DARPA Augmented Cognition

Technology Integration Experiment (TIE)

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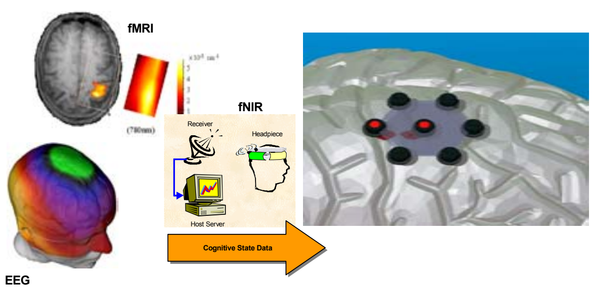
Jeffrey G. Morrison, Ph.D.
SPAWARSYSCEN – SD

David Kobus, Ph.D.
Mark St. John, Ph.D.
Pacific Science & Engineering Group

AugCog Phase 1 Objective

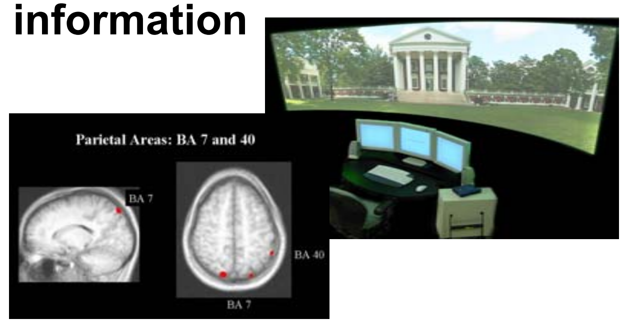
Assess cognitive state(s) in real-time

First demonstration of real-time spatial and temporal imaging of brain activity with one technology



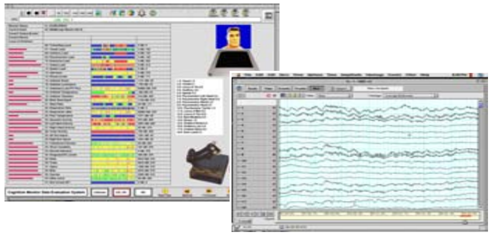
Accomplished using fNIR (a non-invasive brain recording technology) to measure and monitor cognitive state in real-time (<1min)

Cognitively designed information system made it easier for people to encode, store, and retrieve information



Results indicate that the users demonstrated a 131% improvement in memory

Cognition Monitoring system detected cognitive state shift (Verbal to Spatial) in <1min using EEG signals



First example of real-time, online processing and characterization of brain function based on incoming cognitive state data (<1min)

Achieve through the development of robust, non-invasive, real-time cognitive state detection technology.

Program Objectives (FY02-FY06)

Build Cognitively Aware Computational Systems to Enhance Human & Computer Performance

AugCog will enable computational systems to dynamically adapt to users by developing the means to:

Phase 1: <u>Measure cognitive state</u>

- **Technology Integration Experiment as stepping stone**

Phase 2: <u>Manipulate cognitive state</u>

Phase 3: <u>Automate cognitive state manipulation</u>

Phase 4: <u>Demonstrate and test in operational scenarios</u>

AugCog Execution Strategy:

Capability to Measure ⟶ Basis for Manipulation

Phase I TIE Objectives

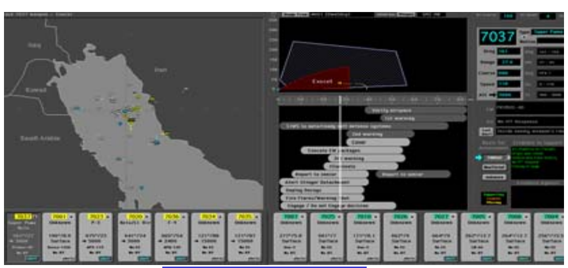
1. Demonstrate detection of “cognitive state” in an applied context.
2. Integrate independently developed gauges using the same people performing the same task, at the same time.
3. Showcase and document potential application for *manipulating* cognitive state.
4. Assess and document maturity and identify issues and efficacy for Phase 2.

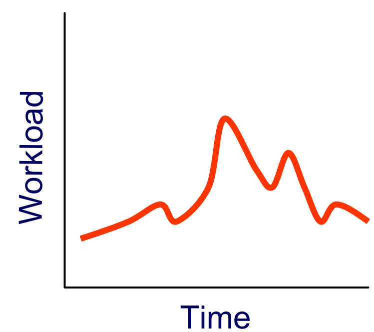
TIE Assessment Strategy

1. Develop a common test task for validating gauges
2. Conduct research with a common set of subjects, under common conditions, with a common protocol.
3. Report to take the form of a "Consumer Reports" for prospective Users of Technologies & Gauges
   - Performers assess their own gauges
     - TIE Mgm't Identifies Topics (Questions)
     - Performers' Executive Summaries become Appendices to final report
     - Incorporate transition primer(s) / User Guides
   - Collect Subjective Reports
     - TIE Management team to document Integration issues with development teams (BMH & PSE)
     - Survey Subject Participants for their perception
   - Document as many issues as possible likely to be relevant to transition.

Identifying a Cognitive Test Task

- What do we need in a cognitive task to assess cognition?
  - Task needs to systematically allow manipulation of as many aspects of “cognition” as possible so as many gauges as possible can be compared with a common context.
  - Task must incorporate complex cognition - consistent with military decision-making environments.
  - Task must provide quantifiable task performance data to validate against cognitive state gauges.
  - TIE to define common test protocol for task





Task → Protocol → Assess Gauges

Air Warfare Task

Transit Task:
Spatial Orientation, Executive Processing (planning), Long & Short Term memory

Situation Awareness / Monitoring Task:
Visual-spatial search, signal detection, Time-critical reaction time, identification, Spatial Memory and Mental Rotation

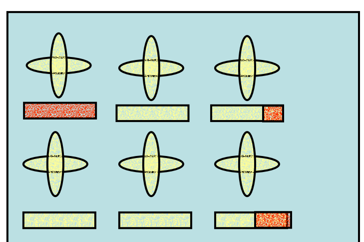
Fire Control:
Procedural Memory, Executive Processing, visual search, tactical planning

tive
sion,

- Too complex for casual use with untrained participants.
  - Most component tasks involved high levels of cognitive processing.
  - Significant scheduling component across tasks
  - What do we mean by "Cognitive State"?
  - What Dimensions of cognition are most salient?
  - How do we manipulate task so as to assess diagnosticity of gauges?

Need a simpler task !!

Navigation Planning Charts



Auditory Alerts, Incoming Verbal Communications, etc.
1----------2----------3

Haptic Alerting

Spatial Orientation, Visual tracking, Planning

Resource management, Attention, planning, Number facility

Auditory Monitoring, Collaboration / Communication Tasks

Allocation of Attention, Touch perception, Spatial memory

CWA Development Tasks

Gauge Technology (CWA Performer)	Development Task Characteristics
EEG, (Sarnoff, Princeton, UNM)	Visual Search, distracter, Memory, A/V attention, Verbal / Spatial Memory,
Arousal (Clemson, U of H)	High arousing video game, Time Stress, Environmental Stressors
Pupil Changes (SDSU)	Spatial Search, Dual Attention Task, Driving simulation
fNIR (Drexel, U of Penn, NOVASOL, Electrical Geodesics)	A/V Attention, Verbal/Spatial Memory, Autonomic / Novel response

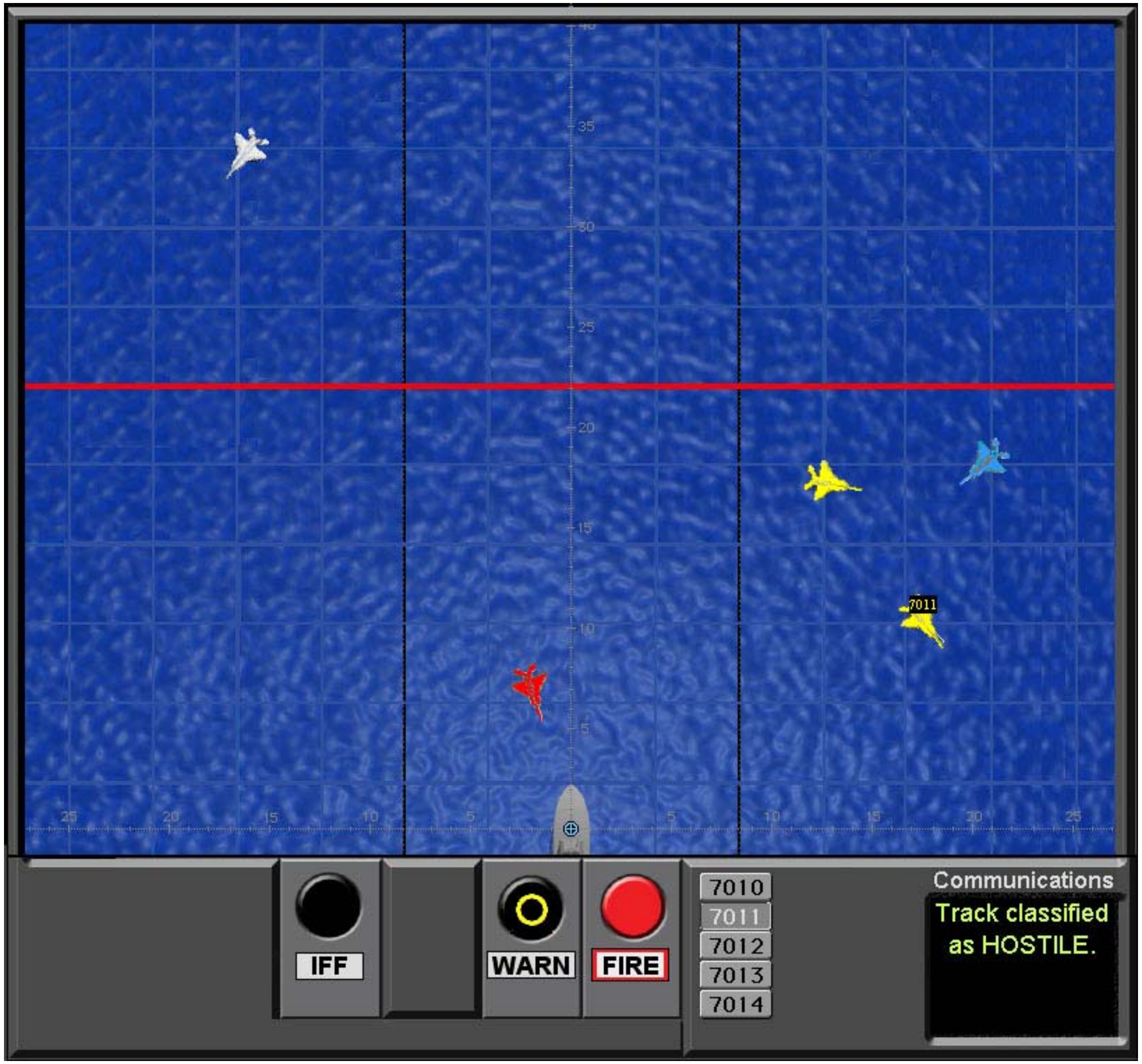
Warship Commander Task (WCT): Final Development Criteria

- Ecologically valid: Command and control task
- Engaging for undergraduates
- Multiple channels / modes of input
- Multiple cognitive processes
- Multiple "stages" of cognition
- Independent manipulation
- Amenable to neuro-physiological measures
- Amenable to modulation of interface and taskload
- Needs to be Portable (Standard PC, Single display, etc.)

