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Interactions among Variables in the P300 Response to a Continuous Performance Task in Normal and ADHD Adults

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Abstract

This study investigated the effect of variable interstimulus intervals (ISIs) in a group of normal and ADHD (attention deficit hyperactivity disorder) adults on behavioral reaction time and the auditory P300 event-related potential. This study involved 20 adult subjects with no history of ADHD and 11 adult subjects diagnosed with ADHD. The subjects were instructed to respond to the common stimuli and ignore the rare stimulus. Significant differences in the latency of the P300a, P300b, the amplitude of the P300b, and in the number of false alarms and correct rejections between ISIs were observed in the normal group. The group with ADHD failed to show any significant differences between ISIs. Psychophysical measures of hits showed significant differences for the number of hits for ISI 2 (2 sec) between the two groups. False alarms and correct rejections for all ISIs showed significant differences between groups. Significant group differences were seen for latency of the P300a and P300b at each of the three ISIs, for amplitude of the P300a and P300b for ISI 1 and ISI 3, and for the amplitude of the P300b for ISI 2. There was a greater separation in the group with ADHD between the P300a and P300b suggesting a processing lag in that group.

Key Words: Attention deficit hyperactivity disorder, auditory attention, auditory cognitive processing, auditory continuous performance task, auditory event-related potentials, P300, reaction time, variable interstimulus interval

Abbreviations: : ACPT = auditory continuous performance task; ADHD = attention deficit hyperactivity disorder; AERP = auditory event-related potential; CPT = continuous performance task; ISI = interstimulus interval; RT = reaction time; VCPT = visual continuous performance task

Sumario

Este estudio investigó en un grupo de adultos normales y con ADHD (trastorno de déficit de atención e hiperactividad) el efecto que intervalos interestímulo variables (ISI) ejercen sobre el tiempo de reacción conductual y el potencial P300 auditivo relacionado con el evento. Este estudio involucró a 20 sujetos adultos sin historia de ADHD y a 11 sujetos con diagnóstico de ADHD. Los sujetos recibieron instrucciones para responder a los estímulos comunes e ignorar los estímulos raros. En el grupo normal, se observaron diferencias significativas en la latencia de las ondas P300a y P300b, en la amplitud de la P300b, y en el número de falsas alarmas y de rechazos correctos, producto

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de las diferentes ISI. El grupo con ADHD no mostró diferencias significativas entre las diferentes ISI. Las medidas psicofisiológicas de los aciertos mostraron diferencias significativas para aquellas de la ISI-2 (2 segundos), entre los dos grupos. Las falsas alarmas y los rechazos correctos para todos los ISI mostraron diferencias significativas entre los grupos. Se vieron diferencias significativas de grupo para la latencia de las ondas P300a y P300b, en cada uno de los tres ISI, para la amplitud de la P300a y la P300b en el ISI-1 y el ISI-2, y para la amplitud de la P300b en el ISI-2. Existió una separación mayor entre la P300a y la P300b en el grupo con ADHD, sugiriendo un rezago de procesamiento en ese grupo.

Palabras Clave: Trastorno de déficit de atención e hiperactividad; atención auditiva, procesamiento cognitivo auditivo, tareas de desempeño auditivo continuo, potenciales auditivos relacionados con el evento, P300, tiempo de reacción, intervalo interestímulo variable

Abreviaturas: ACPT = tarea de desempeño auditivo continuo; ADHD = trastorno de déficit de atención e hiperactividad; AERP = potencial auditivo relacionado con el evento; CPT = tarea de desempeño continuo; ISI = intervalo interestímulo; RT = tiempo de reacción; VCPT = tarea de desempeño visual continuo

The P300 is widely recognized and studied as a physiological measure of cognitive processing (Polich et al, 1983). It is of interest in studies on the relationship of orientation, attention, stimulus evaluation, and memory (Yamaguchi and Knight, 1991; McPherson, 1996).

