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AN EXPERIMENTAL SIMULATION OF HEAT EFFECTS ON COGNITION AND WORKLOAD OF SURGICAL TEAM MEMBERS

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MiniAbstract

This experimental study investigates the effect of ambient temperature in the cognitive functioning and perceived workload of burns surgical teams. Response times and accuracy on cognitive tasks were analysed. Results suggest that high ambient temperatures impair cognitive functioning of surgical team members at 60 minutes or longer.

STRUCTURED ABSTRACT

Objective: To isolate heat exposure as a cause of cognitive impairment and increased subjective workload in burns surgical teams.

Summary Background Data: Raising ambient temperature of the operating room can improve burns patient outcomes, but risks increased cognitive impairment and workload of surgical team members. Prior research indicates ambient heat exposure depletes physiological and cognitive resources, but these findings have not been studied in the context of burns surgical teams.

Methods: Seventeen surgical team members completed two surgery simulations of similar complexities in a hot and in a normothermic operating room. During each simulation, participants completed multiple cognitive tests to assess cognitive functioning and the SURG-TLX to self-assess workload. Order effects, core body temperature changes due to menstruation, and circadian rhythms were controlled for in the experimental design. Descriptive statistics, correlations, and mixed ANOVAs were performed to assess relationships between ambient heat exposure with cognitive functioning and perceived workload.

Results: Heat had a main effect on executive functioning and verbal reasoning. Duration of heat exposure (heat*time) increased response times and negatively impacted executive functioning, spatial planning and mental rotation. Perceived workload was higher in the hot condition.

Conclusions: We provide causal evidence that over time, heat exposure impairs cognitive speed and accuracy, and increases subjective workload. We recommend building on this study to drive best-practices for acute burns surgery and design work to enable burns teams to maintain their cognitive stamina, lower their workload, and improve outcomes for patients and surgeons.

Keywords: cognitive demand, physical demand, temperature, work environment, workload

Surgery to remove burnt tissue and facilitate skin repair is pivotal in severe burn survival, with perioperative hypothermia being detrimental to patients with severe burn injury. [1–3] During surgery, for severe cases (>20% TBSA), raising ambient temperature of the operating room can improve patient outcomes [4–6]. However, patient outcomes also rely on the speed and accuracy of surgical teams, and little consideration has been given to the detrimental impact long durations of heat exposure can have on cognitive functioning and subjective workload of surgical team members.

Studies in physiology, cognition, and organizational behavior have established that high ambient temperature can impair cognitive speed and accuracy[7–10] particularly complex, attention-demanding[11] and decision making tasks (e.g., surgery).[12] Heat slows executive functioning after 60-minutes or longer exposures,[8,9,13] but effects of heat on surgical teams during procedures remain unclear.[14] Research shows heat has mixed effects on simple cognitive tests,[15] increases subjective workload,[16] impairs manual dexterity,[17] and sometimes has no performance effects in *short* operative tasks.[18] However, burn surgery in heated operating rooms (30-38°C) can last multiple hours.[19] It is possible that the importance of surgery motivates extra effort to overcome—for a limited period—possible detrimental effects of high ambient heat. If so, subjective workload would be higher despite no observable cognitive impairments.

Subjective workload is consistently higher in hot ambient temperatures [20]. Even small increases in ambient temperature can increase ratings of physical demands and distraction in warmer (26°C) versus cooler (19°C) operating rooms.[18] Heat can increase negative affect and subjective discomfort,[21] and increase perceptions of surgery workload [11,22] Physician burnout is pervasive, caused in part by the human "cost" incurred when implementing practices during surgical procedures that are known to benefit patients, but may increase effort for surgical teams. Heating operating rooms risks increased subjective workload, in addition to impaired cognitive speed and accuracy.[7,21,23]

This study aimed to investigate the impact of heat exposure during surgery on cognitive functioning and subjective workload. Because prior research suggests that activity levels can compound the effects of heat, we additionally considered this factor. Specifically, activity level is associated with higher heart rate and core temperature, which in turn have been shown to impact physical and cognitive performance as compared to lower/resting values.[7,24,25] High physical activity added to cognitively demanding tasks performed in heat depletes the global pool of physical and cognitive resources and can exceed capacity leading to impairment in cognitive performance.[26–28]