WCT– Cognitive Demands

- **Complex Task Environment**
  - Multiple component tasks competing for limited resources
  - Multiple decisions must be performed in the right order (executive function)
  - Inputs and outputs in different modalities (spatial/verbal, Manual/audio)
- **Air Defense task**
  - Information acquisition - Detection of new tracks,
  - Information analysis - identification
    - acquisition of identity (red, blue) or data for making identity, location (proximity to bottom of screen), turning away
  - Executive Decision-making – whether and when to warn and shoot
  - Action implementation – process of warning and shooting
- **Ship Status task**
  - Information acquisition – detection of messages, compute relevance
  - Information analysis – comprehend messages
  - Decision selection – determine appropriate action
  - Action implementation – execute action

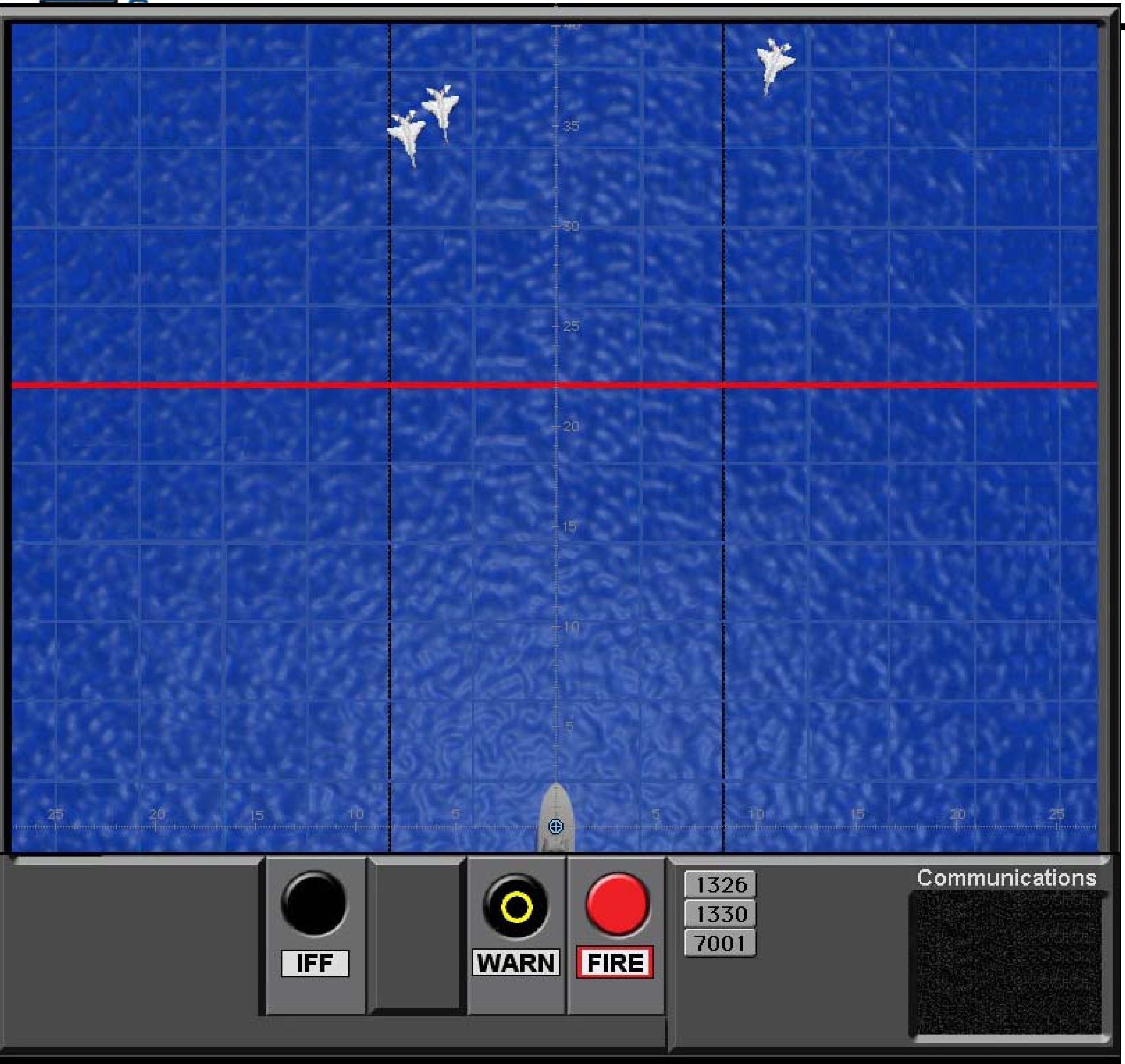
Warship Commander Task



Component Tasks:

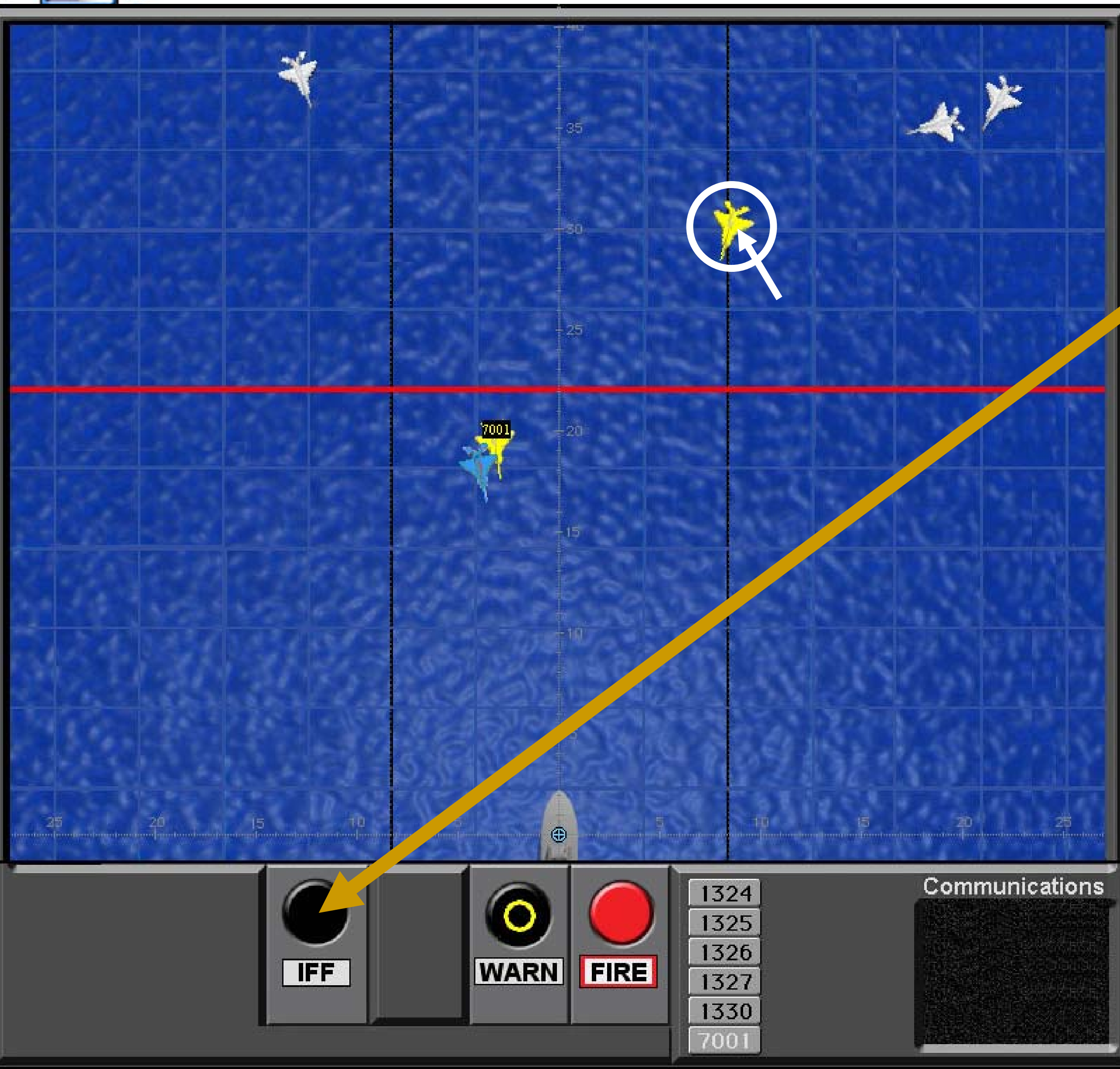
- Airspace monitoring
- Ship status

WCT: Performing the Airspace Task



1. Unidentified tracks (White) enter from the North (Top)

WCT: Performing the Airspace Task



2. Hook and query each track for “Identification Friend or Foe (IFF)”

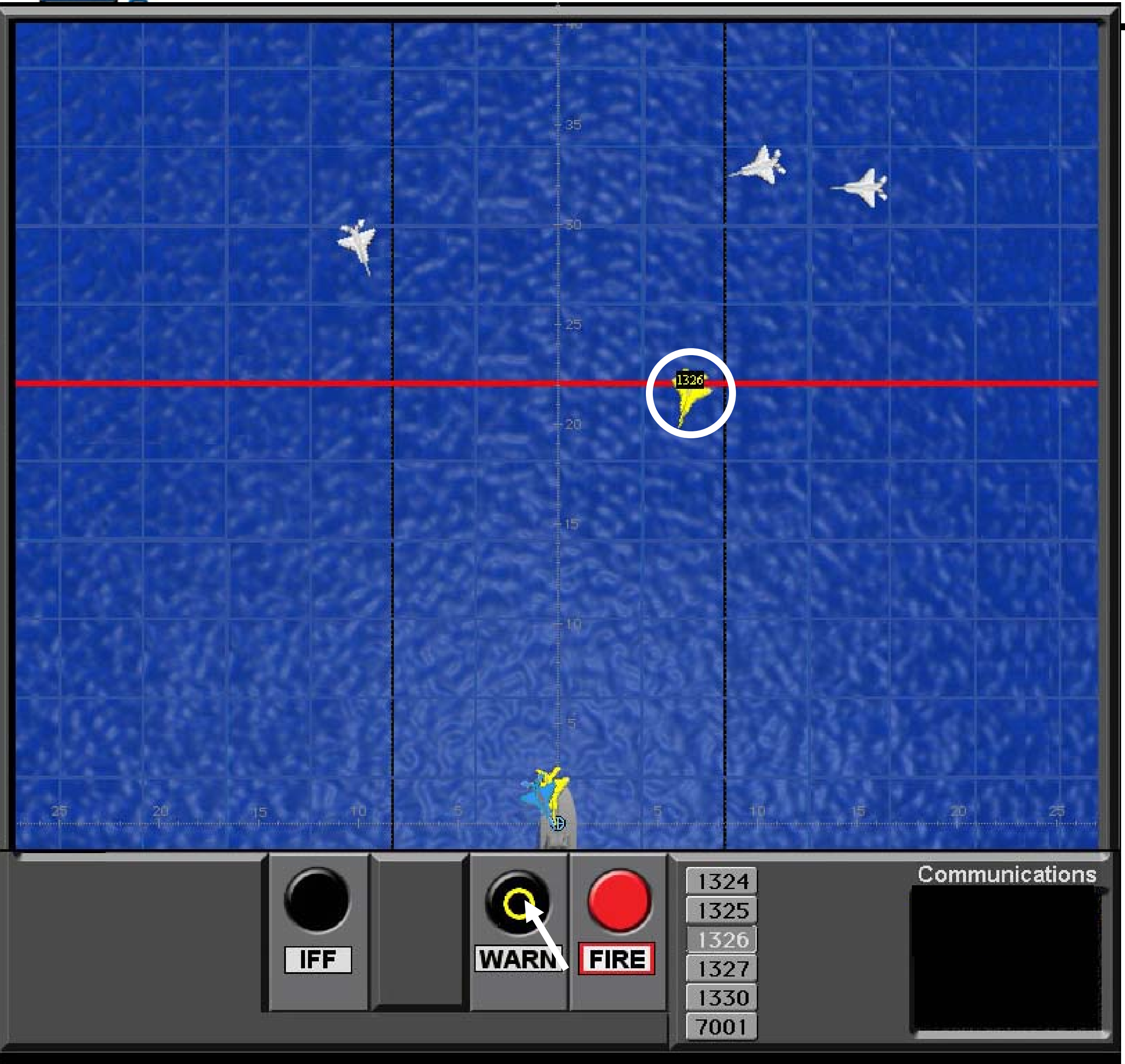
- **White** tracks are *unassessed*
- **Blue** tracks are *friendly*
- **Red** tracks are *hostile*
- **Yellow** tracks are “*unknown*”

