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14. ABSTRACT
The purpose of this project was to examine the efficacy of neurofeedback training to promote emotion regulation during cognitive-motor performance under conditions of mental stress. The model is predicated on the notion that relative left frontal activation is indicative of an adaptive mood state reflective of task engagement. In Phase 1, participants (ROTC candidates) were exposed to competitive mental stress to determine the manner in which brain (i.e., cerebral cortical) processes are perturbed by stress. The manipulation successfully raised physiological and

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Final Report

Proposal Number: 48665L

Individual Differences in Cerebral Cortical Activity During Stress: Understanding and Intervention to Enhance Shooting Performance

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Overview and review of concept.

The overarching purpose of this project, which included two phases, was to examine the efficacy of neurofeedback training to promote emotion regulation during cognitive-motor performance under conditions of mental stress. The project approach and predictions were theoretically based on a number of papers that have appeared in the cognitive neuroscience literature over the last 20 years. Chief among these have been the papers by Davidson and colleagues (2002) regarding the pivotal role of frontally mediated brain processes in emotion, motivation, and emotion regulation. Advances in this area of research have led to the notion that relative left frontal activation is indicative of an adaptive mood state reflective of task engagement or an approach-oriented motivation.

A substantial body of literature has supported that the underlying neural circuitry is reflected in the surface electroencephalographic (EEG) record and can be indexed by a difference score based on the alpha band (8-13 Hz) power measured in the left and right frontal regions, which are generated at sites F3 and F4, respectively, according to the International 10-20 System. (i.e., difference score = F4 alpha power **minus** F3 alpha band power). Relative left activation (the targeted goal of the training) is indicated by a positive score, while right is indicated by a negative score.

In order to execute the program of research, a critical first step (phase 1) was to expose the study participants (ROTC candidates) to mental stress in order to validate our model of the manner in which brain (i.e., cerebral cortical) processes are perturbed by stress. The participants were challenged with a pistol shooting task in light of the fine motor control required, and likely susceptibility to the effects of mental stress, as well as the relevance to military interest. Based on the concept of psychomotor efficiency, which posits refined networking between non-motor and motor brain regions, and reduction of non-essential processes in superior performers (e.g., expert marksmen), under conditions that promote concentration and focus, we predicted that mental stress would evoke increased networking with the motor planning regions and heightened regional cortical activation and that such stress-induced neuromotor "noise" would emerge in greater variability of the aiming trajectory and poorer shooting accuracy, relative to that observed during a low-stress condition. The significance of this work is that previous studies of cognitive-motor processes have been confined to non-competitive conditions, which are likely less stressful, and the present effort is the first to examine brain and behavioral processes during emotional challenge.

Phase 1 study design included order and condition factors. All participants completed both the performance-alone and competitive conditions and the order was counterbalanced. For the purpose of this report, all observed interactions of condition and order were characterized by a difference in magnitude. There were no directional differences due to order. We will highlight the findings for the order that best illustrates the given prediction.

Findings (Phase 1): Relative to the performance-alone condition, we successfully induced a significant level of psychological arousal, albeit modest, by challenging the study participants with a competitive event during which they were evaluated by a superior officer and subjected to social comparison, as well as public display of their performance scores, over the course of a 40-shot one-to-one shooting match for accuracy. The elicitation of elevated arousal during competition was evidenced by subjective self-report and psychophysiological assessment (heart rate, heart rate variability, skin conductance, and psychoendocrinological assessment (i.e., salivary cortisol).

These results support a successful introduction of psychological stress during the Competitive condition. As detailed in **Appendix I** (figures illustrating significant results are provided in the order as discussed below)**,** the participants reported an elevation in state anxiety (approached significance, $p = .058$ (two-tailed test))) accompanied by an increase in perceived stress, as well as a robust elevation in self-reported competitiveness during Competition relative to the Performance-Alone condition. This change in psychological state was accompanied by heightened heart rate throughout the competition. In terms of autonomic balance, the lack of difference in vagal tonus or parasympathetic influence on the heart, as measured by heart rate variability, between the Performance-Alone and Competitive conditions implies that the stress-induced cardiovascular arousal was due to enhanced sympathetic influence as opposed to vagal withdrawal. (Note: further analyses are being conducted beyond the reporting period to examine the heart rate variability during the episodic aiming periods to determine phasic changes in vagal influence on the heart). We also noted that heart rate variability was similarly elevated during the target shooting periods relative to the pre-condition baselines, regardless of Condition (i.e., Competition or Performance-Alone). Such a rise in vagal influence may be indicative of an emotion regulatory coping response while engaged with the target shooting task, which would be related to attentional processing as referred to in the classic work of John and Beatrice Lacey.

Additional assessment of physiological state via skin conductance, which was measured episodically during the 40 aiming periods prior to each shot and then averaged over the trials for each participant, unexpectedly revealed significantly higher responsivity during Performance-Alone relative to Competition. However, further analyses to decompose the directionality of the resultant waveform response clearly revealed more negative deflections during Performance-Alone, which are indicative of reduced sympathetic activity. This result was interpreted as superior emotion regulation during the Performance-Alone condition or, conversely, as a relative lowering of such arousal management during Competition. Such an interpretation is consistent with the emergent picture of overall arousal elevation during Competition.

Finally, the psychoendocrine response, as measured by salivary cortisol that was sampled at four successive time points during each of the two conditions, revealed a successive decline over the duration of the Performance-Alone condition, while no such decline over time was observed during Competition. Such a difference between conditions in terms of the temporal dynamic of cortisol response again implies superior emotion regulation during Performance-Alone and, conversely, a relative loss of the ability to manage emotion during the Competition when arousal was elevated.

Changes in the Central Nervous System (Phase 1)

The primary measure of activation examined was the EEG spectral power in the alpha band (8-13 Hz), which was further classified into low alpha power (8-10 Hz) and high alpha power (10-13 Hz). The former is indicative of generalized arousal while the latter band is indicative of task-specific attentional processes. No differences in low-alpha power during the aiming periods prior to trigger pull were observed between the Competition and Performance-Alone conditions for low alpha, which would indicate a similar level of central engagement during the two conditions. However, a relative reduction or desynchrony of alpha power across the topography of the cerebral hemispheres was observed during the aiming period in Competition, which is indicative of enhanced attentional processing. Such a finding appears adaptive in light of the moderate elevation in arousal during Competition. Furthermore, a relative increase in high-alpha power was observed during the aiming period (i.e., approaching the trigger pull) of Performance-Alone, which would imply a progressive relaxation of regional cortical activity during aiming. This phenomenon was absent during the arousal induction state associated with Competition. Furthermore, and consistent with our predictions, there was an increase in coherence, which is indicative of cortico-cortical communication, during Competition. This effect was primarily observed during Order 1 (i.e., proceeding from Performance-Alone to Competition). Such an elevation in coherence during the relatively aroused Competition state implies increased communication between non-motor and motor regions of the cerebral cortex and the possible introduction of neuro-motor "noise" into the system. Of note, we observed the same pattern of results for both theta and alpha power. The former is thought to be indicative of hippocampal memory-related processes. In sum, and consistent with our predictions, the relative increase in theta and alpha band coherence during Competition can be interpreted as more 'effortful' processing under conditions of mental stress. This interpretation is further supported by subjecting the EEG data during the respective aiming periods of Performance-Alone and Competition to Independent Components Analysis (ICA), a blind separation technique that can decompose the resultant EEG record into spatially independent and temporally dynamic components or ingredients. In essence, we observed an increase in the binding or clustering of these components during Competition with a template or base component that was specifically tied to degraded or poor performance in the aiming period during shooting. In essence, the relative component clustering during Competition implies increased complexity of central neural processes during mental stress, in addition to the relative activation (i.e., desynchrony of high alpha power) and the increased cortico-cortical communication (i.e., elevated theta and alpha band coherence).