METHODS

Setting and Participants

We used a within-person, crossover experimental design to test effects of performing 2.5-hour burn surgery simulations in normothermic (23°C) and hot (34°C) ambient temperatures. Total heat exposure during simulations was 3-hours inclusive of prep and clean-up. Although allowed toilet breaks, all participants remained in the room for the entirety of both simulations. Healthcare employees volunteered to participate following a familiarization session where the research team described the study and administered measures. Participants were divided into two surgical teams in which they performed both simulations on either two Sunday afternoons (n = 5), or two Thursday mornings (n = 12). Both simulations were performed at the same time of day to control for effects of circadian rhythm. Condition (normothermic vs. hot) was counterbalanced to control for order effects. Simulations were performed four weeks apart to control for effects of menstruation on core body temperature. No participants reported recent heat exposure that acclimatized them.

Experimental Protocol

Food/fluid and activity were reported for the 24 hours prior to the simulation, and participants were instructed to maintain the same intake and activities before the second simulation. To objectively measure internal temperature, participants ingested a core body temperature pill (CorTemp, HQ Inc., Palmetto, USA) eight hours prior to the start of their simulation. After arriving at the hospital, participants changed into scrubs and entered one of the operating theatres where they perform surgery during regular operating hours. At the beginning of the simulation, participants took four cognitive tests, a survey on iPads (Apple iPads, 9.7" wi-fi 6th gen 2018, 32gb), and physiological measures. At 30 minute intervals throughout the simulation, a subset of the four cognitive tests were administered followed by survey measures of workload. Testing lasted approximately 5 minutes.

The simulation replicated an excision and grafting procedure of a patient with burns to face, arms, legs, and abdomen at 20% of total body surface area (n = 5, Sunday). More surface area (40%) was simulated for the Thursday group (n = 12) to maintain equivalent workload compared to the Sunday group. Equivalent surface area of burns and alterations to body locations were used in the second simulation, to maintain similar task characteristics while preventing practice effects. An anatomically correct mannequin typically used as the 'patient' in medical training was used during the simulation and was surgically dressed previously by an experienced burns surgeon with different colored bindings representing different degrees of injury. During the simulations, participants performed the responsibilities of their typical surgical roles to create a real-life scenario. For example, physiotherapists moved the mannequin's arms to replicate their activities in real surgery. The Human Research Ethics Committee of the University of Western Australia (RA/4/20/4520) and South Metropolitan Health Service Human Research Ethics Committee approved the protocol (PRN RGS0000000833).

Heat Exposure

Ambient temperature was directly manipulated and maintained by hospital room controls. Duration of heat exposure was measured in 30-minute intervals corresponding to timepoints when cognitive tests were administered. All four tests were administered at the beginning (0 minutes) and end (180 minutes) of each simulation. A subset of tests was selectively administered at each 30-minute interval during the simulation due to time constraints. Measurement points for each cognitive test ranged from three to six (minute 0, 30, 90, 120, 150, 180).

Activity Level

Considering the impact physical activity has on cognition, high and low levels of activity were measured. Participants were labeled as active (stood for ≥ 75% of the simulated surgery) versus sedentary (seated for ≥ 75% of the simulated surgery) based on observational data and consultation with senior medical staff (>20 years experience in burn surgeries).

Cognitive functioning: speed and accuracy

Cognitive speed was measured by response time in milliseconds (ms). Cognitive accuracy was assessed by number of correct answers provided and number of errors committed on each test. Supplemental Digital Content, **http://links.lww.com/SLA/C748**. Four cognitive functions (inhibitory control, mental rotations, spatial planning, and verbal reasoning) were deemed relevant to surgery based on a review of skills and abilities listed for surgeons and anaesthetists in O*NET Online, a national work analysis database for the U.S. Further consultations and pilot-testing with surgical staff informed the final selection, (see Figure, Supplemental Digital Content 1, **http://links.lww.com/SLA/C748**, showing cognitive test displays).

