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ERP and Behavioral Correlates of Temporal Processing Dysfunction in Schizotypy

A thesis submitted in partial fulfillment of the
requirement for the degree of Bachelor of Science
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by

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Abstract

Symptoms of schizophrenia have been attributed to deficits of temporal processing. Research suggests that patients with schizophrenia have an accelerated internal clock. The current research employs a finger-tapping task to assess timing abilities in schizotypy—a constellation of personality traits with features similar to schizophrenia—and utilizes electrophysiological methodologies to explore the neural activity associated with temporal processing. Analyses revealed that both response variability in the finger tapping procedure and the amplitude of the N100 omission-evoked potential are associated with schizotypal personality measures. The results are consistent with previous research and further indicate that the amplitude of the omission-evoked potential may be an indicator of formation of temporal interval representations.

ERP and Behavioral Correlates of Temporal Processing Dysfunction in Schizotypy

Cognitive dysfunction is a fundamental deficit in schizophrenia. Investigations of underlying cognitive processes responsible for the phenomenology of schizophrenia frequently suggest that timing mechanisms are important contributors to the disorder. Fundamental characteristics of schizophrenia, such as disorganized behavior and disordered thought, have been explained by “cognitive dysmetria.” Failures to integrate input, prioritization, retrieval, and responses to contextual information manifest as symptoms commonly observed in schizophrenia (Andreasen, Paradiso, & O’Leary, 1998). The cognitive dysmetria model attempts to account for symptoms on the basis of neural circuitry functions, but does not provide explanation for how the circuitry is abnormal or damaged. A related model, the “disconnection” model, provides possible mechanisms for these abnormal cognitive processes. The disconnection model suggests that functional integration is disrupted by impairments in the regulation of activity-dependent changes in synaptic connectivity (Friston, 1999; McGlashan & Hoffman, 2000). It has been hypothesized that these changes in synaptic connectivity are related to the neurotransmitter Dopamine. For example, dopamine is hypothesized to be crucial to timing mechanisms in patients with schizophrenia. Dopamine antagonists have been shown to decrease timing operations, whereas dopamine agonists increase timing (Meck, 1983, 1986; Rammsayer, 1999).

Support for the cognitive dysmetria model of schizophrenia also comes from lesion, neurophysiological and neuroimaging studies which implicate a number of brain regions, including the prefrontal cortex (PFC), thalamus, and cerebellum. Abnormalities

in the PFC have long been indicated as contributors to behavioral and cognitive symptoms (Kraepelin, 1971). The PFC's afferent and efferent connections with all cortical and several subcortical brain regions may explain how abnormal processes in that region are related to such a broad range of symptoms, such as impaired language processing and motor timing. Furthermore, magnetic resonance studies have revealed that reduced frontal lobe size is related to executive function impairments and symptomology in schizophrenia, and that patients with schizophrenia have significantly smaller frontal lobes (Baare et al., 1999; Andreasen et al., 1994). Research has also suggested that, when compared to healthy controls, patients with schizophrenia have less blood flow to the frontal lobes, a phenomenon sometimes referred to as "hypofrontality" (Ingvar & Franzen, 1974; Buchsbaum et al., 1982, 1990; Farkas et al., 1984). In a meta-analysis reviewing over 200 studies comparing executive functions of clinical populations to healthy controls, Heinrichs and Zakzanis (1998) concluded that patients with schizophrenia perform more poorly across many widely-used neuropsychological tests of cognitive function than controls. Taken together, the findings of structural, functional, and neuropsychological differences in disordered individuals imply frontal lobe abnormalities are integral to the phenomenology of schizophrenia. However, many lesion and imaging studies conclude that frontal lobe functioning is only part of an executive function network that also includes non-frontal brain regions (Alvarez & Emory, 2006).

Andreasen's cognitive dysmetria model also highlights the contributions of thalamic disturbances in the etiology of schizophrenia. Specifically, the thalamus—which modulates sensory input and motor output—has a reduced size and fewer white matter projections to the prefrontal cortex in patients with schizophrenia in comparison to non-

psychiatric controls (Andreasen et al., 1994; Konick & Friedman, 2001). Imaging studies have confirmed that, compared with control subjects, the prefronto-thalamic-striatal circuit is less active during time estimation tasks, suggesting that timing dysfunction in schizophrenia is linked to abnormal thalamo-cortical mechanisms (Volz et al., 2001).

Dysfunction of the cerebellum has received considerably less attention. However, support for Andreasen's cognitive dysmetria hypothesis—which considers the cerebellum as critical to the cognitive underpinnings of the disorder—comes from evidence of decreased blood flow to the cerebellum during cognitive tasks among people with schizophrenia (Andreasen, et al., 1996; 1994). There are numerous connections between the cerebellum and the PFC, which suggests the cerebellum may play some role in cognitive functions performed by the PFC (Andreasen et al., 1994). Research suggests that the cerebellum may be more directly linked to cognition. Lesion studies have provided evidence that the cerebellum plays a major role in several cognitive operations, including representation of temporal information (Ivry & Keele, 1989; Malapani & Fairhurst, 2002) and error detection (Fiez et al., 1992). Moreover, transcranial magnetic stimulation over the cerebellar vermis produces greater variation in finger tapping in healthy subjects (Theoret, Haque, & Pascual-Leone, 2001). However, a review of cerebellar involvement in schizophrenia reveals inconsistent results for the role cerebellar deficits plays in timing deficits (Picard, Amado, Mouchet-Mages, Olie, & Drebs, 2008).

The link between neurobiological evidence for timing dysfunction and schizophrenia is strengthened by reports of poor performance on timing tasks. Individuals with schizophrenia report distorted experiences of time (Johnson & Petzel, 1971; Tysk, 1983; Rammsayer, 1990; Elvevag et al., 2003). Specifically, patients overestimate short

time intervals and underproduce when instructed to generate a precise time interval. In other words, when individuals with schizophrenia are asked to report the duration of a criterion interval, they report that the duration of the given interval is longer than the objective duration; when asked to produce a precise interval of time, they tend to produce durations shorter than the objective duration (Tysk, 1983).

