Final Progress Report to the Agency for Healthcare Research and Quality

Title of Project	Validity assessment of a real-time indicator of attentional load and task-induced fatigue in the MIS environment
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Abstract

Purpose: We sought to assess whether blood flow velocity (BFV) of the middle cerebral arteries (MCAs) can serve as a real-time indicator of attentional load, attentional resource depletion, and task deterioration in the laparoscopic environment. As experts are expected to experience lower attentional load, the present study also investigated whether MCA BFV can differentiate between novice and expert laparoscopists.

Scope: Successful surgical outcomes necessitate that surgeons detect critical information. The detection of critical cues (vigilance) is attentionally demanding and vigilance deteriorates over time (vigilance decrement). This decrement co-occurs with declines of BFV of the MCAs; a phenomenon that is consistent with declines in attentional resources causing the vigilance decrement. Beyond the demands posed by vigilance, laparoscopists' attentional resources are further stressed by the disruption of hand-eye mapping that is caused by viewing the tissue from a camera's perspective.

Methods: Expert and novices laparoscopists completed a two-phase experimental study. Phase 1 entailed performing a laparoscopic training task. Phase 2 required the performance of a laparoscopic task and a concurrent vigilance task. Both phases employed an easy and a difficult camera condition.

Results: Phase 1 BFV results were sensitive for differentiating between novice and expert laparoscopists but did not possess the sensitivity for differentiating between varying camera-induced attentional load levels. Phase 2 provided preliminary support that MCA BFV declines co-occurred with the vigilance decrement, indicating attentional resource depletion in the laparoscopic environment. Follow-up studies are needed to clarify this preliminary finding.

Keywords: vigilance, attention, laparoscopy, transcranial Doppler sonography, middle cerebral arteries, MIS

2. Objective of the Study

Successful surgical outcomes necessitate that surgeons detect critical information pertaining to the patient and the surgery. The detection of critical cues (aka vigilance) is attentionally demanding (i.e., requires substantial attentional [information-processing] resources)[1]. These resources are limited and utilized by attentionally demanding (difficult) tasks[2]. Furthermore, insufficient resources impede task performance, and prolonged performance of an attentionally taxing task depletes attentional resources (task-induced fatigue). The perceptual-motor distortions inherent in laparoscopy, like the disruption of hand-eye mapping, place additional strain on these resources[3]. When the laparoscope (camera) is located to the surgeon's side, the disruption of hand-eye mapping intensifies and, thus, attentional demands further increase[3]. As practice allows adaptation to these distortions[4], laparoscopic trainees who have not yet adapted to them are at an increased risk of experiencing high attentional load and task-induced fatigue. The perceptual-motor distortions inherent in the laparoscopic environment might result in trainees having insufficient resources for vigilance, and vigilance is paramount for successful surgical outcomes. Prior vigilance research linked deteriorating vigilance—a right hemisphere dominant task—with declines in the blood flow velocity (BFV) of the right middle cerebral artery (MCA)[5], which carries 80% of the blood to its associated hemisphere[6]. These findings support that vigilance is attentionally demanding, resulting in the depletion of attentional resources, which in turn results in vigilance deterioration. As accurate vigilance is essential for surgical success, the question arises whether changes in BFV of the MCAs can serve as a real-time indicator of attentional load as well as task-induced fatigue in the laparoscopic environment. This question has not yet been answered empirically.

Therefore, the ***objective*** of the present study was to validate changes of BFV of the MCAs as real-time indicators of attentional load, task-induced fatigue, and performance deterioration in the laparoscopic environment. The *rationale* for the proposed study was that, once changes in BFV of the MCAs have been shown to be valid real-time indicators in the laparoscopic environment, this technology can result in improved patient safety, as surgical trainees who are too overwhelmed with the task might be identified and receive additional support or be removed from the surgical task.

To test our objective, the following specific aims were pursued:

1. Assess whether BFV of the MCAs is sensitive for identifying different levels of attentional load induced by varying degrees of disruption of hand-eye mapping in the laparoscopic setting. We hypothesized that difficult disruptions result in higher BFV of the MCAs than easy disruptions, with novices experiencing higher BFV than experts.

