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Does Sensory Gating Vary According to the
Neurological Threshold Axis of Dunn's Four Quadrant Model in Typical Adults?

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This scholarly project reflects individualized, original research conducted in partial fulfillment of the requirements for the Occupational Therapy Doctorate Program, The University of Toledo.

Abstract

Objective: This study examined differences in sensory gating along the neurological threshold axis of Dunn's four quadrant model of sensory processing.

Method: Electroencephalographic measures were used to examine sensory gating ability in 65 typically developing adults ages 18-55. Event related potentials were recorded in response to repeated pairs of stimuli to the median nerve on the participants' non-dominant wrists. Sensory gating was quantified as the ratio of the amplitude of the first-stimulus P50 to the amplitude of the second-stimulus P50. The *Adolescent/Adult Sensory Profile* was administered to determine the participants' sensory processing pattern and their neurological threshold score.

Results: Results were not significant in terms of identifying a relationship between sensory processing patterns along the neurological threshold with gating ability. However, results did show trends in support of the direction of the hypotheses.

Conclusion: This study provides preliminary evidence to support the claim that a relationship exists between sensory gating and sensory processing patterns. However, additional research is warranted.

Does Sensory Gating Vary According to the Neurological Threshold Axis of Dunn's Four
Quadrant Model in Typical Adults?

Sensory Processing Disorder

Sensory modulation, according to Miller and Lane (2000), is the process in which neural signals about the intensity, frequency, duration, complexity and novelty of sensory stimuli are interpreted and adjusted by the central nervous system to enable adaptive behavior. It is proposed that sensory processing disorder (SPD) reflects difficulty organizing the neural signals to sufficiently engage in appropriate responses and behaviors (Miller, Anzalone, Lane, Cermak, & Osten, 2007). A. Jean Ayres (1963) was the first to examine this idea. Her research involved, “the association between sensory processing and behavior in children with learning, developmental, emotional, and other disabilities” (Miller et al. 2007, p. 135). Ayres proposed that sensory processing deficits lead to functional problems (Miller et al., 2007). These functional problems can include reacting adversely or failing to respond to sensations in daily life. As a result, children with sensory processing disorder are hindered from full participation in daily occupations that provide them with a means to learn life skills, develop social relationships, and meet biological needs (Chang, Parham, Blanche, Schell, Chou, Dawson, & Clark, 2012). Consequently, children that lack the opportunity to participate in these situations may present clinically with developmental delay and maladaptive behaviors. Due to the consequences manifested from sensory processing difficulties, many researchers have worked to show the underlying neurology. It has been suggested that one of the underlying neurological problems in SPD may be impaired sensory gating (Davies & Gavin, 2007). Sensory gating is a minimization of the neurological response to repeated or extraneous sensory stimuli (Davies, Chang, & Gavin, 2008).

Dunn's Four Quadrant Model

Winnie Dunn (1997) has put forth a model of sensory processing. In this model, Dunn describes a horizontal axis depicting behavioral regulation strategies and a vertical axis of neurological threshold intrinsic to the individual. The horizontal axis is a continuum ranging from passive to active regulation strategies. When a person is said to have a passive self-regulation strategy he/she allows the events of the environment to occur around them; where an individual with an active self-regulation strategy seeks to control the amount of stimulation he/she receives (Dunn, 2007). The vertical axis is a continuum ranging from low to high neurological thresholds. The neurological threshold is described as the intensity of a stimulus sufficient to generate a response. When an individual has a low neurological threshold he/she will be much more responsive to stimuli and when a person has a high neurological threshold he/she will not notice things as easily as others because of requiring much greater intensity.