These behaviors may be manifestations of the increased speed of an internal clock mechanism in the brain (Creelman, 1962; Treisman, 1963; Treisman, Faulkner, Naish, & Brogan, 1990). This “internal clock” model assumes that timing in the brain is represented by pulses emitted by a pacemaker and counted by an accumulator. The number of pulses accumulated during a defined interval becomes the stored representation of time. In healthy individuals, this mechanism has been linked to activity in the cortico-thalamic-striatal pathway and the cerebellum (Buhusi & Meck, 2005), which are regions associated with neural communication deficits in patients with schizophrenia (Andreasen, et al., 1998). Imaging studies of finger tapping in schizophrenia have suggested that the cerebellum is critical for performance during synchronized (tone-paced) tapping—possibly due to its influence in generating coordinated motor sequences (Del Olmo, Cheeran, Koch, & Rothwell, 2007; Rao et al., 1997). It has been suggested that the cerebellum is the region in which the internal timekeeper is located (Theoret, et al., 2001). Conversely, during self-paced tapping, the striatum has been implicated as a region crucial to the internal representation of time (Maquet et al., 1996; Rao et al., 1997).

Models of timing have been derived to delineate the independent contributions of internal timekeeping and motor operations to overt timing (Wing & Kristofferson, 1973;

Carroll, O'Donnell, Shekar, & Hetrick, 2009; Semjen et al., 2000). One such model, the two-process Wing-Kristofferson model (Wing & Kristofferson, 1973), estimates the differential effects of the variances of motor timing and internal clock timing on self-paced tapping variance. According to the model, a central timekeeper, the internal clock, generates signals which trigger motor commands instructing the effector to respond at the end of each interval. Because there are two separate processes involved in finger tapping performance, each process can differentially contribute to tapping variance (Wing and Kristofferson, 1973).

In a study by Levitt-Binnun and colleagues (2007), subjects receiving TMS applied to the motor cortex were unaware of changes in their motor sequence—perhaps due to an automatic error correction process—but were aware of changes in tapping precision. This suggests that internal timekeeping is a higher-level function than motor functions. The Wing-Kristofferson model may provide further evidence that motor operations are more automatic than the cognitively-driven internal clock. The model assumes that, as computed by a lag-1 autocorrelation, adjacent intertap intervals will be negatively correlated because timing mechanisms will balance short intervals with long intervals (Wing, 1980; Carroll et al., 2009). For example, a negative autocorrelation of $r = -.05$ suggests that a comparison between the tapping interval and the stored representation of the criterion interval indicates that the tapping needs to be adjusted. This negative correlation implies that the internal clock achieves perfect timekeeping ability. An autocorrelation of $r = 0.0$ indicates that the internal clock is generating highly irregular pulses and that a comparison between tapping and interval representation does not signal a need for adjustment (Carroll et al., 2009). Perhaps because pulse generation

is irregular, the amount of time required to accumulate the number of pulses that match the amount stored as the representation of time is variable. Due to this variation, the autocorrelation is zero.

Investigations of auditory mismatch negativity provide information about temporal processing functions in the brain without confounding other cognitive processes such as attention (Davalos, Kiskey, & Freeman, 2005). Mismatch negativity is a frontal negative deflection that occurs after some deviance in otherwise regular stimuli. Using mismatch negativity to study temporal processing is ideal because the negative deflection resulting from deviation from standard stimuli is an automatic response that does not confound other cognitive processes such as attention or memory. In experiments using omitted stimuli as the deviant stimuli, omission-evoked mismatch negativity, or the omission-evoked potential, is observed approximately 100ms after the time at which the omitted stimuli is expected to occur (Todd, 2006; Janata, 2001; Hughes et al., 2001). This N100 component is reflective of the internal representation of auditory stimuli and, for short-duration intervals, is likely to be produced in the auditory cortex (Janata, 2001; Naatanen, 1992). The N100 component may also reflect activity in frontal regions, and although input is primarily generated from the auditory cortex, it is difficult to measure separately over this region (Naatanen & Winkler, 1999). The N100 is thought to reflect activity related to the comparisons between internal representations of time and current stimuli (Janata, 2001). In order to generate an omission mismatch negativity, an internal representation of time is necessary, although the brain potential can be emitted independently of an expectation that an omission will occur (Todd, 2006; Janata, 2001).

Although N100 can be generated by stimulus omission, the component can also reflect early stages of automatic encoding of stimulus during stimulus presentation (Naatanen & Winkler, 1999). Following the formation of stimulus representation—which presumably requires approximately 200ms for completion—the newly-formed representation is “subjectively silent,” meaning there are no remarkable characteristics of the ERP (Naatanen & Winkler, 1999, p. 846.) This sensory-memory system can only be explored using mismatch negativity paradigms (Naatanen & Winkler, 1999).

Despite behavioral evidence for an increased internal clock mechanism in schizophrenia, questions remain about the neural basis for temporal processing dysfunction. The aim of this study is to characterize behavior and neural activity associated with encoding standard time intervals, and maintenance and reproduction of these intervals in the absence of external cues. The present task requires participants to tap in synchrony with a series of evenly-spaced tones and to maintain the same tapping rate during a period of tone omissions. Tone-paced tapping in the present task is intended only to provide an externally-produced standard time interval to encode and attempt to reproduce. Previous research suggests that, compared to self-paced tapping, timekeeping remains stable during synchronized tapping (Semjen, Schulze, & Vorberg, 2000; Ivry & Hazeltine, 1995). It has been suggested that working memory is an important aspect of temporal processing, as the representation of time is recorded by the internal clock and transferred to memory for storage and later comparison (Malapani & Fairhurst, 2002). However, although working memory is likely a key component of timing, it is independent of the internal clock and does not appear to be related to timing dysfunction in schizophrenia (Elvevag et al., 2003). Thus, the possibility of deficient working

memory contributing to tapping performance rather than or in conjunction with a disturbed internal pacemaker or internal generator is not considered in the present study.

To shed light on dysfunctional temporal processes in schizophrenia and adding to sparse research using schizotypal personality disorder to investigate these mechanisms, the current study employs the finger-tapping task to investigate temporal processing in schizotypy. A psychometric schizotypy scale was used to assess personality traits common to schizophrenia. In accordance with the perspective that schizophrenia is a spectrum disorder, schizotypy personality disorder falls on a spectrum between normal populations and schizophrenia and is useful in elucidating schizophrenic processes (Gruzelier, 2003). As displayed in the Appendix, diagnostic criteria for both the personality disorder and the psychotic disorder are similar and both have similar syndromal structures of cognitive or perceptual distortions, interpersonal dysfunction, and disorganized behavior (American Psychiatric Association [*DSM-IV-TR*], 2000; Gruzelier, 2003). Few studies have investigated timing mechanisms in schizotypy. Sarkin, Hilliz, Granholm, and Dionisio (2002) administered the Schizotypal Personality Questionnaire (SPQ; Raine, 1991) and tested participants' ability to reproduce intervals of time ranging from one to 25 seconds. No group differences were found between high and low scorers (Sarkin et al., 2002). Another study has investigated the relation of SPQ scores with performance on a temporal bisection task. Similar to findings in schizophrenia research (Elvevag et al., 2003), high scorers had an decreased bisection point and demonstrated decreased temporal sensitivity (Elvevag et al., 2003; Lee, Dixon, Spence, & Woodruff, 2006).