2. Determine the predictive validity of the BFV of the MCAs as an indicator of secondary task (vigilance) performance in the laparoscopic environment. We hypothesize that changes in BFV of the MCAs correlate with performance of a secondary vigilance task. As vigilance is right hemisphere dominant, we hypothesized that stronger correlations will be observed for the right MCA.

3. Determine contrasted group's validity of the BFV of the MCAs as an indicator of skill level in the laparoscopic training environment. We hypothesized that, compared to trainees, experts experience a lower initial increase of BFV as well as lower rate of the subsequent decline of BFV over time.

3 Scope

3.1.1 Background: Resource (Attentional Load) Theory and Assessment

Tenets of resource theory. Attention is commonly conceptualized as "energy" that is available for cognitive information-processing[2]. Tenets of resource theories include that (1) resources are limited and are required for the performance of tasks; insufficient resources impede task performance, (2) difficult tasks necessitate more attentional resources than easy tasks, and (3) prolonged task- performance can deplete its associated attentional resources (i.e., task-induced fatigue).

Attentional load assessment. Dual-task methodologies can assess attentional load. Stefanidis and colleagues[7] used a dual-tasking paradigm in which participants performed a prioritized laparoscopic knot-tying task and a concurrent, secondary visuospatial vigilance task. The results indicated that trainees and expert surgeons had comparable knot-tying performance. However, trainees' performance on the vigilance task was inferior to that of experts, indicating that they had less availability of spare cognitive resources. Attentional load can also be assessed via questionnaires. The NASA Task Load Index (NASA-TLX)[8,9] is the most widely utilized mental workload questionnaire. Higher global NASA-TLX scores have been associated with poorer performance during laparoscopic training[10]. Yet, neither questionnaires nor dual-tasking paradigms are feasible real-time indicators of attentional load or the depletion of attentional resources (task-induced fatigue).

However, vigilance research has indicated that declines of BFV of the right middle cerebral artery (MCA) are consistent with the observed vigilance decrement. These findings support that BFV decline of the MCA reflects declining attentional resources in real time[11].

For instance, researchers have suggested that BFV of the MCAs might be a useful real-time indicator for identifying air traffic controllers who have reached critical levels of task-induced fatigue[12]. Cerebral BFV is assessed with transcranial Doppler sonography (TCDS). Note that other scanning techniques such as fMRI are not feasible for real-time monitoring in the surgical theatre or the training environment, as they require participants to remain still[13].

3.1.2 Background: BFV (Blood Flow Velocity) of the MCAs (Middle Cerebral Arteries) and Vigilance

BFV of the MCAs: Transcranial Doppler sonography (TCDS) has been used for assessing BFV changes of the cerebral arteries during cognitive task performance, focusing mostly on the MCA[14] as it carries 80% of the blood to its associated cerebral hemisphere[6]. Generally, the MCA supplies blood to most of its associated hemisphere[14], with the exception of the superior portion of the parietal cortex, the inferior portion of the temporal lobe, and the occipital lobe. Research has indicated that (1) BFV of the MCA increases as participants engage in cognitive activities[15] and that (2) BFV of the MCA increases as task difficulty increases[12]. The increased blood flow is triggered by cognitive task performance; neural activity leads to increases in cerebral metabolism, which involves the production of CO_2, a waste product that needs to be removed. The CO_2 removal results in increased blood flow toward the given brain area. The BFV changes of the MCA are not triggered by the MCA's own vasomotor activity, as its diameter remains mostly constant due to its large size, but by increased blood demands caused by increased metabolism in areas perfused by the MCA[12]. Prior research has indicated that acceptable levels of test-retest levels regarding TCDS-assessed BFV changes across a variety of different cognitive tasks and PNS activity (like blood pressure and heart rate) have limited impact on cerebral BFV changes measured via TCDS[12].