“ When these 2 continua intersect, 4 basic patterns of sensory processing emerge” (Dunn, 2007, p. 85). These include: sensation seeking, sensation avoiding, sensory sensitivity, and low registration. A person with a sensation seeking sensory processing pattern has a high neurological threshold and an active self-regulation strategy. He/she would actively seek out stimulation intense enough to obtain his/her threshold. An individual with a sensation avoiding sensory processing pattern has a low neurological threshold and an active self-regulation strategy. He/she would tend to limit sensory input to him/herself because too much input becomes overwhelming. A person with a sensory sensitivity sensory processing pattern has a low neurological threshold and a passive self-regulation strategy. He/she would be uncomfortable in a high intensity situation but may not withdrawal from it like those with a sensation avoiding processing pattern. A person with a low registration sensory processing

pattern has a high neurological threshold and a passive self-regulation strategy. He/she would tend not to seek out stimulation and tend to miss things due to a high threshold for stimulation (Dunn, 2007). Sensory processing patterns rise to the level of sensory processing disorder when the associated behaviors interfere with daily life. According to the *Sensory Profile*, two standard deviations from the mean in any quadrant illustrate sensory processing disorder.

Existing research suggests differences in neurological processes along the range of neurological thresholds. Jagiellowicz, Xu, Aron, Aron, Cao, Feng, and Weng (2010) measured neuroticism and introversion with the Highly Sensitive Person scale. Those with high sensitivity (introverts) reported noticing many subtleties in the environment. Sensory processing sensitivity was shown to make more of a contribution to differences in brain response, as measured by functional Magnetic Resonance Imaging than personality variables (Jagiellowicz et al., 2010). Aron and Aron (1997) proposed that sensory processing sensitivity is evident in behaviors. Their study found that sensitivity correlated with emotionality and introversion, where individuals with high sensitivity are most likely to be introverted (Aron & Aron, 1997). Ben-Sasson, Carter, and Briggs-Gowan (2010) examined the relationship between sensory over-responsivity (SOR, representing both sensory sensitivity and sensory avoiding) and behavior/temperament in children. They found, “the child’s actions to deal with overwhelming sensations have developmental consequences directly through their avoidance or indirectly through caregiver’s preventative adaptations to the child’s SOR” (Ben-Sasson et al., 2010, p. 1199). For example, tactile and auditory stimuli accompany many academic and social activities. If a child has SOR towards these sensory stimuli, then it may impact his/her participation in these occupations. This lack of participation may result in developmental delays with deficits in adaptive responses to new environments or challenges (Ben-Sasson, Carter, & Briggs-Gowan, 2009). Reynolds and

Lane (2008) conducted a review of the literature regarding sensory over-responsivity as a frequent co-occurring diagnosis with ADHD, Fragile X syndrome, and autism. From a combination of the findings in the reviewed literature and three pediatric case studies they conducted, these researchers suggest that there is sufficient evidence for sensory over-responsivity as a stand-alone diagnosis (Reynolds & Lane, 2008).

Prior Research

One hypothesis being investigated is that the disruption of sensory gating can lead to abnormalities in attention-related information processing and thus influence participation in functional occupations (Durukan, Yucel, Erdem, Kara, Oz, Karaman, & Odabasi, 2011). Davies and Gavin (2007) demonstrated that children with SPD, as defined by the parental responses to the standardized *Sensory Profile*, showed less sensory gating ability than typically developing children. In a cross-sectional analysis, sensory gating ability increased with age in typically developing children, but in children with SPD no such increase was evident (Davies, Chang, & Gavin, 2010). Further analysis of gating can be used to accurately distinguish between children with SPD and typically developing children (Davies & Gavin, 2007; Davies, Chang, & Gavin, 2010; Gavin, Dotseth, Roush et al. 2011). Gavin and colleagues (2011) found that children with SPD display unique brain processing mechanisms when compared with typically developing children when presented with auditory stimulation using paired clicks or tones which varied in frequency and intensity. In these studies, participants with any type of sensory processing disorder were pooled together for analysis.

EEG and ERPs

Davies and Gavin (2007) utilized recordings of brain activation in response to sensory stimulation in order “to examine the association among brain structure, function, and behavior

related to sensory processing abilities” (p. 177). Electroencephalogram (EEG) detects brain activity and can be utilized during presentation of a stimulus or performance of a task.

Electrodes are placed on the scalp and the recordings are amplified and digitized. Segments of the EEG that are time-locked to a repeated stimulus can be averaged and shown in the form of a wave known as an event related potential (ERP). “ERPs are graphical displays of the brain’s electrical activity typically associated with a specific, defined event” (Davies & Gavin, 2007, p. 177). Two features of the ERP waveform can be measured: the amplitude and the latency.

