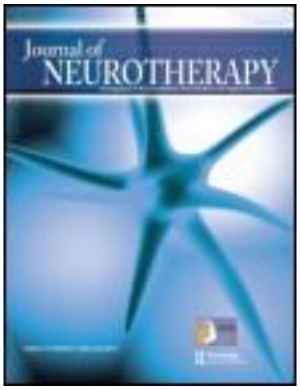

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SYMBOL DIGIT AND THE QUANTITATIVE EEG

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The coordination of allocation resource model of brain functioning examines the relations between quantitative EEG (QEEG) variables and cognitive performance on specific tasks. The Digit Symbol (DS) subtest of the Wechsler Adult Intelligence Scales has proven to be a sensitive measure in a variety of clinical conditions. A conceptually and empirically similar task (Symbol Digit [SD]) was employed to examine the QEEG correlates of successful functioning. A sample of 119 participants engaged in a modified SD test for 200 seconds while QEEG data were obtained. The participant verbally provided the matching number to the examiner to avoid any motor component of the task. There were negative relations between performance and magnitudes across almost all locations and across a wide bandwidth (0–64 Hz). Negative relations to SD performance were also observed for increased relative power of beta1, whereas positive relations were found for absolute values of coherences of alpha, beta1 (13–32 Hz), and beta2 (32–64 Hz). The results showed the importance of spectral correlation coefficients (SCC) in cognitive functioning, in particular the SCC values within the frontal region and in the 13–64 frequency range.

INTRODUCTION

The following discussion outlines the basics of quantitative electroencephalography (QEEG), the relevance of the Digit Symbol (DS) test to clinical conditions and the use of neuropsychological tests to identify the processes required for success on the DS. The hypothesis of the research is that there are identifiable QEEG patterns of performance that will confirm the findings of the other medical diagnostic investigations reported.

QEEG MEASURES

Over the years, research studies have generally defined the frequency ranges according to standard practice and have employed the scalp locations defined by the 10-20 system (Jasper, 1958). The frequency definition ranges have typically been delta, 0–4 Hertz; theta, 4–8 Hz; alpha, 8–13 Hz; beta, 13–25 Hz. The ranges have been dependent upon hardware and software definitions as well as the preferences of individual researchers. Some studies have examined frequencies above 32 Hz and reported on the added value in studying these frequencies (Thornton, 2000, 2001, 2002; von Stein & Sarnthein, 2000).

There are two types of data available to QEEG analysis. The first involves the activity at a scalp location and examines the different frequencies in terms of measures such as magnitude (M), relative power (RP), peak frequency (PF), symmetry (Sym), and peak amplitude (Pka). The second type of data quantifies the association between locations with concepts of phase (P) and coherence (spectral correlation coefficient, or SCC). This article employs the following bold capitalized letters to represent

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the variables employed for this analysis. Due to previous research (Thornton, 2001), only M, RP, and SCC and P values for the 13–64 Hz were examined. These variables had proven to be the critical QEEG variables in successful cognitive activity.

Activation Measures

M: Absolute magnitude/microvolts: the average absolute magnitude (defined in microvolts) of a band over the entire epoch (1 s).
RP: Relative magnitude/microvolt or relative power: the relative magnitude of a band defined as the absolute microvolt value of the particular band divided by the total microvolt value generated at a particular location across all bands.

Connectivity Measures

The algorithms employed in the Lexicor software generated the coherence and phase values obtained in this research. Lexicor employs the term spectral correlation coefficient (SCC) for the coherence calculation. Different hardware and software companies have employed different algorithms in calculating these values. The results reported in this article for SCC and P relationships using the Lexicor software are not necessarily the same results that would be obtained with algorithms provided by other equipment manufacturers. The only published analysis between concurrent performance on cognitive activation tasks and the QEEG variables have been conducted with the Lexicor measures.

C: Coherence or SCC: the average similarity between the waveforms of a particular band in two locations over the epoch (1 s) and is conceptualized as the strength or number of connections between two locations and is a correlation of the magnitudes.
P: Phase: the time lag between two locations of a particular band as defined by how soon after the beginning of an epoch a particular waveform at one location is matched in a second location.

To reduce the large number of variables and to be consistent with the generator concept in the EEG literature, Thornton (2002) developed the flashlight calculation. The concept of a flashlight assumes that a particular location emits a signal, in a defined frequency that is projected to all cortical locations. The value for a flashlight variable at a specific location, and in a specific bandwidth, is calculated by summating the coherence values with the remaining 18 locations. Abbreviations will employ a combination of the shorthand letters presented. For example, **CA** refers to coherence (SCC) alpha and **RPA** refers to relative power of alpha.