Inhibitory control was measured by a computerized adaptation of the Stroop task,[29] in which participants click on one of two words (targets) that displays the color of the word portrayed at the top of the screen (probe). This is a widely used test of response inhibition that requires concentration on relevant information to correctly respond despite the presence of distracting information. The probe and targets may be either congruent or incongruent with the word written that describes a color. Cognitive difficulty of the Stroop task varies by the amount of distraction embedded in the incongruence of probe and targets. Mental rotation was assessed with a second cognitive test that required participants to mentally rotate two shape patterns on screen simultaneously, and indicate if the two shape patterns were identical.[30] A verbal reasoning test[31] required participants to indicate if statements that described displayed shapes were logically true or false (e.g., "Circle does not contain square."). Verbal reasoning is a complex task that has not been tested in prior studies of cognitive effects of heat exposure. It is potentially used during surgery when team members communicate with each other and must quickly decide if something is logically accurate or not. To assess spatial planning we included an adapted version of the Tower of London test.[32] Participants rearrange balls one at a time on branches of a tree-shaped frame and attempt to do so with the fewest total moves.

Workload Questionnaire

Subjective workload was measured via self-reported survey items. Perceived work overall workload was assessed by items from the Surg-TLX[33] measure that asked "How mentally fatiguing was the procedure?" "How physically fatiguing was the procedure?" "How hurried or rushed was the pace of the procedure?" "How complex was the procedure?" Participants responded to each item on a sliding scale anchored by 0 = *Not at all,* 50 = *A moderate amount,* 100 = Completely.

Data Analysis

Data analyses were conducted in SPSS Version 26 (IBM, Armonk, NY). Univariate and multivariate outliers were screened given the sample size which could be overly influenced by extreme scores. Questionnaire items were screened for careless responding.[34] Descriptive statistics were performed on participant characteristics. Normally distributed variables were reported as means and standard deviations. Repeated measures of cognitive speed (reaction time) and accuracy (number correct, number of errors) were compared using three-way mixed ANOVAs with condition, time in the simulation, and activity level as the three independent variables. ANOVAs analyzed the main effect of heat, interactions of heat and time, heat and activity level, and three-way interaction of heat, time, and activity level. Bonferroni post-hoc tests were performed to identify significant differences between conditions. Dependent *t*-tests were bootstrapped, and effect sizes for ANOVAs (η_p^2) and *t*-tests (Cohen's *d*) guided interpretation of results to a greater extent than significance thresholds (*p* values) in accordance with best practice for small samples.[35] Accordingly, we interpreted results with substantial effect sizes ($\eta_p^2 \geq .10$; Cohen's $d \geq .20$).

RESULTS

Seventeen healthcare employees who worked in burn surgery participated in this study. Two participants worked at the consultant level and supervised others as part of their jobs. Descriptive statistics for the participants are provided in Table 1. The Thursday and Sunday groups were statistically equivalent in terms of: age, time in the job, work hours per week, height, weight, gender, fatigue, minutes to fall asleep, or minutes spent awake during the night (p = .11-.97). As a manipulation check, self-reported complexity of the simulation was equivalent between hot (M = 25.57, SE = 6.64) and normothermic (M = 31, SE = 5.51) simulations $t(13)$= -.77, p = .46. State alertness at the start of the simulation was equivalent between normothermic and hot conditions (p = .33 - .73). Subjective thermal sensation was rated 1.60 to 1.83 points higher in the hot condition versus normothermic at all timepoints ($p < .001$) using the 8-point scale (0=unbearably cold to 8=unbearably hot).[36] After an hour of heat exposure, core body temperature was significantly higher (.26-.37°C; p = .00 - .004) in the hot condition compared to normothermic.

Cognitive Speed

Heat slowed response times to three of four stimuli presentations of the Stroop-like task assessing inhibitory control that displayed a probe (word was congruent with its color vs. word and color of word were incongruent) and target (word was congruent with color vs. word and color of word were incongruent). For the congruent probe and congruent targets stimuli presentation, the main effect of heat explained 26% of the variance in response time, and showed significant (p = .04) slowing in hot (M = 1494.49, SE = 62.25) versus normothermic (M = 1392.94, SE = 40.02). In the incongruent probe and congruent targets stimulus presentation, in the hot condition, responses were 162.02 ms slower than normothermic at 90 minutes ($t(15)$ = -1.79, p = .10, d_{rm} = -0.52), and 109.25 ms slower at 150 minutes ($t(15)$= -2.01, p = .06, d_{rm} = -0.38). For the incongruent probe and incongruent targets, in the hot condition, responses were 202.63 ms slower at the start ($t(15)= -2.28$, $p = .04$, $d_{rm} = -.54$), and 154 ms slower at 90 minutes ($t(15)= -2.16$, $p = .06$, $d_{rm} = -0.49$). On the mental rotations task, response times showed no significant changes. Table 2 shows ANOVA results of differences in response time, and Figure 1 graphs differences in speed between conditions.

