Neurophysiological Predictors of Team Performance

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Abstract. Objective: To identify benchmark neurophysiological measures that predict performance at a teaming level. Advanced Brain Monitoring has a track record of success in identifying neurophysiological metrics that impact expert behavior. For example, we characterized negative and positive predictors for marksmanship skill; persons with higher HF:LF Norm metrics of Heart rate variability (HRV, an indication of anxiety) during a benchmarking auditory passive vigilance task did not achieve expert marksman performance while those with above average visuospatial processing ability achieved greater levels of expertise. In the current research, we explored the ability of benchmark neurophysiological metrics to predict team performance in two large scale studies. Significance: Identifying neurophysiological metrics of teaming ability and performance as part of a team can provide potential screening mechanisms or developmental data to help build optimal teams and improve team interactions for different types of contexts in which teams may operate.

Keywords: leadership, neurophysiology, qEEG, prediction.

1 Introduction

Identifying leadership potential is a growing interest in military, academic, and industry applications. Many applications using personality profiling have been used to some success, however, these are self report mechanisms and do not access the internal processes that may contribute to leadership potential. Waldman and colleagues [1] argue that neurophysiology may provide more ecologically-valid assessment of psychological constructs associated with leadership.. Recent advances in the technical design of the qEEG hardware and software platforms enable practical application of qEEG in studying leadership potential during live teaming exercises. The main advantage of the qEEG-based team assessment is that it is continuous, and it does not require disruption of the ongoing team process. For example, [2] utilized the qEEG data for modeling team dynamics in complex military tasks.

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Previous studies have found that neurophysiological profiles may identify predictors for those that were able to obtain expert status in a marksmanship task. The current study sought to determine the potential of using neurophysiological predictors for identifying leaders.

2 Materials and Methods

2.1 Participants

The students at a business school in the U.S. (Arizona State University) formed 43 teams of either 4 or 5 individuals. The overall sample comprised 201students with the mean age of 24.28 years. The participants were ethnically diverse (63.5% were Caucasian, 14.2% were Asian, and17.3% were Hispanic) and gender balanced (54.2% were males).

The students at a business school in Europe (ESADE, Barcelona) formed 31 teams of either 4 or 5 individuals. The overall sample comprised 146 students with the mean age of 28.7 years. The participants were ethnically diverse (61.5% were Caucasian, 20.7% were Asian, and 15.6% were Hispanic) and gender balanced (64.4% were males).

2.2 Protocol

All subjects were asked to complete a set of 3 benchmark tasks with simultaneous EEG: a 3-choice active vigilance task (3CVT), an auditory passive vigilance task (APVT), and a visual passive vigilance tasks (VPVT). Subjects completed these tasks as individuals before being assigned to teams of 3-5 people. The 3CVT required subjects to discriminate one primary target (presented 70% of the time) from two secondary non-target geometric shapes that were randomly interspersed over a 20 min period. Participants were instructed to respond as quickly as possible to each stimulus. A brief training period was provided prior to the start of the task to minimize the practice effects. The VPVT asked participants to keep pace with a visual stimuli that was presented every 2 seconds. Participants were instructed to depress the space key each time the stimuli was presented. The APVT was identical to the VPVT except that an auditory stimuli was presented in the APVT.

In the first study, we had advanced, business undergraduate students in a leadership course at Arizona State University attempt to solve the Ethical Decision Challenge™ from Human Synergistics/Center for Applied Research, Inc. of Chicago, Illinois. The exercise requires participants to rank 10 biomedical and behavioral research practices (all of which involve human subjects) in terms of their relative permissibility and acceptability [3-4]. This provides participants with an opportunity to engage in ethical analysis and decision-making. Examples of the practices include:

- Withholding study design information on purpose from participants when such information might skew their behavior within the study

– Conducting high risk but very important research when: a) there is no direct benefit to the participants, b) subjects are fully informed about the research and its risks, and c) they are capable of deciding whether or not to participate

While monitored for qEEG and qECG assessment, participants were given 5 minutes to initially read the problem statement, followed by an additional 10 minutes to provide their respective, individual solutions. They then repeated the task in a team process involving 4 or 5 individuals. The goal was to find a solution that all team members could "live with". The team process lasted 30-45 minutes. This allowed teams to complete the task without excessive time pressure and without generating participant fatigue or disinterest. To derive performance scores, solutions for both individuals and teams can be compared against expert scoring. In this study, the average solution of 800 members of Institutional Review Boards (IRBs) served as the normative scores. These IRBs had been established by various hospitals, universities, and research organizations throughout the U.S.