Amplitude is measured in microvolts and latency is measured in milliseconds post stimulus. The ERP components are defined as deflections from baseline where *P* indicates positive deflections and *N* indicates negative deflections. The number in the label of the wave is the latency in milliseconds. The particular wave of interest in sensory gating is the P50 wave—a positive deflection 50 milliseconds post stimulus. The reduction of the amplitude of P50 when a second stimulus is presented as compared with the response to the first stimulus represents gating (Davies & Gavin, 2007).

The Present Study

The purpose of this study was to test for differences in sensory gating along the neurological threshold axis of Dunn’s model. Description of sensory gating across the range of sensory processing patterns would further support the use of sensory gating in identification of sensory processing disorder. The primary hypothesis was that individuals with sensory sensitivity and/or sensory avoiding patterns would have less effective sensory gating than individuals with sensory seeking and/or sensory registration. The secondary hypothesis was that gating would vary according to neurological threshold.

Other hypotheses of the principal investigator were also tested in a larger study of which this project is a part; therefore, other procedures that extend beyond testing the stated hypothesis were conducted.

Method

Participant characteristics

Healthy adults between the ages of 18-65 were recruited through convenience sampling. Exclusion criteria included major medical diagnosis, current or past neurological diagnosis, and habitual smoking. Further inclusion criteria were intact near vision and cognition. Participants were compensated with a gift card in the amount of \$10 for their complete participation. Sessions took place at the University of Toledo Main Campus.

Materials

Materials needed included: data sheet to record descriptors, MMSE, Clark's Chart near vision exam, consent forms, writing utensils and paper, E-prime software and response pad to administer questions and collect responses, isolated electrical stimulation device, and EEG collection and digital data storage apparatus.

Measures

The standardized assessment, the adult/adolescent version of the *Sensory Profile*, correlating with Dunn's four quadrant model of sensory processing has been used as a diagnostic tool for those demonstrating behaviors consistent with sensory processing disorder (Brown, Tollefson, Dunn, Cromwell, & Filion, 2001). The *Adolescent/Adult Sensory Profile* (Brown & Dunn, 2002) was modified from the original version, which was developed by Dunn and colleagues for children aged 3-10. Items used in the original assessment were chosen based on a literature review of sensory histories completed by researchers where the items induced atypical

responses to various sensory stimuli. Once the items were selected they were then categorized into six sensory systems and two behavior categories. The six sensory systems were termed: touch, movement, body position, visual, auditory, and taste/smell (Dunn, 1999, p. 13). The two behavior categories included activity level and social/emotional (Dunn, 1999, p. 14). It was then decided to categorize the items differently retrieve the most relevant data. They were categorized into 3 categories labeled: sensory processing, sensory modulation, and behavioral and emotional responses. The sensory processing category reflects sensory processing items and their relevance to daily life. These items include: auditory processing, visual processing, vestibular processing, touch processing, multisensory processing, and oral sensory processing (Dunn, 1999, p. 14). The modulation group reflects combinations of modulated input for use in daily life. These items include: sensory processing related to endurance/tone, modulation related to body position and movement, modulation of movement affecting activity level, modulation of sensory input affecting emotional responses, and modulation of visual input affecting emotional responses and activity (Dunn, 1999, p. 15). The last group is termed behavioral and emotional responses. This group is made up of items that may be a result of the child's sensory processing abilities. Items include: emotional/social responses, behavioral outcomes of sensory processing, and items indicating thresholds for response (Dunn, 1999, p. 15).

Factor analysis was done to determine whether items were organized into independent groupings. 44 items shown to be sources of variance and were eliminated from the assessment. As a result the factor structure was strengthened. The *Sensory Profile* is administered as a booklet that identifies items that are indicative of the child's sensory processing in a particular sensory processing category. Each item is rated on a five point Likert scale based on how often the behavior occurs (always, frequently, occasionally, seldom, never). Then the raw scores are

tallied and compared to scores of a normative population. Scores that fall within one standard deviation of the mean are deemed *typical performance*; scores that fall between one and two standard deviations of the mean are deemed represent a *probable difference*; and scores that fall beyond one standard deviation of the mean are deemed to represent a *definite difference* in sensory processing.