Latency and amplitude of the P300 have been used as indices of the timing and nature of a subject's cognitive response to a stimulus (Johnson, 1988). The P300 has a scalp-recorded vertex-positive potential with a latency of approximately 300 msec from stimulus onset having an amplitude of approximately 12--15 µV (Duncan-Johnson and Donchin, 1979; Karis et al, 1984; Polich, 1986a, 1986b; McPherson, 1996).

The latency of the P300 appears to be a function of stimulus processing time, which includes recognition and categorization of the stimulus. Stimulus processing time has been found to be independent of response production time (i.e., behavioral reaction time) (Kutas et al, 1977; Pritchard, 1981; Howard and Polich 1985). Ritter et al (1972) and Courchesne (1978) reported that the P300 latency is representative of the speech information processing: The faster the information is processed, the shorter the latency of the P300. Furthermore, Goodin et al (1983) suggested that a decrease in the P300 latency indicates an increase in cognitive capabilities.

The amplitude of the P300 is inversely related to the probability of task occurrence and to subjective expectancy (Sutton et al, 1965; Johnson, 1988). As the meaning of the stimulus becomes more significant to the subject, the amplitude of the P300 increases.

A bimodal P300, which occurs under certain stimulus conditions, consists of an "a" and "b" component (P300a, P300b). The P300a occurs in response to large stimulus differences regardless of attending state, while the P300b occurs only when the subject is actively discriminating between stimuli (Roth et al, 1980; Squires et al, 1975; Polich, 1986a, 1986b). Squires et al (1975) and Polich (1986a) have identified a P300a component occurring during an ignore condition in response to an infrequent stimuli and a P300b component occurring when the subject is actively attending to the rare stimuli. Squire et al (1975) indicated that the mean latency of the P300a was between 220 and 280 msec, and the P300b had its main peak between 310 and 380 msec. The P300a has the largest amplitude at either Fz or Cz, whereas P300b is largest either at Cz or Pz; they are indices of different brain processes (Squire et al, 1975). McPherson further explains:

> P300a has been correlated with stimulus novelty and becomes more robust with a low predictability of occurrence for the target. The P300a does not appear to be related to any mental or motor response and hence may be recorded without specific patient participation, although attention is a factor. The P300b is related to the task involved in the detection of the target stimuli and becomes more robust with target response. [1996, p. 13]

The P300 may be elicited using a variety of stimulus modalities, such as auditory, visual, or somatosensory (Sutton et al, 1965; Johnson, 1988, 1989). The current study utilizes an auditory modality to elicit the P300 in both a normal and an ADHD (attention deficit and hyperactivity disorder) population. Research has shown that the P300 latency in intellectually impaired subjects is longer than in intellectually normal subjects, suggesting that the P300 reflects general cognitive function (Howard and Polich, 1985). In addition, Polich et al (1983) reported that the P300 latency is related to short-term memory capacity. Short-term memory is essentially a temporary storage that acts as working memory for cognitive processing (Russel, 1981; Polich et al, 1983). It is in conjunction with working memory that the P300 latency reflects individual cognitive capabilities (Ladish and Polich, 1989). The P300 has been shown to be a good measure in the study of cognition, and cognitive abnormalities have been well demonstrated in the ADHD population (Sohmer and Student, 1978; Douglas, 1984; Salamat and McPherson, 1999).

ADHD has been characterized by a short attention span associated with a learning disorder (Satterfield and Braley, 1977), inappropriate and excessive motor activity, impulsiveness, distractibility, and a disruption of normal auditory processing (Douglas, 1972; Loiselle et al, 1980). Cognitive abnormalities characterized by a deficit in integration, planning, and organization (Shue and Douglas, 1992) have also been documented in the ADHD population (Sohmer and Student, 1978; Douglas, 1984).

ADHD diagnosed in adults has not received as much attention as in children. Prevalence in school-age children is estimated to be 3--5% (DSM-IV; American Psychiatric Association, 1994), while the prevalence in adults is estimated to be about 2% (Biederman et al, 1995). Children who have been diagnosed with ADHD are more likely to have parents who also manifest symptoms of the disorder (DSM-IV; American Psychiatric Association, 1994; Biederman et al, 1995), whereas adults exhibiting ADHD symptoms are most likely to have had the disorder as children (Gualtieri et al, 1985; Biederman et al, 1995; Schubiner et al, 1995). Luber (1991) estimated that 20% of children diagnosed as having ADHD will carry that disorder into adulthood. Biederman et al (1994) found demographic, psychosocial, and cognitive features reflected in male and female adult ADHD subjects to be similar to those of male and female children diagnosed with ADHD.