WCT: Performing the Airspace Task

3. Yellow Tracks are more complex & Require additional queries.

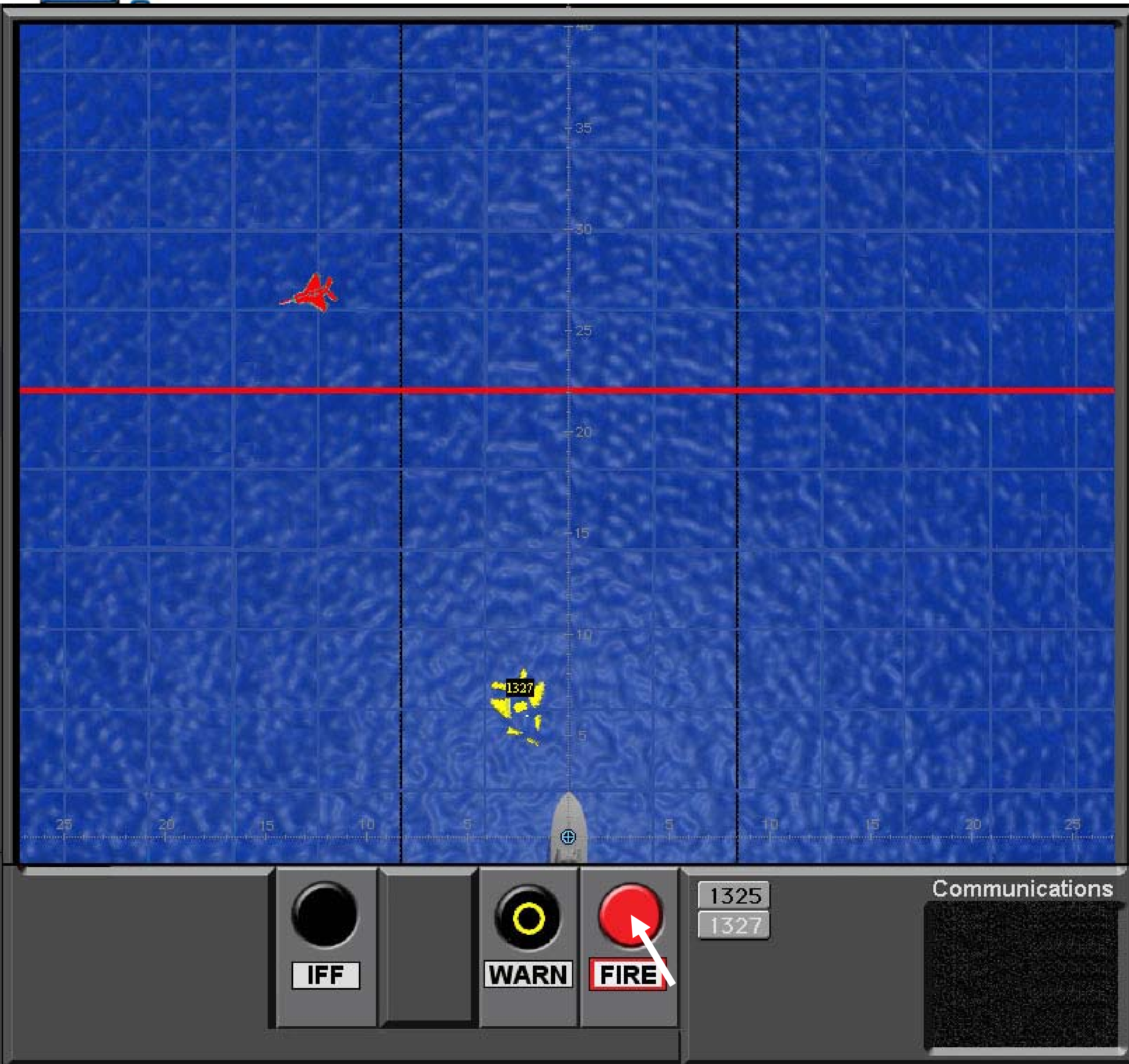
- Use the Communications window to find out more about yellow tracks
- User must remember the evaluation

WCT: Performing the Airspace Task



4. Yellow- “Potentially Hostile” tracks must be warned after crossing the red Line of Engagement (LOE)

WCT: Performing the Airspace Task



5. Must Fire on Yellow tracks *if they do not turn away within 3 seconds after warning. Cannot fire on them until warned.*
6. Red tracks *must* be fired on, (without warning), if they cross the LOE

WCT: Independent Variables

1. Number of Tacks/ wave. (Waves of 6, 12,18 or 24 tracks)
2. Track complexity. (High or Low number of “unknown” (yellow) tracks)
3. Presence or absence of secondary “Ship Status” task

Ship status task

3: Look at text window for multiple choice (as time allows)

1. 550
2. 337
3. 115
4. 094

4: Attempt to recall last relevant data

"Last course was … 115 or 550???"

2: Listen for queries

"This is the Captain, what is our current course?"

5: Response selection & Execution

Operator responds by pressing the number key on keyboard corresponding to their choice.

1: Monitor Audio Messages

- "Current water level is 5-5-0"
- "Ship's course is 1-1-5"

Prospective “Gauge” Assessment Issues

Component Sensors: EEG Heart Rate Variability Pupil Dilation, etc. Sensor Transition Issues & Imperatives	Specificity / Diagnosticity "cognitive state" Communication Modality Spatial Verbal Executive Function
Gauge Sensitivity To: Task Load Communication Modality	Temporal resolution Spatial Resolution Functional Resolution
Gauge computation (cycle) time	Ease of integration with other systems
Time to configure	Comfort / wearability / intrusiveness
Consistency (Variability) for different subjects under different conditions	Potential factors reducing utility
Costs: Procurement Per use	Potential to Predict & how far
Number and complexity of sensors driving Gauge	Relative Compatibility with other systems (Ease of Integration)
Accuracy	Importance to maintaining cognitive state?

TIE: Gauge Assessment

- How is data collected for gauge use?
- Are there integration issues between gauges?
- What does the gauge measure?
- Can gauge values be provided in real-time?
- How well did the gauge detect changes in task load or performance?
- How reliable was the gauge across participants?
- What are the transition issues for each gauge?

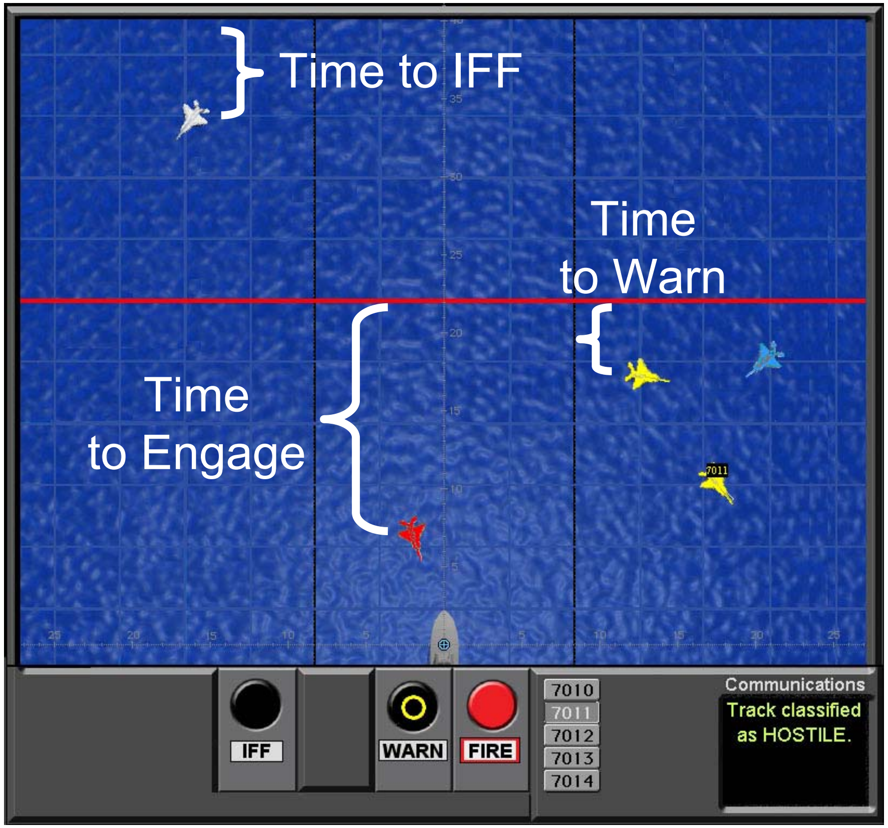
Phase I TIE Results

- Empirical Assessment:
  - Detection of cognitive state as compared to task manipulations
  - Consistency within and across users
  - Integration of multiple sensors
  - Performer Analyses (Appendices)
- Questionnaire:
  - Technology & Integration Issues
  - Lessons Learned / Recommendations
  - Calibration Requirements
  - Actual & Potential Physical Footprint
  - Capabilities & Limitations (beyond TIE experience)

WCT: Dependent Variables

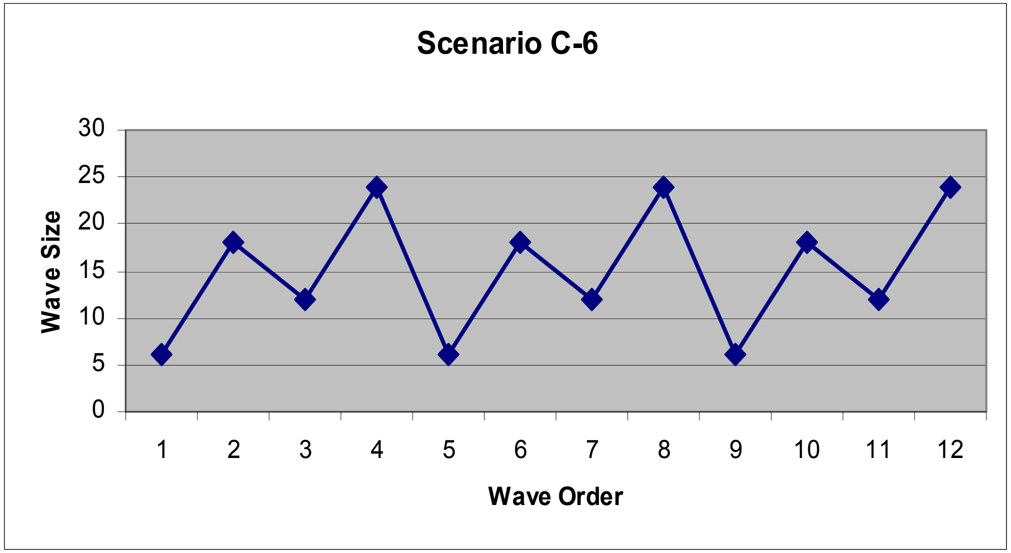
- **WCT software records: scenario events, event time, user response time, and errors. Data sent to the computer parallel, serial and Ethernet ports in real time.**
- **Air Defense Task measures:**
  - Response Time to Identify Friend or Foe (IFF)
  - Response Time to Warn
  - Response Time to Engage
  - Errors of Commission
  - Errors of Omission
  - Number of Tasks Pending
  - Game Score (Percent of correctly completed tasks out of possible tasks per wave of tracks)
- **Ship Status Task measures:**
  - Response Time
  - Percent Correct