The validity of the *Sensory Profile* has been tested. Content validity was established through the use of a literature review to develop the items, expert review was used for wording and proper placement, and category analysis was used to ensure that items were placed in the appropriate categories agreed upon by researchers. Construct validity was tested by comparing scores on the *Sensory Profile* with scores on the *School Function Assessment*. Responses on the two tests correlated, demonstrating both convergent and discriminant validity. For example there were high correlations between *School Function Assessment* performance items and fine motor/perceptual items on the *Sensory Profile*. High correlations were also found between *School Function Assessment* socialization items and the behavior interaction part and modulation part of the *Sensory Profile*. Low correlations were found between *School Function Assessment* sections that capture daily routines and sensory sections of the *Sensory Profile*. A clinical group study was conducted to see if the *Sensory Profile* could differentiate between the groups of typically developing children and those with autism. On nearly 90% of the items children with autism performed significantly differently than the normative group of children.

Subsequently, the authors aligned the test items with the quadrant model (Dunn, 2006). For each quadrant, scores are similarly compared to the mean, Psychometric studies done on the *Sensory Profile* have tested the reliability and validity of quadrant scores. Reliability was tested by internal consistency (.47 to .91) and standard error of measurement (.92 to 2.89).

The *Sensory Profile* for children was the basis of the development of the adult/adolescent version of the *Sensory Profile* as, “Dunn’s model of Sensory Processing depicts sensory processing preferences as stable traits; therefore, applying the model to adults is inherently reasonable” (Brown, Tollefson, Dunn, Cromwell, & Filion, 2001, p. 76). One study was done to test the face validity the quadrant categorization of the items of the *Adolescent/Adult Sensory Profile* where judges were told to place each item into its respective quadrant. All but one item was sorted correctly. Item reliability was determined based on internal consistency. Internal consistency for each quadrant ranged from .639-.775. The Standard Error of Measurement (SEM) is another way to evaluate the reliability of a measure; the smaller the SEM, the more reliable the measure. The SEM for the *Adolescent/Adult Sensory Profile* ranged from 3.58 to 4.51 (Brown & Dunn, 2002). Factor analysis was also done on the *Adolescent/Adult Sensory Profile*. Low registration and sensation seeking factors were consistent; however, items on sensory sensitivity and sensation avoiding had two factors in common. This could be due to the fact that both of these quadrants make up the low end of the neurological threshold axis (Brown et al., 2001). Convergent and discriminate validity were measured by comparing the scores of the *Adolescent/Adult Sensory Profile* with the *New York Longitudinal Scales (NYLS) Adult Temperament Questionnaire*. Evidence for convergent validity was supported by moderate correlations between the two assessments in all quadrants except low registration. The weak correlations with the low registration quadrant may provide evidence for discriminate validity (Brown & Dunn, 2002). Construct validity was tested by the hypotheses: “persons with low thresholds will have a greater amplitude of skin conductance response than persons with high thresholds; persons with high scores on sensation avoiding and low registration would be quick to habituate but for different reasons; persons with high scores on sensory sensitivity and

sensation seeking would be slow to habituate but, again, for different reasons” (Brown et al., 2001, p. 78-79). Additional skin conductance research has been used to provide further evidence for convergent validity. Twenty occupational therapy students participated in a skin conductance research study. Five were sorted into each quadrant. A one way ANOVA as well as follow up Tukey’s test were used to analyze data and showed a statistically significant difference in responsivity between all groups. Tukey’s test revealed that the sensory sensitivity and the sensory avoiding groups were more responsive than the low registration and the sensory seeking quadrants. Trials to habituation were also tested. Analysis revealed a statistically significant difference across all groups. Tukey’s revealed that sensory sensitivity and sensory seeking groups took more trials to habituate than those in the low registration and sensory avoiding quadrants (Brown & Dunn, 2002). Reliability of the *Adolescent/Adult Sensory Profile* was revised to ensure the sensation avoiding subscale was improved. Brown and Dunn (2002) state that the “psychometric evidence documented in this manual [*Adolescent/Adult Sensory Profile*] provide a basis for the claim that scores from the profile can provide reliable and valid inferences about an individual’s sensory processing patterns” (p. 59).