Digit Symbol

The DS subtest of the Wechsler IQ presents the participant with nine symbols with a number below each symbol. The subject is presented with rows of the symbols and has to write in the corresponding number that is provided in the translation code, presented in the first row. In the IQ measures, the participant is allotted 90 s to complete the task, and the total number correct is calculated as the performance. This measure has been considered an index of processing speed. However, motor execution has proven to be a critical determining element on this type of test (Crowe et al., 1999). Performance on the DS was explained by copy speed (35% of variance) and visual scanning speed (34% of variance), but not by memory performance (5% of variance; Joy, Fein, & Kaplan, 2003).

The DS is also highly correlated with overall IQ, with .71 and .74 correlations on the Wechsler Adult Intelligence Scale (WAIS) for ages 25 to 34 and 45 to 54 years, respectively (Matarazzo, 1972). Performance on this test peaks between 18 to 21 years, then shows rapid decline with increasing age (Wechsler, 1958). Other standardization data with the WAIS (Birren & Morrison, 1961) and WAIS–R (Kaufman, Reynolds, & McLean, 1989) showed correlations between age and digit symbol score of −.46 and −.54, respectively. The DS test has high test–retest reliability (Matarazzo & Herman, 1984).

Clinical Conditions

The DS task has proven to be a sensitive test in distinguishing between clinical conditions. Persons with schizophrenia do more poorly on this subtest relative to their performance on other subtests than do other clinical groups (Payne, 1961). Leeson et al. (2010) studied 53 first-episode psychosis patients and 53 healthy controls, one-to-one matched for sex, age, and full-scale IQ, and compared them on WAIS subtests. The performance of the two groups was equivalent on all WAIS subtests except DS, on which the schizophrenic patients performed significantly worse. A meta-analysis (Dickinson, Ramsey, & Gold, 2007) showed that, out of a wide range of neuropsychological measures, performance on the DS test was by far the most sensitive index differentiating schizophrenia patients from controls.

Yoran-Hegesh, Kertzman, Vishne, Weizman, and Kotler (2009) found that adolescents with Asperger's syndrome performed significantly worse than controls on the DS test. Subjects with autism spectrum disorder showed their lowest IQ scores on measures (WAIS–R/WISC–R) of the DS tasks in both the Goldstein, Johnson, and Minshew (2001) and Majiviona and Prior (1999) studies. Glosser, Butters, and Kaplan (1977) reported impaired performance on the DS task of the WAIS for patients with alcoholic Korsakoff disease, patients with right hemisphere damage, and chronic alcoholics. Luria (1974) reported an association between mood and DS performance with affective psychoses showing significant relations to their mood at the time of the test. This relation was not found for those with nonaffective psychoses.

Brain Damage. Mercer et al. (1998) found that brain injury affected all supplemental measures on the WAIS–R NI (as a neuropsychological instrument). In particular, strong effects were noted for the scales of Digit Symbol (raw score), Digit Symbol Copy (raw score), Free Recall Digit Symbol, Spatial Span Backward, and Sentence Arrangement. The Digit Symbol Substitution Test (DSST) has been reported to be a highly consistent and reliable indicator of brain damage (Russell, 1972; Wechsler, 1958).

Death and Aging. The DS test has been related to several important variables in the elderly population. Poor performance on the DS test (in combination with slow gait) has been implicated in greater risk of mortality and of developing disability (Rosano & Newman, 2008). Hall, Dubin, Crossley, Homqvist, and D'Arcy (2009) found a significant relation between the DS task and mortality with a decrease of 1 *SD* in performance associated with a 28% increased risk of mortality over the 10-year follow-up interval. Lafont et al. (2010) found that the DS test was the best indicator of the risk of impaired driving in Alzheimer disease and normal aging. Tabert et al. (2006) reported that a combination of short-term memory and the DS performance strongly predicted the change from mild cognitive impairment to Alzheimer's diagnosis. The combined predictive accuracy of these two measures for the change in diagnosis by 3 years was 86%. Tierney, Moineddin, and McDowell (2010) found similar results in predicting dementia and showed that two tests, Rey Auditory Verbal Learning Test short and delayed verbal recall and WAIS–R DS were significant predictors of dementia.

Medical Imaging

Medical imaging studies have provided an additional perspective on the problem. Functional magnetic resonance imaging (fMRI) is a technique that measures changes in brain activity during tasks (Huettel, Song, & McCarthy, 2009). Rypma and Prabhakaran (2009) conducted an fMRI study that showed prefrontal activity was related to working memory performance. Using a DS task designed to minimize working memory requirements to focus on processing aspects, they found that prefrontal and parietal activity in some areas were positively related to performance, whereas some prefrontal areas were negatively related to performance.