Air Task Response Time Measures

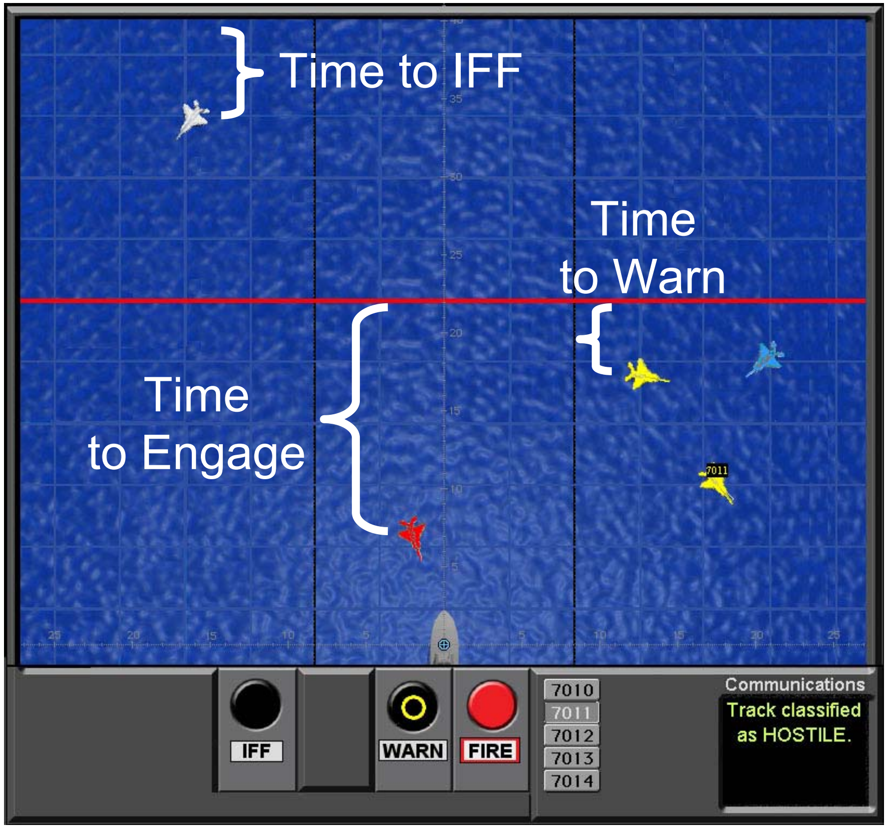


Air Defense Task: Response Time Dependent Measures

Task load: Wave Size Manipulation



Air Task Response Time Measures



TIE Basic Research Design

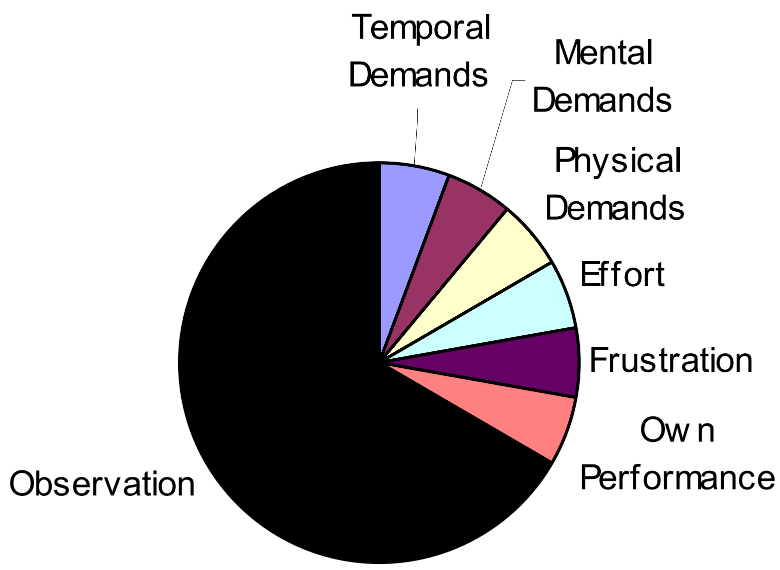
Each data collection session manipulated 3 aspects of task load:

1. **Number of tracks per wave**
   - Each scenario consisted of 12 waves
   - 6, 12, 18, or 24 tracks per wave
2. **Track difficulty** - Yellow tracks require more processing
   - High proportion of yellow tracks within each wave (67%)
   - Low proportion of yellow tracks within each wave (33%)
   - Difficulty was high for two scenarios and low for two scenarios
3. **Ship status task**
   - Task requires auditory/verbal processing and memory
   - Task was “on” for two scenarios and “off” for two scenarios

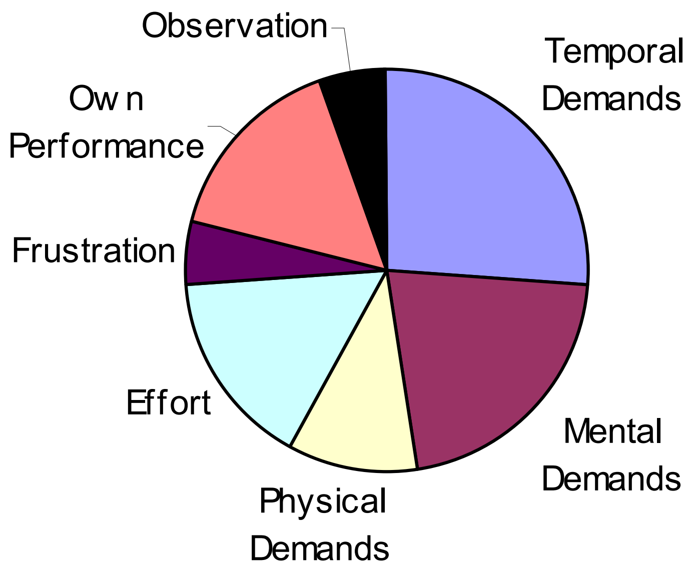
WCT Perceived Workload Demands

Subjective effort ratings for Warship Commander Task (WCT)

Low Task Load Period

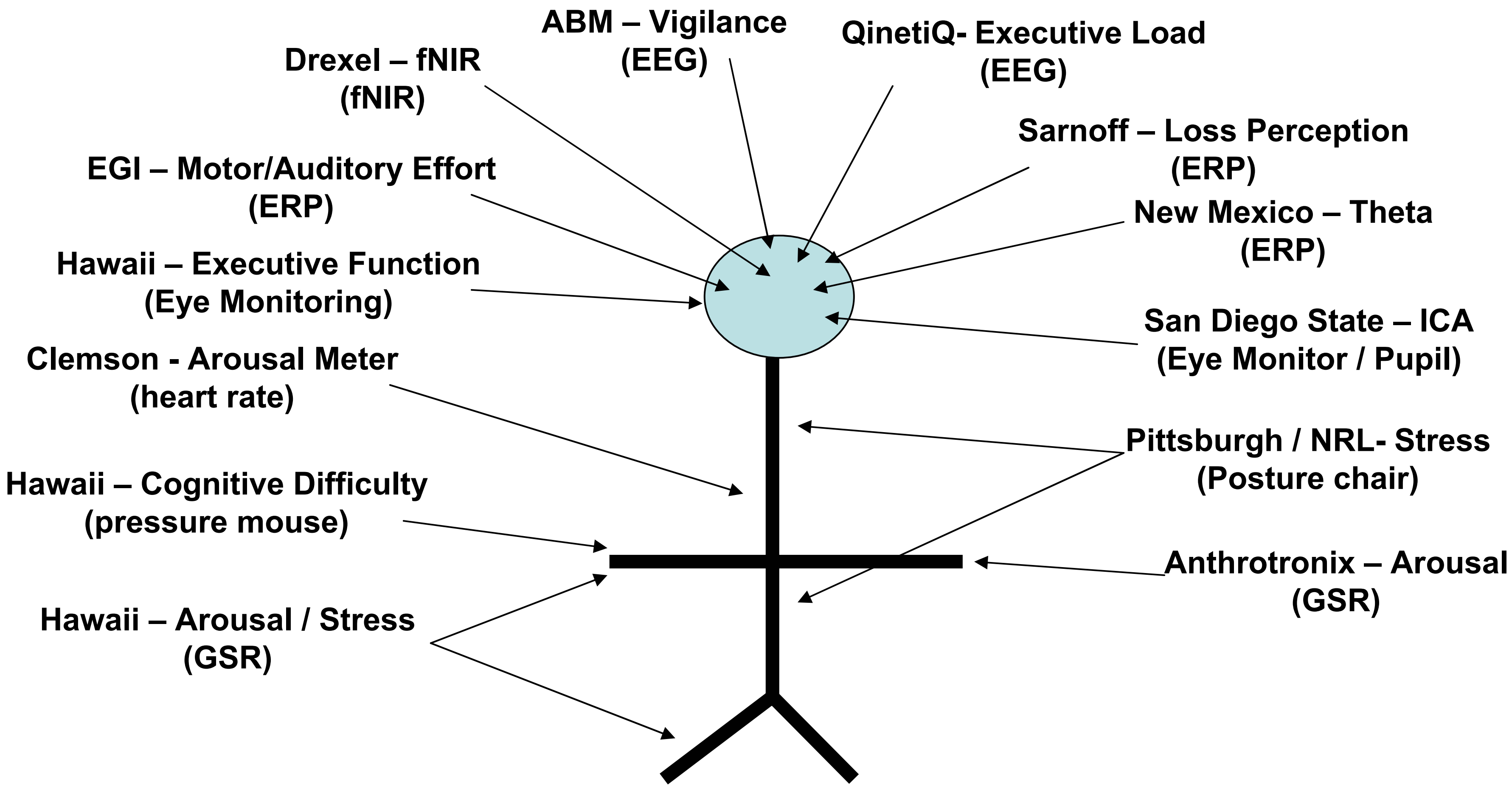


High Task Load Period



WCT manipulations were successfully manipulating aspects of cognition as validated by the NASA TLX

Teaming: Sensors Evaluated at TIE



- *Given demands for access to head, EEG / ERP requirements drove TIE teaming*

Gauge	Sensor Type	Developer
fNIR		
fNIR (left)	Blood Oxygenation	Drexel U
fNIR (right)	Blood Oxygenation	Drexel U
EEG-Continuous		
Percent High Vigilance	EEG	ABM
Probability Low Vigilance	EEG	ABM
Executive Load	EEG	QinetiQ
EEG-ERP		
Motor Effort	ERP-IFF	EGI
Auditory Effort	ERP-Engage Sound	EGI
Loss Perception	ERN-Error Sounds	Sarnoff/Columbia
Gauge	NA	U New Mexico
Arousal		
Arousal Meter	Inter-Heart Beat Interval	Clemson U
Arousal	GSR	U Hawaii
Arousal	GSR	AnthroTronix
Physiological		
Head-Monitor Coupling	Head Posture	U Pitt/NRL
Head Bracing	Body Posture	U Pitt/NRL
Back Bracing	Body Posture	U Pitt/NRL
Perceptual/Motor Load	Mouse clicks	U Hawaii
Cognitive Difficulty	Mouse pressure	U Hawaii
Index of Cognitive Activity	Pupil dilation	SDSU

Team 1-2-3-4

SDSU

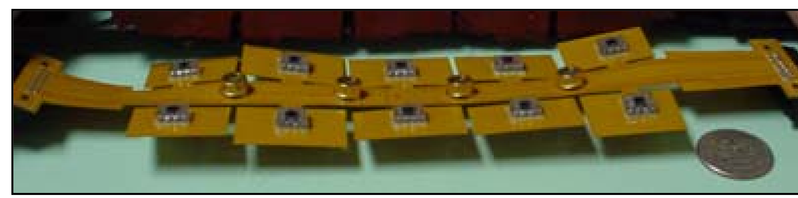
- San Diego State University
  - Index of Cognitive Activity (ICA)
  - Worked with all teams to provide a common “cognitive state” measure.

Team 1 (n = 6)

- Clemson University:
  - Arousal Meter
- University of Pittsburgh & Naval Research Laboratory:
  - Head/Monitor Coupling, Head Bracing, Back Bracing
- Electrical Geodesics, Inc:
  - Motor Effort, Auditory Effort

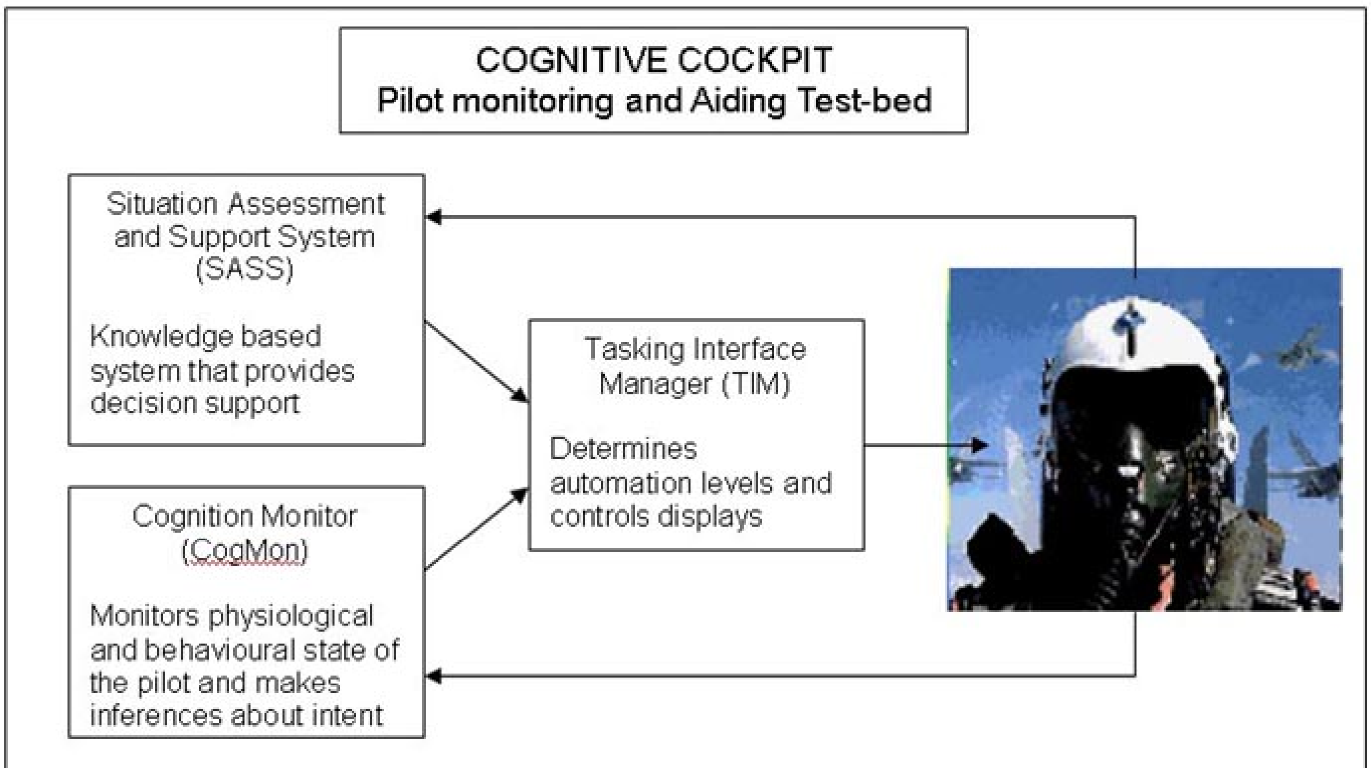
Team 2 (n = 8)