Cognitive Accuracy

High ambient temperature during surgery impaired cognitive accuracy by lowering the number of correct answers on cognitive tasks during hot surgery. Tables 3 and 4 show results of testing for differences in cognitive accuracy (number correct, errors). Figure 2 depicts changes in number of correct answers, and Figure 3 displays errors. At the end of the simulation, participants provided 1.35 *fewer* total correct answers to the mental rotations task in the hot ($M = 18.76$, $SE = 0.98$) versus normothermic ($M = 20.12$, $SE = 0.84$) condition $t(16)= 1.35$, $p = .05$, $d_{rm} = 0.35$. At 90 minutes, participants in hot ($M = 50.06$, $SE = 3.22$) versus normothermic ($M = 57.24$, $SE = 2.30$) gave 7.18 fewer correct answers to the Stroop-like task $t(16)= 2.63$, $p = .02$, $d_{rm} = 0.60$. At 150 minutes, participants provided 3.47 fewer correct answers in hot ($M = 53.24$, $SE = 3.22$) than normothermic ($M = 56.71$, $SE = 2.34$) condition $t(16)= 2.27$, $p = .04$, $d_{rm} = 0.26$. However, this effect should be interpreted with caution because the bootstrapped confidence interval of the mean difference includes zero. For the verbal reasoning task, on average, participants provided .98 fewer correct answers in the hot ($M = 21.56$, $SE = 1.38$) compared to normothermic ($M = 22.54$, $SE = 1.43$) condition ($F(1, 15) = 1.64$, $p = 0.22$, $\eta_p^2 = 0.10$). On spatial planning, at 60 minutes, participants provided 1.53 fewer correct answers in hot ($M = 8.29$, $SE = 0.65$) versus normothermic ($M = 9.82$, $SE = 0.45$) condition $t(16)= 2.12$, $p = .05$, $d_{rm} = 0.66$.

High ambient heat was expected to impair cognitive accuracy in a second way—by increasing errors. On the mental rotations task, at 90 minutes into the simulation, participants made 1.5 more errors in the hot ($M = 4.44$, $SE = 0.66$) versus normothermic ($M = 2.94$, $SE = 0.62$) condition $t(15)= -2.67$, $p = .02$, $d_{rm} = -.59$. At the end of the simulation, participants made 1.44 more errors in the hot ($M = 3.19$, $SE = 0.80$) versus normothermic ($M = 1.75$, $SE = 0.34$) condition $t(15)= -2.00$, $p = .06$, $d_{rm} = -.53$. The Stroop-like task showed that heat increased number of errors in both sedentary and active participants, but active participants made an average of .49 more errors in the hot ($M = 1.91$, $SE = .34$) versus normothermic ($M = 1.43$, $SE = .37$) condition whereas sedentary participants increased by 0.10 errors in heat on average. Verbal reasoning errors showed a three-way interaction of heat, time and activity level (F(2, 26) = 1.53, p = 0.24, $\eta_p^2= 0.11$) that explained 11% of the variance in verbal reasoning errors. The interaction of heat and time is different depending on activity level of the participant during surgery. As the line graphs show, errors decreased over time in normothermic surgery or maintained a low level of errors throughout the hot simulation. However, in the active group, errors increased from 0-120 minutes and then dropped at the end of the hot simulation ($M = 2.14$, $SE = .47$) or continued to increase in the normothermic simulation ($M = 2.57$, $SE = .51$). Spatial planning errors were unaffected by heat.

Subjective Workload

High ambient temperature was predicted to increase subjective workload. Mental fatigue was rated 11.71 points (one a scale of 0-100) higher in hot surgery (M = 12.71, SE = 3.79) versus normothermic (M = 24.43, SE = 4.30) condition $t(13)$= 2.86, p = .01, d_{rm} = -.46. Physical fatigue was rated 13.50 points higher in hot (M = 9.93, SE = 2.59) versus normothermic (M = 23.43, SE = 5.27) condition $t(13)$= -2.38, p = .03, d_{rm} = -.46. Further, participants reported feeling more hurried or rushed in hot (M = 14.07, SE = 3.46) versus normothermic (M = 23.79, SE = 5.59) condition $t(13)$= -2.07, p = .06.