Finally, in terms of cortical assessment, we did not observe a decline in frontal asymmetry (i.e, F4 minus F3 alpha power) during Competition, which would be indicative of withdrawal motivation and negative affect. However, we did observe a significant alteration in parietal asymmetry (i.e., a relative reduction during Competition), which is indicative of heightened anxious-arousal according to a model advanced by Wendy Heller at the University of Illinois.

As such, it is clear that mental stress, induced by manipulation of the social environment and induction of competition, was reflected in the central and peripheral measures of arousal and indicative of a moderately aroused state. We predicted that the increased neuromotor "noise" associated with the aroused state would translate into degraded performance as indicated by lower shooting accuracy. We did not observe inferior accuracy during Competition, but did observe a progressive increase in movement dysfluency or 'jerk' during the aiming periods of this condition. Such a kinematic alteration during Competition implies effortful co-contraction of the muscles involved with arm positioning during aiming on the target.

Phase 1 Bottom Line. The manipulation successfully raised physiological and central arousal as expressed as heightened cortical activity and more complex brain dynamics. This altered state was expressed as more effortful performance as indicated by the kinematic analysis of the aiming trajectory. Under moderate arousal we observed an adaptive state (i.e., the participates were attending better as indicated by desynchrony of high alpha during competition). In future studies, there is a need to arouse participants to extreme levels of performance relevant stress in order to examine deleterious responses as would be associated with the battlefield.

Phase 1 demonstrated that we could elevate stress in the laboratory (albeit to a moderate degree), an induction prerequisite to the conduct of Phase 2, which was an attempt to train emotion regulatory processes.

Findings (Phase 2).

Before describing the results of the neurofeedback training study, we would like to report the related findings of a companion study conducted in our laboratory, which confirmed a significant relationship between the magnitude of frontal EEG alpha asymmetry (i.e., F4 minus F3 log-transformed alpha power) and cognitive-motor performance under conditions of mental stress. This investigation was conducted just prior to the initiation of Phase 2 and revealed that undergraduate volunteers who exhibited more positive indices of frontal asymmetry showed superior reaction times and working memory performance under conditions of emotional challenge induced by negatively valenced emotion-eliciting stimuli (i.e., scenes from Lang International Affective Picture Series) and induction of electric shock. These preliminary findings (reported in an unpublished dissertation) provided confidence in the relevance of the EEG frontal asymmetry metric, which we targeted for change (i.e., elevation) in our neurofeedback intervention, to emotion regulation and cognitive-motor performance under conditions of challenge. In essence, this study provided an additional foundation for Phase 2, beyond that provided by Phase 1.

Description of Phase 2 results (see Appendix II - figures illustrating significant results are provided in the order as discussed below**)**. After completion of Phase 2, the initial set of analyses were conducted to assess the efficacy of the Neurofeedback training to elevate frontal EEG asymmetry (F4 minus F3 alpha power) in an attempt to enhance emotion regulation. The participants were provided with nine such training sessions during which they initially monitored the display of a computer screen, which presented a visual image related to their cortical asymmetry, for a 30-minute period broken into six successive 5-minute epochs separated by one minute of rest. The control group played a computer game during this period. The neurofeedback training or computer game playing was followed by shooting practice during which each participant shot 40 trials. As such, the intervention protocol uniformly allowed for skill training for both the neurofeedback training and control groups in addition to the contrast training for emotion regulation.

The analysis for treatment efficacy revealed an initial superiority of the neurofeedback training group to elevate frontal asymmetry (during the first three sessions), but no significant group differences were revealed over the full course of training that was comprised of the nine sessions. Figure X illustrates the mean levels of frontal asymmetry (averaged over 30 minutes within each session) for the two groups for each of the nine sessions. One can see the relative elevation in the Neurofeedback group, which was consistent with our goal, but the magnitude of variability precluded achievement of a significant difference between the groups.

Despite the failure to observe such an intended treatment effect, we proceeded to analyze the psychological, physiological, electroencephalographic, and performance data in a Groups x Time (pre-training vs post-training) factorial ANOVA as the possibility of treatment effects remained beyond the detection of the analysis described above.

As such, we contrasted the two groups during an initial competition and after the training period. This contrast also allowed us to observe the impact of shooting skill acquisition training on the various measures, since both groups practiced target shooting in a similar manner over the nine sessions. We observed that both groups significantly elevated their target shooting accuracy from pre-test to post-test.

In terms of psychological arousal we observed no differences between the groups during the pre-test and post-test or over time in terms of self-reported state anxiety, perceived stress, confidence, competitiveness, or relaxation. The uniformity of the psychological states was reflected in the lack of group differences and over time for heart rate, heart rate variability, skin conductance, or salivary cortisol measures. We did observe that these measures were reflective of elevated arousal during the two target shooting competitions (i.e., pre- and post-test) compared to their respective baseline periods, but the magnitude of response was undifferentiated by group. This failure to find group differences was contrary to prediction, but provides further support of an ineffective emotion regulation intervention.

However, in support of our model of psychomotor efficiency, which predicts refinement and relative relaxation in brain processes associated with expertise and motor skill learning, we observed a remarkable increase or synchrony of EEG alpha power (i.e., low-alpha) across the general scalp topography for both groups (neurofeedback training and control) during the post-test competition relative to that observed during the pre-test competition. Such a change provides robust support for our cognitive motor neuroscience model of central processes during skill acquisition even under conditions of emotional challenge. Such a finding is non-trivial and increases our confidence that we have strong support for our model of expert performance. Note that this finding, in concert with those of Phase 1, also increases our confidence that mental stress reverses the refinement and regional relaxation associated with expertise. Collectively, these findings provide a strong foundation for further investigative efforts of human performance in that we have further supported our model of the critical brain processes associated with learning and performing "under pressure." Interestingly, no differences over time were noted in spectral power for high-alpha power (i.e., 10-13 Hz), which can be interpreted as a maintenance of task –specific attentional engagement over time. This interpretation seems reasonable in light of the skill level of the study participants who made modest gains in ability while we would expect to see an increase or synchrony of high-alpha band power with further skill development such as would occur over longer-term training.

