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Association Between Operating Room Noise and Team Cognitive Workload in Cardiac Surgery

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Abstract

Excessive intra-operative noise in cardiac surgery has the potential to serve as source of distraction and additional cognitive workload for the surgical team, and may interfere with optimal performance. The separation from bypass phase is a technically complex phase of surgery, making it highly susceptible to communication breakdowns due to high cognitive demands and requiring tightly coupled team coordination. The objective of this study was to investigate team cognitive workload levels and communication in relation to intra-operative time periods representative of infrequent vs. frequent peaks in ambient noise. Compared to 5-minute segments with no peaks in noise at all, segments with the highest percentage of noise peaks (≥10%) were significantly associated with higher team members' heart rate before, during, and after noise segments analyzed. These noisier segments were also associated with a significantly higher level of case-irrelevant communication events. These data suggest that case-irrelevant conversations associated with a greater degree of excessive peaks in noise may be associated with team workload levels, warranting further investigation into efforts to standardize communication during critical surgical phases.

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Keywords

noise level; cognitive workload; heart rate; cardiac surgery; teams

I. Introduction

The impact of surgical flow disruptions (SFDs) on cognitive workload has been explored in the operating room (OR), demonstrating a relationship between performance impairment in surgery and increases in mental workload [1]. Of the various types of SFDs, interest has developed surrounding the role of noise in the OR [2]. According to the World Health Organization's 1995 report, intra-operative noise levels should remain below 35 decibels (dB) [3], a level considered to fall into the "soft" noise range based on the more recent noise level classifications published by the American Academy of Audiology [4]. Though noise levels as high as 120 dB are often generated through equipment-related activities [5], preventing excessive levels of noise during critical phases may be integral in reducing SFDs [6].

Previous work has identified that surgical phases with the highest levels of noise tend to be those requiring a high degree of standardized and inter-team communications (i.e., pre-incision time-out, post-operative debrief) [7]. Based on these observations, it is reasonable to consider that high levels of noise across an entire intra-operative phase may be beneficial due to higher levels of team communication, and perhaps representative of effective teamwork. It is also possible, however, that during phases requiring a high degree of temporal and team-based coordination (e.g., separation from cardiopulmonary bypass), high levels of noise may in fact be the source of SFDs. Furthermore, this approach [7] has not taken into account the fluctuations in noise levels, or similarly, the effect of isolated peaks in noise on factors including communication content and patterns, or cognitive workload levels.

Analysis of intra-operative noise peaks suggests a greater tendency for the surgical team to engage in case-irrelevant conversations during times encompassing more frequent noise peaks [8]. While the conclusions from this previous work suggest that peaks in noise demand attentional resources that may impair effective communication styles, a relationship between noise peaks and cognitive workload has yet to be established.

Self-report instruments such as the SURG-TLX [9] represent validated measures to approximate various dimensions of cognitive workload within cardiac surgery teams [10]. Domain-specific constraints of the OR, however, require participants to recount their impressions of cognitive workload levels, introducing recall bias and minimizing the granularity of responses. To increase the objectivity and level of granularity obtained, unobtrusive sensors capturing psychophysiological indicators of cognitive workload have become a feasible and valid alternative to subjective approaches representing a single time point. Heart rate (HR) in particular is an indicator of cognitive workload [11], [12] that can easily and continuously be obtained in operative settings [13].

The objective of this exploratory work was to investigate the relationship between segments of time characterized by absent (low-noise) vs. frequent (high-noise) peaks in noise in the

OR and a team measure of cognitive workload (HR averaged across team members) during the separation from bypass phase of on-pump cardiac surgery procedures. This phase is particularly complex, considered high-demand by the team [14], and requires high levels of communication and coordination. Secondary qualitative analysis explored how the nature of the conversations contributing to noise levels may differ according to the noise level recorded. Based on prior research, we hypothesized that noise levels would be associated with a greater indication of SFDs and higher team cognitive workload.

II. Methods

A. Participants

This research complied with the American Psychological Association Code of Ethics and was approved by the Institutional Review Board at VA Boston Healthcare System and Harvard Medical School (IRB#3296). Informed consent was obtained from all participants, which included patients and all OR staff involved with the procedures.

Data were collected during 18 non-emergent cardiac surgery procedures (N=14 coronary artery bypass graft, N=4 aortic valve replacement). Core surgical staff monitored included attending surgeons (N=3), attending anesthesiologists (N=5), perfusionists (N=4), and OR scrub nurses (N=4).

B. Equipment and measures

Data acquisition involved collecting continuous noise levels from the OR, collecting continuous HR data from the core surgical team members, and recording audio and video streams to capture behavioral dynamics within the entire OR from two angles.