DISCUSSION

To our knowledge, this is the first study to investigate and report increased cognitive impairment and subjective workload due to high ambient temperature during burn surgery. In the experiment, four cognitive tests were administered at multiple timepoints during two simulations (hot and normothermic) to 17 surgical team members. As intended, the data collected provide initial evidence of the impact of high ambient temperature on cognitive functioning and subjective workload among surgical team members.

Most importantly, results indicate that heat exposure impairs cognitive performance regardless of the specific cognitive function being assessed. The type of impairment—slowing, fewer correct answers, or more errors—depends on the cognitive function. Heat slowed executive functioning, impacting inhibitory control in the Stroop-like task, but not the relatively simple task of mental rotations. Heat exposure lowered the number of correct answers across every cognitive function, and errors increased on all except spatial planning. Unlike total correct answers, the relationship between heat and cognitive errors was impacted by activity level. At a higher level of activity, ambient heat had a more detrimental effect on cognitive accuracy. High physical activity increased errors on inhibitory control, and verbal reasoning in the middle of the procedure.

As expected, heat exposure raised subjective workload such that there was more mental and physical fatigue, and time pressure in hot surgery compared to normothermic—despite equivalent task complexity in each simulation. This second main finding aligns with extant research showing subjective workload rises as physical demands of thermoregulation in extreme thermal environments rise.[20]

Consistent with global workspace theory of limited internal resources to use for physical and cognitive demands, the pattern of findings suggest that the duration of heat exposure impacts cognitive accuracy and slows response time on all cognitive functions except relatively simple cognitive tasks.[26,37] Heated surgery drains physical resources via dehydration, manual dexterity impairment, higher core temperature and heart rate – as higher subjective alertness is maintained.[17] Where job resources are limited,[38] internal resources can increase state alertness to maintain surgical performance until increased effort can no longer compensate for physical resource depletion. Consistent with these findings, interactions of heat and time in this study show observable decrements in cognitive performance after heat exposure of 60 minutes or longer.[8,9,13]

In line with previous research, effect of heat on cognitive speed and accuracy varied by test. Inconsistent with literature showing cognitive performance on complex tasks to be vulnerable to decrements due to heat exposure,[7,39] the error rate on the complex task of verbal reasoning was unaffected yet the relatively simple task of mental rotations was affected. The unaffected error rate may be due to sampling error or the need for longer heat exposure when core temperature may reach hyperthermia (38.5°C). Future studies with larger samples and longer heat exposure can test these explanations.

Implications

Results from this experiment have implications for work design, or redesign of burn surgery team members[40] and other healthcare workers who work in physical environments that have thermal stressors, and other types of stressors. Working in heated surgery beyond three hours without breaks likely will impair cognitive accuracy and slow response times to some types of tasks. In heated burn surgery, speed and accuracy among surgical team members are crucial for patient outcomes. Future research should investigate interventions to limit effects of heat exposure on surgical team members. Gender, age, weight, fatigue and alertness, hydration, and role during surgery should all be considered in the development of an intervention. Individualized adjustments should be tested to build out evidence-based profiles of employees who could most benefit from interventions to aide them in managing physical demands of heated surgery.[41] In conjunction with person characteristics one can consider team roles and work characteristics to develop interventions to help employees meet physical job demands.

Limitations and Future Directions

One limitation of this study is the small sample size, which introduces sampling error and makes the data susceptible to the influence of extreme cases. We thoroughly addressed outliers in the data and increased our focus on effect sizes when interpreting results. Analyzing the data with outliers and outliers removed did not change statistical conclusions and robust methods were used where possible. Further this sample size is typical of experiments testing effects of ambient temperature on cognition.[7,21] Future research is needed to replicate across health centers, methods of care delivery, and wider age ranges of surgical team members. Some patients (e.g., children) require OR temperatures of 40-43°C, for example. More extreme temperatures drain physical resources faster and have detrimental effects on executive functioning, increase subjective workload, and can have a curvilinear effect on cognitive speed depending on the duration of heat exposure.[42]

Second, using a mannequin simulation as a burn patient, may have limited the psychological fidelity of the simulation. We also acknowledge that interruptions in the simulation may not have had the same sense of disruption as real-life surgery. Inhibitory control may be more depleted during surgery when interruptions unexpectedly occur after multiple hours in a heated operating room. Future research is needed to test cognitive effects of disruptions *in vivo*. Further research is also needed to test two new hypotheses that stem from the finding that increased cognitive errors were associated with high activity levels. First, higher activity levels during heat exposure may increase impulsivity. Second, activity level may have a stronger effect after longer durations of heat exposure.