Vigilance: Vigilance requires the detection of brief, unpredictable signals over time[16]. Prior research indicated that vigilance performance typically declines over time (aka vigilance decrement). This decline occurs typically within the first 30 minutes[17]. Faster declines have been observed in difficult vigilance paradigms (see Warm et al. 2015[1], for review). Recent neuroergonomics research provides strong evidence that vigilance is attentionally demanding and that the vigilance decrement is caused by task-induced fatigue (depletion of attentional resources). Specifically, fMRI research has implicated multiple brain systems in the vigilance decrement[18], as decreased activity in the following systems correlated with the vigilance decrement: anterior cingulate cortex (ACC), the right middle prefrontal gyrus (MFG), and the right inferior parietal cortex (IPC). The ACC, MFG, and IPC are all systems that are perfused by the MCA. Prior TCDS research indicated that decreased BFV of the MCA_{right} corresponds to the vigilance decrement, as vigilance is right hemisphere dominant. Importantly, this decline in BFV has not been observed when operators passively viewed a vigilance display, without having to identify any signals[5]. Thus, the decline of BFV of the MCA_{right} has been attributed to the depletion of attentional resources rather than boredom or declines in arousal[11,19]. Consistent with BFV changes of the MCA_{right} reflecting attentional resource demands as well as the depletion of these resources in the vigilance setting, research indicated that vigilance tasks that place greater demands on the attentional system result in (1) an initially higher BFV of the MCA_{right}[20] and (2) a steeper subsequent decline of this BFV of the MCA_{right}. Importantly, the observed BFV pattern matched the observed vigilance decrement (i.e, steeper vigilance performance decrements were associated with steeper declines in BFV of the MCA_{right})[21].

3.2 Data Collection Setting

Data was collected in a quiet room at the following medical centers: Texas Tech University Health Sciences Center in Lubbock, TX, the University of Cincinnati Medical Center in Cincinnati, OH, and the University of Texas Health Sciences Center at Houston in Houston, TX.

3.3 Participants:

We recruited two groups: novices and expert surgeons. Novices were defined as medical students in either their first or second year of medical school, as they typically do not have any surgical experience. Expert surgeons were defined as residents in their last 2 years of residency, fellows, and attending surgeons from the following specialties: general surgery, gynecology, urology, and orthopedics.

Of the 71 participants who took part in this study, the data of 58 participants is reported. Not every participant's data is included because of issues that arose during data collection. The most prevalent issue was that the BFV signal of either the left, right, or both MCAs could not be obtained in a reasonable time frame. The demographic information for the surgical novices (medical students) and expert surgeons is outlined below.

Medical students: The data of 33 medical students (16 women and 17 men) are included in the results section below. Participants were recruited from the Texas Tech University Health Sciences Center in Lubbock, TX. Their ages ranged from 21 years to 31 years (mean = 25.09, SD = 2.45). One medical student was sinestral, and 32 were dextrals, as indicated by the Edinburgh Handedness Inventory[22]. Twelve medical students were in their first year of medical school, and 21 were in their second year of medical school. Twenty-six had no prior laparoscopic experience, three reported that they had observed laparoscopic procedures, two reported that they had used a laparoscopic simulator previously, and two did not disclose their prior laparoscopic experiences. The majority (26) of participants reported being Caucasian, three reported being Hispanic or Latina, two reported being Black or African American, one reported being Asian or Pacific Islander, and one reported being more than one ethnicity. ADHD was the only medical condition reported among all the participants; this was reported by one medical student only. Participants use of caffeine and nicotine is displayed in Table 1. Their medication use is displayed in Table 2.

Expert surgeons: The data of 25 experts (11 women, 14 men) are included in the data analyses below. Their ages ranged from 28 to 55 (Mean = 35.73, SD = 7.14). As indicated by the Edinburgh Handedness Inventory, 21 experts were identified as dextrals, two were sinestrals, and two were ambidextrous (with a slight preference for the right hand). Fifteen experts were in their last 2 years of residency, one expert was a fellow, and nine experts were attending surgeons. Eleven experts described themselves as general surgeons, seven as urologists, two as minimally invasive surgeons, and the following fields of expertise were chosen by one expert/each: MIS and bariatric surgery, trauma, colorectal surgery, urogynecology, and OB/GYN.