Biswal, Eldreth, Motes, and Rypma (2010) examined individual differences and brain region activation patterns with a high-demand DS task and low-demand visual vigilance task. However, the authors noted that different researchers have shown that task performance is tied to both greater activity and less activity. Other elements such as task difficulty, individual differences, and experience with the task could account for these changes. Gevins and Smith (2010) had previously reported (with

QEEG data) that successful working memory task performance depends upon activation of parietal locations and less prefrontal activity.

Other functional data using positron emission tomography (PET) and fMRI suggest that reduced activation is related to successful performance on a Ravens matrices task. Reduced PET and fMRI activity levels are hypothesized to correspond to the QEEG millivolt measures. Activity levels can also be understood in terms of connection activity. Rypma et al. (2006) suggested that the increased connections between brain regions may correlate with reduced task related neuronal activity levels and improved performance. Usui et al. (2009) performed a modified DS (mDS) task and a control task. The control task was a simple graphomotor response during fMRI data acquisition, which was intended to rule out the motor component of the task. The mDS provided the numbers and asked the subject to draw the symbols.

Greater activation patterns between the mDS task and the symbol copy control task were located in a fronto-parietal cortical network, including the bilateral inferior frontal sulci, left middle frontal gyrus (close to the frontal eye field), and left posterior parietal cortex. This pattern was interpreted as visual search process and/or updating of working memory during the mDS task. It is of some interest that there was a positive correlation between performance (number of correct responses) and activations in the bilateral inferior frontal regions, which correspond to the EEG locations between F3-C3 and F4-C4. It is also of some interest to note that during the control task there was no significantly activated area that positively correlated with the number of correct responses, which rules out the predictive role of motor involvement in the task.

Nakahachi et al. (2008) examined frontal lobe activity during the DS using multichannel near-infrared spectroscopy, a noninvasive functional imaging technique that does not interfere with the DS procedure. The spectroscopy method noninvasively detected cortical changes in hemoglobin (oxyHb) and used 52 measurement points. The baseline condition asked subjects to draw circles at a voluntary pace, to control for hand movements. Significant increases were found in oxyHb in more than 70% of the locations, with increases being more pronounced in the left hemisphere. Several locations showed significant positive correlations between changes in oxyHb and DS performance. However, there was no significant difference between hemispheres regarding the correlation of changes in oxyHb and the DS performance. Locations with a positive correlation between changes in oxyHb during the DS and the raw scores were suggested to correspond with BA 10, 9, 46, and probably BA 8, based on their locations, mainly in medial regions close to Fpz, and a convergence of these locations near Fp1, which is thought to correspond to BA 10. A review by Ramnani and Owen (2004) of the anterior prefrontal cortex and BA 10 proposed a specific role of this region in coordinating outcomes of multiple separate cognitive operations to cater to higher behavioral goals or to integrate information from regions across the supramodal cortex. Notable increases in oxyHb were also found over the opercular, triangular, and orbital parts of the inferior frontal gyrus, and the dorsolateral prefrontal cortex.

Diffusion Tensor Imaging (DTI) assesses structural aspects of white matter connectivity (Basser, 1995). The DTI measures of structural connectivity are associated with the QEEG measures of functional connectivity, namely, coherence and phase. DTI studies found changes in white matter structure were significantly correlated with brain abnormalities and executive function impairment, including information-processing slowing, in aging populations (Deary et al., 2006; Kennedy & Raz, 2009; Kochunov et al., 2009; Kochunov et al., 2007; Madden, Bennett, & Song, 2009; Salat et al., 2005; Sullivan, Rohlfing, & Pfefferbaum, 2010). Venkatraman et al. (2011) noted that increased global atrophy and small vessel disease of the white matter were associated with slower processing speed. However, some elderly individuals with these problems did maintain processing speed. The authors investigated the role of microstructure indices of DTI and magnetization transfer imaging damage and found these microstructure indices were associated with lower DS scores, whereas macrostructure gray matter and white matter hyperintensities were not related. These relations were independent of age, race, gender, minimental status score, systolic blood pressure, and myocardial infarction.

The research hypothesis is that the QEEG results will confirm the location findings of other medical diagnostic research on the DS and provide a different viewpoint of how DS performance is related to the QEEG variables.