Although previous research relies predominantly on behavioral and imaging techniques, a major focus of this experiment is to use electroencephalography to characterize neural activation associated with tone- and self-paced tapping within the context of schizophrenia. Although this is largely exploratory, previous research on healthy participants is driving some hypotheses regarding the electrophysiological correlates of temporal processing. Because temporal processing is impaired at an early processing level in schizophrenia, as evidenced by reduced amplitudes of the mismatch negativity potential (Davalos et al., 2005; Michie, 2001), it is hypothesized that amplitude of the N100 during early tone omissions will be related to schizophrenic personality traits. Furthermore, because Todd (2006) reports that poorer performance during behavioral measures of temporal processing correlate with reduced sensitivity to omitted stimuli, it is predicted that the reduced amplitude of the omission-evoked N100 will be related to poor performance of the finger tapping task.

Method

Participants

Twenty-three participants (15 female, mean age=19.13, SD=1.25) were recruited from a small liberal-arts university. In exchange for participation, participants received credit towards a psychology course. Four participants were excluded from data analysis due either to a failure to follow task directions (N=1) or technical malfunctions during the EEG recording session (N=3). Subjects were administered a demographic questionnaire assessing education level (M=13.13 years, SD=1.18), years of musical training (M=4.3, SD=3.8), psychiatric and neurological history, and handedness. Participants were free from self-reported neurological disease and psychiatric diagnoses (with the exception of

one diagnosis of “Depression”). All had normal hearing acuity. The Institutional Review Board of the College of William and Mary approved this study and informed consent was obtained from all participants.

Before beginning the experiment, participants completed a Schizotypal Personality Questionnaire (SPQ)—a measurement of Schizotypal Personality Disorder consisting of yes-or-no 74 questions, with each “yes” answer contributing to the overall points. Higher scores indicate the participant has shared features of schizotypy (Raine, 1991). The SPQ assesses symptoms of schizotypy based on nine subscales that are key features of the personality disorder, such as “unusual perceptual experiences” and “constricted affect” (see Raine, 1991). For analyses of variance, groups of low (N=9) and high (N=10) scores for total SPQ score were formed by dividing the sample about the median (Median=16 points). All scores equal to or greater than the median were assigned to the “high SPQ” group.

Procedure

Participants were instructed to use their right index finger to tap a button on a response device. The response device was positioned on a table, with participants’ wrist rested on the table surface. Participants were instructed to tap their finger at the same pace as a series of tones, to continue tapping at the same pace when the tones were omitted and to continue tapping when they resumed.

Each trial consisted of three segments. The first segment consisted of a series of pacing tones, during which participants were instructed to tap synchronously with the tones. The tones were omitted from the second segment; however, participants were expected to continue tapping at the rate established by the pacing-tone segment. This

segment is hereafter referred to as the “self-paced” stimulus type. Although there were no audible tones during the self-paced tapping segment, “stimuli” during this segment refers to the expected temporal position of the tones. Tones were reinstated at the start of the third segment, during which participants continued tapping. This segment is hereafter referred to as the “tone-paced” stimulus type.

To prevent learning, four different inter-tone intervals (350ms, 450ms, 550ms, 650ms) were used throughout the experiment. Within each trial, the inter-tone intervals were constant and were selected pseudorandomly. The number of stimuli in each segment (practice, self-paced, or tone-paced) varied randomly between ten and 15 tones/omissions. To include all trials, only the first ten tones of the self- and tone-paced segments were analyzed. Tones had duration of 50ms and were delivered through foam earphones at 65db. Trials were separated by 8000ms and during the last 5000ms of the between-trial interval a visual cue prepared participants for the next trial.

Behavioral data and analysis

Behavioral data were analyzed using MatLab. Across trials for the self- and tone-paced segments of the task, mean deviation of the tap from the onset of the stimulus (“tapping deviation”), variance of the inter-tap interval, and coefficient of variation (*CV*) for the inter-tap interval were computed. A 2 (stimulus type: self- or tone-paced) X 2 (SPQ score: low or high) repeated measures ANOVA was used to assess group differences for each behavioral measure.

Electrophysiological data and analysis

Electrophysiological data were recorded continuously at 2000 samples per second using a DBPA-1 Sensorium bio-amplifier (Sensorium Inc., Charlotte, VT) with an analog

high-pass filter of 0.01 Hz and a low-pass filter of 500 Hz. Recordings were made using fabric caps bearing 72 Ag-AgCl sintered electrodes while participants were seated in an electrically shielded booth. EEG recordings were made using a forehead ground and a reference at the tip of the nose. Vertical and horizontal eye movements were recorded from peri-ocular electrodes placed on the superior and inferior orbits and from electrodes placed at the lateral canthi respectively. All impedances were adjusted to within 0-20 kilohms at the start of the recording session.

EEG data were analyzed off-line using EMSE (Source Signal Imaging, San Diego, CA). Data were corrected for ocular artifact using independent components analysis (Jung et al., 2000). Data were then segmented between -100ms and 1000ms with respect to stimulus onset and baseline corrected over the pre-stimulus interval. Segmented data were then averaged for each subject within each condition. Mean amplitude and peak latency of components P1 and N100 for self-paced tapping and N100 for tone-paced tapping were correlated with SPQ scores and behavioral measures. Frontocentral electrode Fz and parietocentral electrode Pz were selected for analysis because these sites had the largest amplitudes for the components (see Figure 2). Mixed measures ANOVAs were computed to identify differences between groups (low/high SPQ) in mean amplitude and peak latency for both self-paced and tone-paced conditions with within-subjects factors of position in segment (i.e. self-paced or tone-paced tapping; hereafter “position”) and inter-tone interval. In order to identify possible differences in neural responses for earlier tones compared to later tones, positions in each segment were divided into pairs; since only the first ten tones of the tone-paced segment were analyzed,

the first two tones were paired together, third and fourth were paired, and so on, up to the tenth tone, creating five pairs of tones.

Wing-Kristofferson model and analysis

Behavior during in self-paced finger tapping was also accounted for using a mathematical model formulated by Wing and Kristofferson (1973). This two-process model that delineates internal clock and motor sources of variance (see Figure 3).