The total number of laparoscopic procedures performed during the last year ranged from 1 to 3000 (mean = 570.96 , SD = 700.66), with the percentage of procedures during the last 12 month ranging from 0% to 99% (Mean = 44.20, SD = 29.89). Fourteen expert surgeons reported being Caucasian, eight were Asian or Pacific Islanders, one was Black or African American, and two did not report their ethnicity. Their caffeine and nicotine use is displayed in Table 1, and their medication usage is displayed in Table 2.

Table 1
Frequency of Caffeine and Nicotine Data

	Frequency of Caffeine Use					
	Don't use caffeine	12-24 hours ago	6-12 hours ago	3-6 hours ago	1-3 hours ago	within 1 hour
Novices	9	7	3	5	9	0
Experts	1	5	7	6	5	1

	Frequency of Nicotine Use					
	Don't use nicotine	12-24 hours ago	6-12 hours ago	3-6 hours ago	1-3 hours ago	within 1 hour
Novices	31	1	0	0	1	0
Experts	24	0	0	0	0	1

Table 2
Medication Use Reported by Research Participants

	# of participants reporting medications	Medications reported
Novices	7	Proventil, Flonase, Truvada, Trinessa, Sertraline, Loseasonique, Robinul, Tylenol, Aleve
Experts	2	Tylenol, Multivitamin

Note. The medications were taken between 90 min and 14 hours prior to the research participation. Review of the literature on PubMed failed to provide support that any of the listed medications impact cerebral blood flow (CBF) or cerebral perfusion pressure, which serves as a surrogate indicator of CBF.

4.0 Method

4.1 Study Design:

The three specific aims were assessed using a two-phase design. Specific Aim 1 was assessed with Phase 1, but specific aims 2 and 3 were assessed with Phase 2. Phase 1 and 2 occurred in the same experimental session.

Phase 1: Experts and novices performed a laparoscopic training task (peg-transfer task) in a laparoscopic simulator for 12 minutes. The simulator projects its interior (pegboard) onto a monitor and induces the perceptual-motor distortions inherent in the laparoscopic environment. Participants performed the peg-transfer task in either an easy or a difficult condition. In the easy camera condition, the camera that projects the pegboard onto the monitor is positioned directly in front of the participant (0° condition). In this condition, the forward and a left-right movement of the instrument tip inside of the simulator were portrayed as such movements on the monitor. In the difficult condition, the camera was positioned 90° to the participant's side, projecting a side view onto the monitor. In the 90° condition, a leftward movement and forward movements of the instrument tip inside the simulator were viewed as a forward movement and as rightward movement on the simulator's monitor, respectively. Sixteen novices were assigned to the 0° camera condition, and 17 novices were assigned to the 90° condition. Thirteen experts were assigned to the 0° condition, whereas 12 experts were assigned to the 90° condition. This phase entailed a 2 (expertise levels: novice versus expert) × 2 (difficulty levels: easy 0° condition vs. difficult 90° condition) between-groups design.

Phase 2: Experts and novices performed the peg-transfer task for 40 minutes, using the same camera condition as during Phase 1. While performing the peg-transfer task, participants performed a concurrent vigilance task. As the 40-min period was partitioned into eight 5-min periods, Phase 2 constituted a 2 (expertise level: novice vs expert) × 2 (difficulty levels: easy 0° condition vs. difficult 90° condition) × 8 (periods) mixed design.

4.2 Interventions and Measures

Easy and difficult peg-transfer task condition: Prior research indicated that the 0° condition (camera positioned directly in front of the participant) is much easier when compared to the 90° condition (camera located 90° to the right of the participant), as indicated by superior performance profiles[3,4]. Thus, the present study used these camera conditions to induce varying levels of attentional load in operators.

Peg-transfer performance: The peg-transfer task required participants pick up the transfer item with one grasper, transfer it in the air to the other grasper and place it on the other side of the pegboard. Participants were instructed to transfer the transfer items as fast as possible without dropping them and to transfer the items back and forth between the two sides of the pegboard .The transfer task utilized in the present study is similar to that employed by the Fundamentals of Laparoscopic Surgery Skills Training. Peg-transfer performance was assessed using two measures: (1) number of completed transfers and (2) accuracy (ratio of drops/transfers). Transfer data were recorded with E-prime 3.0.