In the second study, conducted at the ESADE business school in Barcelona, Spain, the problem solving task addressed a corporate social responsibility case of the Levi Strauss Company involving child labor issues in Bangladesh [5]. Over approximately 40 minutes, students initially read the case (as individuals), formed a solution to the issues mentioned in the case, and recorded their respective solutions through a computer interface. After being fitted for qEEG and qECG assessment, they then engaged in a team discussion process involving 4 or 5 individuals. The goal was to derive a common solution to the issues mentioned in the case. The team process lasted up to an hour, including time for the recording (by one of the team members) of a solution onto a computer file. To derive performance scores, solutions for both individuals and teams were rated by two trained coders in terms of effective problem solving, decisiveness, and level of ethical development displayed in those solutions. The coders worked independently and showed high levels of inter-rater reliability in their scoring.

2.3 Leadership Performance Metrics

Both studies rated leadership similarly, although the second was more fine grained. The leadership scores involved other team member's assessment (for each respective team member) through a survey at the conclusion of the team task. In the first study, only shared leadership was assessed, while in the second, we added a more fine grained assessment.

In the second study, Leadership scores for each subject were assessed by the other team members in a survey that covered the following aspects of leadership:

- *transformational leadership* [6-7] - intellectual stimulation (i.e., helping others to examine and solve problems in new ways) and inspirational motivation (i.e., expressing confidence and enthusiasm about goals and what needed to be accomplished)

- *emergent leadership* [8-9] - the overall degree to which the team members relied on and considered a respective team member to have shown the leadership role during the team task.

All members of a respective team rated the other members (excluding himself). As the level of agreement among the subjects was high, these scores were averaged to provide a single score for each leadership measure for each subject. In the second study, these scores were averaged to identify the overall leadership score for each individual. The leadership scores were then ranked by team, with those with the highest scores categorized as “Leaders”, those with the lowest scores assigned the category of “non-leader”, and those in the middle assigned “Team-member”. These categories were then used in the ANOVA to examine what neurophysiological metrcs are predictive of leadership role.

2.4 qEEG/ECG Data Recording and Signal Processing

The wireless B-Alert sensor headset [10] was used to acquire qEEG data of all subjects during the benchmark sessions. The qEEG recordings during the team process were synchronized with the respective videos. The qEEG data from 9 sites (POz, Fz, Cz, C3, C4, F3, F4, P3, and P4) were recorded with a sampling rate of 256 samples per second. The qEEG signals were first filtered with a band-pass filter (0.5-65Hz) before the analog to digital conversion and then the sharp notch filters were applied to remove environmental artifacts from the power network. The algorithm [11] was utilized to automatically detect and remove a number of artifacts in the time-domain qEEG signal, such as spikes caused by tapping or bumping of the sensors, amplifier saturation, or excursions that occur during the onset or recovery of saturations. Eye blinks and excessive muscle activity were identified and decontaminated by an algorithm [11] based on wavelet transformation.

From the filtered and decontaminated qEEG signal, the absolute and relative power spectral densities (PSD) were calculated on an epoch-by-epoch basis for each 1Hz bin from 1 to 40 Hz by applying fast Fourier transformation (FFT) to the 50% overlapping 1sec overlays of the qEEG data. In order to reduce the edge effect, the Kaiser window was applied to each overlay. Furthermore, the FFT on three successive overlays was averaged to decrease epoch-by-epoch variability. The following PSD bandwidths were extracted: theta slow (3-5 Hz), theta fast (5-7 Hz), theta total (3-7 Hz), alpha slow (8-10 Hz), alpha fast (10-12 Hz), alpha total (8-12 Hz), beta (13-30 Hz), and gamma (25-40 Hz).

In order to explore the applicability of neurological alertness quantification in estimation of the psychological metrics, we also included into the analysis the outputs of the B-Alert model [11-12] that quantifies engagement levels and identifies cognitive state changes. It is an individualized model that selects the most discriminative PSD variables, derives coefficients for a discriminant function, and classifies subject's cognitive state for each epoch into one of the four levels of alertness: sleep onset, distraction/relaxed wakefulness, low engagement, and high engagement.