According to the model, clock intervals, $c(i)$, are encoded during the tones portion of the task and are the internal representation of the inter-tone intervals. Paired with each tone, $t(i)$, is a subsequent response, $r(i)$, that is subject to variable motor delays, $m(i)$, influenced by motor operations. The inter-tap interval, $ITI(i)$, is the internal representation of time between two successive taps adjusted for the motor delays occurring before and during the current tone-tap sequence.

$$ITI(i) = c(i) + m(i) - m(i-1), i > 1$$

Furthermore, as a consequence of adjustments in clock intervals due to motor delays, successive inter-tap intervals should balance each other, so that a shorter-than-average inter-tap interval will be followed by a longer-than-average inter-tap interval and vice versa. Thus, the model assumes that a lag-1 auto-correlation between inter-tap interval, $ITI(i)$, and its adjacent inter-tap interval, $ITI(i+1)$, will be a function of clock and motor sources of variance. A correlation of $r=-0.05$ indicates that all variance in inter-tap interval results from motor delay variations and internal representation of time is perfect; a correlation of $r=0.0$ is indicative of high variability in internal-clock mechanisms. To test the applicability of this model to schizotypy, autocorrelations were calculated for both groups.

The variance of inter-tap interval is equal to the sum of internal-clock and motor variance,

$$\text{Var}(\text{ITI}) = \text{Var}(c) + 2\text{Var}(m),$$

where motor variance is equal to the negative lag-one auto-correlation between successive inter-tap intervals,

$$\text{Acorr}(\text{ITI}(i), \text{ITI}(i+1)) = -\text{Var}(m).$$

Mean internal clock and motor variance during self-paced segments were computed for each participant across each inter-tone interval. Clock variance, $\text{Var}(c)$, and motor variance, $\text{Var}(m)$, were correlated with SPQ score and ERP measures. Differences between groups were analyzed by employing a 2X2 repeated measures ANOVA with stimulus type as the within-subjects factor.

Results

Behavioral

A Pearson product-moment correlation was used to determine whether history of musical training was related to performance. This analysis produced a significant correlation between years of musical training and deviation during self-paced tapping, $r(19) = -.459, p < .05$. The negative correlation suggests that increased years of musical training is related to earlier tapping. Similarly, a correlation between years of musical training and coefficient of variance was reported, $r(19) = -.487, p < .05$, indicating that individuals with more musical training tapped more consistently. The possibility of musical training as a confound is briefly discussed.

For tapping deviation, a significant main effect was observed for stimulus type, $F(1,17) = 80.256, p = .000$. Specifically, participants tapped earlier with respect to the tone

onset during tone-paced tapping ($M = -69.484$, $SD = 3.248$) compared to self-paced tapping ($M = -29.830$, $SD = 4.419$).

Results from a repeated measures ANOVA assessing differences in variance of inter-tap interval revealed a main effect for stimulus type, $F(1,17) = 70.200$, $p = .000$. Specifically, average variance was greater for self-paced tapping ($M = 93.676$, $SD = 4.515$) than tone-paced tapping ($M = 56.138$, $SD = 4.266$).

Repeated measures ANOVAs were also employed to compute differences in coefficient of variance, cv . There was a main effect of stimulus type, $F(1,17) = 64.230$, $p = .000$. CV was greater during self-paced tapping ($M = .180$, $SD = .009$) than tone-paced ($M = .110$, $SD = .008$).

Electrophysiological

Results from a repeated measures ANOVA indicated that the mean amplitude during tone-omissions at site Pz, had significant main effects of position for component N100, $F(4,68) = 8.785$, $p = .000$. As Figure 4 depicts, the amplitude of the first two tones in the segment was greater than the remaining tones. Due to this difference, all following analyses of ERPs during tone omissions only include tones one and two.

During the tone-paced segment of the task, mean amplitudes at channel Fz had significant main effects of position at component N100, $F(4,68) = 26.058$, $p = .000$. The mean amplitude of the first two tones of the segment was greater (more negative) than tones three through ten (see Figure 5). Tones three through ten were not significantly different from each other. For this reason, all following analyses regarding tone-paced tapping include an average of the measures across tones three through ten. Tones one and two are excluded from the analyses. We interpret the difference at tones one and two as

an incomplete formation of timing representation, and the stability of the ERP by tone three as the completed process (Naatanen & Winkler, 1999; see discussion).

Behavior and ERP relationship

The relationship between electrophysiological measures and behavior was explored by employing Pearson product-moment correlations. During tone-paced tapping, the variance of the inter-tap interval was significantly correlated with the mean amplitude of N100, $r(19) = -.498$, $p < .05$. Also, results suggested a correlation between *cv* and the mean amplitude of N100, $r(19) = -.468$, $p < .05$. Essentially, increases in variance correlated with increases in amplitude (greater negativity) for N100 at channel Fz. Behavior during tone-paced tapping also predicted various ERP measures during self-paced tapping. *Cv* of tone-paced tapping correlated with mean amplitude of P1, $r(19) = -.514$, $p < .05$; and tapping deviation during tone-paced tapping was predictive of mean amplitude of N100 for self-paced tapping, $r(19) = .474$, $p < .05$. In other words, high variability during tone-paced tapping was related to lower amplitudes of the omission-evoked N100.

Personality

A repeated measures ANOVA assessing personality differences in tapping deviation revealed a main effect of SPQ score, $F(1,17) = 4.859$, $p = .000$. Participants with high SPQ scores ($M = -56.676$, $SD = 4.383$) tapped earlier than low-scoring participants ($M = -42.638$, $SD = 4.620$).

Differences between groups were also assessed for variance of inter-tap interval. An interaction was reported between stimulus type and SPQ score, $F(1,17) = 4.925$, $p = .040$ (see Figure 6). For both groups, variance during self-paced tapping is similar.

Participants with low SPQ scores had greater variance during tone-paced tapping than those with high scores.

Wing-Kristofferson model

To test the assumption of the model that a lag-1 autocorrelation between successive inter-tap intervals will indicate either motor or internal clock variability, a Pearson product-moment correlation was calculated for both groups. The model predicts that perfect internal timekeeping will produce a series of inter-tap intervals with a lag-1 autocorrelation of $r = -.05$, and high variability in internal timekeeping will yield an autocorrelation of $r = 0.0$ (Carroll et al., 2009). In accordance with the model's assumption, the lag-1 autocorrelation for the low SPQ group was $r = -.05$ ($SD = .018$) and $r = -.028$ ($SD = .017$) for high SPQ, indicating more accurate timekeeping in low-scoring participants.