BFV of the MCAs: During both phases of the experiment, blood flow velocity of the middle cerebral arteries was assessed with a digital transcranial Doppler sonography system. Blood flow velocity was measured in cm/sec and was transformed into ratios using baseline data. Baseline data was obtained at the beginning of Phase 1. Thus, a ratio of 1 indicates that BFV is identical to that observed during the baseline period. A ratio < 1 indicates that BFV declined compared to that observed during the baseline period, and a ratio > 1 indicates increased velocity compared to baseline data.

Vigilance performance: An auditory vigilance task was employed during Phase 2. This task required participants to discriminate between sounds of differing durations. In this task, the target signal was a 200-ms burst of white noise; the non-target sound consisted of a 247.5-ms white noise burst. Sounds were updated every 2 seconds (i.e., event rate = 30 events/minute). The vigil was 40 minutes in duration and contained 1200 sounds (target and non-targets) in total. The full vigil was divided evenly and, without the participant's knowledge, into eight 5-minute periods that each contained 150 sounds. In each period, the probability of a target signal was 5.33%, that is, eight of 150 stimuli in each period were target signals for detection. Participants indicated target signals by pressing a foot pedal. Detection accuracy was recorded throughout the vigil using E-Prime 3.0. Vigilance performance was analyzed using A', a non-parametric sensitivity measure. Larger A' values indicate higher sensitivity (performance).

5.0 Results

Analyses for Specific Aims 1:

As stated above, specific aim 1 was to:

> Assess whether BFV of the MCAs is sensitive for identifying different levels of attentional load induced by varying degrees of disruption of hand-eye mapping in the laparoscopic setting.

This specific aim was assessed using the data collected during Phase 1. The data are shown in Figure 1. The analyses of these data were based on 33 medical students and 24 experts (one expert’s data was not included due to a data recording issue that occurred in Phase 1). The data were analyzed using a 2 (levels of expertise: novice vs expert) × 2 (camera conditions: 0° vs 90 ° condition) × 2 (hemispheres: left vs right hemisphere) mixed ANOVA on the BFV ratios. The only significant result that was observed was an expertise main effect, $F(1, 53) = 8.369$, $p = .006$, $n_{partial}^{2} = 0.136$, indicating that novices (Mean = 1.173. SE = .014) had a significantly higher BFV than experts (Mean = 1.109, SE = .017). Although it can be seen in Figure 1 that there was a tendency for novices but not experts to have higher BFV in both the left and right MCAs in the difficult (90°) camera condition when compared to the easy (0°) camera condition, the main effect for camera condition was not significant, nor was any interaction that involved the camera condition significant.

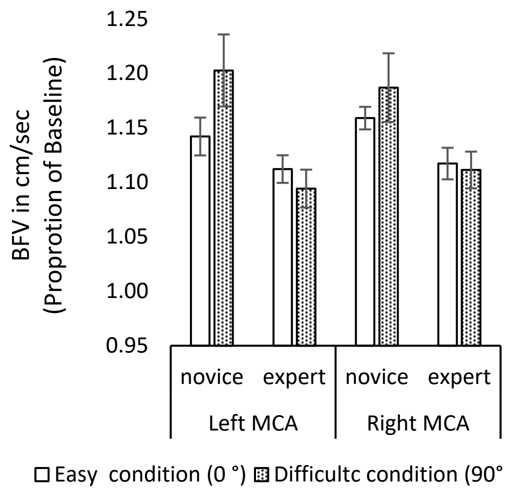

Figure 1. BFV ratios observed for novices and experts in the easy and difficult camera conditions in Phase 1. Error bars are SE.

Analysis of Specific Aim 2:

As stated above, specific aim 2 was to:

> Determine the predictive validity of the BFV of the MCAs as an indicator of secondary task (vigilance) performance in the laparoscopic environment

Vigilance performance was assessed using A’. Four probable outliers were winsorized. As can be seen in Figure 2, A’ decreased over time. Hierarchical linear modeling of the change in A’ using the standardized scores after centering from the grand mean indicated that the decrease in level over the eight periods was statistically significant (slope estimate = Υ_{11} = -0.081, $t(57) = -5.30$, $p < .0001$).