One measure of assessing ADHD by means of a cognitive task is the use of a continuous performance test (CPT) (Trommer et al, 1988). The CPT is a test of attention where the subject is asked to respond to a specified target (rare stimulus) and not to respond to a nontarget (common stimulus). Attention is represented by the number of correct responses. Inattentiveness is represented by errors of omission (not responding to target stimulus) and impulsivity is represented by errors of commission (responding to a nontarget stimulus) (Trommer et al, 1988).

Conners (1992) developed a computerized visual continuous performance task (VCPT) that examines the effect of ISI on (reaction time) RT, number of hits, number of omissions (misses), and number of commissions (false alarms) in an "oddball" paradigm using letters presented on a computer monitor. Conners (1992) stated that a true continuous performance task requires the subject to respond continuously to all stimuli except the target stimulus. Continuous responses assure a large enough sample for RT to be useful as a valid measure.

Salamat and McPherson (1999) reported on the effect of variable ISIs on RT as well as the latency and amplitude of the P300 in a normal adult population using an auditory continuous performance task (ACPT). The ACPT protocol that Salamat and McPherson (1999) used was similar to Conner's VCPT protocol. Salamat and McPherson used three ISIs of 1, 2, and 4 seconds in the presentation of 1000, 1500, and 2000 Hz tones that served as the common stimuli, and a 250 Hz tone that served as the rare stimulus. RTs as well as the number of hits, misses, false alarms, and correct rejections were recorded. The subjects were instructed to ignore the rare stimuli and respond only to the common stimuli.

Salamat and McPherson (1999) showed significant correlations between visual and auditory reaction times, suggesting that responses to the two tasks were similar. The study also reported significant correlations between ISI, reaction time, P300 latency, correct rejections, and false alarm rates, using the ACPT paradigm. A statistically significant increase in reaction time was also observed as ISI increased. It was concluded that RT and variable ISIs in an ACPT could be used as a valid indicator of cognitive and attentional processes in the brain as reflected in the P300. Thus attentional processes could be quantified objectively by measuring the latency and amplitude of the P300 component of the auditory event-related potential (AERP) while the subject performed an ACPT.

Since the P300 has been shown to be central in the study of cognition and its physiological correlates, and given that disorders of cognition are present in individuals with ADHD, it is reasonable to examine the relationship of the P300 in subjects diagnosed with ADHD. The present study uses the ACPT paradigm adapted by Salamat and McPherson (1999), in which the effect of variable ISIs on RT were measured in both a normal and an ADHD population of adults. The purpose of the present study was to investigate the effect of the variable ISI on reaction time, and on the latency and amplitude of the P300a and P300b using an ACPT paradigm with an adult ADHD population. The numbers of hits, misses, correct rejections, and false alarms were evaluated in relation to the components of the auditory P300a and P300b.

METHOD

Subjects

This study involved 20 audiologically normal subjects, ages 17 to 25 years with no history of ADHD, and 11 (6 male, 5 female) audiologically normal subjects, ages 19 to 31 years, diagnosed with ADHD. The McCarney Attention Deficit Disorders Evaluation Scale (McCarney, 1989) was administered to each participant and scored in accordance with the DSM-IV criteria (American Psychological Association, 1994). No individual with a reported history of drug abuse, alcohol abuse, schizophrenia, or head trauma was included in this study. All subjects read and signed an informed consent form approved by the Institutional Review Board on Human Subject Research at Brigham Young University. The normal subject group was selected from those who participated in the research for our previous paper (Salamat and McPherson, 1999). The research was conducted in accordance with the Declaration of Helsinki.[1]

All subjects' pure-tone air-conduction thresholds were at or below 20 dB HL for 250, 500, 1000, 1500, 2000, and 4000 Hz, with symmetrical hearing sensitivity (within ±5 dB) for these frequencies. Each subject demonstrated a centrally fused image at 70 dB HL for 250, 1000, 1500, and 2000 Hz. All subjects had normal, bilateral tympanograms (Margolis and Holler, 1987). Both crossed and uncrossed acoustic reflexes were present at 500, 1000, and 2000 Hz.