Discussion

The present data suggest that temporal processing deficits are important to understanding behavioral deficits in schizotypal personality disorder. Tapping variance and coefficient of variance were greater during self-paced than tone-paced tapping. These findings are consistent with previous research comparing tapping variability in synchronous and continuation tapping (Ivry & Hazeltine, 1995; Semjen et al., 2000). As Semjen and colleagues (2000) posit, repeated presentation of the standard tone allows for more precise interval encoding during synchronous tapping. In accordance with their findings, the interpretation of the current results is that error correction mechanisms comparing overt tapping to the onset of the tones during the tone-paced tapping decrease

the tapping variability compared to self-paced tapping, in which no such error correction mechanisms are present.

An interesting finding was that participants also tapped earlier with respect to the tone during tone-paced tapping compared with self-paced tapping. This is unusual because it leads to the appearance that participants were actually more accurate (tapping closer to the stimuli) during tone omissions. An explanation for this effect may be best derived from animal studies using the peak-interval procedure (Roberts, 1998). When trained to press a lever after a criterion interval in the absence of external cues, rats tend to increase their tapping in the time immediately before and after the criterion time. A graphical depiction of this effect resembles a normal distribution around the target duration. During training, when rats are expected to press a lever at the presence of a stimulus, rats tend to increase the amount of lever presses immediately prior to the stimulus; however, once the stimulus has been presented, lever presses sharply decline. The interpretation of the current finding that participants tapped earlier during the tone-paced segments rather than the self-paced segments reflects this phenomena; finger taps during tone-paced tapping were likely generated exclusively prior to the tones, whereas during self-paced tapping, taps were generated both before and after the time of the stimulus omission, therefore bringing the average closer to zero (Roberts, 1998).

Tapping variance during tone-paced tapping was greater for participants with low SPQ scores. This result is contrary to research in which patients with schizophrenia tapped with greater variation than healthy controls (Carroll, et al., 2009). Although Carroll and colleagues claim that healthy participants have less tapping variability, other research suggests that as inter-tap interval decreases, variation also decreases (Semjen,

Schulze, & Vorberg, 2000; Wing, 1980). In fact, this is compatible with the interpretation of the present data. Although not statistically significant, the high SPQ group tended to produce shorter inter-tap intervals than the low SPQ group. Semjen et al. (2000) conclude that faster clocks are associated with lower variation, which explains the reduced tapping variation and indicates an accelerated internal clock. Although variance was lower among those scoring high on the SPQ, performance as measured by deviation from the tone onset during both tapping segments was poorer in the high SPQ group than the low SPQ group. In addition to variance, group differences were also reported in tapping deviation. Participants with high SPQ scores tapped earlier with respect to the tone, suggesting poorer approximation of the expected onset of the tone. Taken together, the variance and tapping deviation during tone-omissions indicates that the high SPQ group was less successful than the low SPQ group at forming interval representations. The similar variance during self-paced tapping may be attributed to a variety of other cognitive factors, such as working memory (Elvevag et al., 2003; Malapani & Fairhurst, 2002) or motor operations (Carroll et al., 2009). Further research investigating the reasons behind the lack of group differences for self-paced tapping is warranted.

The results of the present study also revealed that greater amplitude of N100 during tone-paced tapping was related to greater variance of inter-tap interval during tone-paced tapping. Although the results do not support the hypothesis that personality would relate to amplitude of N100, personality indirectly relates to ERPs of interval representation. As previously reported, an ANOVA revealed that individuals with high scores on the SPQ exhibited lower tapping variance during tone-paced tapping than those with low scores. This was unexpected because previous research had shown that

individuals with schizophrenia exhibit more behavioral variability. Importantly, however, the finding of lower variance with higher SPQ scores is consistent with computational models of the “internal clock” which predict that the variance of the temporal representation of an interval decreases with the duration of the interval (Semjen, Schulze, & Vorberg, 2000; Wing, 1980). Thus, people with fast clocks, those who are expected to score high on the SPQ, will have shorter interval representation durations, and consequently have lower variance.

Tapping variability was also associated with the amplitude of the N100 ERP. In addition, SPQ score was associated with both tapping variability and tapping deviation. The interpretation of these correlations is that insufficient formation of timing representations related to schizotypal personality, as evidenced by reduced variation and increased tapping deviation, is reflected in reduced neural activity during synchronous tapping.

Another interesting aspect of the data was that the N100 component of the ERP to the tones during tone-paced tapping was significantly larger in response to the first two tones of a sequence. Previous research has found that forming an internal representation of a time interval takes approximately 200ms (Foyle & Watson, 1984; Hawkins & Presson, 1977; Naatanen & Winkler, 1999; Tervaniemi, et al., 1994). Thus, one possibility is that the differences in the ERPs are reflective of temporal sensory integration. That is, the ERP to the first pair of tones represents the neural activity associated with stimulus encoding, and the return to baseline after the third tone reflects completion of encoding. Future research may determine that the time (e.g., number of

tones) required for stimulus encoding is useful variable to consider for analyses of group differences.

Increased variability during tone-paced tapping also related to decreased amplitude of P1 during self-paced tapping. Additionally, poorer tapping performance, as measured by tapping deviation, correlated with a decrease in N100 amplitude during self-paced tapping. This suggests that the degree to which the tones were sufficiently encoded, as evidenced by tone-paced tapping performance, influenced neural responses to the tone omissions. Poorer development of the interval representations resulted in a blunted P1 and N100, or reduced temporal sensitivity, during the tone-omissions. The emergence of a P1 component during tone omissions remains an anomaly. The literature resoundingly considers P1 an obligatory auditory response to stimuli (Kujala, Kallio, Tervaniemi, & Naatanen, 2001; Tervaniemi et al., 1994; Todd, 2006). It is unclear why P1 is elicited without the presentation of auditory stimuli, as no studies report similar findings.

The results of the Wing-Kristofferson lag-1 autocorrelation correspond with the previous interpretations. According to the model, an autocorrelation of $r=-.05$ indicates that participants have perfect timekeeping and $r=0.0$ indicates highly varied, irregular timekeeping. In accordance with this assertion, the high SPQ group had an autocorrelation of $r=-.028$ and the low SPQ group had an autocorrelation of $r=-.05$. In other words, the low-scoring group achieved excellent internal timekeeping during self-paced tapping, whereas the high-scoring group experienced more timekeeping irregularity. Following the finding that the present autocorrelations correspond with previous research indicating that participants with schizophrenic traits have internal clock

deficits (Johnson & Petzel, 1971; Tysk, 1983), it is concluded that the Wing-Kristofferson model is potentially applicable to the study of temporal processing in schizotypal personality disorder. Although the data support the autocorrelation hypothesis, there were no significant results supporting the separation of clock and motor variance during self-paced tapping. Future experiments to test the complete applicability of the mathematical model to schizotypy may yield more conclusive results if measures were taken to ensure larger sample sizes and a broad spectrum of SPQ scores. Additionally, to study the contributions of motor and internal clock variance to tone-paced finger tapping, a mathematical model including error-correction mechanisms formulated by Semjen and colleagues (2000) may shed light on the formation of representation of temporal intervals.