Of note, and in accord with predictions, we did observe a reduction in EEG coherence in the neurofeedback training group during the aiming period at the time of the post-test competition relative to that observed in the control group. Such a finding implies significant refinement of cortico-cortical communication or reduction of nonessential communication between non-motor and motor planning regions of the brain, which a number of our previous studies have revealed associated with superior performance. The relative refinement of such networking in the brains of the neurofeedback group cannot be unambiguously credited to the neurofeedback training, but may be related to some non-specific or placebo element of the intervention. At any rate, the reduction in coherence is exactly what our model of skill acquisition would predict, but it is interesting that it only occurred in the neurofeedback group. In addition, we did not observe any differences between the groups in the clustering of ICA components or over time fro pre-competition to the post-competition periods of assessment. Such a lack of difference is consistent with the general picture of a lack of distinction between the groups except for the differences noted above for EEG coherence. Finally, in terms of cerebral cortical dynamics, the groups were undifferentiated in terms of any change in frontal EEG alpha asymmetry during the aiming periods of the two competitions. In fact both groups exhibited a similar decline in frontal asymmetry from pre- to post-test. Such a finding implies a similar engagement in terms of the motivation and emotion regulation as indexed by the frontal circuitry.

The marked degree of similarity in the two groups over time also emerged in the similarity in the quality of target shooting performance. Both groups exhibited an increase in accuracy at the time of the post-test competition and both groups showed a similar decline in the variability of the aiming point trajectory while engaged with the target. In addition, regarding kinematic assessment, both groups showed a similar rise in movement dysfluency or 'jerk' of the aiming point. Such a finding seemed counter-intuitive until we discovered elevated 'jerk' in expert target shooters vs novices through complementary analysis of another data set. Such a finding provided an interpretive framework within which to decipher the results. As such, it appears that the improvement in performance was associated with refinement of cortical processes and a kinematic profile that became more akin to the patterns observed in experts.

Phase 2 Bottom Line. Study results provided further support for our model of psychomotor performance such that relative efficiency of cortical processes was observed following motor skill training, even under conditions of social evaluation and mental stress. A number of parameters of neurofeedback training need to be reconsidered for future studies of emotional regulation/neurofeedback training (such as consideration of individual differences (i.e., genotype), nature of visual feedback displays, skill level of participants, number of training sessions provided, and targeted cortical locations for neurofeedback as relevant to skilled performance).

References:

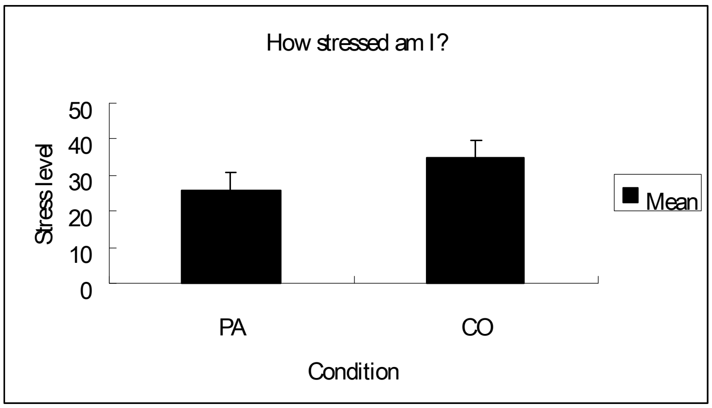
Busk, J. & Galbraith, G. C. (1975). EEG correlates of visual-motor practice in man. Electroencephalography and Clinical Neurophysiology, 38, 415-422.

Davidson, R. J. (2002). Anxiety and affective style: Role of prefrontal cortex and amygdala. Biol Psychiatry, 51, 68-80.

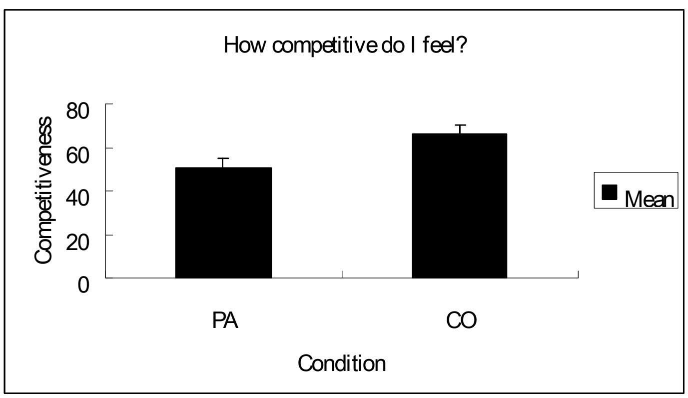
APPENDIX I: Phase 1 findings

PREDICTION: There will be an elevation of self-reported stress during Competition

This prediction was supported and provides verification of the arousal manipulation



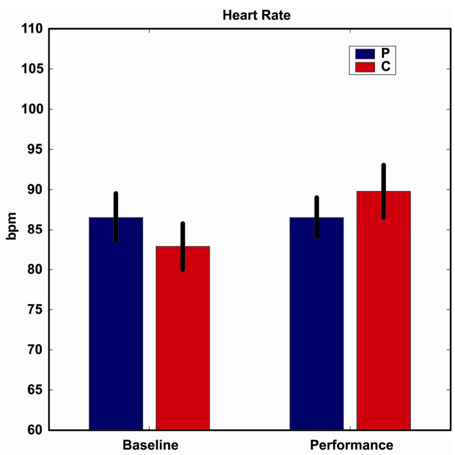
F(1, 16)= 7.715, p= 0.013, ES= 0.3929
Practice: 25.706 (4.983) < Competition: 34.788 (4.98)



F(1, 16)= 8.869, p= 0.009, ES = 0.67
Practice: 50.606 (4.591) < Competition: 66.175 (4.078)

PREDICTION: There will be an elevation of heart rate during Competition

This prediction was supported and provides verification of the arousal manipulation



Heart rate during baseline and performance periods for both the performance-alone (P in blue) and the competitive period (C in red).

Method

EKG was sampled at 256Hz. 10% of the signal was removed from both the beginning and end of the EKG collected for all segments (baseline and task performance for competition and performance alone) to reduce any transient effects associated with initiating or completing a given condition. The remaining 80% of EKG represents a stable measure of cardiac activity during a particular level of engagement. The inter beat interval (ibi), defined as the time in ms between positive peaks in the QRS complex of EKG. HR in bpm was computed from the average ibi.