Noise: A B&K 735 Sound Level Meter (B&K Precision, Yorba Linda, CA) was placed in the center of the OR to capture second-by-second sound pressure level (SPL) measured in decibels. This device captures sound between 30 dB and 130 dB at a resolution of 0.1 dB with an accuracy of ±1.5 dB and was set to A-weighting to capture general noise sound level (dB(A)).

Heart rate: Each member of the core surgical team – including the attending surgeon, attending anesthesiologist, perfusionist, and scrub nurse – was equipped with a 3-lead ambulatory ECG device (MindWare Technologies LTD, Westerville, OH) capturing ECG waveforms at a sampling rate of 500 Hz, and a wireless AVX lapel microphone (Sennheiser, Wedemark, Germany).

Behavioral dynamics and phase of the operation: Two P1375 network cameras (Axis Communications, Lund, Sweden) were configured with wide angles and positioned to capture inter- and intra-team dynamics throughout the OR.

C. Analysis

The separation from bypass phase of each cardiac surgery procedure was annotated by coding audio/video recordings according to previous work [15]. Within each procedure, the separation from bypass phase was further segmented into consecutive, non-overlapping

5-minute segments. Five minutes is considered the standard time range for calculating short-term HR and heart rate variability components [16], while also allowing the observation of a variety of behaviors, conversations, and noise level changes. Given the synchronized acquisition times across devices, matching timestamps across data were utilized for analysis.

Across the 17 procedures analyzed, a total of 98 five-minute segments were identified. In total, the separation from bypass phase was 25.83 minutes on average (standard deviation: 12.19 minutes). Adopting previous methodology used in this field [8], noise level data from all 5-minute segments were scanned to identify elevations in noise level exceeding 70 dB(A) on a second-by-second basis. Following this step, the number of individual peaks was transformed to a percentage to represent a comparable frequency of elevations in noise for each segment.

Of the 98 total segments, 18 segments were observed to have zero noise peaks exceeding 70 dB(A), which were classified as low-noise segments. The 18 noisiest segments were also identified and classified as high-noise segments.

HR analysis using Kubios HRV Premium [17] generated a single HR value for each 5-minute segment preceding, encompassing, and following the 36 total noise segments. The nature of this observational design and the inherent variation in baselines across individuals introduced the necessity to normalize physiological data for each individual monitored, enabling comparability within and between providers. The following equation was applied to all 5-minute segments for each individual provider to normalize HR data:

$$Norm_{HR} = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (1)$$

where x refers to the average HR value across the 5-minute segment in question, x_{min} refers to that provider's minimum 5-minute HR value during the entire surgery, and x_{max} refers to that provider's maximum 5-minute HR value during the entire surgery. Normalization of individual segments was conducted to eliminate the effect of variation and couch values within a 0–1 range, where normalized values closer to 0 indicate HR values closer to that provider's observed minimum, and values closer to 1 indicate HR values closer to that provider's maximum (see [18]).

Normalized HR values across providers were then averaged together for each 5-minute segment, generating a normalized Team HR value corresponding to each of the 36 five-minute segments under investigation, as well as 36 five-minute segments preceding and 36 five-minute segments following those under investigation.

Video segments corresponding to each of the 36 noise segments under investigation were then analyzed to classify the nature of conversations. Communications analyzed were those occurring across all teams (including the sterile team of the surgeons and scrub nurse, as well as the anesthesiologists and perfusionists). A previously developed behavioral rating scale was utilized to label communication events as either case-relevant or case-irrelevant [19]. A label for no communication was also included. The duration of each communication

event was noted, resulting in percentages to represent a comparable frequency of case-relevant, case-irrelevant, or no communication for each segment.

III. Results

Low-noise segments (N=18) represented 5-minute episodes with zero peaks in noise above 70 dB(A). High-noise segments (N=18) represented 5-minute episodes with the highest percentage of second-by-second samples exceeding 70 dB(A), averaging 19.57% in total.

A two-way ANOVA with repeated measures was performed to analyze the effect on Team HR incurred by noise level (low-noise vs. high-noise) and time point (5 minutes before, 5 minutes during, and 5 minutes after specific segments). Simple main effects analysis showed that noise level had a statistically significant effect on Team HR ($p < 0.001$), such that low-noise segments induced lower Team HR, regardless of the time point in question. However, simple main effects analysis showed that time point did not have a statistically significant effect on Team HR ($p = 0.532$). Finally, this analysis revealed that there was no interaction between the effects of noise level and time point ($F(2, 102) = 0.361$, $p = 0.818$). Similarly, (Fig. 1).