A possible confound of musical training was explored in this study. On a task in which participants had to press a key for the duration of a criterion tone, Franek et al. (1991) observed that musicians more accurately approximated the duration of the tone than non-musicians. The results of the current study are somewhat at odds with this finding. Years of musical training correlated negatively with tapping deviation. Participants with more years of training tapped earlier with respect to the tone yielding a larger error in terms of absolute deviation from the tone stimulus. A study investigating finger tapping in pianists concluded that pianists had faster finger tapping movements as a result of faster motor movements (Aoki, Furuya, & Kinoshita, 2005). Thus, the current interpretation of this study's training-tapping correlation is that the difference is likely attributable to motor operations rather than cognitive mechanisms.

Although there was no direct link between neural activity reflective of deficient temporal processing and scores on the SPQ, it is implicitly suggested that the two are related. The findings that decreased tapping variance and early tapping are related to high SPQ scores correlated with reduced omission-evoked potentials suggests that participants with many traits common to schizophrenia are ineffective at forming representations of temporal intervals. The results were expected to reveal an accelerated internal clock as the mechanism responsible for deficits in representation formation, however, the data only partially supported the hypothesis. No significant group differences were observed in the inter-tap interval, internal clock variance, or latency of early components of the omission evoked potentials. The lack of significant group differences in the latency of components during tone-omissions suggests that the tones were expected at the same time for both groups. A larger sample size may reveal differences in the latencies between groups. The overall results of this study provide evidence that schizotypal personality traits are related to performance on overt timing tasks, and the neural activity associated with performance predicts performance. Analyses revealed that tapping variation is predicted by personality measures and the amplitude of the N100 component during tone omissions. The implications of these findings are that participants who score high on a psychometric schizotypy scale poorly form representations of timing intervals.

The research necessary to understand the exact relationship of temporal processing to symptoms of schizophrenia spectrum disorders is still incomplete. Further research is warranted to determine whether temporal processing is a specific deficit in the phenomenology of schizophrenia spectrum disorders or whether it is deficient as a result of a more global deficit. However, the current study adds to the growing body of

evidence that deficits in temporal processing in schizophrenia and schizotypal personality disorder have behavioral manifestations that may explain symptoms of the disorders.

Future applications of this and similar research may include using temporal processing measures to diagnose schizophrenia spectrum disorders and influence treatment protocols.

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Appendix

Schizophrenia Diagnostic Criteria

Characteristic symptoms: Two (or more) of the following, each present for a significant portion of time during a 1-month period (or less if successfully treated):

1. delusions
2. hallucinations
3. disorganized speech (e.g., frequent derailment or incoherence)
4. grossly disorganized or catatonic behavior
5. negative symptoms, i.e., affective flattening, alogia, or avolition

Note: Only one Criterion A symptom is required if delusions are bizarre or hallucinations consist of a voice keeping up a running commentary on the person's behavior or thoughts, or two or more voices conversing with each other.

Social/occupational dysfunction: For a significant portion of the time since the onset of the disturbance, one or more major areas of functioning such as work, interpersonal relations, or self-care are markedly below the level achieved prior to the onset (or when the onset is in childhood or adolescence, failure to achieve expected level of interpersonal, academic, or occupational achievement).

Duration: Continuous signs of the disturbance persist for at least 6 months. This 6-month period must include at least 1 month of symptoms (or less if successfully treated) that meet Criterion A (i.e., active-phase symptoms) and may include periods of prodromal or residual symptoms. During these prodromal or residual periods, the signs of the disturbance may be manifested by only negative symptoms or two or more symptoms

listed in Criterion A present in an attenuated form (e.g., odd beliefs, unusual perceptual experiences).

- *Schizoaffective and Mood Disorder exclusion:* Schizoaffective Disorder and Mood Disorder With Psychotic Features have been ruled out because either (1) no Major Depressive, Manic, or Mixed Episodes have occurred concurrently with the active-phase symptoms; or (2) if mood episodes have occurred during active-phase symptoms, their total duration has been brief relative to the duration of the active and residual periods.
- *Substance/general medical condition exclusion:* The disturbance is not due to the direct physiological effects of a substance (e.g., a drug of abuse, a medication) or a general medical condition.
- *Relationship to a Pervasive Developmental Disorder:* If there is a history of Autistic Disorder or another Pervasive Developmental Disorder, the additional diagnosis of Schizophrenia is made only if prominent delusions or hallucinations are also present for at least a month (or less if successfully treated).

Schizotypal Personality Disorder Diagnostic Criteria

- A. A pervasive pattern of social and interpersonal deficits marked by acute discomfort with, and reduced capacity for, close relationships as well as by cognitive or perceptual distortions and eccentricities of behavior, beginning by early adulthood and present in a variety of contexts, as indicated by five (or more) of the following:
1. ideas of reference (excluding delusions of reference)
 2. odd beliefs or magical thinking that influences behavior and is inconsistent with subcultural norms (e.g., superstitiousness, belief in clairvoyance, telepathy, or "sixth sense"; in children and adolescents, bizarre fantasies or preoccupations)
 3. unusual perceptual experiences, including bodily illusions
 4. odd thinking and speech (e.g., vague, circumstantial, metaphorical, overelaborate, or stereotyped)
 5. suspiciousness or paranoid ideation
 6. inappropriate or constricted affect
 7. behavior or appearance that is odd, eccentric, or peculiar
 8. lack of close friends or confidants other than first-degree relatives
 9. excessive social anxiety that does not diminish with familiarity and tends to be associated with paranoid fears rather than negative judgments about self

- B. Does not occur exclusively during the course of Schizophrenia, a Mood Disorder With Psychotic Features, another Psychotic Disorder, or a Pervasive Developmental Disorder.

Figure Caption

Figure 1. Location of electrodes Fz and Pz on the scalp.