Engagement X Condition X Order ANOVA:

Engagement main effect : F(1,16)=10.713, p=0.005
Engagement x Condition interaction : F(1,16)=18.914, p=0.000
No interaction with Order

Post hoc significant differences between:

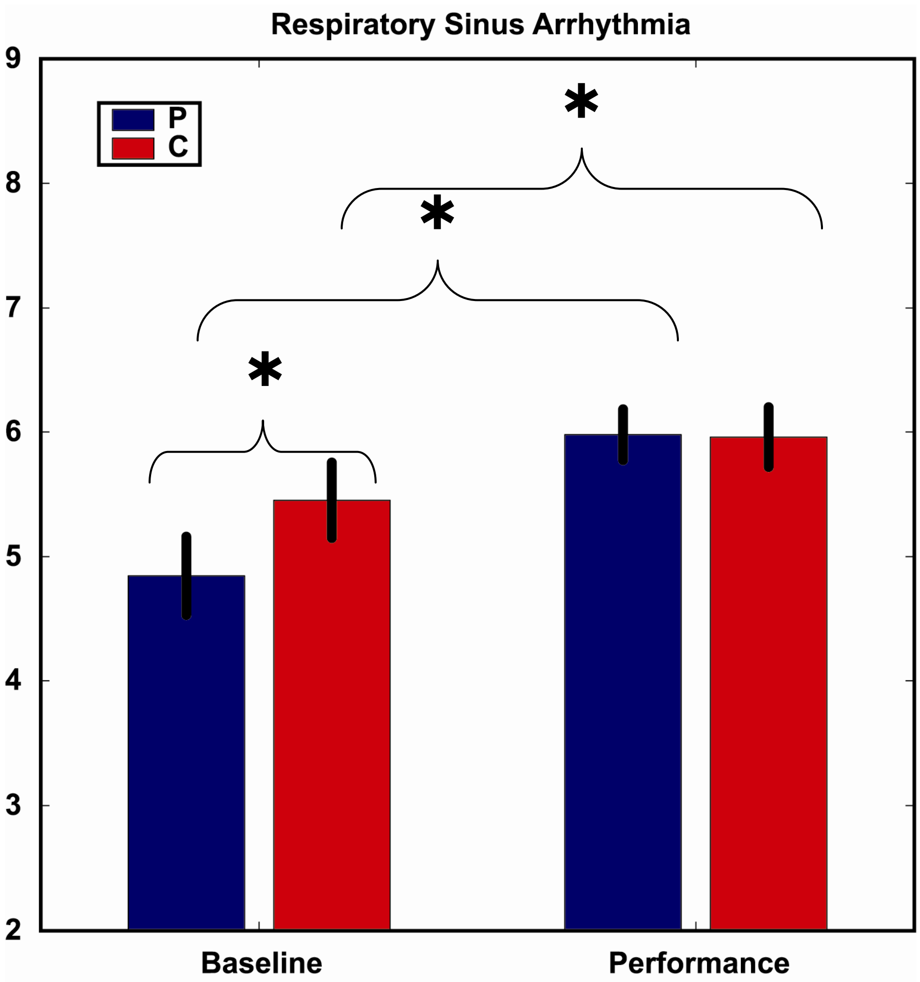
P and C at baseline : effect size = 0.3160
P and C at during performance: effect size = 0.2548
Baseline and Performance for C: effect size = 0.5295

Summary

Although post hoc significant differences were found between performance alone and competition during both baseline and task performance, the value of these finding must be consider cautiously given the small Cohen's *d* effect size. As expected, HR during competition is significantly higher then during the baseline prior to competition

PREDICTION: There will be a reduction in heart rate variability (i.e., vagal tone withdrawal) during Competition

This prediction was not supported and, therefore, implies sympathetic determination of the observed increase in heart rate



<u>Method</u>

EKG was sampled at 256Hz. 10% of the signal was removed from both the beginning and end of the EKG collected for all segments (baseline and task performance for competition and performance alone) to reduce any transient effects associated with initiating or completing a given condition. The remaining 80% of EKG represents a stable measure of cardiac activity during a particular level of engagement. The inter beat interval (ibi), defined as the time in ms between positive peaks in the QRS complex of EKG. The respiratory sinus arrhythmia (RSA) was computed from the ibi using MXedit software. RSA is an index of vagal influence with higher values of RSA associated with an increase in vagal influence.

Engagement X Condition X Order ANOVA:

Engagement main effect

$F(1,16)=18.735$, $p=0.001$

Condition main effect

$F(1,16)=4.643$, $p=0.047$

Engagement x Condition interaction

$F(1,16)=13.047$, $p=0.002$

No interaction with Order

Post hoc significant differences between:

P and C at baseline

effect size = 0.5061

Baseline and Performance for P

effect size = 1.0680

Baseline and Performance for C

effect size = 0.4406

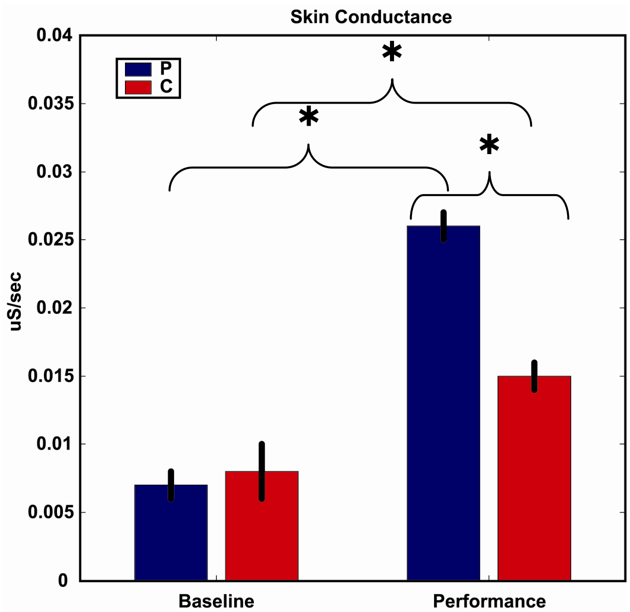
Summary

Significantly higher RSA was found during the baseline prior to competition compared to performance alone and significantly higher RSA was found during task performance compared to baseline for both competition and performance alone. These findings are contrary to expectations. The fact that RSA is not different between conditions during task performance but is significantly higher during task performance then baseline suggest that a certain level of vagal influence is required for and related to the task. Evaluation of sympathetic influence may be helpful.

PREDICTION: There will be an elevation of skin conductance during Competition

Contrary to prediction there was heightened response during Performance-Alone (see Panel A). However, decomposition of the response revealed more negative deflections during Performance-Alone, which implies lower arousal (see Panel B).

