

# **EEG Indices Distinguish Spatial and Verbal Working Memory Processing: Implications for Real-Time Monitoring in a Closed-Loop Tactical Tomahawk Weapons Simulation**

Chris Berka, Daniel J. Levendowski, Gene Davis, Michelle Lumicao, Caitlin Ramsey  
Advanced Brain Monitoring, Inc.

Kay Stanney and Leah Reeves  
University of Central Florida

Susan Harkness Regli and Patrice D. Tremoulet  
Lockheed-Martin Advanced Technology Laboratories

Working memory overload is one of the key contributors to operator errors during complex tasks. The capacity of human working memory has been defined as the number of items that can be held in conscious attention for use in a specific task or for later long-term storage. The constraints of working memory are particularly relevant during skill acquisition where working memory capacity is frequently exceeded. Traditional models characterize working memory as having two separate and relatively autonomous subsystems: verbal (i.e., phonological loop) and spatial (i.e., visuo-spatial sketchpad), but contemporary models suggest further disassociation (potentially based on sensory modality). Recent investigations suggest that working memory capacity can be enhanced by utilizing verbal, spatial, or alternative sensory modalities in a complementary manner.

The development of an effective method for monitoring working memory load and delineating the verbal and spatial components could greatly enhance the speed and efficiency of human-system interaction, particularly during computer-based training. A real-time monitor could identify periods of spatial and/or verbal working memory overload and provide adaptive aiding, such as switching from verbal or spatial presentation formats to meet operator requirements. However, frequent switching between one modality or task and another may incur a “cost” associated with switching due to stimulus competition, ambiguity, or distractions. Thus, it is essential to develop an understanding of how best to leverage the multimodal capacity of working memory without incurring such costs.

As a first step towards developing a real-time neurophysiological working memory index that could trigger such adaptive aiding, a wireless electroencephalographic (EEG) system was used to acquire data during three working memory tasks: one spatial and two verbal. The platform was designed with elements of a Tactical Tomahawk Weapons Simulation so that elements of the simple tasks could later be combined into a more operationally realistic test environment.

In the first verbal task, participants were instructed to listen for and remember alphanumeric missile ID’s (“listen task”). The second verbal task involved self-paced mental addition with addends briefly visible on the monitor (“math tasks”). The spatial task required memorization of the location of missiles on a grid (“spatial task”).

A wireless EEG headset acquired data from 9 monopolar sites referenced to linked mastoids (F3, F4, Fz, C3, C4, Cz, P3, P4, POz) and 2 bipolar sites (Cz-POz, Fz-POz). Approximately 30 1-second epochs of EEG data per participant per task were extracted from the three task conditions: listen, math and spatial. Following decontamination of artifacts from the EEG, power spectra for each 1 Hz bin between 3 – 40 Hz were computed, generating a total of 78 EEG variables for each epoch for each channel (total of 11 channels). Stepwise discriminant function analysis was then used to select the variables that best discriminated the three conditions across participants.

Five classification models were developed. Model 1 (Mid-line – Bi-polar) used selected variables obtained from the bi-polar recordings (FzPOz and CzPOz) plus the B-Alert classifications from the three mid-line sensor sites. Model 2 (Midline- A) used selected variables obtained from the two bi-polar and three mono-polar recordings from the three mid-line sites plus the B-Alert classifications. Model 3 (Lateral – All) used selected variables obtained from mono-polar recordings from six lateral sites. Model 4 (Mid and Lat) used selected variables from the Midline All and Lateral All models. Model 5 used selected variables obtained from the mono-polar and bi-polar recordings from six sites in the central and parietal regions plus the B-alert classifications. The same data were used to develop and test the model. The classification results were obtained using a cross-validation linear discriminant function (Table 1).

Using 43 variables from the mid-line and lateral model, an overall classification accuracy of 71.6% was obtained across subjects and conditions. Contrary to expectations, the frontal sites contributed less significant variables than the central or parietal sites (Table 2). This may reflect the simplicity of the task and the limited amount of executive function required for subjects to complete the tasks. Model five was developed to demonstrate the predictive capability of a model with no input from the frontal region during these tasks. Surprisingly, the mid-line sites alone provided 60% discrimination between the tasks. Using the midline and lateral combined, the right hemisphere sites provided the largest number of discriminating variables, probably reflecting the influence of the spatial memory task.

Table 1: EEG classification accuracy

Model	No. Sensors	No. Channels	# variables	Percent of epochs correctly classified			Class Accuracy
				Listen	Math	Spatial	
Midline - Bipolar	3	2	11	57.4	37.6	57.8	50.8
Midline - All	3	5	22	61.7	56.8	63.8	60.1
Lateral – All	6	6	26	69.1	53.3	55.5	59.4
Mid and Lat- All	9	11	43	73.5	68.1	73.4	71.6
Mid and Lat – C and P	6	7	41	70.4	61.1	66.5	66.0

Table 2: Mid and Lat Model: variables selected by site

Site	Monopolar			Bipolar	
	Left	Right	Midline		
Frontal	1	5	0	FzPOz	6
Central	6	5	3	CzPOz	5
Parietal	2	6	3	B-Alert Class	1
Totals	9	16	6	12	

These data establish the feasibility of characterizing EEG correlates specific to verbal and spatial working memory in a simple task environment. The variables obtained can be computed in real-time to provide a second-by-second assessment of verbal and spatial indices. If these indices in combination with other physiological or behavioral inputs are shown to relate to the degree of working memory overload, they could provide a valuable contribution to real-time adaptive aiding of human-system interaction. Any such aiding must be implemented judiciously, as any gains realized could be tempered if the costs for modality-switching are high.