Instrumentation

A Grason-Stadler 1710 audiometer was used for hearing evaluation, and a Grason-Stadler Middle Ear Analyzer 1733 was used to obtain tympanometric peak pressure and acoustic reflexes. A Cadwell Spectrum 32 signal processor was used to collect the AERPs. AERPs were elicited with binaural 250, 1000, 1500, and 2000 Hz tone bursts presented through TDH-50P earphones with MX 15 AR cushions at an intensity of 70 dB HL. A 5 msec rise/fall time and 65 msec plateau time were used. A total of 200 tones was presented for ISIs of 1, 2, and 4 seconds, and 50 artifact-free tone presentations were allocated for each frequency. Filters were set for a .53 to 70 Hz bandpass (6 dB down, 12 dB/octave). A 500 msec sample window was obtained for each trial that included a 100 msec pre-analysis sample.

An electrode cap (Electrocap International) was used to place 22 silver-silver chloride electrodes over the scalp using the 10-20 international system (Committee on Methods of Clinical Examination in Electroencephalography, 1958). The electrode montage was referred to linked mastoids, A1 and A2 (inverting). Fpz was used as a ground electrode.

Impedance at each electrode site was at or below 5 kΩ with inter-electrode impedance differences no greater than 500 ohms. Myogenic activity from eye movement was monitored from an electro-oculogram using two electrodes, one placed below and one placed above the left eye. Eye movements caused the samples to be rejected from the average. Acoustic signals for the ACPT were generated through a Tucker-Davis Technologies, System II. Signals were calibrated in dB HL (ANSI, 1989).

Procedure

All testing was completed in a sound attenuating room that met the criteria for permissible ambient noise during audiological testing for unoccluded ears (ANSI, 1991). Subjects were seated in a recliner chair.

Auditory event-related potentials were obtained using an ACPT paradigm adopted from the CCPT protocol (Conners, 1992). The ACPT consisted of four tones and three ISIs randomly presented with no single condition occurring in succession. The subjects were required to respond by pushing a button in response to "common" tones (1000, 1500, and 2000 Hz) and withholding the response to the "rare" tone (250 Hz). Both the common and the rare tones were averaged in separate computer buffers for each ISI (1, 2, and 4 sec). Likewise, the behavioral reaction times for each ISI of the common tones were recorded separately. The number of hits, misses, correct rejections, and false alarm rates were recorded separately for each ISI. Each tone and ISI combination had an equal probability of occurrence, with the common tones occurring 75% of the time and the rare tone occurring 25% of the time.

Each subject was provided with a practice session to become familiar with the testing procedures. During the practice session subjects listened to both the common and rare tones, becoming conditioned to respond only to the common tones and to withhold the response to the rare tone. Two replicable recordings were obtained from each subject, with a ten-minute rest period between the first and second recordings.

Data Analysis

The P300 complex (i.e., P300a and P300b) was defined as the third positive peak in the long latency auditory evoked potential occurring after stimulus onset and the first positive peak following the N200. The P300a was identified as the first peak in the P300 complex, and the P300b was identified as the second peak in the P300 complex. The amplitudes of the P300 complex were measured from baseline to the peak of the P300a and P300b. The latency was measured from stimulus onset to the peak of the P300a and P300b. The waveforms were not identified as to which group, or trial, the sample occurred during scoring of the waveforms.

Behavioral reaction times were recorded from stimulus onset until button press. Reaction times and P300 amplitudes and latencies, along with the number of hits, misses, correct rejections, and false alarms, were measured for each ISI in both groups.

RESULTS

An analysis of variance (Wilk's Lambda) for repeated measures failed to show significant differences between trials for any of the variables used in this study for either group ($F[27,31] = 0.51$, $p > .05$). Consequently, the data were combined by averaging the two trials for both groups (Table 1).