METHODS

Participants

Participants were patients ($N = 119$) at a general mental health clinic who had undergone an activation QEEG evaluation as part of the initial evaluation for attention deficit disorders (ADDs), traumatic brain injury (TBI), learning disability (LD), memory problems, and normal individuals seeking better cognitive performance. The mean age was 28.22, ranging from 7 to 65. There were 44 female and 75 male participants, 108 right-handed and nine left-handed participants, and two participants who classified themselves as ambidextrous. Documentation regarding the diagnosis (i.e., ADD, ADHD, LD) was typically not readily available (except with TBI), which renders accurate classification problematic. In addition, it was not the goal of the research to understand how the different clinical conditions respond to the DS task. However, the difference between the response pattern of adult and children was examined due to previous research (Thornton, 2001) indicating a distinct difference and clinical research focus on adults.

Task

A modified Symbol Digit Task (mSDT) was constructed, which was presented visually on a computer screen in a Microsoft Excel spreadsheet. The participant was asked to provide the number corresponding to the image presented in the translation row at the top of the Excel spreadsheet. This approach is the opposite of what is required in the DS task, where the numbers are provided and the subject draws the symbols. This verbal response approach avoids the motor component of the DS task. There were 10 images per line. The examiner entered the number verbalized by the subject to bypass the motor component of the task. The participants were instructed to provide the numbers until 200 s had passed.

This task is similar to the SDT employed by other researchers. The SDT has proven to be sensitive in distinguishing patients with Multiple Sclerosis. The SDT has also been tied to epilepsy, organic solvent exposure, Parkinson's, aging, exercise, the P3 component of the event-related brain potentials, substance abuse, schizophrenia, sleep apnea, brain tumors, and traumatic brain damage (Straus, Sherman, & Spreen, 2006). A meta-analysis (Joy & Fein, 2001) of four DS studies indicated a mean correlation between SDT and DS of $r = .74$, indicating that the tests share approximately 50% of their variance. Morgan and Wheelock (1992) reported a correlation of .91 between the DS and SDT test. SDT also shares with DS a strong negative relationship with age (Joy & Fein, 2001). Female individuals outperform male individuals on this task (Jorm, Anstey, Christensen, & Rodgers, 2004; Smith, 1991). Test–retest coefficients at 6 months were .79 (Uchiyama et al., 1994).

As a baseline condition, participants were asked to raise their right index finger whenever a laser light was shown on the back of a laminated sheet of upside-down Spanish text for 200 s. This visual attention (VA) task served as the baseline condition for comparison to a modified SDT.

Figure 1 presents the mSDT task as presented to the participant with the first three cells filled in as an example of the response requested.

ǿ	Ω	ή	Ш	Љ	Þ	Ħ	Θ	ש	ج
1	2	3	4	5	6	7	8	9	0
ή	Љ	ש	Ω	Θ	ǿ	Ш	ج	Ħ	Þ
3	5	9							

FIGURE 1. Modified Symbol Digit task. *Note*. Top two rows provide the translation key. Bottom two rows are the task with the first three responses filled in.

EEG Recording

Brain activity was recorded using a 19-channel QEEG hardware device (Lexicor Medical Technology, Augusta, GA). Bandpass filters were set between 0.0 and 64 Hz (3 dB points). The signals that passed were analyzed with a fast Fourier transform, which uses cosine-tapered windows and provides spectral magnitude in microvolts as a function of frequency. The sampling rate was set to 256 to allow for examination up to 64 Hz. An Electro-Cap was fitted to the participant. The electrodes were positioned at 19 scalp locations according to the standard 10–20 system (Jasper, 1958) with ear-linked references. The scalp was prepped with rubbing alcohol and Nu-Prep, and the 19 electrodes were filled with Electro-gel. The earlobes and forehead were prepped with rubbing alcohol and Nuprep. Impedances were maintained below 10 KOhm at all locations. Gain was set to 32,000 and the high pass filter was set to off.

The measurements available through the software provided by Lexicor Medical provided the numeric values of the QEEG variables. The data were artifacted for eye movements and EMG activity as well as other possible sources of contamination (Thornton, 1996). The bandwidths were grouped according to the following divisions: delta, .00–4 Hz; theta, 4–8 Hz; alpha, 8–13 Hz; beta1, 13–32 Hz; beta2, 32–64 Hz.

RESULTS

A correlational analysis examined the relations between the total score (TS; total correct – total errors) and the variables of gender and handedness. The second correlational analysis examined the relations between the total score and the QEEG variables. Table 1 presents the relations between success on the task and participant variables.