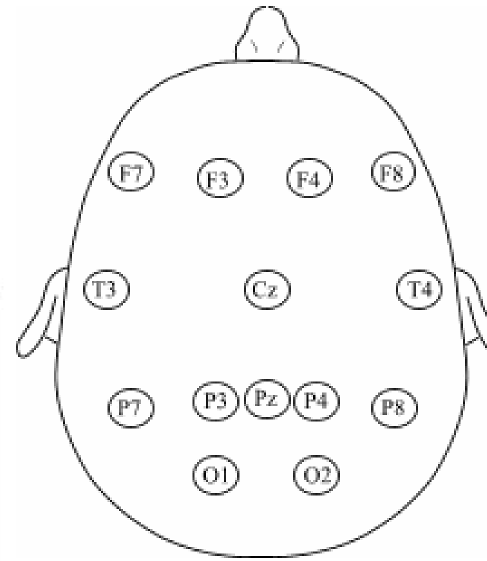
- **Drexel University:**
  - Functional Near Infrared – Brain Imaging (fNIR)
- **Advanced Brain Monitoring:**
  - Percent High Vigilance, Probability Low Vigilance
- **University of Hawaii:**
  - Arousal and Stress



Team 3 (n = 6)

- QinetiQ
  - Executive Load





Team 4 (n=5)

- Sarnoff:
  - Loss Perception
- University of New Mexico:
  - Theta Power
- Anthrotronix:
  - GSR Arousal

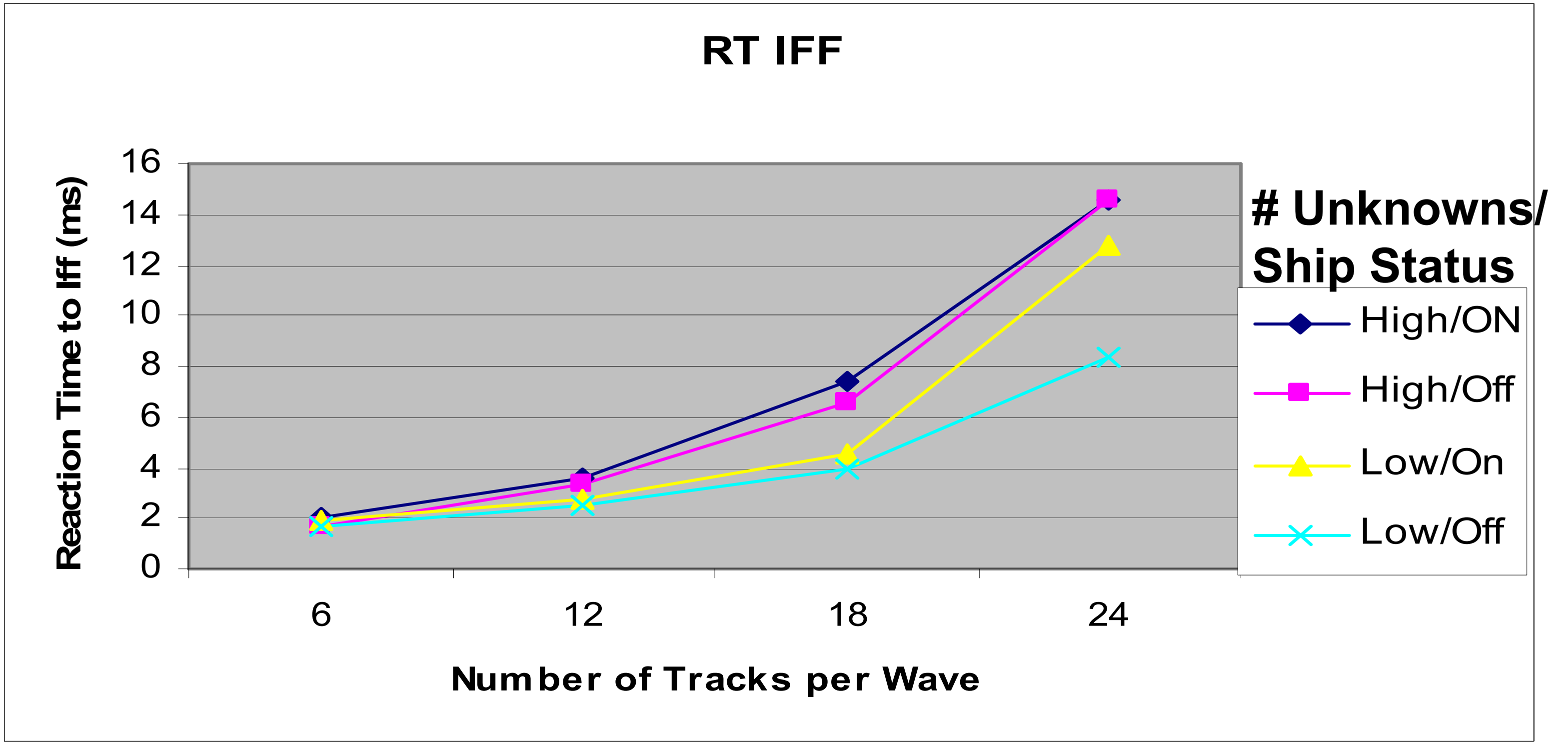
AugCog Phase I

TIE Results

TIE Results: Task Performance

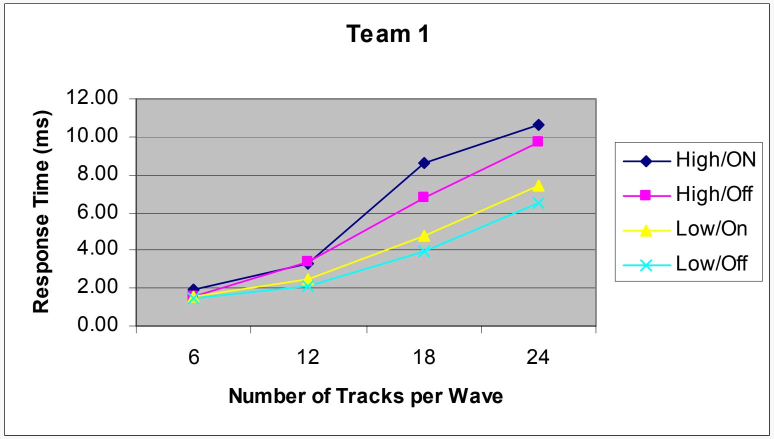
RT IFF Results across all teams.

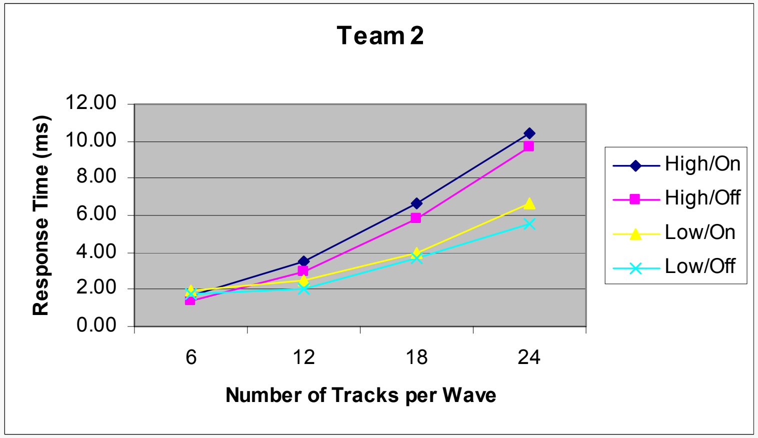
- ***WCT task manipulations were consistent with pilot studies***
- ***True for all levels of all task manipulations***
- ***Comparable results across all teams***

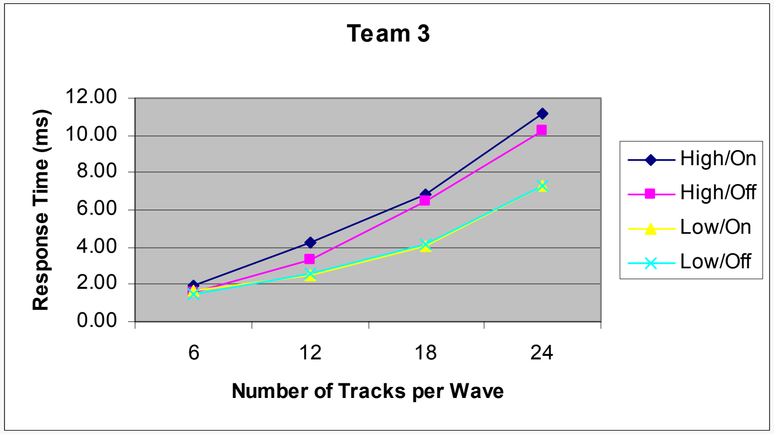


All Task load manipulations created predicted performance effects across all research teams.

RT-IFF Results by Team







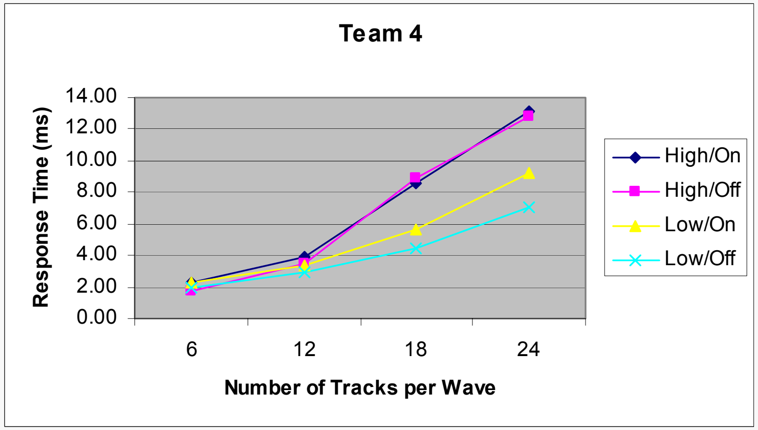


Table 2. Statistical results of the three task load factors on the WCT performance measures by team and overall.