Conclusions

The experimental design of our study provides initial, causal evidence that over time, high ambient heat impairs cognitive speed and accuracy, and increases subjective workload. Our purpose is not to question patient benefits of heated surgery, but instead to enhance best-practices by considering impacts of procedures on surgical staff. Work design alternatives should be considered to make patient-care standards sustainable for those who operate regularly. We recommend building on this study to drive best-practices for acute burns surgery and redesign work so surgical teams can maintain cognitive stamina and manage subjective workload to improve outcomes for patients and those who operate on them.

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FIGURE AND TABLE LEGENDS

Main Manuscript

Figure 1. Line graphs of Cognitive Speed Differences Between Conditions (response times in milliseconds). Larger values in the graph indicating slower, and therefore, worse cognitive functioning. Error bars = 95% confidence intervals

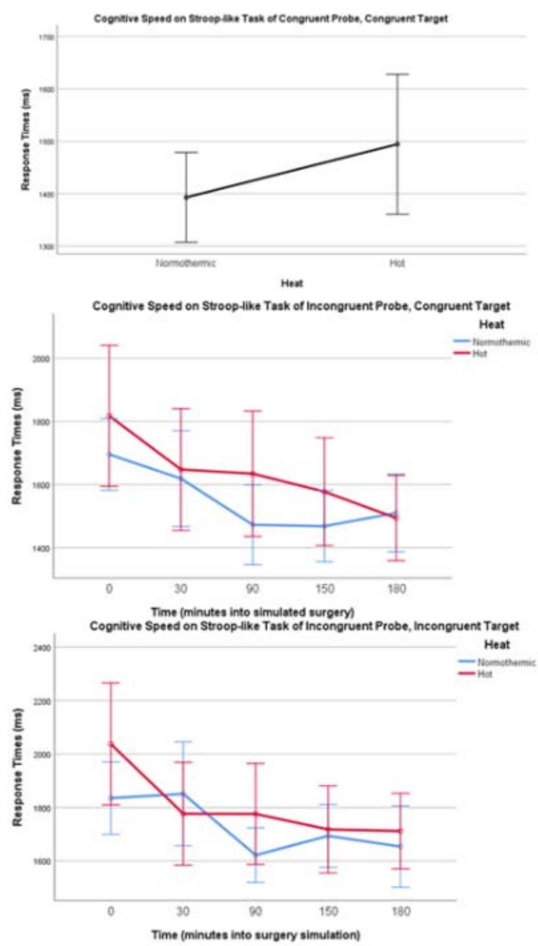

Figure 2. Cognitive Accuracy Differences Between Conditions by Total Number Correct. Smaller values in the graph indicates fewer correct answers, and therefore, worse cognitive functioning. Error bars = 95% confidence intervals.

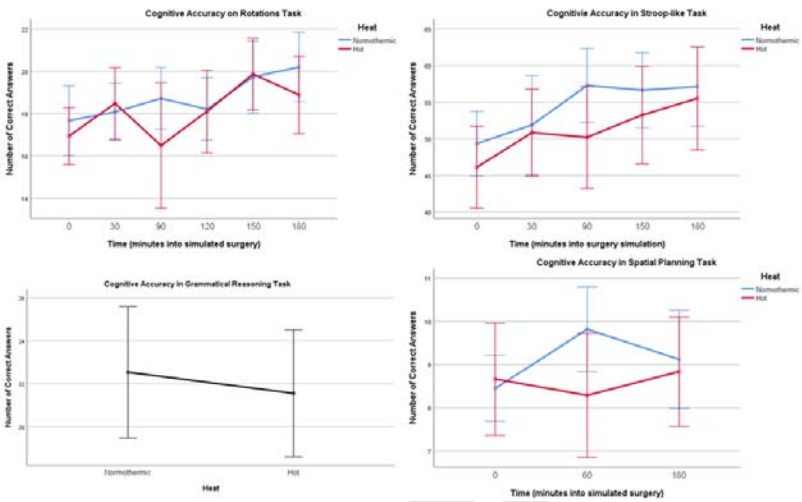

Figure 3. Cognitive Accuracy Differences Between Conditions by Errors Committed. Larger values in the graph indicate more errors, and therefore, worse cognitive functioning. Error bars = 95% confidence intervals. Time is measured as minutes into simulated surgery.