The p300 latency and amplitude components of the event related potential for the correct targets during the 3CVT task were also extracted. All individual trials of correct target responses were extracted; any trials that exceeded +/- 50 µV were removed, as were those with excessive artifact. All appropriate trials were then averaged and the maximum amplitude between 200-500 ms was determined, along with the latency of the maximal amplitude.

The B-Alert headset is enabled for the collection of heart rate, using a two lead set up, where one lead is place on the upper right collar bone and the other the lower left rib. Data is then sampled at 256Hz and the R-R spike indentified using proprietary algorithms, and the beat-to beat heart rate and heart rate variability measures are calculated per international standards [13].

2.5 Data Analysis

First, correlation analysis was performed to explore if any neurophysiological metrics were related to the leadership scores (shared in the first study, transformational and shared in the second).

As an initial investigation into what predictors might contribute to leadership development potential, we examined all neurophysiological metrics with 1-way ANOVA, comparing the leadership roles assigned (Leader, Non-Leader, Team-member) across the three benchmark tasks.

In order to explore the development of a predictive algorithm based on benchmark neurophysiology, we used the variables identified in the ANOVAs in a discriminate function analysis. We explored both a 3 class (Leader, Non-Leader, and Team Member), and a 2 class (Leader, Team Member) model.

3 Results

In this section the following results are presented: (1) statistically significant correlations between the neurophysiological measures during benchmark tasks and leadership at the individual levels, (2) ANOVA outcomes for neurophysiological metrics across leadership roles based on scores.

3.1 Correlations

Correlation analysis showed that small but significant correlations occurred between the individual level leadership scores and neurophysiological metrics. Table 1 shows the significant correlations for the first study (Shared leadership only), while table 2 shows the significant correlations for study 2 (transformational leadership, shared leadership).

3.2 ANOVA Results

No significant results occurred for the first study, indicating the single shared leadership metric is insufficient. For the second study ANOVA analysis revealed two distinctive patterns. First, during the VPVT, a passive visual vigilance task, we see significant increase in the Theta bands for the Leaders compared to the Non-Leader and Team-member categories. The ANOVA revealed a main effect for both Central Theta: $F(2, 134) = 3.29$, $p < .05$; and Left Theta: $F(2, 134) = 4.79$, $p < .01$. Post hoc analysis reveled that Leaders had the greatest activation, followed by the Non-Leaders, with the Team Members having the least activation. These data are shown in Figure 1.

A similar but inverse pattern of activation was found in the Frontal and Midline regions in Slow Theta (5-7 Hz), but not in overall or fast Theta during the Passive Auditory vigilance task (APVT). ANOVA revealed significant activation difference in the Slow Theta in the Frontal region: $F(2, 134) = 4.05$, $p < .05$, as well as the Midline region, $F(2, 134) = 4.05$, $p < .05$. Post hoc analysis found that while the Leadership role still had the greatest activation, the team members had the next greatest with the least being the Non-leaders.

Table 1. Correlations from Study 1compare subjectively scored shared leadership and neurophysiological metrics during an ethical decision making tasks associated with human subject informed consent protocols (Study1) and Child labor in developing countries (Study 2)

Neurophysiology Metrics	Pearson's R		
	Study 1	Study 2	
	Shared	Shared	Emergent
Frontal_AlphaSlow_8_10	0.206779		
Frontal_AlphaFast_10_13	0.236309		
Frontal_AlphaTotal_8_13	0.219375		
F3_Gamma_31_40			0.201425
Central_Gamma_31_40			0.200233
Left_Gamma_31_40			0.212858
HRV_pFreq_LFHFRatio		0.205656	
P300_Fz_Amplitude		0.371654	
P300_F3_Amplitude		0.40748	0.239428
P300_F4_Amplitude		0.216757	
P300_F4_Latency		-0.24146	
P300_C3_Amplitude	0.206123	0.279236	0.270103
P300_C4_Amplitude	0.263649		
P300_Cz_Latency	0.221524		
P300_POz_Amplitude	0.200265		
P300_P3_Amplitude	0.274717		
P300_POz_Latency		-0.32695	-0.34109
P300_P3_Latency	0.234837		
P300_POz_Amplitude	0.200265		