Panel A

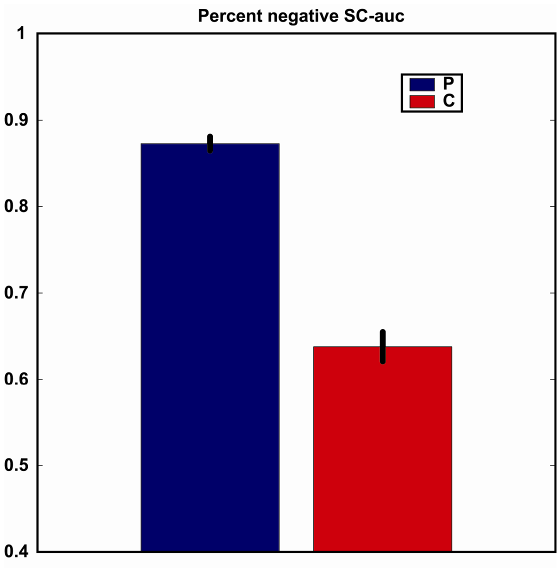


<u>**Engagement X Condition X Order ANOVA:**</u>
Engagement main effect: $F(1,15)=89.705$, $p=0.000$
Condition main effect: $F(1,15)=17.303$, $p=0.001$
Engagement x Condition interaction: $F(1,15)=30.401$, $p=0.000$
No interaction with Order

<u>**Post hoc significant differences between:**</u>
P and C at during performance: effect size = 2.6092
Baseline and Performance for P: effect size = 4.0196
Baseline and Performance for C: effect size = 1.1796

<u>**Summary**</u>
SC-ph is significantly higher in when engaged in task performance compared to baseline for whether alone or during competition. This would be expected since baseline doesn't include the event of pulling the trigger During task performance, SC-ph is significantly higher when performing alone compared to competition. Interpretation of this finding is difficult since the computation of SC-ph includes both positive and negative deflections of skin conductance.

Panel B



Phasic Skin Conductance (SC-ph)

Additional Methods

In order to determine the nature of the difference in SC-ph between performance alone and competition during task performance, the percentage of negative deflection in SC-ph was computed. A negative deflection represents a decrease in SC.

Condition X Order ANOVA:

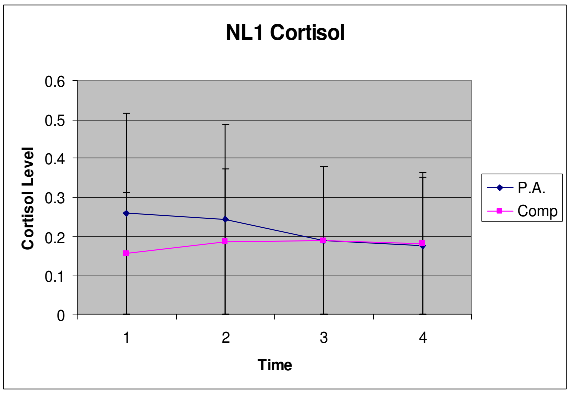
Condition main effect: $F(1,16)=147.6$, $p=0.000$

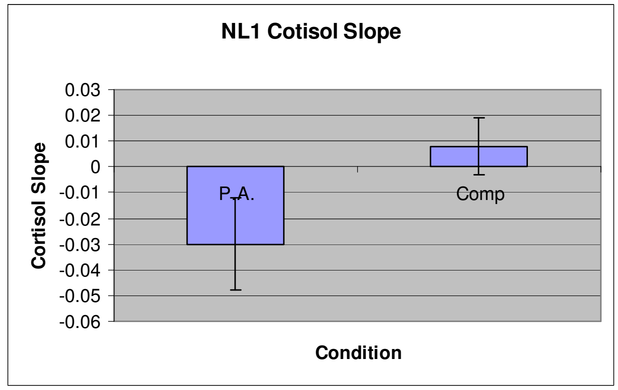
Summary

The higher SC-ph seen during performance alone largely represents a negative deflection, which corresponds to a decrease in SC. This is consistent with expectations that SC would decrease more during performance alone compared to competition since there are no significance consequences (financial, evaluative, status) associated when performing alone.

PREDICTION: There will be an elevation of cortisol during Competition

This prediction was partially supported as a progressive attenuation of the magnitude of cortisol response was observed during Performance-Alone, which was absent during Competition



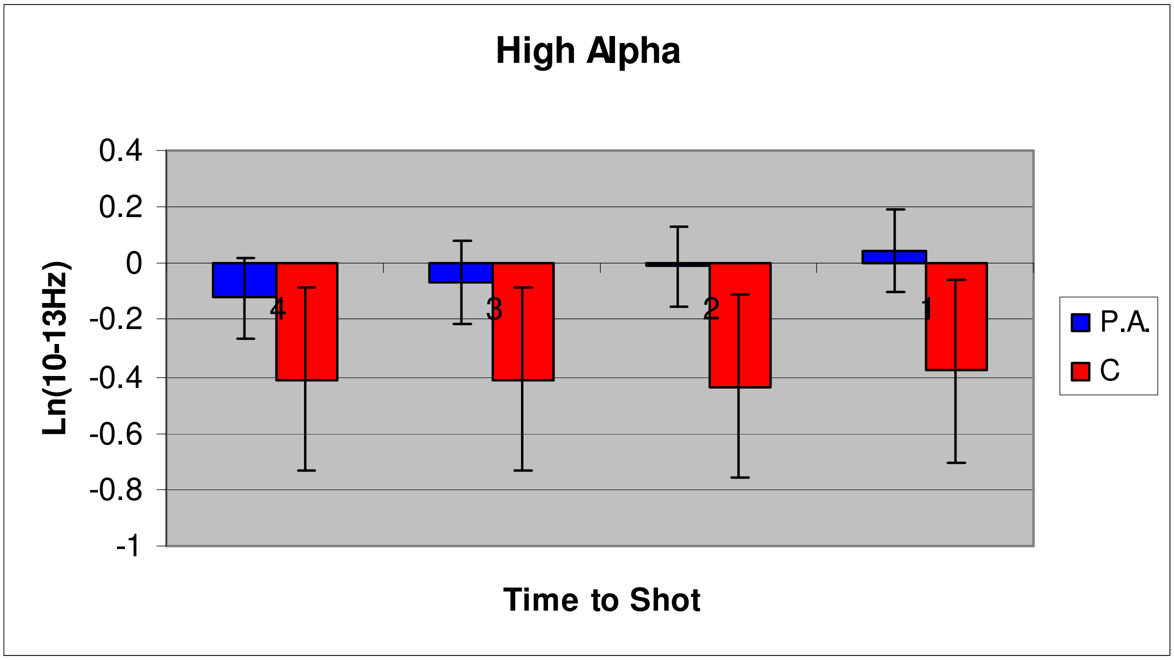


ANOVA 2x2x4 (left panel above)
Order x Condition x Epoch
Condition*Epoch
$F(3,39)=4.150$ $p=0.048$ $\varepsilon=0.436$ Greenhouse-Geisser
Post hoc comparisons indicate no differences between contrasts of interest (e.g. time 1 PA vs C).

ANOVA 2 x2 (right panel above)
Order x Condition
Condition*Epoch
$F(1,13)=5.062$ $p=0.042$ ES= 0.18
A first order polynomial was fit to the slope of each line (PA and C). The results show a reduction in cortisol during performance alone while the competition shows a relatively stable pattern.