High- and low-noise segments were classified according to the nature and duration of communication events: case-relevant, case-irrelevant, or no communication. A higher percentage of time reflecting case-irrelevant communication events was associated with higher-noise segments compared to lower-noise segments ($t(34) = -2.105$, $p = 0.021$). No statistically significant difference was detected between the percentage of time reflecting case-relevant communication events during high- vs. low-noise segments ($t(34) = -0.372$, $p = 0.356$).

IV. Discussion

Overall, segments representing higher levels of noise were associated with higher Team HR before, during, and after the noise segments analyzed, as well as a higher proportion of case-irrelevant communication events compared to segments representing lower levels of noise. While in some cases higher noise levels may be representative of case complexity and adaptability to demands (e.g., actions directed towards recovering from an unexpected event or discussions surrounding the need for additional equipment), these data suggest that team workload levels during a phase of normative surgeries requiring targeted, protocolized communication and high degrees of inter- and intra-team coordination may suffer from excessive irrelevant conversations.

In addition to these features, the phase analyzed – separation from bypass – is of particular interest when considering teamwide cognitive workload levels given its unique distinctions. Previous work incorporating hierarchical segmentation and a cognitive task analysis approaches elucidated 6 sub-steps, 5 decision points, and 3 critical communications associated with the separation from bypass phase of cardiac surgery. According to self-reported responses during cued-recall video-based protocols, this phase incurred the highest degree of cognitive demands across the team collectively [14]. Similar findings using

self-reported instruments corroborate the potential for cognitive workload to interfere with standard procedures during this phase of surgery in particular [20].

Additional work relying on expert clinical involvement using a Delphi technique has also illustrated the critical role of communication while separating from bypass [21], which is particularly susceptible to team mental model misalignment [22]. Further, cognitive overload during this phase has been associated with lapses in clinical judgment [23], leading to potential patient harm.

Segments of time lacking substantial peaks in noise during this critical phase, while the team was weaning the patient from bypass, were characterized in this study primarily by relevant conversations or no communication at all, and associated with lower Team HR values. These observations suggest that more sparing, but efficient and task-oriented, communication events are associated with lower team cognitive workload levels.

Along these lines, crew resource management (CRM) approaches adopted from the aviation industry and applied to the operating room (see [24]) have proven feasible and valuable tools for improving targeted communication, perceptions, and behaviors [25], [26]. The enforcement of the “sterile cockpit” in aviation represents another possible solution to minimize the frequency of excessive noise peaks in the operating room, [27] reducing extraneous cognitive load among surgical team members.

Future work should isolate individual features of noise to explore the impact of specific frequencies on subsequent behaviors, communication events, and cognitive workload levels of surgical teams.

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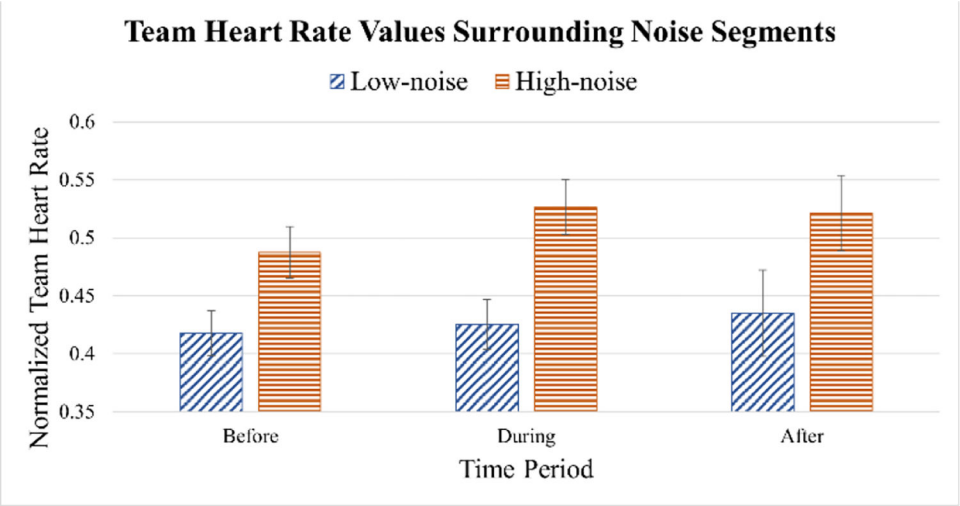

Fig. 1.

Normalized team heart rate values and standard error of the mean for the 5-minute segments before, during, and after the noise segment of interest. Bars with diagnal blue lines indicate normalized team heart rate for segments classified as low-noise (zero noise peaks exceeding 70 dB(A); N=18 segments), while bars with orange horizontal lines indicate normalized team heart rate for segments classified as high-noise (≥ 10% of samples reflect noise peaks exceeding 70 dB(A); N=18 segmetns).