TABLE 1. Digit Symbol Performance and Gender and Handedness

	Correlation with total score
Gender	.12 (*ns*)
Handedness	.12 (*ns*)

There was a curvilinear relation between age and performance as indicated in Figure 2. The score increases from age 14 to age 20 years before beginning a gradual decline.

These results are consistent with respect to age, as previous research had reported an age effect with respect to performance on the DS task in a normal population. The mean score on this DS task was 73.6 ($SD = 25.5$) with a minimum score of 5 and maximum of 128.

The second analysis looked at the relations between the QEEG performance and TS on the task. The analysis examined the relative power and millivolt values of the five frequencies during the digit symbol task as well as the coherence and phase values for the alpha (8–13 Hz), beta1 (13–32 Hz), and beta2 (32–64 Hz) frequencies, which were calculated according to the flashlight metaphor. In addition, the degree of activation from the visual attention task was calculated for the millivolt and relative power values of the five frequencies. The standard deviation increases in the coherence flashlight values as well as individual pairs for the beta2 frequency were calculated as the initial data collection was indicating a pattern in this variable. Figure 3 presents the millivolt values. As the figure indicates, increased millivolts across all frequencies were negatively correlated with task performance.

Figure 4 presents the head figures that relate frontal lobe activity to performance. The absolute value of the relative power of beta1 in the frontal lobe was negatively correlated with TS. The remaining head figures present the frontal activation patterns from the visual attention control condition. The standard deviation value of the variable during the visual attention condition was employed to calculate the standard deviation change in the SDT task. For example, the second head figure from the left indicates that the more the participant increased the relative power of delta at the Fp1 and Fp2 locations the better were the TS score. This pattern is similar in the remaining head figures. The pattern appears to indicate that the more the participant "relaxes" the frontal lobe the more successful was the performance. If the frontal lobes are activated in terms

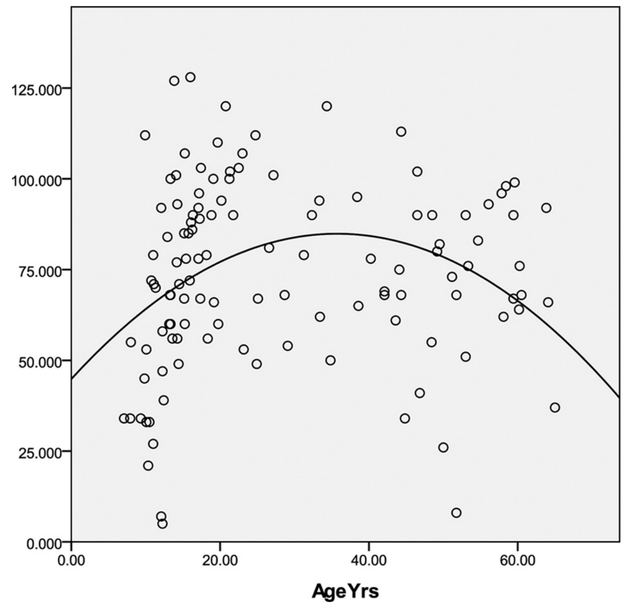

FIGURE 2. Symbol Digit task score (number completed – number wrong) is presented on the vertical axis and age is presented along the horizontal axis. *Note.* The relation is curvilinear peaking around age 20.

of beta1, then decreased (TS) performance occurs.

Figure 5 presents the coherence flashlight values for the three frequencies during the task and the coherence beta2 SD changes in values when comparing the visual attention to the SDT. The visual attention task was the baseline. The following equation was used to determine the standard deviation change: (Symbol Digit QEEG variable value – VA QEEG variable value)/

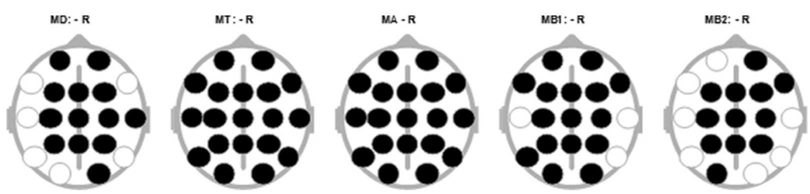

FIGURE 3. Relations between millivolt measures and Symbol Digit performance. *Note.* All black enclosed circle locations indicate a significant negative correlation between the value of the variable and total score. MD = millivolt delta; MT = millivolt theta; MA = millivolt alpha; MB1 = millivolt beta1; MB2 = millivolt beta2; −R = negative relation between QEEG value and task performance.