PREDICTION: There will be relative desynchrony of high-alpha EEG power during Competition

This prediction was supported

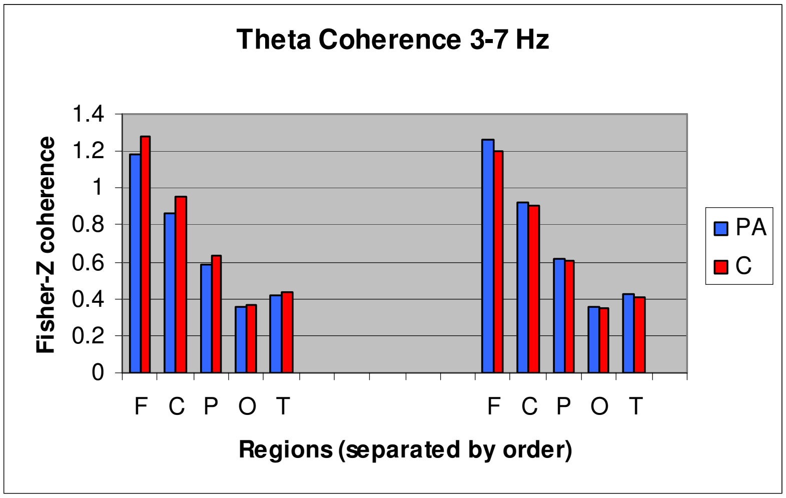


Note: Time to Shot refers to the successive one-second epochs leading to trigger pull from left to right.

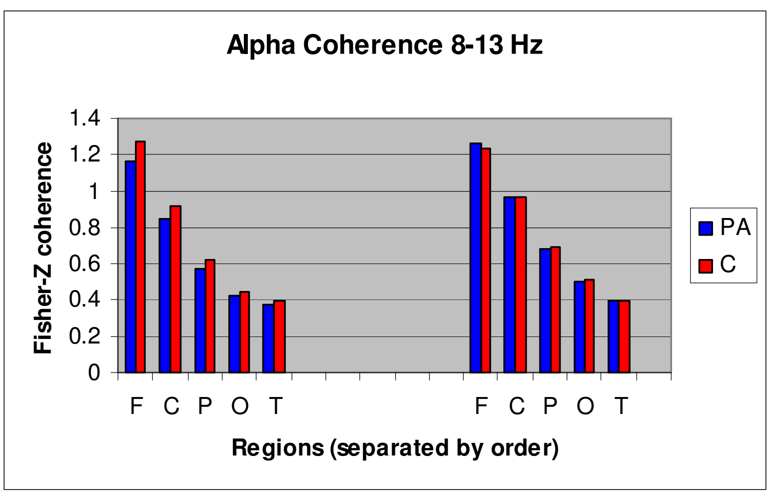
Condition*Epoch $F(3,15)=3.889$ $p=0.031$
Regardless of time to shot, the Competition condition resulted in relative desynchrony compared to the Performance-Alone condition. Furthermore, progressive synchrony was revealed over time within the Performance-Alone condition. This finding is consistent with the concept that optimal performance should occur in conditions where psychological stress is at a minimum allowing more cortical refinement. However this effect is superseded by an order interaction. Specifically, this effect is driven by order 2.

PREDICTION: There will be an elevation of EEG coherence (i.e., cortico-cortical communication to motor planning region) during Competition

This prediction was supported and is revealed



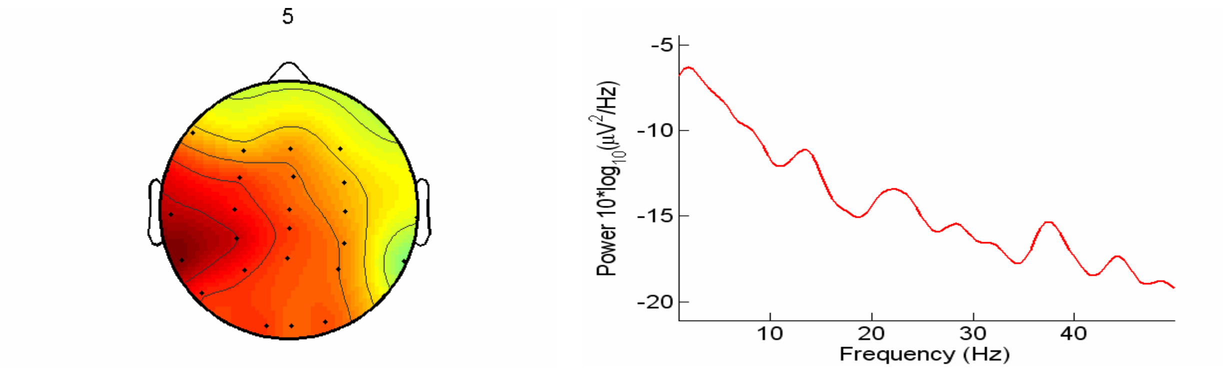
Condition*Region*Order F(4,14)=3.165 p=0.048 ES= Frontal .516, Central .784
Observed Results: Post hoc comparisons between meaningful regions showed significant increases in the frontal and central regions during Competition compared to Performance-Alone in order 1.

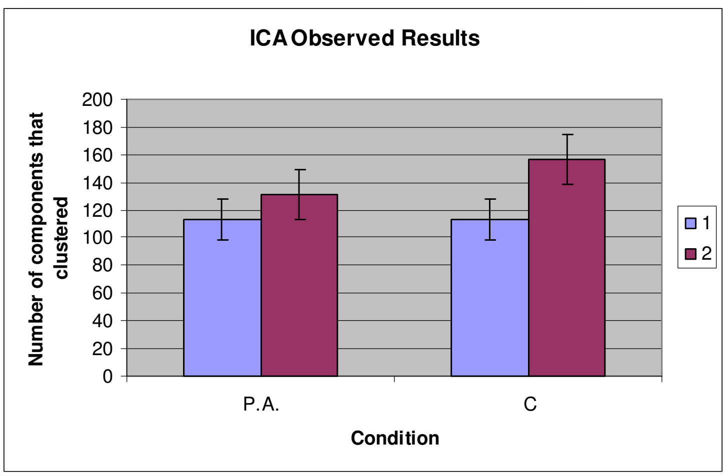


Condition*Region*Order, F(4/14)=4.490 p =0.015 ES= Frontal .558 Central .441
Observed Results: Similarly, post hoc comparisons between meaningful regions showed significant increases in the frontal and central regions during Competition compared to Performance-Alone in order 1.

Prediction: We predict that increased complexity (indexed by increased clustering to noise template) reflects recruitment of non-essential cortical activity during psychological stress and thus more components should cluster to the noise template in competition compared to performance alone.

This prediction was supported





Observed Results : Although there was a main effect due to Condition, $F(1,17)= 5.705$ $p =0.029$, the Condition*Order interaction superseded this effect. Post hoc comparisons indicate that there is significant increased in clustering to the noise template during competition compared to performance alone in order 2. In addition there is a significant difference within competition between order 1 and 2, with order 2 showing greater complexity compared to order 1. There is no difference between order 1 and order 2 during performance alone. Lastly, order 1 shows no significant difference between condition.