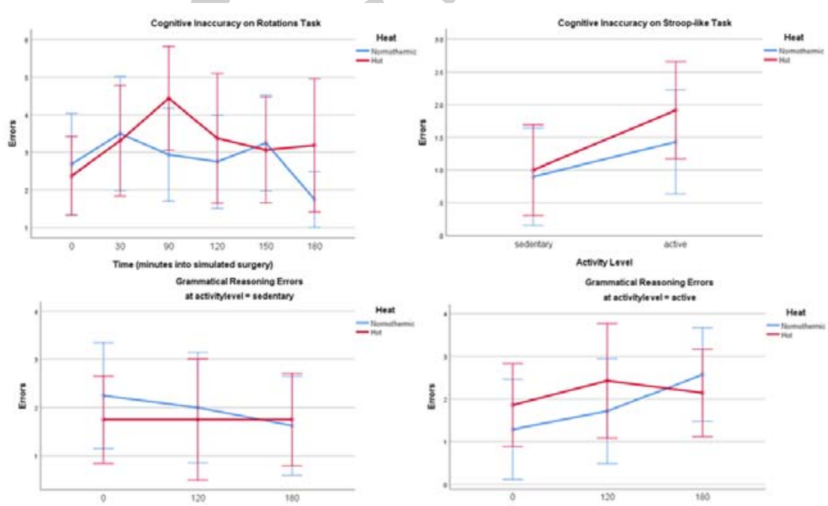

Table 1.	Sample characteristics						
			Mean n = 17	**Standard Deviation**	**Median n = 17**	**Interquartile Range (Q1, Q3)**	**Range (Min, max)**
Age, years			35.59	7.49	36.00	(29.5, 41)	(22, 49)
BMI							
	Male, n (%)	8 (47.1%)	27.22	24.25	7.36	(20.44, 42.54)	(22.24, 32.16)
	Female, n (%)	9 (52.9%)	24.28	22.35	4.88	(19.69, 34.98)	(21.30, 26.36)
Height, cm			171.29	8.74	170.00	(166.25, 178.75)	(156, 187)
Weight, kg			75.82	18.37	70.10	(60.85, 86.7)	(55.7, 124.4)
Handed, right, left, ambidextrous		15, 1, 1					
Occupation							
	Surgeon	4	(23.53%)				
	Anaesthetist, tech	4	(23.53%)				
	Nurse	5	(29.41%)				
	Physiotherapist	3	(17.65%)				
	Occupational Therapist	1	(5.88%)				
Job tenure, years			9.60	5.18	10.00	(5.29, 14.5)	(1, 18)
Hours worked per week			41.43	12.79	40.00	(36, 45)	(16, 75)

Note. All participants reported having normal or corrected to normal vision. Zero participants taking medications known to affect the central nervous system or allergies to silicone, which is a material used in the ingestible pill that measured core body temperature. Participants wore the same clothing for each simulation (scrubs, surgical gowns, enclosed shoes, gloves, hair nets, aprons and face shields if required). Surgeons also wore face shields.

Table 2. Mixed ANOVA Results for Response Times as Dependent Variable.

Main Effect and Interactions	**Cognitive Tests**	***df***		***F***	***p***	η_p^2
Heat	Rot avg	1	15	0.58	0.46	0.04
	DT CC	**1**	**14**	**5.01**	**0.04**	**0.26**
	DT CI	1	13	0.61	0.45	0.04
	DT IC	**1**	**13**	**1.74**	**0.21**	**0.11**
	DT II	**1**	**14**	**1.78**	**0.20**	**0.11**
Heat * Activity level	Rot avg	1	15	0.04	0.84	0.00
	DT CC	1	14	0.05	0.83	0.00
	DT CI	1	13	0.09	0.77	0.01
	DT IC	1	14	0.80	0.39	0.05
	DT II	1	14	0.04	0.85	0.00
Heat * Time	Rot avg	5	75	0.60	0.70	0.04
	DT CC	4	56	1.19	0.33	0.08
	DT CI	4	52	0.41	0.81	0.03
	DT IC	**4**	**56**	**1.68**	**0.17**	**0.11**
	DT II	**4**	**56**	**4.34**	**0.00**	**0.24**
Heat * Time * Activity level	Rot avg	5	75	0.34	0.89	0.02
	DT CC	4	56	0.22	0.93	0.02
	DT CI	4	52	0.23	0.92	0.02
	DT IC	4	56	0.57	0.68	0.04
	DT II	4	56	0.43	0.79	0.03

Note. DT = Double Trouble, the Stroop-like task. Rot = Rotations task. CC = congruent probe, congruent targets. CI = congruent probe, incongruent targets. IC = incongruent probe, congruent targets. II = incongruent probe, incongruent targets. Boldface = substantial effect sizes (≥ .10) indicating meaningful differences found.