The Mini Mental State Examination (MMSE, Rovner & Folstein, 1987) was used as a screening procedure to ensure intact cognition as one of the inclusion criteria. The MMSE is a tool that can be used to systematically and thoroughly assess mental status. It is an 11-question measure that tests five areas of cognitive function: orientation, registration, attention and calculation, recall, and language. The maximum score is 30. The inclusion criterion of intact cognition was substantiated by the scoring criteria of at least 25 in order to participate in the study.

Another inclusion criterion is that of intact near visual acuity. Therefore, Clark's Chart Eye Exam was used as another screening procedure. With correction, participants were asked to hold the examination card 14" from their face and read the smallest line aloud. The minimum score was at least 40/20 to qualify for participation in the study.

EEG recordings

Brain activity data were recorded through electroencephalography (EEG). 16 scalp electrodes were positioned according to the standard 10-20 placement and held by a skullcap with separate wells for each electrode. Wells were filled using plastic syringes with an electrolyte gel (Parker Signa, Fairfield, NJ). Scalp electrode sites included FP1, FP2, F3, Fz, F4, C3, Cz, C4, T7, T8, P3, Pz, O1, Oz, and O2. Eight additional electrodes were placed on the participants. These were taped in place and the gel was applied. The sites included: left and right mastoid process, left and right temple, Fz, cervical spine, and left and right Erb's points.

The data were recorded via a 24 channel Active Two biopotential measurement system (Amsterdam, Netherlands). It interfaced with a laptop PC via USB2.0 for data storage and display/analysis using ActiView software (Wilmington, NC). Data were sampled at 16 KHz and digitized at 24 bits.

Median nerve stimulation

The stimulating electrode (Digitimer Ltd., Hertfordshire, England) has two metal discs of 1 cm diameter, held 4 cm apart by a hard plastic bar. Electrolyte gel (Parker Signa, Fairfield, NJ) was applied to each disc and the stimulator was held in place with skin-sensitive tape or a loose wrapped elastic band. The stimulator was placed approximately 2 cm up the arm from the base of the thumb, ulnar to the prominent tendons. An electromyography pad electrode was applied to the forearm of the participant proximal to the stimulator, and connected by flexible thin,

insulated wire to a metal, isolated surface to ground the stimulus current. The stimulator can deliver median nerve stimulation (MNS) either by manually pushing a trigger button or delivering a 5 V TTL pulse via computer through a trigger port.

Procedures

Data were collected in two sessions, a testing session and an EEG session. Session order was random and counterbalanced across populations. Upon scheduling participation, participants were asked to refrain from caffeine and social smoking for 8 hours prior to the start of EEG sessions. Before providing informed consent, the participants were given the opportunity to experience the MNS by holding the stimulator with their index and middle fingers and pressing the trigger button to deliver a 200 microsecond, 1 mA pulse. If participants were willing to continue, the researcher obtained informed consent. Next, a screening to assess inclusion/exclusion criteria and obtain demographic information was given, including age, gender, regular smoking, current major medical diagnoses, current or past neurological diagnoses, the Mini Mental State Examination (MMSE), the Clark's Chart Eye Exam (with correction as customary for participants) at 14", hand dominance, and regular medications. These were recorded (see Appendix A for Screening Data Sheet).

Some of the data collected in the testing session relates to other hypotheses being tested by the principal investigator. The elements of the testing session included Dunn's Sensory Profile, self-identification of a sensory processing pattern, Eysenck's Personality Questionnaire-Brief Version, and rating of picture, administered in counterbalanced, random order.

See Figure 1 for a diagram of the equipment configuration. Participants were seated in a high-backed, padded desk chair with height set to allow them to place both feet comfortably on the floor. Using E-Prime software (E-Prime, Pittsburg, PA), instructions were presented in large,

bright green font against a background on a computer monitor at a comfortable height for viewing (set by adjusting the height of the console table as needed for each participant). In the testing session, participants were trained and tested for 100% accuracy in the use of a 5-button response box. The response box (approximately 8X8X1.75" in size, with weight less than one pound) was positioned on a console table at a right angle to the monitor on the participant's dominant side such that the participant can comfortably reach all buttons while supporting his/her forearm on the table or arm rest. Response buttons one through five lit up sequentially while simultaneously being named on the screen. The participant had the opportunity to practice pressing each button. The participant was then tested by being prompted to press each button, in random order. Testing was repeated until participants demonstrated 100% accuracy.