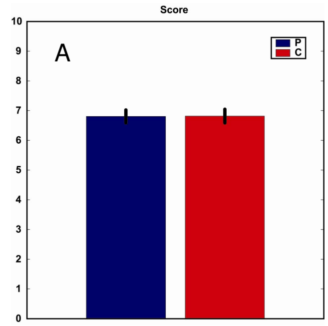
PREDICTION: There will be a decline in the quality of motor performance during Competition

This prediction was supported and is revealed below.

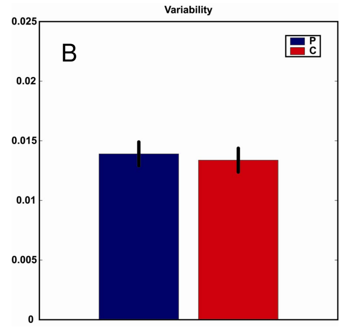
Normalized Jerk (NJ)

No differences were found for shooting performance between conditions using traditional outcome and performance measures (see figures A and B).

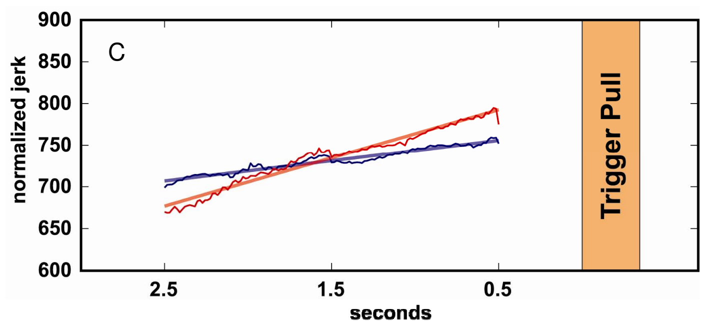
<u>Methods</u>
Normalize jerk is a unitless measure of the dysfluency based on the third derivative of position (or the rate of change in acceleration). The aiming point trajectory on the target in mm was sampled at 66Hz The tangential displacement with respect to shot was computed for the 3s period prior to trigger pull. The dynamic change in normalized jerk was computed using a 1s moving window. The dynamics for each condition were averaged across shots for each subject and fitted with a first order polynomial to determine slope (see figure C). NJ was also examined for the final second prior to trigger pull.

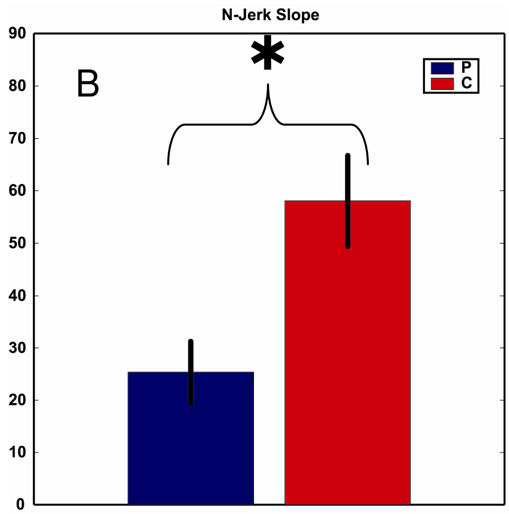


No significant findings for Score



No significant findings for Variability



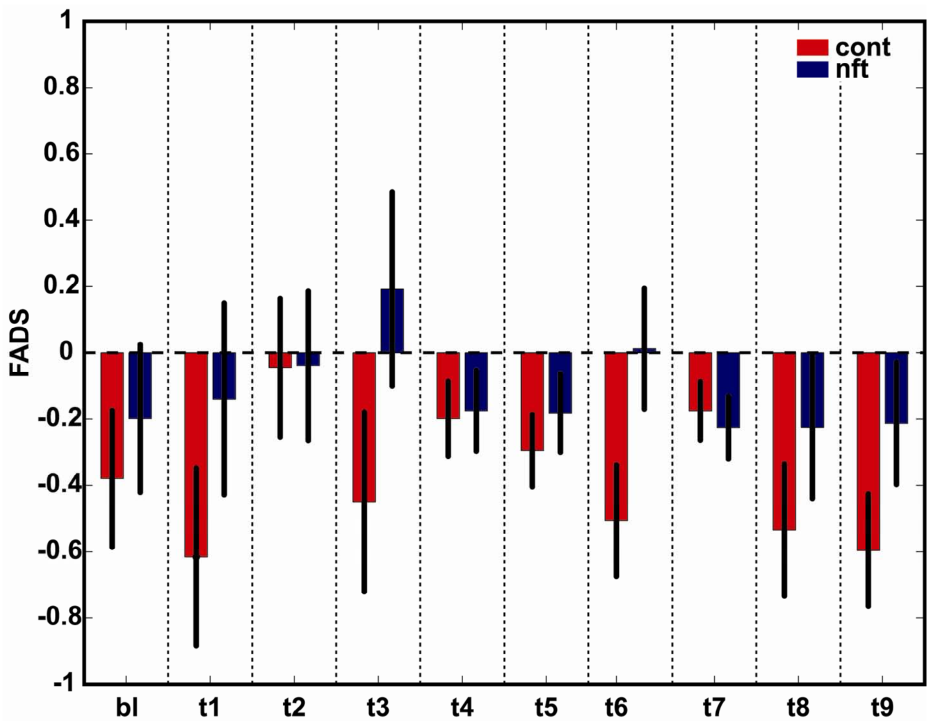


<u>Summary</u>
A significant increase in aiming dsyfluency is seen during the final second before trigger pull in competition compared to performance alone. In isolation this result might be interpreted as a disturbance in motor performance cause by the stress of competition. However the significantly steeper slope seen with the change in NJ at trigger pull approaches suggests that the differences seen in NJ between competition and performance alone are likely related to time constraints in the competition condition. Expert marksmen have higher NJ than novice shooters. Increase NJ maybe related to co-contraction of opposing muscle activated to steady the point of aim while engaging the resistance of the trigger.

APPENDIX II: Phase 2 findings

PREDICTION: There will be an elevation of EEG frontal asymmetry over neurofeedback training sessions

This prediction was not fully supported, but a relative increase is shown below in the neurofeedback group during the first three sessions. In addition, the frontal asymmetry is higher in the neurofeedback group, but no significant difference due to variability of the response.