Figure 1

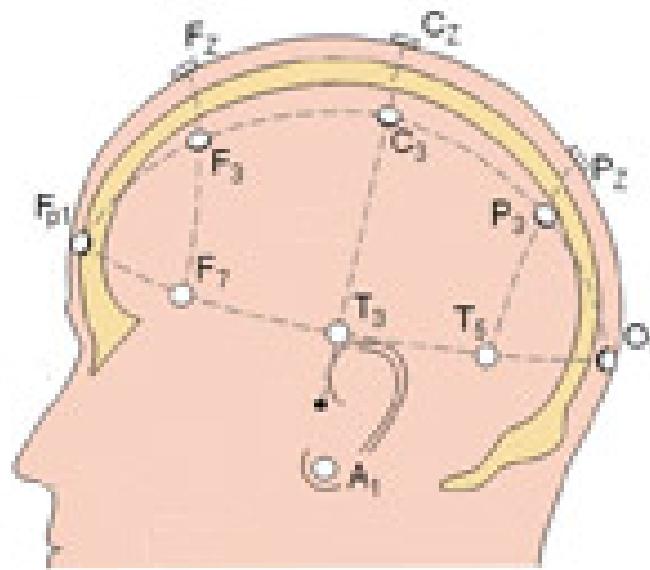


Figure Caption

Figure 2. Wing-Kristofferson two-process model of self-paced timing.

Figure 2

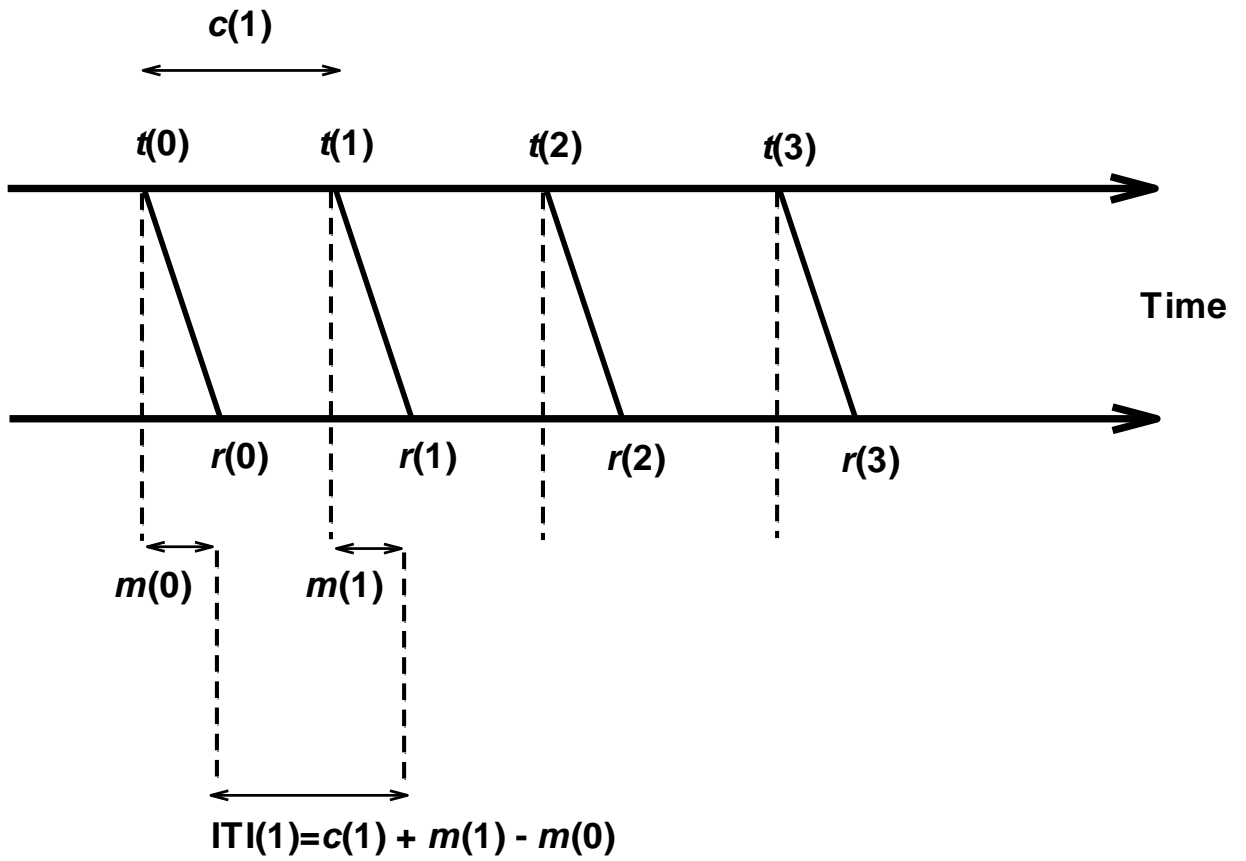


Figure Caption

Figure 3. (A) Grand-averaged (N=19) ERP responses to tone omissions during self-paced tapping for channels Fz, Cz, and Pz. (B) Topographical depiction of scalp distribution. P1 was pronounced at frontocentral sites; N100 was most pronounced at parietal sites.