Completion of the Sensory Profile for Adults/Adolescents (Dunn, 1997).

The *Adult/Adolescent Sensory Profile* is a self-report, standardized assessment of sensory processing patterns. It contains 60 items. Each item describes a behavior that may occur in response to a sensory stimulus or sensory stimuli. For example, "I like how it feels to get my hair cut", "I am bothered by unsteady or fast moving visual images in movies or TV", and "I trip or bump into things". Respondents endorse each item using a Likert scale that reflects the proportion of opportunities in which they demonstrate the indicated behavior ranging from 1, Never (<5% of opportunities) to 5, Always (>95% of opportunities). Using E-Prime software, each item was presented on a computer monitor and participants entered their responses through the 5-button response box. After each item, participants were presented with their response and given a chance to change their response before moving on to the next item. Responses were entered into a file (file type proprietary to E-Prime) named by participant code. Responses were exported to Excel and/or SPSS for analysis.

Sensory Gating

During the EEG session recordings of somatosensory evoked potentials (SEP) and SEP gating were measured in random, counterbalanced order. The intensity of the MNS was determined through a stair-stepping procedure as follows: The stimulator was applied to the median nerve on the non-dominant wrist. The stimulus was set to the lowest intensity. The trigger button was used in the procedure for determining the intensity of the MNS. The intensity was increased 0.1 mA at a time until the participant indicated he/she has felt the MNS. The participant was asked to indicate whether he/she has felt each MNS. The interstimulus interval was variable, and some false positives were included. The first perceived intensity was recorded as the first MNS threshold value. Then the intensity was increased 0.2 mA for the next pulse and subsequently decreased 0.1 mA until the participant reported no longer perceiving it. The value 0.1 mA above that was recorded as the second MNS threshold value. This was repeated until eight threshold values have been recorded. The mean of these eight was set as the MNS threshold value for the participant. Next, the participant was told that he/she would experience 100%, 125%, 150%, 175%, and 200% of his/her MNS threshold value. The highest intensity tolerated by the participant was used (2 participants tolerated 150%, 3 tolerated 175%, and the remaining tolerated 200%). The average stimulus intensity utilized was 2.2 ± 0.8 milliAmps. The stimulus delivery PC and E-Prime software were used to deliver TTL trigger pulses to the simulator to activate the MNS while recording EEG signals.

The sensory gating protocol involves 300 pairs of MNSs, 150 of which were used for assessing the hypothesis of this project and 200 of which were used for testing other hypotheses of the principal investigator. Each stimulus lasted 200 microseconds. The interstimulus interval during pairs was 500 milliseconds, start-to-start. The interval between pairs was eight seconds,

start-to-start. In each of 100 trials, 3 MNS pairs were delivered while the participants were presented with a visual image on the PC monitor. In 50 trials, the image was an extra large fixation cross. In the remaining 50 trials the image was a photograph of everyday items that are suggestive of tactile experiences (for testing of other hypotheses). Trials were delivered in random order.

Data Analysis

Sensory processing pattern, relative to the neurological threshold of the four-quadrant model.

Using the results of the *Sensory Profile* quadrant scores, we categorized participants into four groups:

- a) High Threshold: those whose scores fell into the “more than other people” or “much more than other people” (+1 or +2 standard deviations from the mean) in the quadrants with high thresholds (Low Registration and/or Sensory Seeking) *and* their scores in the low threshold quadrants (Sensory Sensitivity and/or Sensory Avoiding) were “similar to most people” (within one standard deviation of the mean);
- b) Similar: those whose scores in all quadrants were “similar to most people”;
- c) Low Threshold: those whose scores fell into the “more than other people” or “much more than other people” (+1 or +2 standard deviations from the mean) in the quadrants with low threshold quadrants (Sensory Sensitivity and/or Sensory Avoiding) *and* their scores in the high thresholds (Low Registration and Sensory Seeking) were “similar to most people” (within one standard deviation of the mean); and
- d) Mixed: all remaining participants, specifically those who had scores that were “less than other people” or “much less than other people” (-1 or -2 standard deviation from the

mean) in any quadrant *and/or* scores that were “more than other people” or “much more than other people” in quadrants with opposite thresholds (high and low, for example Sensory Sensitive *and* Low Registration).