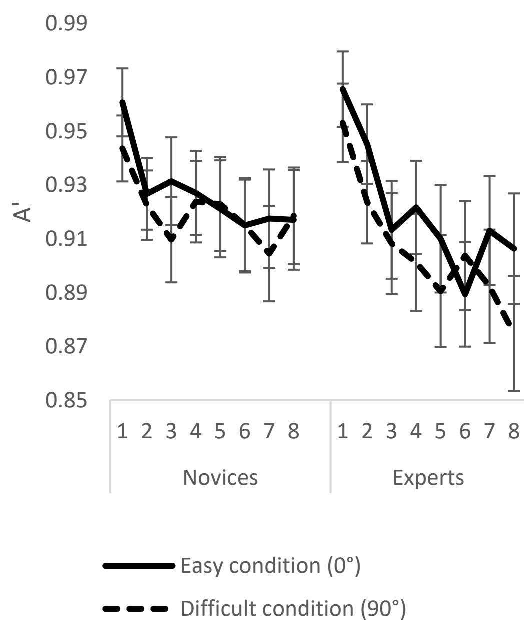

Figure 2. A’ observed during the eight 5-min periods. Error bars are SE.

Additional analyses indicated a trend toward this slope differing between experts vs. novices (Y_{12} = -0.079, *t(348)* = -1.88, *p* < .061).

A hierarchical linear model was computed to determine whether changes in BFV of the MCAs predict vigilance performance. The results indicated that the within-person centered BFV does predict the within-person centered A’ standardized measures, (for right MCA: t(df 57) =5.23, p < .0001). In the present study, the left MCA provided a slightly stronger prediction than the right MCA, as indicated by the left MCA having lower AIC scores (AIC left MCA: 965; AIC right MCA: 971.2), indicating a better model fit. Using the left and right MCA as centered predictors, the right MCA does not significantly improve the prediction of the standardized A’ scores beyond the prediction accounted for by the left MCA. As predicted, there was a interaction between expertise and the right MCA (t(404) = 2.85, *p* < .0047), such that the effect of the right MCA (centered) was stronger for experts than for novices.

Analysis for Specific Aim 3: As stated previously, specific aim 3 was to:

> Determine contrasted group’s validity of the BFV of the MCAs as an indicator of skill level in the laparoscopic training environment.

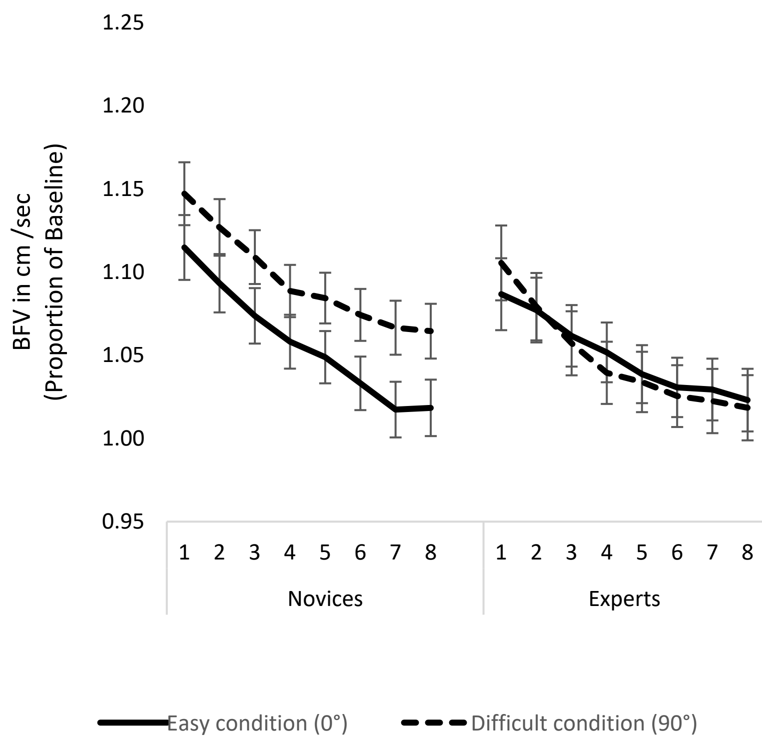

Figure 3. BFV (averaged over hemispheres) observed during the eight 5-min periods of Phase 2. Error bars are SE.