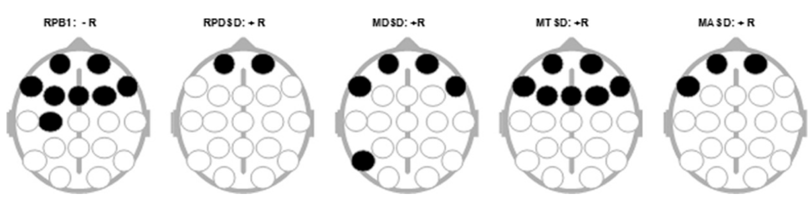

FIGURE 4. Relations between relative power and frequency activation measures. *Note.* Increase refers to change in variable value comparing the value during the visual attention task to the value during the Symbol Digit task employing the SD of the visual attention variable to calculate the SD change. All black enclosed circle locations indicate a significant correlation between the value of the variable and total score. RPB1 = relative power of beta1; RPSDD = standard deviation increase in relative power of delta; MSDD = standard deviation increase in magnitude of delta; MTSD = standard deviation increase in magnitude of theta; MASD = standard deviation increase in magnitude of alpha; −R = negative relation between QEEG value and task performance; +R = positive relation between QEEG value and task performance.

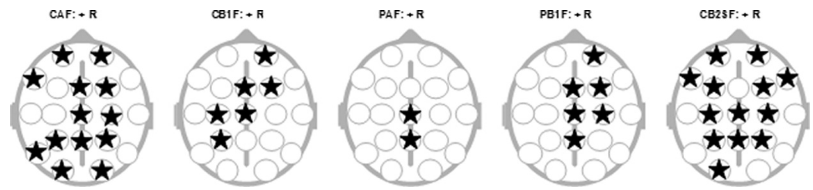

FIGURE 5. Coherence values and standard deviation coherence beta2 changes. *Note.* Star figure represents the origin of the flashlight. All star enclosed circle locations indicate a significant positive correlation between the value of the variable and total score. CAF = coherence alpha flashlight locations; CB1 F = coherence beta1 flashlight locations; PAF = phase alpha flashlight locations; PB1 F = phase beta1 flashlight locations; CB2SF = standard deviation changes in the coherence beta2 flashlight locations, visual attention vs. SDT task; +R = positive relation to task performance.

(*SD* of VA QEEG variable value). As the figure indicates, performance on the SDT task is predominantly an issue of the absolute level of coherence activity and coherence beta2 activation.

Table 2 examines the individual significant effects by location and frequency. Frontal refers to interconnections between all frontal locations (F7, Fp1, Fp2, F8, F3, F4, Fz). Posterior refers to interconnections between all posterior locations (T5, P3, Pz, P4, T6, O1, O2). The frontal-posterior category refers to all connections between frontal and posterior locations (F7-T5, F7-P3, etc.; F3-T5, F3-P3, etc.). The central label refers to all connections involving T3, C3, Cz, C4, and T4. Column 2 labeled Max. Possible per Location refers to the maximum number of significant connections that are possible given the locations employed. Column 9 label CB2SD refers to the standard deviation degree of activation from the visual attention condition. Column 10 is a total of the significant effects across all frequencies and the CB2SD significant effects. Column 11 provides that maximum number of possible significant relations across all frequencies and CB2SD per location. Column 12 provides the percentage of possible significant effects that are obtained by dividing column 10 by column 11. As the table indicates, the frontal lobe appear to be the major focus of the successful connection activity both in terms of the absolute value of the coherence value and activation of the beta2 coherence activity.

A separate examination of the child's response pattern and adult pattern was investigated. This analysis was based upon previous research (Thornton, 2001) that indicated a different effective response pattern in children (ages 10–14) and adults (older than 14).

Figure 6 examines the absolute value of the coherence and phase values across all three frequencies examined between the locations indicated by the lines. The purpose of this analysis is to ascertain if there is a general frontal lobe or if the significant effects are focused in specific locations. The figure presents only the strongest pattern by requiring four significant values across the three frequencies examined (alpha, beta1, beta2). Each location has six possible significant relations to other frontal lobe locations. As the figure indicates the Fp2 location has 24 significant patterns, whereas Fp1 has 14 significant patterns, thus indicating some degree of focus to the frontal lobe effect. These results are in line with the Nakahachi et al. (2008) study.