Task Load Factors	Team	# prtcpnts	RTIFF F	RTIFF *p*	RTWarn F	RTWarn *p*	RTEngage F	RTEngage *p*	PctGS F	PctGS *p*	ECommis F	ECommis *p*	EOmiss F	EOmiss *p*	TPending F	TPending *p*
Number of Tracks per Wave	1	6	27.1	**0.003**	64.1	**0.000**	44.4	**0.000**	27.8	**0.000**	24.7	**0.000**	36.9	**0.001**	244.4	**0.000**
	2	8	59.4	**0.004**	55.8	**0.000**	24.1	**0.000**	19.2	**0.000**	33.5	**0.000**	33.7	**0.000**	282.1	**0.000**
	3	6	30.2	**0.001**	30.2	**0.000**	27.1	**0.003**	9.3	**0.001**	22.5	**0.001**	13.1	**0.012**	138.5	**0.000**
	4	5	52.9	**0.000**	91.8	**0.000**	35.2	**0.000**	41.0	**0.000**	13.9	**0.000**	46.6	**0.001**	275.7	**0.000**
Track Difficulty	1	6	14.9	**0.012**	49.7	**0.001**	21.9	**0.005**	27.9	**0.003**	17.7	**0.008**	31.3	**0.003**	335.9	**0.000**
	2	8	22.3	**0.002**	69.1	**0.000**	27.8	**0.001**	48.9	**0.000**	17.4	**0.004**	37.5	**0.000**	297.4	**0.000**
	3	6	17.0	**0.009**	21.7	**0.006**	14.9	**0.012**	11.3	**0.020**	23.9	**0.005**	9.4	**0.028**	155.2	**0.000**
	4	5	62.2	**0.001**	41.8	**0.003**	80.7	**0.001**	184.6	**0.000**	1.5	0.283	126.3	**0.000**	463.9	**0.000**
Secondary Verbal Task	1	6	9.3	**0.029**	27.2	**0.003**	15.5	**0.011**	6.7	**0.049**	0.4	0.579	8.5	**0.033**	44.9	**0.001**
	2	8	6.4	**0.040**	25.8	**0.001**	16.5	**0.005**	13.9	**0.008**	0.1	0.754	18.3	**0.004**	67.7	**0.000**
	3	6	2.8	0.156	24.9	**0.004**	9.3	**0.029**	19.7	**0.007**	0.0	0.868	34.0	**0.002**	16.0	**0.010**
	4	5	14	**0.020**	6.7	0.060	7.9	**0.049**	6.6	0.062	0.1	0.806	8.7	**0.042**	21.7	**0.010**
# Tracks	Overall	8	66.9	**0.000**	85.4	**0.000**	38.9	**0.000**	38.8	**0.000**	61.6	**0.000**	38.2	**0.000**	285.0	**0.000**
Difficulty	Overall	8	34.8	**0.001**	90.0	**0.000**	31.8	**0.001**	46.1	**0.000**	37.0	**0.000**	35.2	**0.001**	430.5	**0.000**
2nd Verbal	Overall	8	19.9	**0.003**	41.0	**0.000**	21.3	**0.002**	15.5	**0.006**	0.0	0.864	21.1	**0.003**	57.5	**0.000**

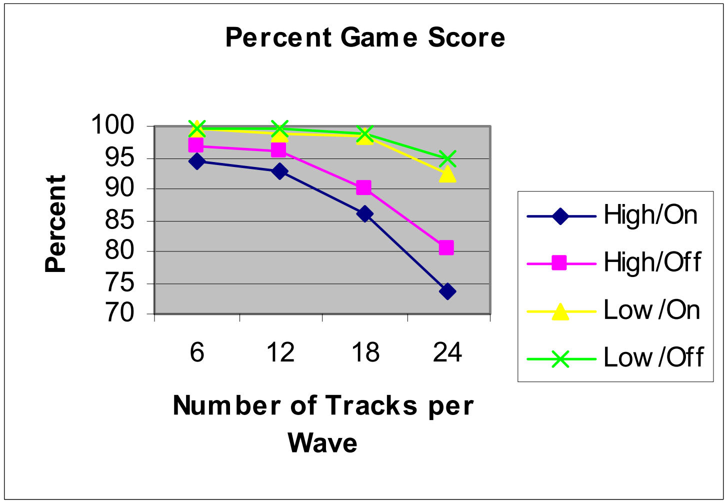
a significant effect

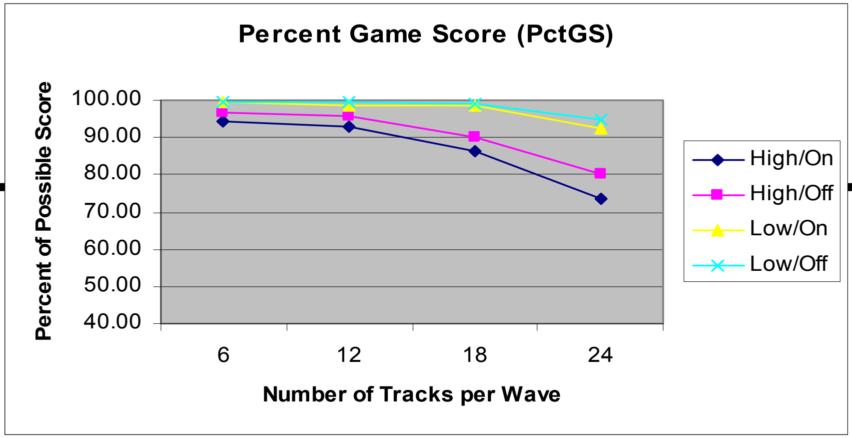
a *marginal* effect

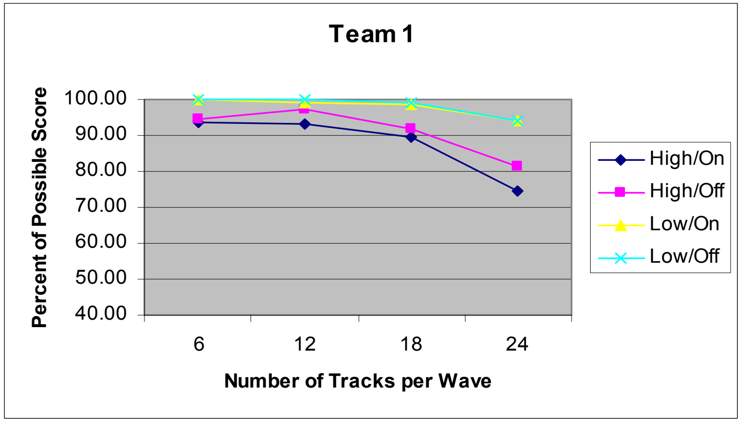
a *potential* effect

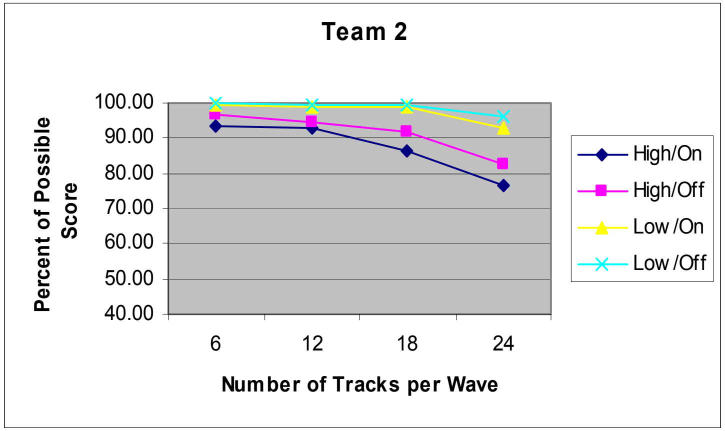
Table 3. Significant interaction results and pairwise comparisons.

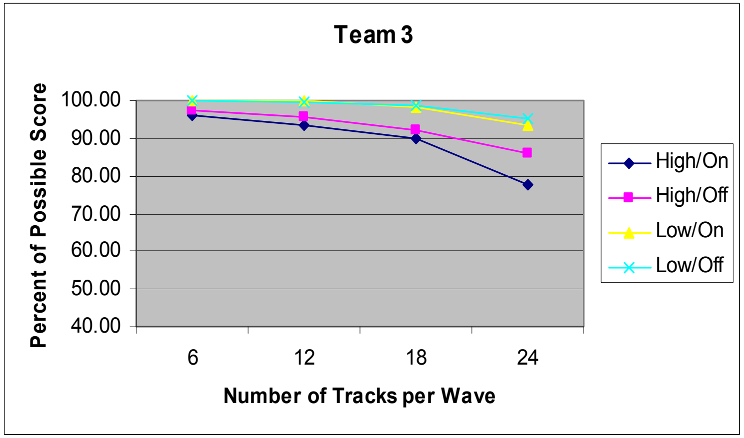
Interactions	RTIFF	RTWarn	RTEngage	PctGS	EC	EO	Pending
# Tracks by Track Difficulty	x	x	x	x	x	x	x
# Tracks by Secondary Verbal			x	x		x	x
Track Difficulty by Secondary Verbal		x	x	x		x	x
# Tracks by Track Difficulty by 2nd Verbal						x	
Pairwise Comparisons by Wave							
6<12	x	x	x		x	x	x
6<18	x	x	x	x	x	x	x
6<24	x	x	x	x	x	x	x
12<18	x	x	x	x	x	x	x
12<24	x	x	x	x	x	x	x
18<24	x	x	x	x	x	x	x

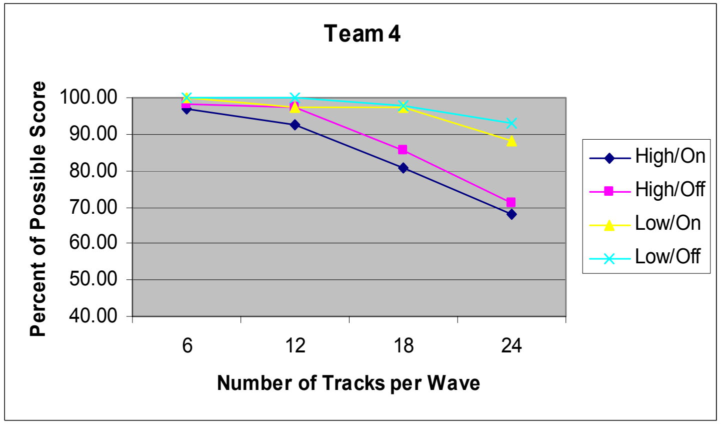



Percent Game Score (PctGS)
Percent of Possible Score
100.00
90.00
80.00
70.00
60.00
50.00
40.00
6
12
18
24
Number of Tracks per Wave
High/On
High/Off
Low/On
Low/Off


Team 1
Percent of Possible Score
100.00
90.00
80.00
70.00
60.00
50.00
40.00
6
12
18
24
Number of Tracks per Wave
High/On
High/Off
Low/On
Low/Off


Team 2
Percent of Possible Score
100.00
90.00
80.00
70.00
60.00
50.00
40.00
6
12
18
24
Number of Tracks per Wave
High/On
High/Off
Low /On
Low /Off


Team 3
Percent of Possible Score
100.00
90.00
80.00
70.00
60.00
50.00
40.00
6
12
18
24
Number of Tracks per Wave
High/On
High/Off
Low/On
Low/Off


Team 4
Percent of Possible Score
100.00
90.00
80.00
70.00
60.00
50.00
40.00
6
12
18
24
Number of Tracks per Wave
High/On
High/Off
Low/On
Low/Off

Validating the Task

- Did each of the three task load factors significantly affect performance on the task similarly for each Team?
  - – Number of tracks per wave Yes
  - – Track difficulty Yes
  - – Secondary task Yes

Evaluating Gauges against Objective Task Performance

How well does each gauge detect changes in task load?

- Three-way repeated measures ANOVAs were computed for the three manipulations of task load
  - Number of tracks per wave
  - Track difficulty
  - Secondary task

How reliable or consistent were each of the gauges?

- Correlation analysis of gauges
- Correlation analysis of subject for each gauge

Gauge	Sensor Type	Performer	Task Load Factors: Number of Tracks per Wave (6,12,18,24)	Track Difficulty (Hi/Lo)	Secondary Verbal Task (On/Off)	Consistency Across Participants
			●	○	○	◒
			●	○	○	◒
			●	◍	○	◒
			●	○	○	◒
			●	◒	○	●
			◍	○	◍	●
			○	◒	◍	◒
			◍	○	●	◒
			●	○	○	●
				○	●	●
				○	○	●
				○	○	●
				○	○	◒
				○	○	◒
				○	○	○
Head Bracing	Body Posture	UPitt/NRL	◍	○	◍	◒
			○	◍	○	◒
			●	●	○	●
			●	●	○	●
			○	○	●	○

- 11 Gauges showed effects for track load, 5 others were marginally significant

- 8 gauges showed significant effects for Tracks per wave

- 2 gauges showed significant effects for Track Difficulty and
- 3 gauges showed significant effects for Secondary Verbal Memory Task

- Most Gauges were consistent across participants

Potential for Interference?