This specific aim was assessed with data observed during Phase 2. The observed BFV ratios are portrayed in Figure 3. The analysis for specific aim 3 is based on 33 medical students and 25 expert surgeons. The 40-min experimental period was partitioned into eight 5-min periods. A 2 (levels of expertise: novice vs expert) × 2 (camera conditions 0° vs 90 ° condition) × 2 (hemispheres: left vs right hemisphere) × 8 (periods) mixed ANOVA was computed on the BFV ratios. The ANOVA was interpreted using the Greenhouse-Geisser correction to adjust for violations of the sphericity assumption. The only significant effect that was observed was a period main effect, *F*(2.006, 108.326) = 101.494, *p* <.001, $n^{2}_{partial}$ = 0.653. This main effect indicated that BFV declined over the course of the experimental periods. Although there appears to be a tendency for novices to have higher BFV ratios than experts, especially in the difficult (90°) camera condition, the camera condition main effect and interactions involving the camera condition failed to reach significance.

5.2 Discussion

Specific Aim 1: The goal for specific aim 1 was to determine whether changes in BFV profiles are sensitive for indicating the different levels of attentional load induced by an easy (0°) versus a difficult (90°) camera condition. Although there was a tendency for BFV to be higher in the 90° camera condition than the 0° camera condition for novices, the camera condition main effect was not significant nor was any interaction that involved the camera effect significant. Thus, the observed effects involving the camera factor were not sufficiently powerful to obtain statistical significance

To ensure that the camera conditions induce different levels of difficulty, the performance data (number of completed transfers and accuracy) were each analyzed using a 2 (levels of expertise: novice vs expert) × 2 camera conditions (0° vs 90 ° condition) between-groups ANOVA.

Number of completed transfers: This ANOVA indicated a significant main effect for camera condition, $F(1, 54) = 97.024$, $p < .001$, $n^2_{partial} = 0.642$, revealing that significantly more transfers were completed in the 0° condition (Mean = 47.34 , SE = 2.335) than the 90° condition (Mean = 14.654, SE = 2.358). Furthermore, the ANOVA also indicated a significant expertise main effect, $F(1, 54) = 49.089$, $p < .001$, $n^2_{partial} = 0.476$, indicating that the experts completed more transfers (Mean =42.625, SE = 2.504) than the novices (Mean = 19.373, SE = 2.178).

Accuracy: The assessment of the accuracy data indicated a significant main effect for camera condition, $F(1, 54) = 5.034$, $p = .029$, $n^2_{partial} = 0.085$, revealing superior accuracy in the 0° condition (Mean = .129, SE = .132) when compared to the 90° condition (Mean = .551, SE = .113). Please note that improved accuracy is indicated by a lower score.

Thus, even though both peg-transfer performance measures were sufficiently sensitive for identifying difference in difficulty induced by different camera conditions, the BFV data did not possess this sensitivity. However, it is important to note that camera position is only one factor that impacts the difficulty in the laparoscopic training environment. Thus, future research is needed to assess the suitability of MCA BFV profiles for indicating task difficulty (attentinonal load) caused by different factors.

Specific Aim 2: The goal for specific aim 2 was to determine the predictive validity of the BFV of the MCAs as an indicator of secondary task (vigilance) performance in the laparoscopic environment. Consistent with prior vigilance research, we observed the vigilance decrement. This decrement did not differ as a function of camera condition nor expertise level. In the present study, the left MCA BFV provided a slightly stronger prediction than the right MCA BFV for predicting vigilance performance. This finding is slightly inconsistent with prior vigilance research, which indicated that the right hemisphere is more involved in vigilance performance than the left hemisphere[5]. However, it is important to note that the present study also employed a concurrent peg-transfer task that required the use of both hands. Thus, it can be expected that the performance of the peg-transfer task contributed to the observed MCA BFV profiles. As the present study did not include 40-min single task conditions (i.e., a peg-transfer task only and vigilance task only condition, respectively), the observed predictive validity of MCA BFV as an indicator of vigilance performance should be considered preliminary.