All subjects in the normal group showed good reproducibility and identifiable waveform morphology for the P300a and P300b AERP. Although reproducibility and waveform morphology were acceptable for the group with ADHD, there was a greater qualitative variability in the morphology of the waveforms.

Table 1 shows the descriptive statistics for RT and for the number of hits, misses, false alarms, and correct rejections for all three ISIs in both groups. The mean reaction times for the ACPT, across all three ISIs, for both groups are within one standard deviation of each other for each group independently. Table 2 shows the descriptive statistics for the latency and amplitude of the P300a and P300b for the combined trials in both groups. The mean latency and amplitude across all three ISIs are within one standard deviation of each other for each group, independently.

Table 1. Descriptive Statistics for RT, Number of Hits, Misses, False Alarms, and Correct Rejections, Both Groups, Trials 1 and 2 Combined

Variable		ISI 1		ISI 2		ISI 4	
		Normal	ADHD	Normal	ADHD	Normal	ADHD
RT (msec)	Mean	423.89	461.45	451.37	468.10	484.68	506.50
	SD	75.22	74.94	78.69	85.20	92.19	99.54
	Range	259.12–598.84	298.00–635.00	305.72–604.20	316.00–617.00	328.74–649.29	365.00–702.00
Hits	Mean	49.12	48.70	50.00	47.85	49.25	47.85
	SD	2.23	3.26	2.91	3.47	2.73	2.68
	Range	37–52	39–52	36–58	35–52	35–52	40–51
Misses	Mean	0.53	1.65	0.60	2.00	0.70	1.95
	SD	1.92	2.62	2.24	3.32	2.60	2.72
	Range	0–12	0–10	0–14	0–15	0–16	0–11
False Alarms	Mean	1.05	2.35	1.38	3.45	2.15	4.30
	SD	1.06	1.73	1.41	2.11	1.73	2.81
	Range	0–5	0–5	0–6	0–7	0–7	0–9
Correct Rejections	Mean	15.60	14.25	15.48	13.05	14.52	12.60
	SD	1.26	1.71	1.72	2.04	1.83	2.60
	Range	11–17	11–17	10–18	10–17	9–18	8–17

Table 2. Results of ANOVA by ISI, Group 1 (Normal)

Source	SS	df	MS	F	p
RT (msec)	50677.59	2	25338.79	3.85	0.027
Latency (msec)					
P300a	12102.42	2	6051.21	5.72	0.005
P300b	11828.17	2	5914.08	10.29	<0.001
Amplitude (µv)					
P300a	49.69	2	24.84	1.61	0.208
P300b	106.07	2	53.03	3.49	0.037
Hits	8.95	2	4.47	0.97	0.383
Misses	0.30	2	0.15	0.04	0.957
False Alarms	12.77	2	6.38	4.49	0.015
Correct Rejections	13.82	2	6.91	3.98	0.024

Within Groups

Within group analysis (Table 3) showed significant differences in the latency of the P300a and P300b, and for the amplitude of the P300b as well as in numbers of false alarms and correct rejections between ISIs in the normal group. The group with ADHD (Table 4) failed to show any significant differences between ISIs.

Between Groups

Psychophysical measures of hits, misses, false alarms, and correct rejections showed significant differences for the number of hits for ISI 2; however, for ISI 1 and ISI 4 there

Table 3. Results of ANOVA by ISI, Group 2 (ADHD)

Source	SS	df	MS	F	p
RT (msec)	11827.61	2	5913.80	0.82	0.449
Latency (msec)					
P300a	12131.91	2	6065.95	1.21	0.313
P300b	12337.48	2	6168.74	0.96	0.397
Amplitude (µv)					
P300a	28.01	2	14.00	1.16	0.326
P300b	10.56	2	5.28	0.35	0.706
Hit	4.81	2	2.40	0.36	0.695
Miss	0.71	2	0.35	0.06	0.939
False Alarm	19.11	2	9.55	2.53	0.090
Correct Rejection	14.55	2	7.27	2.17	0.133

