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Human Factors Analysis of Goal-Directed Perfusion in Cardiac Surgery

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ABSTRACT

The cardiopulmonary bypass (CPB) phase of cardiac surgery represents a period of time in which the patient is receiving extracorporeal cardiopulmonary support, managed by a human operator: the perfusionist. Previous work has demonstrated that perfusionists perceptions and physiological arousal levels reflect increased cognitive demands (workload) during CPB. Recent evidence supports the use of goal-directed perfusion (GDP) approaches during cardiac surgery, aiming to maintain the delivery of oxygen (DO_2) to the tissues above a defined threshold, which is associated with improved outcomes when done so successfully. This additional requirement to the already complex management of a patient on CPB may consequently induce additional cognitive burden. The goal of this study was to evaluate the relationship between DO_2 levels during CPB and perceived cognitive workload by the perfusionist. Our results demonstrate a significant negative correlation between DO_2 levels and overall demands, mental demands, and situational stress, pointing to the challenges of maintaining DO_2 and calling for further investigation into providing appropriate cognitive support solutions to perfusionists.

Keywords: Human factors, Cardiac surgery, Goal-directed perfusion, Delivery of oxygen

INTRODUCTION

The cardiac surgery operating room (OR) is a complex sociotechnical environment requiring the seamless integration of human-human and human-machine teams. The cardiopulmonary bypass (CPB) phase of cardiac surgery in particular represents a period of time in which the patient is receiving cardiopulmonary extracorporeal support, managed by a human operator: the perfusionist. Perfusionists play a critical role in ensuring patient hemodynamic stability by operating the CPB machine during this time.

Previous work has demonstrated that perfusionists perceive the highest levels of cognitive demands (specifically mental demands, task demands, distractions, and difficulty) during the CPB phase of surgeries. This finding was corroborated by elevated physiological markers of cognitive demand during CPB as well (Lauren R Kennedy-Metz *et al.*, 2020). While others have shown that the processes of initiating and weaning from bypass in particular

incur the highest degree of workload, this work also makes it clear that physiological and perceptual measures of workload, along with visual dwell times on pump modules and all fluctuate throughout the duration of the CPB run (Merkle *et al.*, 2019).

Goal-directed perfusion (GDP) (oxygen delivery [DO_2] $\geq$ 280 mL/min/m^2 during CPB in cardiac surgery) is a more recent recommended practice given the positive results of the Goal-Directed Perfusion Trial (GIFT) (Ranucci *et al.*, 2018). Evidence from the literature has demonstrated the protective effect of GDP approaches in minimizing morbidity and hospital length of stay (Aya *et al.*, 2013), as well as the occurrence of acute kidney injury (Ranucci *et al.*, 2018). However, the additional cognitive burden required by the perfusionist as a result of this approach, along with the heightened vigilance needed to maintain the GDP threshold, is unknown.

The objective of this study was to investigate the relationship between average DO_2 levels during CPB and perfusionists' perceived cognitive workload during cardiac surgery.

METHODS

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, including patients, perfusionists and OR staff. Data were collected during non-emergent aortic valve replacement (AVR) or coronary artery bypass graft (CABG) procedures in the cardiac OR of a tertiary teaching hospital between January 2021 and April 2021.

Experienced perfusionists indicated their perceived cognitive workload immediately after cardiac surgery procedures ($N = 15$) taking place during this time frame. Participants self-reported their perceptions of cognitive workload over the course of the procedure according to the validated SURG-TLX index dimensions: mental demands, physical demands, temporal demands, task complexity, situational stress, and distractions (Wilson *et al.*, 2011; Lauren R. Kennedy-Metz *et al.*, 2020). A two-tailed Spearman's correlation was calculated to investigate the relationship between average DO_2 levels during CPB and SURG-TLX responses.

RESULTS

Fifteen procedures were analyzed (2 AVR and 13 CABG). Patients averaged 66.3 years old (standard deviation: 8.3 years) with an average STS 30-day predicted risk of mortality of 1.03% and 30-day predicted risk of morbidity of 9.36%. The average pump time over the procedures analyzed was 113 minutes (range: 77 minutes to 170 minutes). The average cross-clamp time was 73 minutes (range: 44 minutes to 123 minutes). The average body surface area of the 15 patients involved was 2.15 $m^2 \pm 0.17$ (mean $\pm$ standard deviation).