Score for the neurological threshold axis within the four-quadrant model

To determine participants’ sensory processing patterns, we used the individual item scores from the *Sensory Profile* to calculate a value for the neurological threshold axis of the four-quadrant model. We derived the axis values as follows: To relate to one quadrant of the model, each item of the *Sensory Profile* is indicative of either a high threshold or a low threshold. Accordingly, there are 30 items indicative of a high threshold (15 each from the Sensory Registration and Sensory Seeking quadrants) and 30 indicative of a low threshold (15 each from Sensory Sensitivity and Sensory Avoiding). Each is rated on a 1-5 point scale. To prevent a gap in the distribution, the data were transformed by subtracting one point from each response to creating a 0-4 scale. The sum of low threshold scores was multiplied by negative one, producing a negative score. The scores for high threshold and low thresholds were then added together to derive a score for the neurological threshold score axis within the four-quadrant model. This score ranged from -120 to 120. Respondents who reported equal frequency, intensity, or a combination of those two for high and low threshold behaviors would have scores near zero. Therefore, scores of greater absolute values indicate greater frequency and/or intensity of behaviors indicative of the corresponding threshold level.

Sensory gating

EEG data were referenced to the mastoid processes. The average of signals from all scalp positions was subtracted from each signal. Data were bandpass filtered between 10 and 300 Hz. EEG data were time-locked to stimulus delivery. Same-stimulus trials (i.e. first in the

pair and second in the pair) were averaged. The peak value of the P50 at the C_z electrode was detected between 40 and 85 milliseconds after the stimulus. Data for participants where the P50 in response to the first stimulus was at least 0.5 microVolts were used to assess sensory gating. Sensory gating was quantified as the ratio of the amplitude of the first-stimulus P50 to the amplitude of the second-stimulus P50.

Hypothesis testing

Data were normally distributed. With alpha at 0.05, we tested the primary and secondary hypotheses as follows: The primary hypothesis (individuals with sensory sensitivity and/or sensory avoiding patterns would have less effective sensory gating than individuals with sensory seeking and/or sensory registration) was tested by comparing the SEP gating ratios for participants in the High Threshold and Low Threshold categories with a two tailed student's t-test. The secondary hypothesis (that gating would vary according to the neurological threshold) was tested via correlation between the calculated scores for the neurological threshold axis within the four-quadrant model and the SEP gating ratio for all participants in the High Threshold, Similar, and Low Threshold categories using Pearson's correlation.

Results

Eighty individuals responded to recruiting flyers by contacting the researchers. A total of 65 healthy adults attended a scheduled session, provided informed consent, met inclusion criteria, and completed participation. The average age was 27 ± 8 years (ranging from 18 to 55 years, with 33 of the participants being between the ages of 23 and 25 years). The majority of participants were female (49, or 75%) and right handed (56, or 86%). MMSE scores averaged 29.5 ± 0.8 . The P50 in response to the first MNS of paired pulses at C_z was at least 0.5

microVolts for 35 participants (mean $1.0 \pm 0.4 \mu\text{V}$). See Table 1 for a demographic summary and Figure 2 for a flow chart of participants.

When categorized according to *Sensory Profile* quadrant scores, there were 5 participants in the High Threshold category, 8 in the Similar category, and 8 in the Low Threshold category. The gating ratio was not significantly different between the High Threshold and Low Threshold categories (primary hypothesis $t(df=11) = -9.85$, $p=0.346$, see Figures 3 and 4). The gating ratio did not vary according to the calculated threshold for these 21 participants ($R=-0.310$, $r^2=0.1$, $p=0.172$, see Figure 3). When including participants in the High Threshold, Low Threshold, and Similar categories in a correlation analysis, the gating ratio did not vary according to the calculated threshold score ($R=-0.056$, $r^2=0.003$, $p=0.75$, see Figure 5).

