), and personal concerns (one clinician was pregnant at the time).

4 Discussion

This preliminary study confirms the feasibility of recognizing detrimental psychophysiological influences during cardiac surgery procedures via HRV analysis. To our knowledge, this is the first such case demonstrating ANS activity coinciding with strong self-reported emotion during naturalistic surgery using HRV. The primary finding of this

analysis suggests that despite HCP's extensive experience in the cardiac OR, transient but intense ANS activity (detected through SNS activation and PNS withdrawal) corresponding to self-reported emotional distress may have the potential to disrupt attention processes in even the most qualified of clinicians.

Within the analyzed dataset, there were only two other incidences of LF/HF ratio values exceeding 3 units. In both cases, the percent change between surrounding values and the elevated sample were not nearly as substantially magnified. Audio/video analysis revealed that both instances were associated with detailed teaching moments between the attending anesthesiologist and the trainee, involving discussion of procedure-specific checklists and processes.

The influence of emotional states on a range of cognitive processes [2] and decision-making is well-described [3, 11], yet investigation into its effects in surgery are underexplored. The operative environment is a uniquely data-rich setting equipped with devices automatically capturing a wide range of information regarding patient status, surgery-specific procedures, temporal relationships, and more. Additionally, the OR affords the opportunity for granular team-based, behavioral, technical, and non-technical analysis of the surgical team. It is possible, but not yet common practice, to simultaneously collect physiological data of HCPs in this setting as well. Harnessing these disparate data sources alongside one another in a time-synchronized, continuous fashion allows a more comprehensive exploration and understanding of internal, otherwise unobservable factors influencing surgical processes.

A major implication of this type of work is the possibility of real-time recognition of ANS activity and/or emotional distress, which could enable personalized cognitive engineering coping interventions to proactively mitigate downstream adverse events [12]. Additional studies on our large database of surgical cases are underway to confirm this preliminary observation. Future work is also in the planning process to explore these interactions further.

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References

1. Wiegmann, D.A, ElBardissi, A.W., Dearani, J.A., Daly, R.C., Sundt III, T.M.: Disruptions in surgical flow and their relationship to surgical errors: an exploratory investigation. Surgery **142**(5), 658–665 (2007)
2. LeBlanc, V.R., McConnell, M.M., Monteiro, S.D.: Predictable chaos: a review of the effects of emotions on attention, memory and decision making. Adv. Health Sci. Educ. **20**(1), 265–282 (2014)
3. Mosier, K.L., Fischer, U.: The role of affect in naturalistic decision making. J. Cogn. Eng. Decis. Making **4**(3), 240–255 (2010)
4. Dias, R.D., Ngo-Howard, M.C., Boskovski, M.T., Zenati, M.A., Yule, S.J.: Systematic review of measurement tools to assess surgeons' intraoperative cognitive workload. Br. J. Surgery **105**(5), 491–501 (2018)
5. Wu, A.W., Lipshutz, A.K.M., Pronovost, P.J.: Effectiveness and efficiency of root cause analysis in medicine. JAMA **299**(6), 685–687 (2008)

6. Bizzego, A., Battisti, A., Gabrieli, G., Esposito, G., Furlanello, C.: pyphysio: a physiological signal processing library for data science approaches in physiology. SoftwareX **10**, 1–5 (2019)
7. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology: Heart rate variability: standards of measurement, physiological interpretation and clinical use. Eur. Heart J. **17**, 354–381 (1996)
8. Castaldo, R., Melillo, P., Bracale, U., Caserta, M., Triassi, M., Pecchia, L.: Acute mental stress assessment via short term HRV analysis in healthy adults: a systematic review with meta-analysis. Biomed. Signal Process. Control **18**, 370–377 (2015)
9. Dantas, E.M., et al.: Reference values for short-term resting-state heart rate variability in healthy adults: results from the Brazilian Longitudinal Study of Adult Health—ELSA-Brasil study. Psychophysiology **55**(6), 1–12 (2018)
10. Shaffer, F., Ginsberg, J.P.: An overview of heart rate variability metrics and norms. Front. Publ. Health **5**(September), 1–17 (2017)
11. Albayram, Y., Khan, M.M.H., Jensen, T., Buck, R., Coman, E.: The effects of risk and role on users' anticipated emotions in safety-critical systems. In: Harris, D. (ed.) EPCE 2018. LNCS (LNAI), vol. 10906, pp. 369–388. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-91122-9_31
12. Zenati, M.A., Kennedy-Metz, L., Dias, R.D.: Cognitive engineering to improve patient safety and outcomes in cardiothoracic surgery. Semin. Thorac. Cardiovasc. Surg. **32**(1), 1–7 (2019)