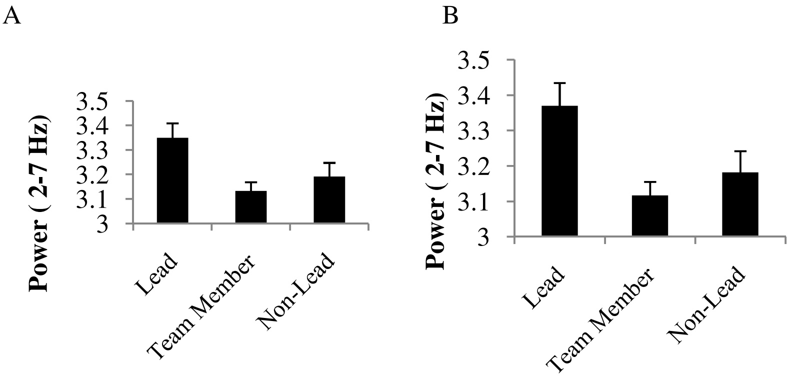

Fig. 1. Theta power (2-7 Hz) in the central (A) and left (B) scalp regions is significantly elevated during the Visual vigilance task for those that emerge as leaders during the ethical decision making task associated with child labor in developing countries. (* indicate significant post-hoc differences from Leaders, Ŧ indicate significant differences from Team Members).

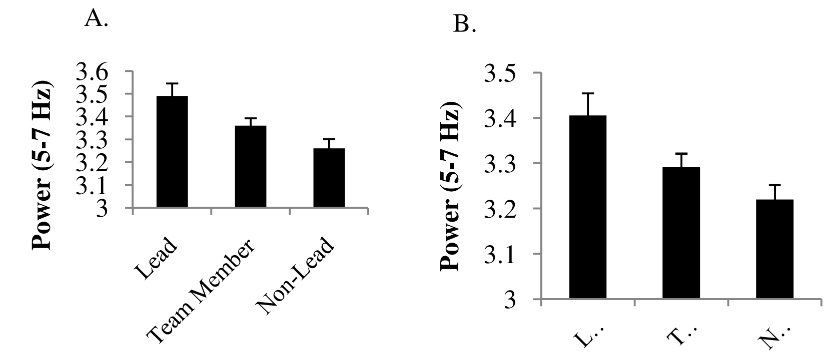

Fig. 2. Slow Theta power (5-7 Hz) in the frontal (A) and midline (B) scalp regions is significantly elevated during the Auditory vigilance task for those that emerge as leaders during the ethical decision making task associated with child labor in developing countries. (* indicate significant post-hoc differences from Leaders, Ŧ indicate significant differences from Team Members).

4 Discussion

The data shown herein demonstrate the potential of neurophysiological predictors of leadership development. Small but significant correlations were shown, particularly in the latency and amplitude of the P300 component across scalp sites, during the 3CVT. Longer latency P300s were associated with lower leadership scores. This finding is consistent with a body of literature linking latency slowing with decreased cognitive ability and slower response times in a variety of tasks [14-17]. ANOVAs revealed that central and left theta during the VPVT and frontal and midline theta during the APVT predict the leadership role later taken during the ethical decision making task associated with child labor in developing countries. There were no such findings in the first study, with the human subject consent issues. This may be due to the inadequacy of the single metric of leadership.

The leadership status was based on team members rating each other, a highly subjective, but ecologically valid assessment. In addition, there is a high degree of variability of these scores. All teams had a clear leader, but the strength of that leader is variable, with the scale of the metric going from 1-5. Most leaders among the groups were ranked in the low to mid 4 range. However some were in the low 3 range. This may indicate low team coherence, dissonance in decision making, etc. In other teams we had several persons score above 4 (although one was always higher), perhaps indicating a strong group decision making process. Further breaking down the analysis by the strength of the leader may lead to additional finer grained analysis that may prove more helpful in identifying effective leaders, not just those most likely to emerge as a leader. In the second study, additional objective third party experts also ranked the leadership status of the team members. These scores may prove more informative than the internal, subjective measures taken and compared in the current analysis.

The tasks used herein were ethical decision making tasks. The "correctness" of each solution was also scored, in the second study, by expert judges. Allowing these metrics to be entered into the model of leadership may prove useful in future analysis.

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