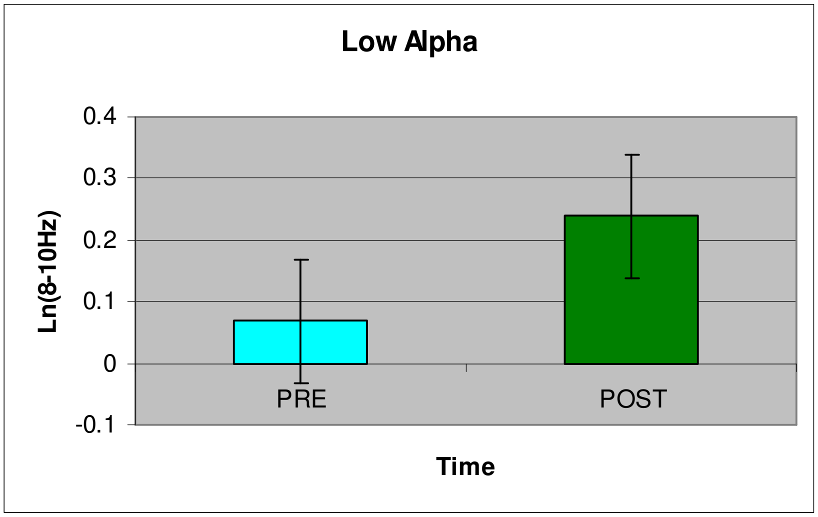
Baseline from 1st day

training days

Group x Training Day x Session
(2x9x6) ANOVA
No differences

PREDICTION: There will be an elevation of EEG spectral power as a result of training sessions and the magnitude of increase will be higher in the neurofeedback group

This prediction was partially supported as both groups showed an increase in power (i.e., alpha synchrony from pre- to post-test

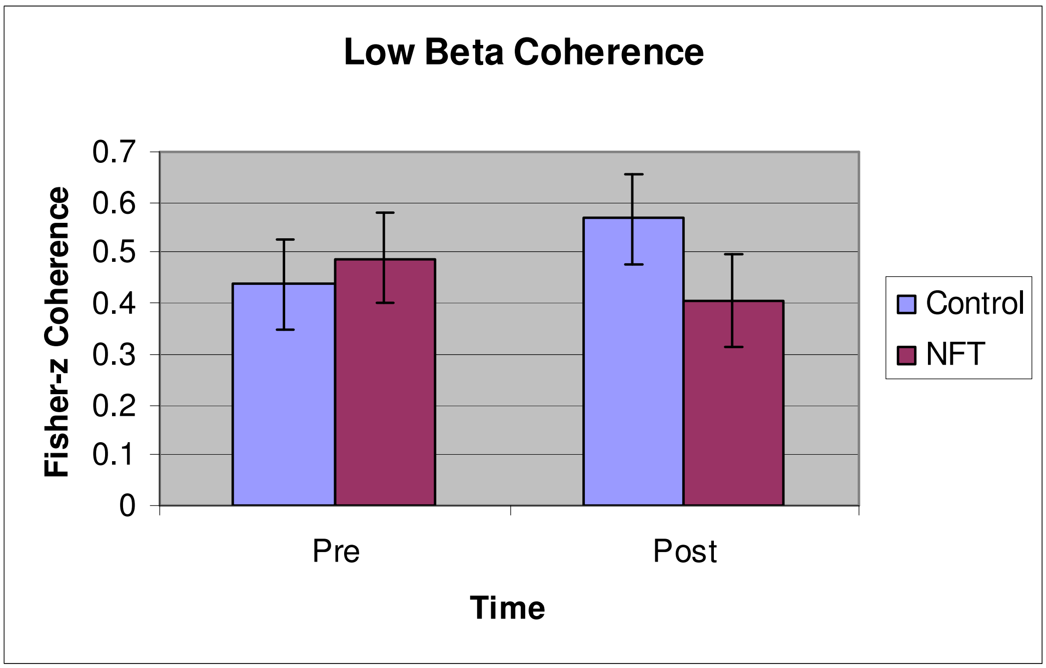


Time main effect: $F(1,14)=4.882$ $p=0.044$

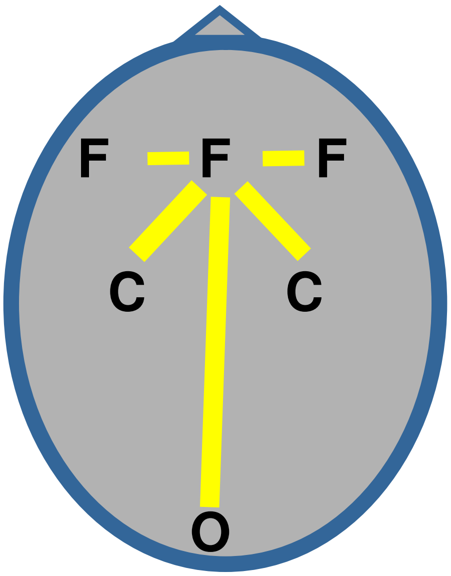
Main effect due to time indicates a training effect increase in low alpha power independent of group. Counter to our predictions we did not see group differences in this general arousal measure.

PREDICTION: There will be a decline in EEG coherence (i.e., cortico-cortical communication to motor planning region) during the post-test competition for both groups, and the magnitude of decline will be greater in the neurofeedback group

This prediction was partially supported



Time*Group interactive effect: $F(1,14)= 6.910$ $p =0.020$
Observed Results: Post hoc comparisons indicate no significant differences between group during the pre test. This is consistent with our predictions since the subjects were randomly assigned to group membership and we expect a equal response to exposure to psychological stress. Importantly post hoc comparisons during the post test show a significant decrease in coherence in the NFT group compared to the control group. This suggests this group exhibits less cortico-cortical networking indicative during psychological stress indicative of more refinement during task execution



NOTE: Yellow lines indicate reduced coherence between specific cortico-cortical electrode pairings in the neurofeedback group relative to the control group at post-test competition. Frontal (F), Central (C) and Occipital (O) sites illustrated. Each of the pairings is referenced to the mid-line frontal which overlies the motor planning region in the brain.

Time*Hemi*Region*Group: $F(4,11)=3.794$ $p =0.036$

Post hoc comparison between contrasts on interest show

1) After training (pre vs post test), the neurofeedback training (**NFT)** group shows a significant decrease in F3-Fz (ES=.480) coherence
    - No other significant differences were found when comparing pre vs post tests with group
2) During the post-test the **NFT** group showed a significant reduction in coherence at F3 (ES=.620), C3 (ES=.578), O1 (ES=.501), F4 (ES=.578), C4 (ES=.624): this suggests that during conditions challenge the NFT group shows a cortical refinement
    - No significant differences were found in the pre test
    - Fz-C3 and Fz-C4 showed decreased coherence following practice (direct connection between premotor and motor) indicating a decrease in coupling associated with a greater efficiency in motor complexity with experience. (Busk and Galbraith, 1975).

PREDICTION: There will be an increase in the quality of performance during the post-test competition for both groups, but that the neurofeedback group would achieve the improved performance in a more efficient manner (i.e., with reduced physiological/emotional arousal)

This prediction was partially supported. Both groups exhibited higher 'jerk' which is characteristic of expert performers at post-test. However, the physiological cost was similar between groups with the exception of lower cortico-cortical communication in the neurofeedback group (illustrated with the blue line).