Table 3. Mixed ANOVA Results for Number of Correct Answers as Dependent Variable.

Main Effect and Interactions	Cognitive Tests	*df*		*F*	*p*	η_p^2
Heat	**DT correct**	**1**	**15**	**3.93**	**0.07**	**0.21**
	Rot correct	**1**	**15**	**1.87**	**0.19**	**0.11**
	GR correct	**1**	**15**	**1.64**	**0.22**	**0.10**
	SP correct	1	15	1.00	0.33	0.06
Heat * Activity level	DT correct	1	15	0.15	0.70	0.01
	Rot correct	1	15	0.02	0.89	0.00
	GR correct	1	15	0.02	0.90	0.00
	SP correct	1	15	0.28	0.60	0.02
Heat * Time	**DT correct**	**4**	**60**	**2.17**	**0.08**	**0.13**
	Rot correct	**5**	**75**	**1.67**	**0.15**	**0.10**
	GR correct	2	30	0.17	0.85	0.01
	SP correct	**2**	**30**	**2.52**	**0.10**	**0.14**
Heat * Time * Activity level	DT correct	4	60	0.28	0.89	0.02
	Rot correct	5	75	0.31	0.91	0.02
	GR correct	2	30	0.86	0.43	0.05
	SP correct	2	30	0.35	0.71	0.02
Heat	**DT correct**	**1**	**15**	**3.93**	**0.07**	**0.21**
	Rot correct	**1**	**15**	**1.87**	**0.19**	**0.11**
	GR correct	**1**	**15**	**1.64**	**0.22**	**0.10**
	SP correct	1	15	1.00	0.33	0.06

Note. DT = Double Trouble, the Stroop-like task. Rot = Rotations task. CC = congruent probe, congruent targets. CI = congruent probe, incongruent targets. IC = incongruent probe, congruent targets. II = incongruent probe, incongruent targets. Boldface = substantial effect sizes (≥ .10) indicating meaningful differences found. **Table 4.** Mixed ANOVA Results for Number of Errors Committed as Dependent Variable.

Main Effect and Interactions	**Cognitive Tests**	***df***		***F***	***p***	η_p^2
Heat	**DT errors**	**1**	**13**	**3.60**	**0.08**	**0.22**
	Rot errors	**1**	**14**	**1.92**	**0.19**	**0.12**
	GR errors	1	13	0.01	0.91	0.00
	SP errors	1	15	0.94	0.35	0.06
Heat * Activity level	**DT errors**	**1**	**13**	**1.56**	**0.23**	**0.11**
	Rot errors	1	14	0.03	0.86	0.00
	GR errors	1	13	0.55	0.47	0.04
	SP errors	1	15	0.14	0.71	0.01
Heat * Time	DT errors	4	52	0.32	0.86	0.02
	Rot errors	**5**	**70**	**1.99**	**0.09**	**0.12**
	GR errors	2	26	0.27	0.76	0.02
	SP errors	2	30	0.48	0.62	0.03
Heat * Time * Activity level	DT errors	4	52	0.81	0.52	0.06
	Rot errors	5	70	0.53	0.75	0.04
	GR errors	**2**	**26**	**1.53**	**0.24**	**0.11**
	SP errors	2	30	0.33	0.73	0.02
Heat	**DT errors**	**1**	**13**	**3.60**	**0.08**	**0.22**
	Rot errors	**1**	**14**	**1.92**	**0.19**	**0.12**
	GR errors	1	13	0.01	0.91	0.00
	SP errors	1	15	0.94	0.35	0.06

Note. DT = Double Trouble, the Stroop-like task. Rot = Rotations task. CC = congruent probe, congruent targets. CI = congruent probe, incongruent targets. IC = incongruent probe, congruent targets. II = incongruent probe, incongruent targets. Boldface = substantial effect sizes (≥ .10) indicating meaningful differences found.