Figure 3

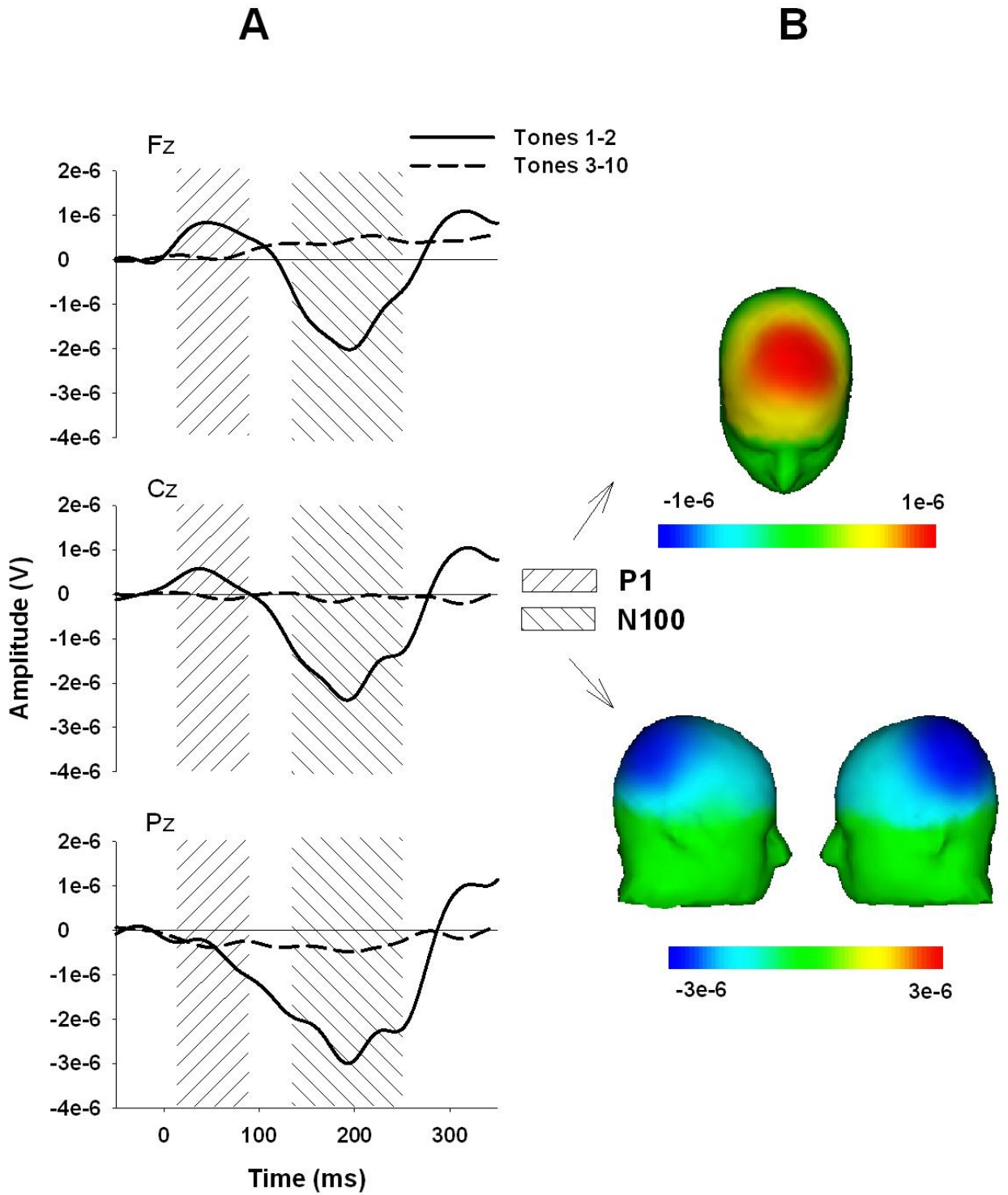


Figure Caption

Figure 4. (A) Grand-averaged (N=19) ERP responses to auditory stimuli during tone-paced tapping for channels Fz, Cz, and Pz. (B) Topographical depiction of scalp distribution. N100 was most pronounced at frontocentral sites.

Figure 4

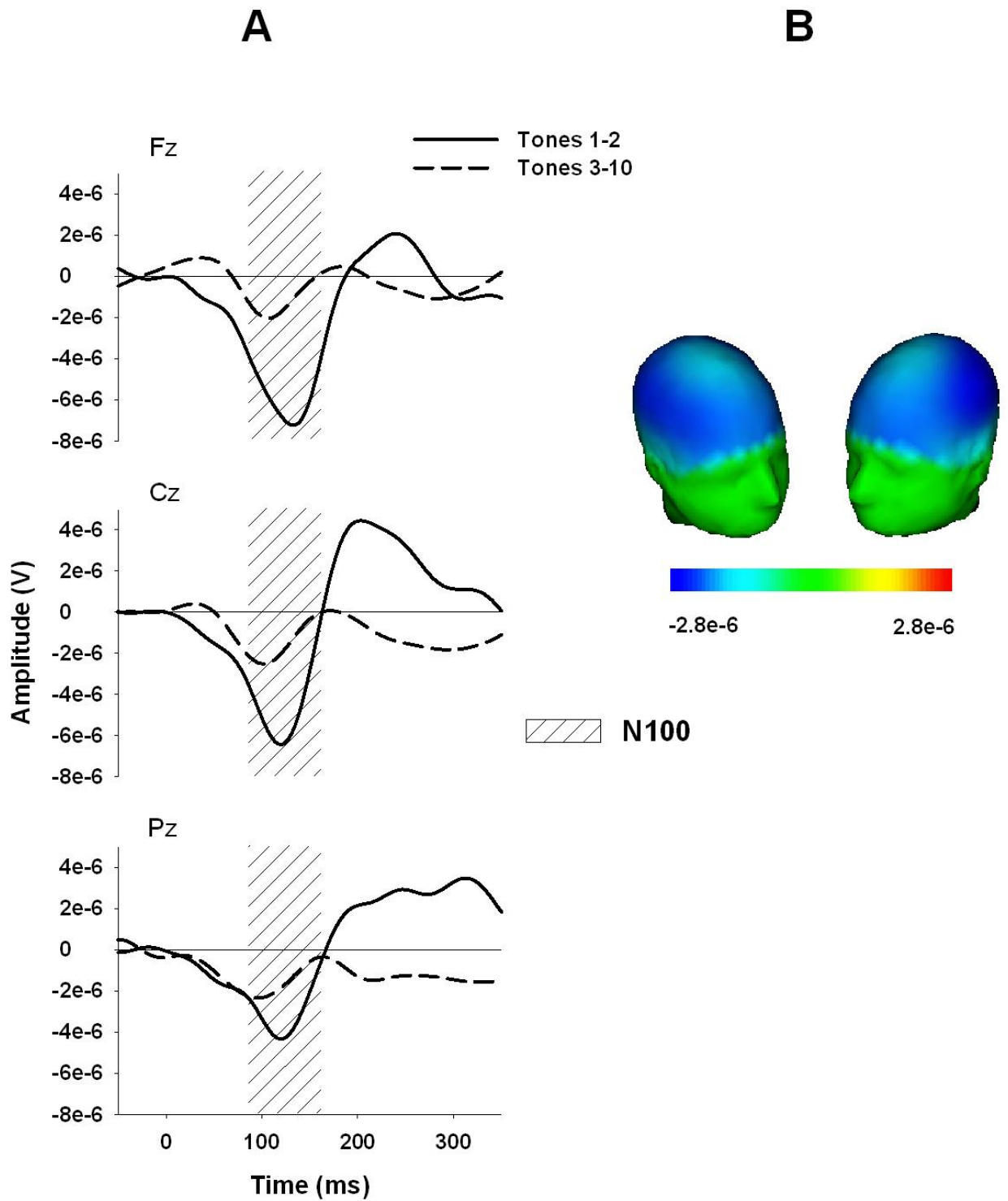


Figure Caption

Figure 5. Variance of inter-tap interval was greater during self-paced tapping than tone-paced tapping for both groups. For both low and high SPQ scorers, the inter-tap interval variance was similar during self-paced tapping. During tone-paced tapping, greater variance was observed in the low SPQ group in comparison with the high SPQ group.

Figure 5