Specific Aim 3: The goal for specific aim 3 was to determine whether MCA BFV profiles possess the sensitivity to differentiate between novice and expert surgeons in the laparoscopic training environment. The assessment of this specific aim focused on the BFV data collected during Phase 2. Phase 2 involved the continuous performance of the peg-transfer task and the concurrent vigilance task for 40 min. Analysis of the BFV data revealed no significant effects involving the expertise main effect nor any interactions involving expertise.

To check whether novices and experts experienced different levels of difficulty at the two camera rotations, performance of the peg-transfer task was analyzed using a 2 (levels of expertise: novice vs expert) × 2 (camera conditions: 0° vs 90 ° condition) × 8 (periods) mixed-design ANOVA on the number of completed transfers as well as accuracy. These ANOVAs were analyzed using the Greenhouse-Geisser correction to correct for violations of the sphericity assumption.

Number of completed transfers: The analysis of the completed transfers indicated a main effect for task-period, $F(4.349, 234.840) = 5.742$, $p < .001$, $n\ ^2_{partial} = 0.096$. This main effect indicated that participants' performance improved over the course of the eight periods. Furthermore, a main effect for camera condition was observed, $F(1, 54) = 66.68$, $p < .001$, $n^2_{p\text{partial}} = 0.553$), indicating worse performance in the 90° condition (Mean = 15.32, SE = .129) than the 0° condition (Mean = 30.18, SE = .128). The significant expertise main effect, $F(1, 54) = 39.69$, $p < .001$, $n\ ^2_{partial} = 0.424$, indicates that experts (Mean = 28.486 , SE = 1.373) transferred more items than novices (Mean = 17.019, SE = 1.195).

Accuracy: The analysis of the accuracy measure indicated a significant camera condition main effect, $F(1, 54) = 10.71$, = *.002*, $n\ ^2_{partial} = 0.165$), indicating superior accuracy in the 0° condition (Mean =.063, SE = .021) versus the 90° condition (mean = .162, SE = .022). No other main effects and interactions were significant for the accuracy data. Please note that a lower score indicates higher accuracy.

Even though the performance profile of the number of completed transfers observed in Phase 2 showed sensitivity for expertise differences, this difference was not reflected in the MCA BFV data of Phase 2. Interestingly, the MCA BFV profiles observed during Phase 1 (see analyses for specific aim 1) indicated higher MCA BFV profiles for novices than experts. Such expertise differences might have been masked by the secondary vigilance task in Phase 2. Thus, the Phase 1 data are supportive for MVA BFV profiles possessing the sensitivity for differentiating between novice and expert surgeons in a single-task laparoscopic training environment.

5.3 Significance and Implications

The present project provides support for the potential of MCA BFV profiles to differentiate between novices and experts on performance of a laparoscopic training task when employing a single-task environment. In addition, the present study provides the preliminary support for the predictive validity of MCA BFV to serve as a real-time indicator of vigilance performance in the laparoscopic training environment. Furthermore, as the easy and difficult camera conditions employed in the present study failed to be reflected in MCA BFV, future research is needed to determine whether BFV of the MCAs is sensitive for identifying task difficulty (attentional load) caused by different factors in the laparoscopic training environment.

6. List of Publications and Products

Klein MI, Greenlee ET, Nguyen T, Gaitonde K, Griswold J, Santana D. Middle cerebral artery blood flow velocity as an indicator of attentional load and attentional resource depletion in the laparoscopic training environment. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting.* 2019;63(1):670-671. doi: 10.1177/1071181319631280.

Nguyen, T, Klein, MI, Grenlee E, Santana, D, Griswold, J, Gaitonde, K Validity assessment of a real-time indicator of task-induced fatigue among novices in the minimally-invasive surgery

environment. Poster presented at the: *Human Factors and Ergonomics in Health Care Symposium*, March 2019; Chicago, IL.

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