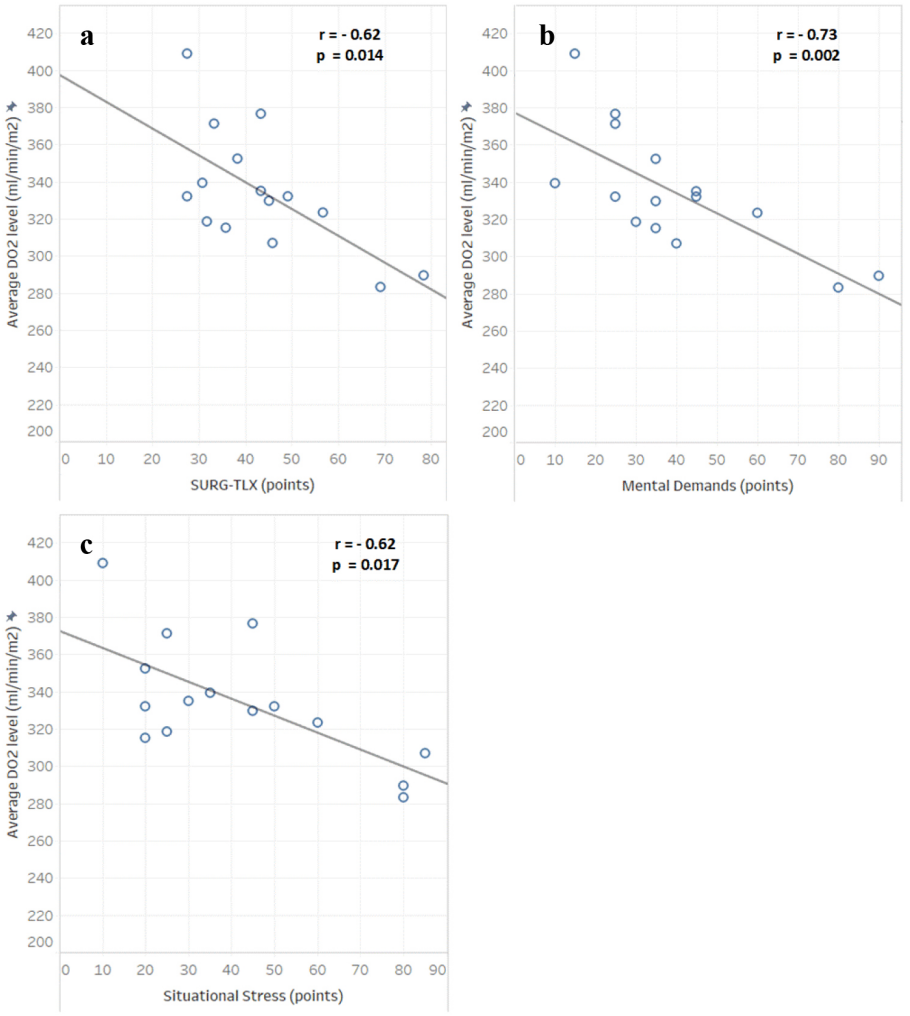

Figure 1: Significant negative correlations were observed between average DO_2 levels and overall perceived cognitive workload (a), DO_2 levels and mental demands (b), and DO_2 levels and situational stress (c).

Lower DO_2 levels (averaged across the duration of the total pump time) were significantly associated with higher overall perceived cognitive workload ($rs(13) = -0.62$, $p = 0.014$), mental demands ($rs(13) = -0.73$, $p = 0.002$), and situational stress ($rs(13) = -0.62$, $p = 0.017$) (Figure 1). No significant correlations were detected between average DO_2 levels and remaining cognitive workload dimensions.

CONCLUSION

This is the first study to evaluate human factors associated with achieving GDP in cardiac surgery. Previous work demonstrating elevated cognitive workload during bypass was conducted without consideration for perfusionists' DO_2 monitoring (Merkle *et al.*, 2019; Lauren R Kennedy-Metz *et al.*, 2020),

which the current work expands upon. Self-reported measures of cognitive workload indicate an elevation in overall demands, mental demands, and situational stress which correspond to lower average DO_2 values, supporting further investigation into perfusionists' cognitive state to avoid episodes of overload and simultaneously facilitate maintenance of GDP.

At centers where real-time DO_2 monitoring equipment is not available, alternative solutions for maintaining goal-directed perfusion measures are warranted, but care must be taken to avoid incurring excessive demands on perfusionists. Cognitive support, in the form of a quick reference tool for example (Srey *et al.*, 2019), may present an easily approachable solution for maintaining targets while minimizing additional cognitive burden. The incorporation of machine learning models to integrate inputs and provide meaningful recommendations based on sub-optimal DO_2 levels has also shown preliminary promise (Dias *et al.*, 2021). Finally, high-fidelity medical simulation may represent realistic and relevant training opportunities in preparation for critical intra-operative events (Merkle *et al.*, 2020).

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