Table 4. Descriptive Statistics for P300 Latency (msec) and Amplitude (µv), Both Groups, Trials 1 and 2 Combined

		ISI 1		ISI 2		ISI 4	
Variable		Normal	ADHD	Normal	ADHD	Normal	ADHD
Latency (msec)							
P300a	Mean	232.76	376.01	248.81	372.32	267.52	329.43
	SD	37.00	68.09	44.33	92.59	45.86	81.79
	Range	203.73–331.35	242.01–471.72	201.20–354.78	203.73–522.77	203.73–356.07	216.49–497.25
P300b	Mean	354.96	482.57	375.69	467.17	389.09	433.97
	SD	32.26	79.35	23.82	98.88	34.06	93.87
	Range	305.82–458.96	331.35–637.63	318.58–446.20	280.30–612.10	318.58–471.72	293.06–586.58
Amplitude (µv)							
P300a	Mean	14.95	8.29	12.79	10.64	13.36	9.70
	SD	4.60	3.51	4.17	5.39	4.05	3.85
	Range	5.66–25.03	3.15–17.88	5.11–21.29	4.02–21.97	6.26–21.97	4.26–20.43
P300b	Mean	17.70	9.26	15.48	10.59	14.53	10.44
	SD	4.51	4.07	4.74	5.32	3.98	4.76
	Range	11.17–27.88	4.68–20.95	9.29–27.88	3.49–20.18	8.46–24.27	5.39–21.16

were no significant differences between the two groups (Table 5). No significant group differences were observed for misses. For both false alarms and correct rejections, significant differences between groups were found for all ISI conditions (Table 5).

Significant differences between the normal group and the group with ADHD were seen for the latency of the P300a and P300b at each of the three ISIs (Table 6). Significant differences were seen for the amplitude of the P300a and P300b for ISI 1 and ISI 4, but only for the P300b for ISI 2.

Correlation coefficients were computed for both the normal and the ADHD group. Within each group, as ISI increased, RT increased; however, significant correlations between RT and the three ISIs were found only for the normal group ($r = 0.336$, $p = 0.009$). Also in the normal group, as ISI increased, the

Table 5. ANOVA by Group, for RT, Hits, Misses, False Alarms, and Correct Rejections, Trials 1 and 2 Combined

Source	SS	df	MS	F	p
RT (msec)					
ISI 1	18805.01	1	18805.01	3.33	0.073
ISI 2	3728.53	1	3728.53	0.57	0.453
ISI 4	6345.09	1	6345.09	6345.09	0.404
Hit					
ISI 1	2.40	1	2.40	0.35	0.555
ISI 2	61.63	1	61.63	6.40	0.014
ISI 4	26.13	1	26.13	3.54	0.065
Miss					
ISI 1	16.87	1	16.87	3.56	0.064
ISI 2	26.13	1	26.13	3.73	0.058
ISI 4	20.83	1	20.83	2.98	0.090
False Alarm					
ISI 1	22.53	1	22.53	13.01	0.001
ISI 2	57.40	1	57.40	20.51	<0.001
ISI 4	61.63	1	61.63	13.37	0.001
Correct Rejection					
ISI 1	24.30	1	24.30	12.01	0.001
ISI 2	78.40	1	78.40	23.33	<0.001
ISI 4	49.40	1	49.40	11.07	0.002

false alarm rate increased ($r = 0.369$, $p = 0.004$), and the number of correct rejections decreased ($r = -0.341$, $p = 0.008$). In the ADHD group, as ISI increased, false alarms increased ($r = 0.369$, $p = 0.036$).

Significant correlations in the normal group of subjects for the three ISIs for the latency of the P300a ($r = 0.405$, $p = 0.001$) and P300b ($r = 0.490$, $p = 0.000$) as well as for the amplitude of the P300b ($r = - 0.302$, $p = 0.01$) were observed. The correlation coefficients showed as ISI increased the mean latencies of the P300a, and P300b increased, while the mean amplitude of P300b decreased. No significant correlations were observed between the three ISIs and either the latency or amplitude of the P300a or P300b in the ADHD group.