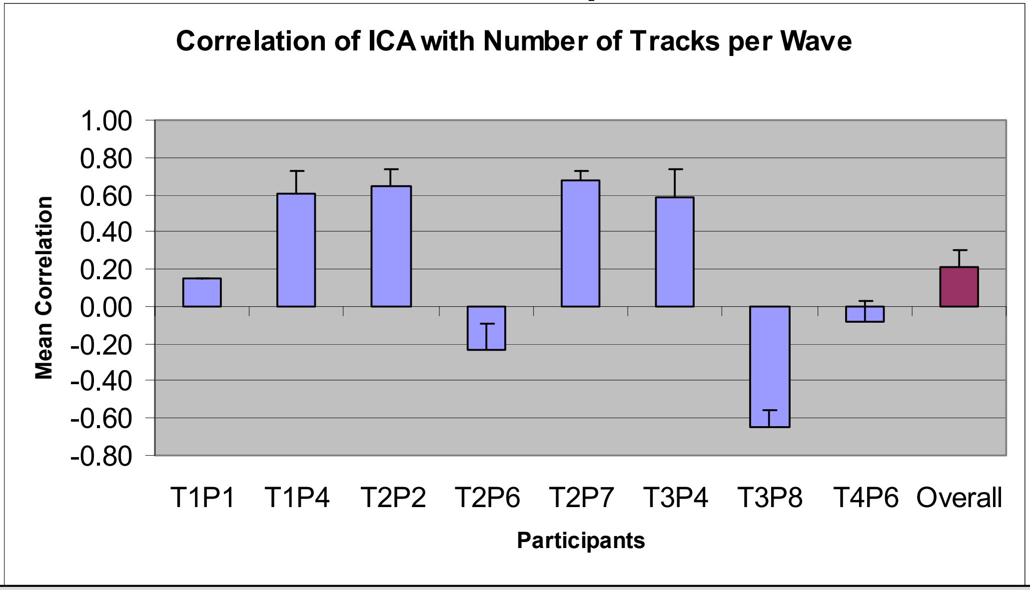
- There were apparently a few interaction problems, e.g.
  – Infra-red light interference (eye tracking and fNIR) – which was solved through shielding

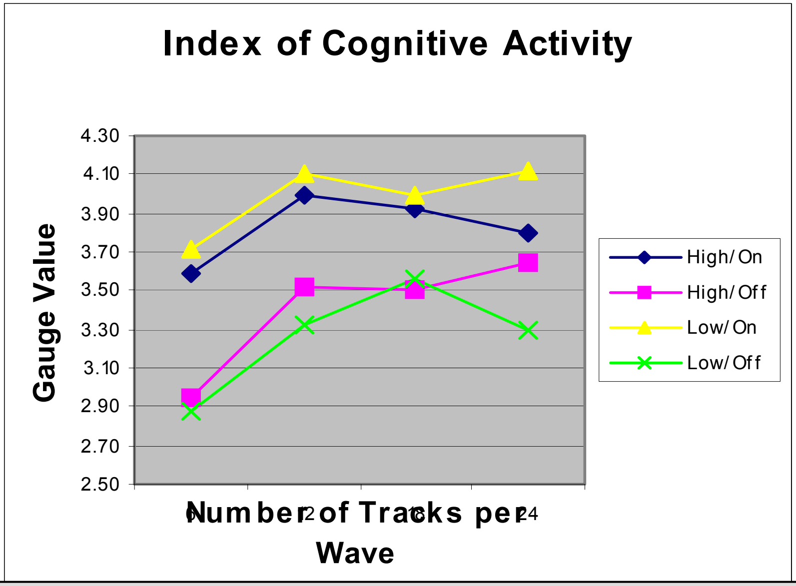
Interference among technologies was less of an issue than expected.

- ***Hardware issues largely addressed in Pre-TIE***
- ***Mechanical integration would likely address remaining issues.***

Potential for Interference?

- But there were apparently a few interaction problems
  - For example, SDSU's 10 hertz phenomenon?





Interference among technologies was less of an issue than expected.

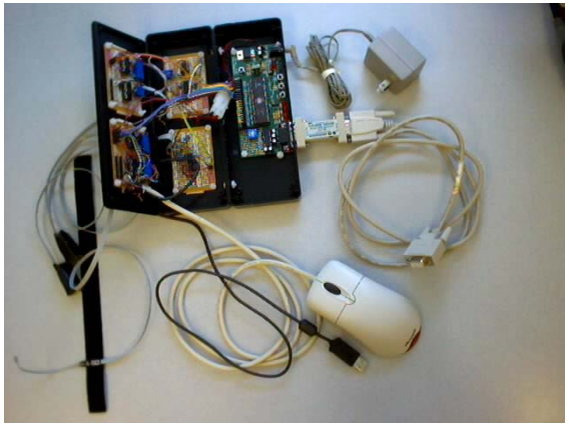
- ***Hardware issues largely addressed in Pre-TIE***
- ***Mechanical integration would likely address issues identified.***

One Example of No Interference

Drexel's fNIR +

ABM's EEG +

Hawaii's pressure mouse



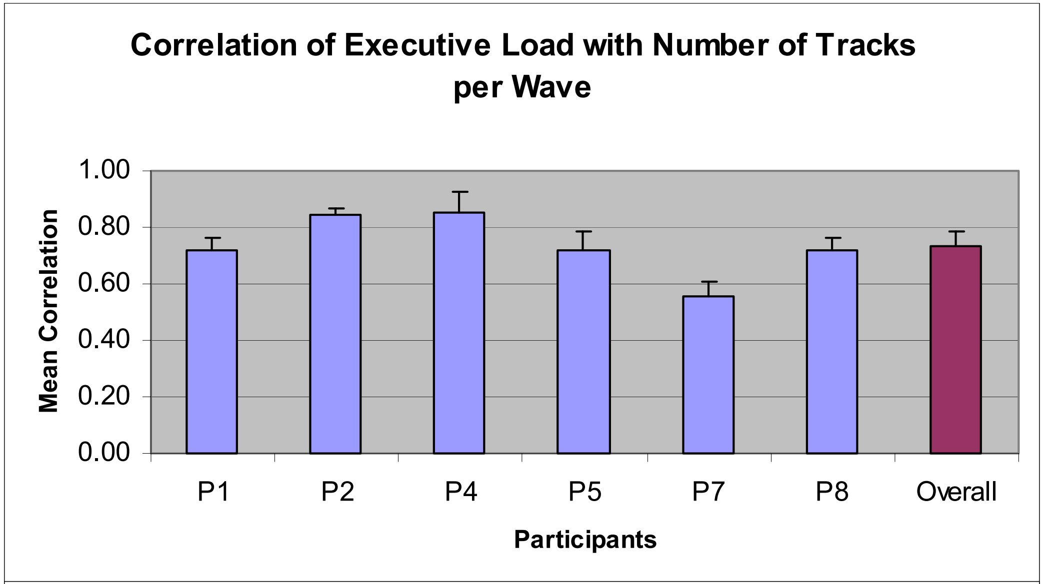
Gauge Consistency

How well and how consistently does each gauge correlate with task load on a wave by wave basis?

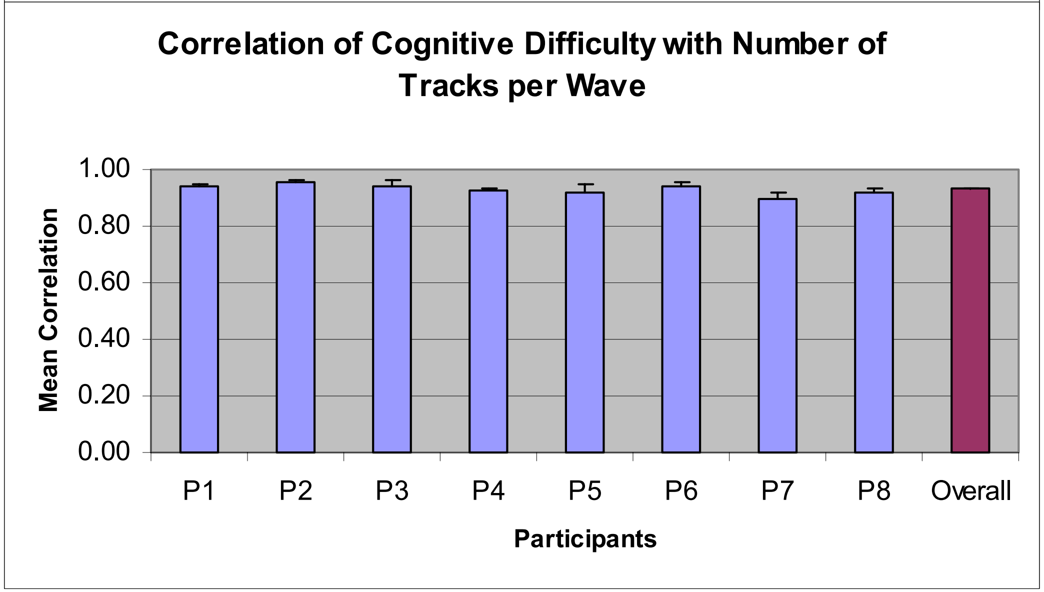
Does a gauge work consistently for every participant?

- Correlation between the value of a gauge and the number of tracks per wave – for each wave of a scenario
- Standard deviation of the correlations across participants