TABLE 2. Distribution of Significant Effects

1	2 Max. possible per location	3 CA	4 CB1	5 CB2	6 PA	7 PB1	8 PB2	9 CB2SD	10 Total	11 Max. possible across all frequencies per location	12 % locations with significant effects
Frontal	21	9	9	8	8	10	6	14	64	21 × 7 = 147	45
Posterior	21	9	4	0	7	3	2	4	29	21 × 7 = 147	20
Frontal-Posterior	49	12	11	0	0	3	0	15	41	49 × 7 = 343	12
Central	80	9	23	2	14	20	8	24	100	80 × 7 = 560	18
Total		39	47	10	29	36	16	57			

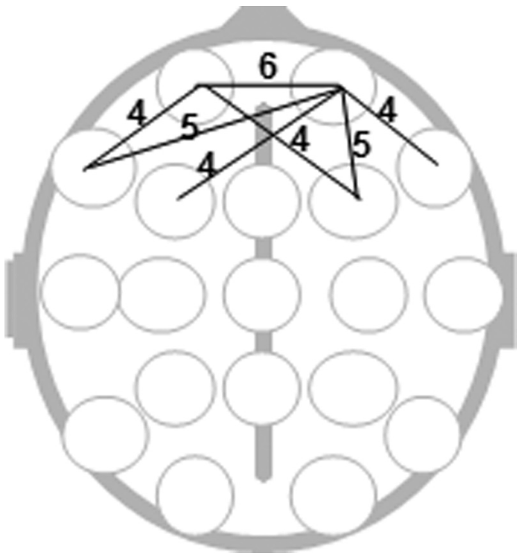

FIGURE 6. Frontal connections summed across three frequencies (13–64 Hz) with four or more significant values, the number adjacent to line indicates the number of significant relations.

Previous research (Thornton, 2001) indicated a different pattern of QEEG variables involvement in cognitive success when children (age 10–14) with adults (older than 14) were compared. An analysis was done to examine if the SDT was sensitive to this age difference effect. Figure 7 presents the variables that were correlated with performance on the task for the 29 children analyzed.

The results indicate negative relations to performance with standard deviation increases (from visual attention) in the relative power of alpha values. There were positive relations between performance and Fp2 variables (magnitude of beta1 and beta2, standard deviation increase in relative power of delta), standard deviation increases in magnitude delta, standard deviation increases in magnitude beta2, and coherence alpha and beta1 flashlight

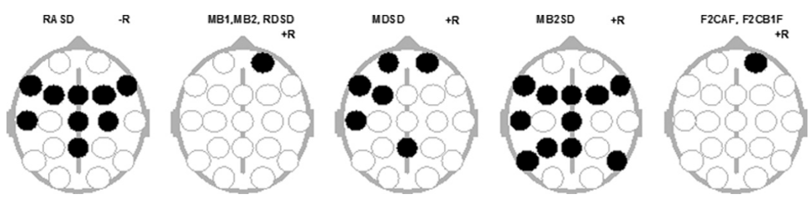

FIGURE 7. Significant performance correlations in children. *Note.* All black enclosed circle locations indicate a significant correlation between the value of the variable and total score. RASD = relative power alpha standard deviation increase; MB1 = magnitudes beta1; MB2 = magnitudes beta2; RDSD = relative power delta standard deviation increase; MSDD = magnitude delta standard deviation increase; MB2SD = magnitude beta2 standard deviation increase; F2CAF = Fp2 coherence alpha flashlight; F2CB1 F = Fp2 coherence beta1 flashlight; −R = negatively correlated with performance; +R = positively correlated with performance.

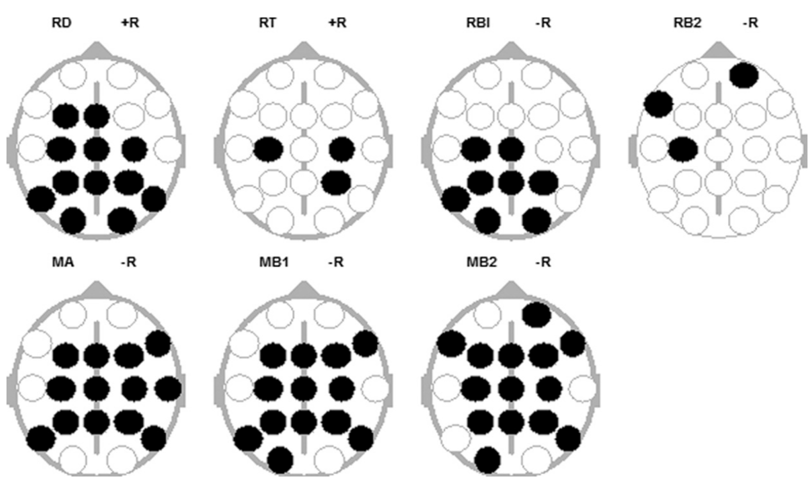

FIGURE 8. Adult significant relations with performance. *Note.* All black enclosed circle locations indicate a significant correlation between the value of the variable and total score. RD = relative power delta; RT = relative power theta; RB1 = relative power beta1; RB2 = relative power beta2; MA = magnitude alpha; MB1 = magnitude beta1; MB2 = magnitude beta2.