Figure 1 shows the grand average for the normal group and the group with ADHD for all three ISIs. One of the interesting observations is that as ISI increased, the P300a and P300b show smaller amplitude differences and shorter latencies between P300a and P300b for the normal group, but not for the group with ADHD. Also there is greater morphological variability in the group with ADHD than in the normal group.

DISCUSSION

The findings in the normal group agree with those of our previous paper on the development of an auditory continuous performance task using both behavioral and electrophysiological measures (Salamat and McPherson, 1999) in adults, suggesting that this paradigm may be useful with a clinical population such as ADHD.

Behavioral sensitivity to a task is measured by the number of hits and false

Table 6. ANOVA by Group, for P300 Latency and Amplitude, Trials 1 and 2 Combined

Source	SS	df	MS	F	p
Latency (msec)					
ISI 1					
P300a	273583.62	1	273583.62	112.13	<0.001
P300b	217107.99	1	217107.99	78.58	<0.001
ISI 2					
P300a	196518.72	1	196518.72	48.49	<0.001
P300b	111595.00	1	111595.00	31.13	<0.001
ISI 4					
P300a	51104.00	1	51104.00	14.17	<0.001
P300b	26851.10	1	26851.10	7.32	0.009
Amplitude (μV)					
ISI 1					
P300a	590.69	1	590.69	32.29	<0.001
P300b	950.96	1	950.96	49.57	<0.001
ISI 2					
P300a	61.84	1	61.84	2.90	0.094
P300b	318.99	1	318.99	13.05	0.001
ISI 4					
P300a	178.95	1	178.95	11.25	0.001
P300b	223.61	1	223.61	12.36	0.001

alarms. Significant differences were seen between false alarms in the normal group as a function of ISI, suggesting differences in task difficulty. The significant correlation between ISI and false alarms in the normal group shows that the number of guesses increased as ISI increased. However, since reaction time also increased with ISI, impulsiveness appears to have also increased in the normal subjects. The group with ADHD failed to show any differences between ISI and the number of hits or false alarms. As ISI increased in the group with ADHD, the false alarm rate increased, showing an increase in guesses similar to that of the normal group. The lack of significant correlation between RT and ISI in the group with ADHD would suggest that with longer ISIs the group with ADHD redirected their attention rather than increasing their guessing due to impulsiveness. These observations are similar to those reported by Conners (1992) using the VCPT: that attention, rather than impulsiveness, appears to be the greatest factor influencing performance in the group with ADHD.

The electrophysiological results are quite consistent with the behavioral results. In the normal group both amplitude and latency of the P300a and P300b showed significant differences across ISIs, and the latency of the P300a and P300b increased with increasing ISI. Since both reaction time and latency are measures of cognitive processing time, and in the normal group reaction time and P300a and P300b latency are significantly correlated, it would seem that longer ISIs required longer processing time for the subjects to make a decision. The increase in false alarms suggests that a "limit" on the time a subject was willing to