Highly Consistent Correlations

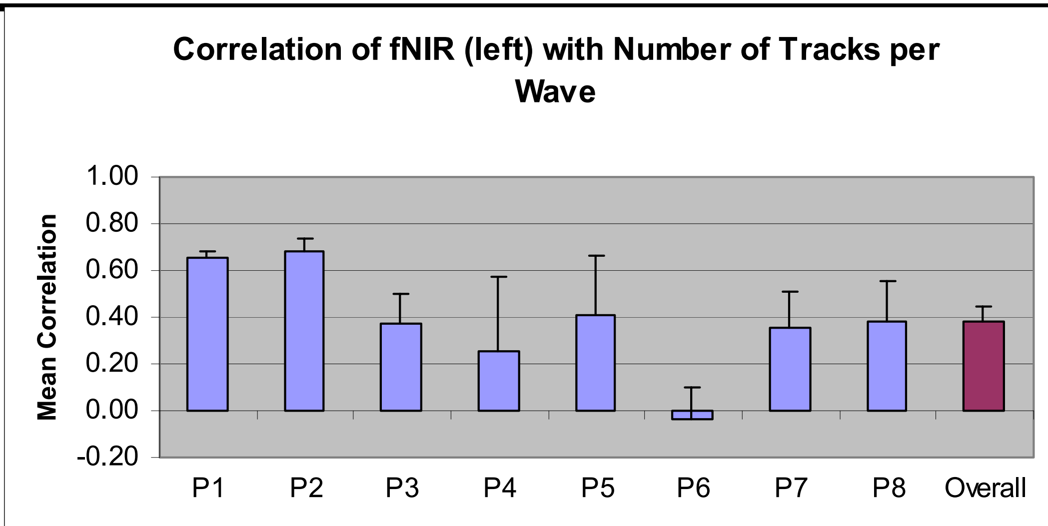


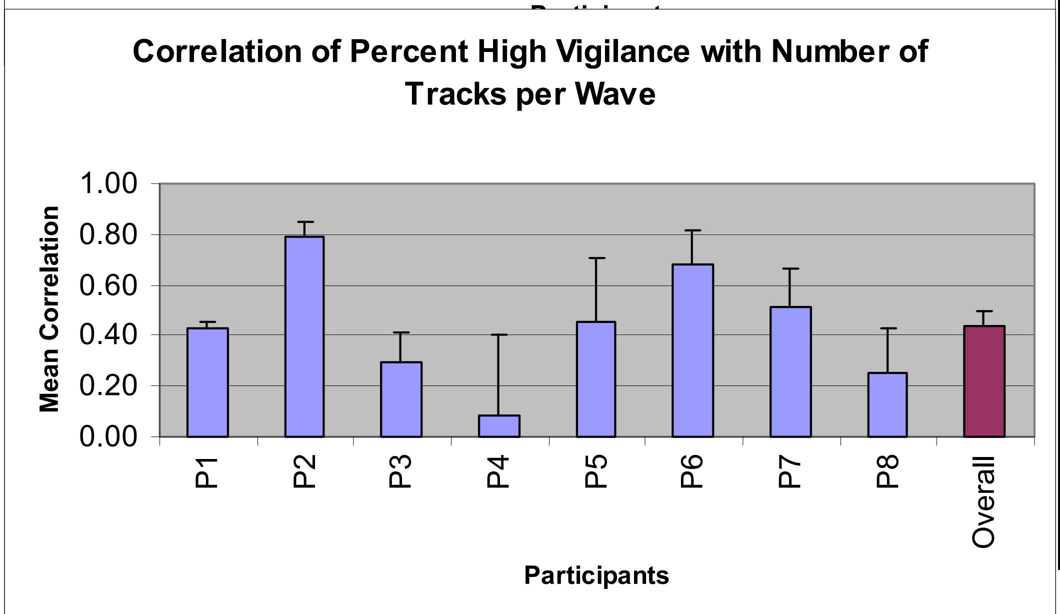
QinetiQ/Bristol



University of Hawaii

Moderately Consistent Correlations



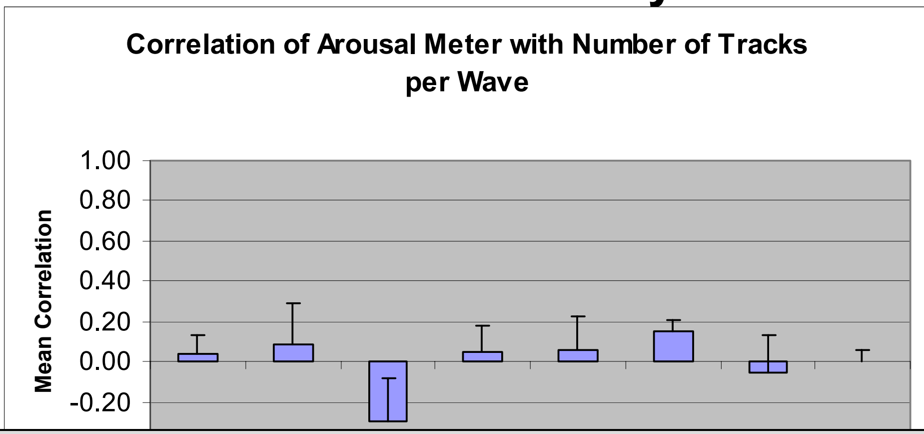


Consistency is an important, continuing issue!

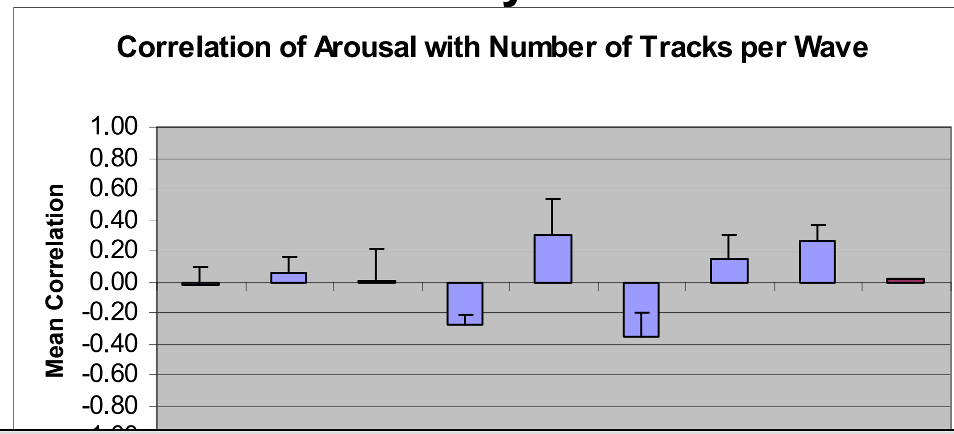
- ***Across individuals,***
- ***Within an individual during a session (fatigue, arousal, etc.)***
- ***Within an individual over a long period of time (experience, training, etc.)***
- ***Implications for reliability, calibration protocols, selection, need for cross-validating gauges etc.***

Arousal Gauges Results

Clemson University

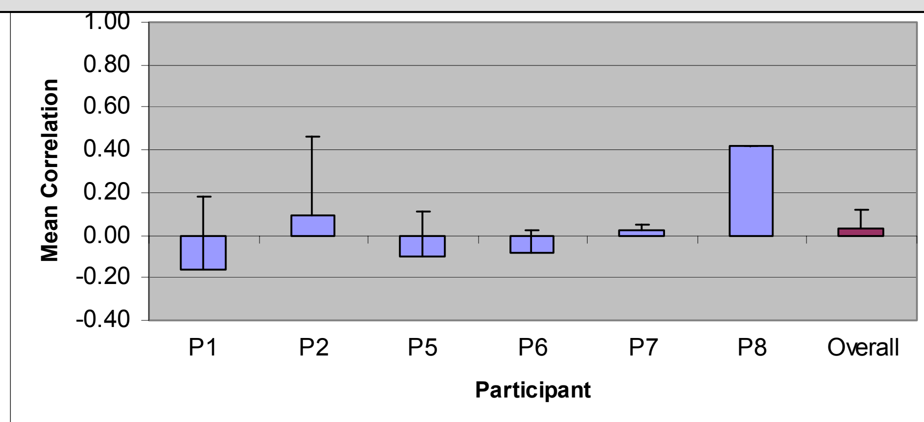


University of Hawaii



Arousal Gauges Were Not Effective with WCT ?!?

- *Nature of Task?*
- *Construct Validity – What do we mean by "Arousal", "Cognitive State"? What is the relationship between arousal & performance?*



TIE Issues for Arousal Gauges

- WCT manipulates:
  - Task load and kinds of cognitive activity
  - But not stress or physical activity or other factors that drive “arousal”
- Questions:
  - Is WCT typical of C2 tasks?
    - If so, then arousal gauges may not be appropriate
    - Other tasks may show arousal
  - Does stress affect performance?
    - “Pucker factor” phenomenon suggests otherwise
    - The stress-performance function appears to be quite complex
- Arousal gauges must demonstrate two things
  - Military (AugCog) tasks that drive arousal
  - Connection to performance in these tasks

Gauge Questionnaire Results

Questionnaire consisted of 3 parts:

- Part I: Team Integration Issues
  - Integration with other sensors
  - Problems identified and sensor deployment learned
- Part II: Gauge Descriptions
  - Sensors used to collect data
  - Future applications
  - Advantages/limitations
- Part III: Gauge Evaluations
  - Self-evaluation by developer of their gauge
  - Transition issues for AugCog Phase II

Summary of Integration Issues

Gauge:	fNIR	EEG-Continuous		EEG-ERP			Arousal			Physiological		
	Drexel University	Advanced Brain Monitoring, Inc.	QinetiQ	Electrical Geodesics, Inc.	Sarnoff Loss Perception	University of New Mexico Theta Power (Anterior-Posterior, Ocular &Visual Source)	Clemson University Arousal Meter	University of Hawaii Arousal & Stress	AnthroTronix, Inc. GSR Arousal	San Diego State University ICA	University of Pittsburgh & Naval Research Lab Head/Monitor Coupling, Head Bracing, Back Bracing	University of Hawaii Perceptual & Motor Load
How well did your sensor integrate with other sensors? Low 1-----5 High	4	4	4	4.25	3	NA	4.25	4.4	4.1	3.5	3.8	4.4
What problems did you have?	Only one probe / Size-does not fit all	Problems combining multiple headgear	Eye tracker headband with EEG	None	Eye tracker with EEG too painful	NR	No time stamp	Too long to attach electrodes	HR, Respiration rate did not correlate with task	Unable to collect data with Team 1 due to 10hz	Head sensors caused interference	Too long to attach electrodes
How likely will problems be resolved in next 6 months? Low 1------5 High	4	4.1	NR	NA	4.5	NA	4	1.3	3.5	2	4.1	1.3
Interference during TIE?	Eye tracker sensor interference	Subject fatigue and discomfort	NR	None	60hz interference with eye tracker	Eye tracker / EEG interference	None	SDSU eye tracker	Physical discomfort, EEG cap chest band disconnected EKG	Under investigation	Eye tracker provided some interference	SDSU eye tracker
New procedures learned during the TIE?	Added new channel & adaptive filter	Learned a quick procedure to attach devices	Reducing to a smaller sensor suite	None	Need to adjust the reading of event markers	Heart rate & GSR	Time sampling requirement	None	Least comfortable sensors should be put on last	Order of applying sensors	Use of real-time movement to trigger other gauges	None
Which other sensors are most difficult to integrate with your sensor?	Any sensor placed on forehead	No headspace available for EEG	fNIR	None	Anything mounted on head is a problem	Anything on EEG electrodes	None	None	Other EKG sensors	EOG sensors on the face	None	None
Which other sensors compliment your gauge?	EEG	FNIR, Pupillometry, Cardio	Modified fNIR/EEG sensors	EKG, Eye tracking	Any mechanical sensor, fNIR	Heart rate & GSR	AM is designed to compliment	EEG	Unable to determine	FNIR and GSR	Posture gauge compliments all others	EEG

Developer Application Recommendations

	Drexel University	Advanced Brain Monitoring, Inc.	QinetiQ	Electrical Geodesics, Inc.	Sarnoff Loss Perception	University of New Mexico Theta Power (Anterior-Posterior, Ocular &Visual Source)	Clemson University Arousal Meter	University of Hawaii Arousal & Stress	AnthroTronix, Inc. GSR Arousal	San Diego State University ICA	University of Pittsburgh & Naval Research Lab Head/Monitor Coupling, Head Bracing, Back Bracing	University of Hawaii Perceptual & Motor Load
Which aspects of WCT best demonstrate feasibility of gauge?	Task difficulty & Time to IFF	Workload / Number of tracks	Dynamic changes in workload	Varying levels of workload	Auditory feedback	Request for information	None	Wave difficulty	Onset of new waves of aircraft	Wave Size	Events calling for immediate, intensive action	Wave difficulty
Which aspects of WCT limited your gauge?	No pause between waves, Excessive hand movement	Eye movements and motor activity	Eye movements and motor activity	A subjective level of effort would be useful	Infrequent occurrence of auditory feedback	Need an objective measure of working memory	Used expert users	None	Lack of penalties and realism	None	Lacks in unpredictability	None

What do we Know?

- Multiple sensors can be combined with minimal interference
- Real-time cognitive state gauge computation is a reality
- Eleven gauges significantly detected changes in task load
  - 2 fNIR, 3 EEG, 1 ERP, 2 Physiological (Mouse Clicks / Mouse Pressure)
  - Five more gauges were marginally or potentially significant
- None of the arousal gauges detected changes in task load
  - Arousal gauges may be inappropriate for WCT type tasks
- Substantial variability between participants in gauge sensitivity
- Identified Specific issues related to the transition of each gauge

What do we still need to know?

Technology Issues:

- Relevance of the construct validity of each of the gauges?
  - What are the gauges *really* measuring?
  - What are the practical precision / specificity limits of the gauges?
- How can we make gauges more reliable across users?
- Does learning / experience effect gauge reliability?

Practical Issues:

- Will the gauge technology be accepted by the user community?
- Can the sensors be easily applied by the user?
- What new constraints might the gauge technology place upon users?
- What are the unique operational interference issues for different applications?

Phase I TIE: Lessons Learned (1 of 2)

- Develop operational definition of gauge constructs *early*.
- Define explicit requirements for what you need gauge to do – *Define quantitative & qualitative exit criteria*
  - What do you need the gauge to tell you?
  - Under what conditions must the gauge work?
  - What do you intend to manipulate based on the gauge?
  - How stable / consistent is that gauge likely to be under the conditions you expect to use it?

Phase I TIE: Lessons Learned (2 of 2)

- Consider how experience or changes in task strategy affect gauge reliability?
- Consider user acceptance issues.
- May want to integrate multiple gauges to address individual differences.
- Consider requirements for proactive vs reactive gauges
- Address gauge integration technologies early
- Test Early – Test Often!
  - Do not underestimate integration requirements
  - Define “Entry & Exit Criterion”

AugCog Phase I TIE Conclusions

- Completed a “first-of-it’s-kind” study of cognitive state gauges
- Multiple sensor technologies combined with minimal interference – numerous integration issues identified
- Real-time computation of sensor data to produce on-line gauge information was demonstrated
  - Eleven gauges significantly detected changes in various aspects of taskload
  - Five more gauges were marginally or potentially significant for changes in aspects of taskload
  - None of the arousal gauges detected changes in task load
- Arousal gauges may be inappropriate for WCT type tasks
- Substantial variability between participants in gauge sensitivity suggests need for additional research
- Built an empirical foundation for manipulation of cognitive state in applied contexts