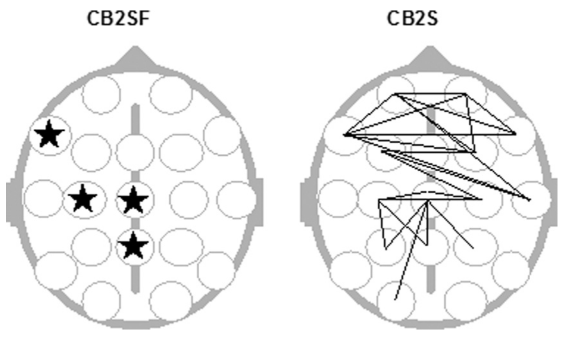

FIGURE 9. Adult: Significant relations between performance and the flashlight locations and individual locations. *Note.* All star enclosed circle locations indicate a significant positive correlation between the value of the variable and total score. CB2SF = coherence beta2 flashlight standard deviation change; CB2S = coherence beta2 standard deviation change.

values from Fp2. The Fp2 location presents an interesting pattern of results with high beta magnitude levels and high coherence alpha and beta1 flashlight values. The beta2 magnitude standard deviation increase presents an interesting comparison to the adult data and indicates contrary results. The adult sample ($N = 90$) underwent a similar analysis. Figures 8 and 9 present the results for the adults.

The results indicate that magnitudes and relative power values (alpha to beta2) were negatively related to performance, whereas relative power values in delta and theta were positively related to performance. The CB2 standard deviation flashlight increases were the only significant increases in flashlight coherence and phase relations. An individual analysis of location pairs indicated that significant CB2 activations showed frontal lobe increases in nine pairs (of the possible 21) and eight significant activation relations (of a possible 15) involving the central and parietal locations.

DISCUSSION

DS and SDT performance has been implicated in several clinical conditions (schizophrenia, alcoholism, autism, Asperger's, aging, Alzheimer's, death, TBI, etc.). This research was conducted to understand the underlying electrophysiology that may be involved in these clinical conditions. The overall results for the entire sample indicated that successful performance is positively correlated with a ''relaxation'' of the frontal lobes and higher values in coherence and phase activity of alpha, beta1, and beta2. Diffusely located standard deviation increases (from the visual attention condition) in CB2 were also related to successful performance. Individual location analysis pointed to a frontal/parietal focus of the CB2 activation patterns. These results are in line with PET and fMRI data that have indicated reduced activity levels (millivolts in the QEEG data) related to successful performance (Ravens) and increased connections (Rympa et al., 2006) related to reduced neuronal activity and improved performance.

When the sample was divided between children (ages 10–14) and adults (older than 14) a differing pattern emerges. For children, standard deviation diffuse increases in beta2 were related to successful performance. Beta activations at Fp2 and CA and CB1 flashlight activity from Fp2 presented an interesting pattern related to success. For adults, diffuse absolute values of beta2 magnitudes (as well as alpha and beta1) were negatively related to performance. The CB2 standard deviation flashlight increases (from visual attention) and frontal and central/parietal individual standard deviation increases in CB2 were significantly related to successful performance. As most of the research on clinical samples involves adult samples, the adult results are more relevant to these conditions. The myelinated fibers are hypothesized to be the underlying structure of the coherence and phase values. The results imply that damage to these fibers may underlie the problems in the clinical samples reported. This correlation has been documented in the Thornton (1999, 2000, 2003) and Thornton and Carmody (2010) research reports that indicate the predominant focus of the electrophysiological damage in the traumatic brain injured subject is in the beta2 (32–64 Hz) coherence and phase values, especially involving the frontal lobes. The deficit coherence and phase values were negatively related to cognitive performance (auditory memory). Increased arousal levels (beta levels) were generally associated with decreased performance on the SDT task for adults, not for children. This pattern was also observed in the TBI group (Thornton & Carmody, 2010).

CONCLUSION

The analysis of the electrophysiological signals underlying performance on the SDT revealed results which may provide a better understanding of the problems reported in the research in several clinical conditions. The hypothesis from these results is that these problems reside in the myelinated fibers connecting different brain regions. Whether interventions directed toward these problems would have any effect on the clinical condition is an open question.

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