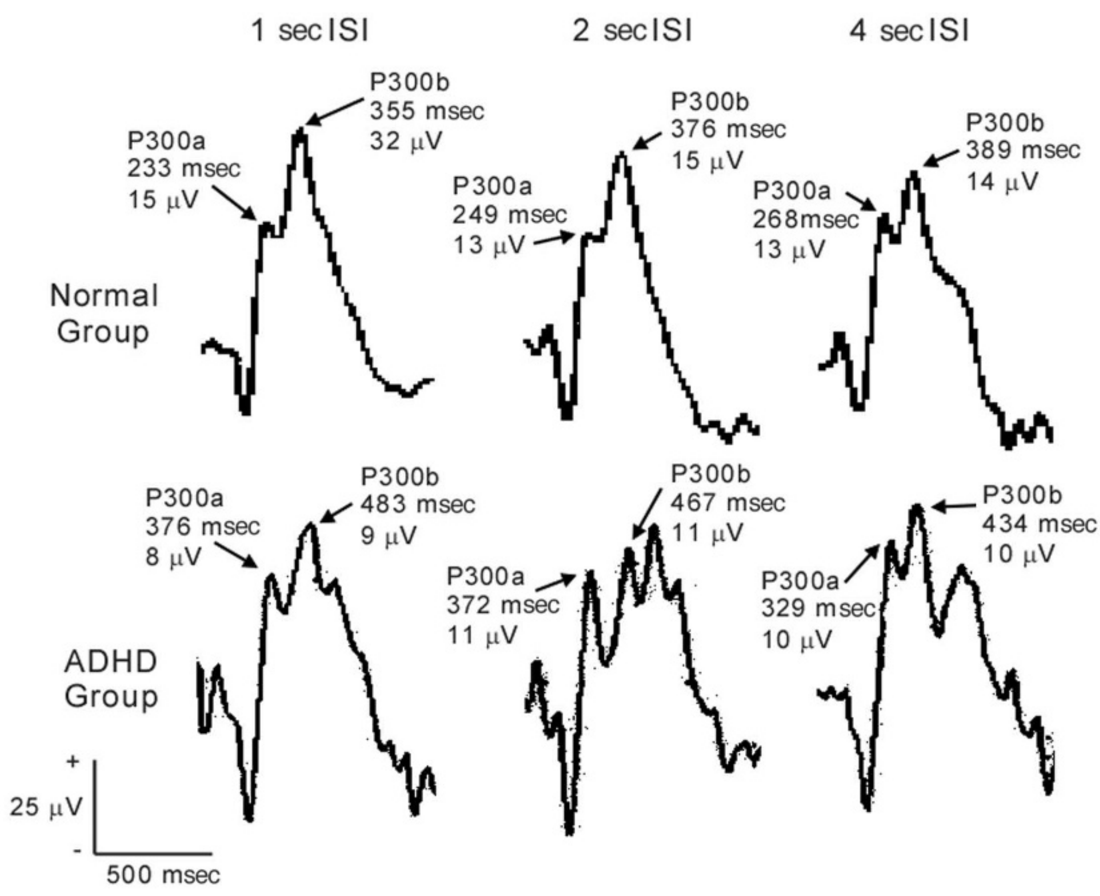

Figure 1. Grand average waveforms for ISIs 1, 2, and 4 of the P300 for both the normal group (top tracings) and the group with ADHD (lower tracings). The grand average waveforms were derived from the CPz electrode.

wait until making a decision. This phenomenon was also observed in the group with ADHD, for which the false alarm rates were correlated with ISI except for a significant increase in the false alarm rate in the group with ADHD compared to the normal group. In addition, RT in the group with ADHD was longer for all ISIs than in the normal group. Thus, although both groups demonstrated an increased rate of guessing with increasing ISI, the group with ADHD showed a significantly higher rate of guessing.

The P300a amplitude has been shown to be influenced by stimulus novelty, while the P300b amplitude has been shown to be influenced by task detection. Both amplitude and latency of the P300a and P300b demonstrated significant differences between the two groups. In the group with ADHD, the amplitudes were reduced and the latencies prolonged relative to the normal group. In addition, the difference in time between the P300a and P300b in the group with ADHD was reduced. The decrease in the P300a and P300b amplitudes would suggest that the individuals with ADHD had difficulty not only in performing the task but also in recognizing the difference in the two stimuli. Furthermore, the greater separation between the P300a and P300b peaks in the group with ADHD indicates that a processing lag occurs between recognizing that there is a difference between the stimuli and actually detecting the task.

There is a great need to continue this investigation and to evaluate factors such as distraction, short-term memory, and impulsiveness. The influence of each factor on an auditory continuous performance task paradigm as used in this study is not entirely clear.

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NOTES

1. The Declaration of Helsinki (Document 17.C) is an official policy document of the World Medical Association (WMA) on ethical principles in medical research involving human subjects. Medical research involving human subjects includes research on identifiable human material or identifiable data. It was first adopted in 1964 (Helsinki, Finland) and revised in 1975 (Tokyo, Japan), 1983 (Venice, Italy), 1989 (Hong Kong), 1996 (Somerset-West, South Africa), and 2000 (Edinburgh, Scotland). Note of clarification on Paragraph 29 added by the WMA General Assembly, Washington, 2002.

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