Discussion

The primary hypothesis (individuals with sensory sensitivity and/or sensory avoiding patterns would have less effective sensory gating than individuals with sensory seeking and/or sensory registration) and the secondary hypothesis (gating would vary according to neurological threshold) were not supported by data analysis. A possible explanation for these results is the reduction in the sample size used for analysis because many participants (30) had small ERPs. This likely reflects use of a low intensity MNS. The MNS was well below the motor threshold in order to maximize participant comfort and compliance, as well as make the stimulus more similar to tactile stimulation rather than proprioceptive input, painful stimulus, or an electrical impulse in the median nerve.

The results did show a trend in support of the direction of the hypotheses. This warrants continuation of the study. In similar studies, Davies and colleagues have described identified less effective gating in children with SPD than children who were typically developing (Davies

& Gavin, 2007; Davies, Chang, & Gavin, 2010). Further work has shown that children with SPD display uniquely different neurophysiological functions when compared to typically developing age-matched peers in relation to the discrimination and organization of stimuli (Gavin, Dotseth, & Roush et al., 2011). The present study depicts a similar relationship where *Sensory Profile* scores associated with sensory modulation disorder, particularly sensory overresponsiveness, are associated with less efficient sensory gating, albeit not statistically significant. If continued data collection and analysis strengthens the findings, there would be several implications for practice.

One implication would be to enhance confidence in Dunn's four-quadrant model of sensory processing. Occupational therapy practitioners widely use this model to assess if an individual may have SPD. With strengthened evidence to support the model, practitioners would then be able to identify and explain SPD to stakeholders, including clients, caregivers, teachers, and those responsible for reimbursement for treatment. This would also provide direction in developing and testing treatment methodologies for those individuals with SPD. Validating Dunn's neurological threshold construct in this model may suggest future research to understand different neural mechanisms of SPD. Use of the calculated threshold score could be used to measure changes in a clients' sensory responsivity. This measure may be useful in documenting the outcomes of therapy. Another implication for practice would include using EEG technology to aid in the identification of SPD or objectively measure treatment effects. Furthermore, future results from continuation of this study, and others, may strengthen evidence that SPD is a stand-alone diagnosis that requires treatment.

Limitations

These results are at risk for type II error due to small sample size, having a subtle independent variable (the low intensity MNS), and dispersion of the dependent variable. The latter may be the result of individual differences. Another reason might be due to imprecision of measures. Three researchers collected data throughout the course of this study and normal human error may have influenced the results. Other limitations of this study include low external validity. The population included in this study was typically developing adults. As such, extremes in sensory processing patterns were not included in this sample. This may reduce generalizability of the results to clinical populations. Also, 51% of the sample was between the ages of 23-25 due to convenience sampling, which is also unrepresentative of the general population. However, though lacking statistical significance, the results of this study were similar to past studies (Davies & Gavin, 2007; Davies, Chang, & Gavin, 2010; Gavin, Dotseth, & Roush et al., 2011).

Future Research and Conclusion

Future studies may utilize a more robust stimulus. Replication of this study with individuals with identified sensory processing disorder may yield different results. These studies would be valuable to pursue because a description of sensory gating abilities across sensory processing patterns would support the use of sensory gating in the identification of sensory processing disorder. As such, this study is clinically significant. The theoretical significance of this study involves validating Dunn's model of sensory processing. This may encourage development of interventions targeted toward disorders of particular sensory processing patterns. Overall, the results of this study provide weak support of the idea of a relationship between sensory gating ability and an individual's neurological threshold. Only with continued research will this relationship be more fully understood.

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Table 1 Participant demographics

n =65

Age (18-55)*	Gender	MMSE	Handedness	Visual Acuity
18-30: 52=80%	Male:	30:44/65=68%	Right:	20/20: 29/65=45%
31-55: 13=20%	16/65=25%	29:13/65=20%	56/65=86%	20/25: 28/65=43%
	Female:	28:7/65=11%	Left:	20/30: 5/65=8%
	49/65=75%	26:1/65=1%	9/65=14%	20/40: 3/65=4%

*33 of the participants were between the ages of 23-25=51%

Figure 1 Equipment configuration

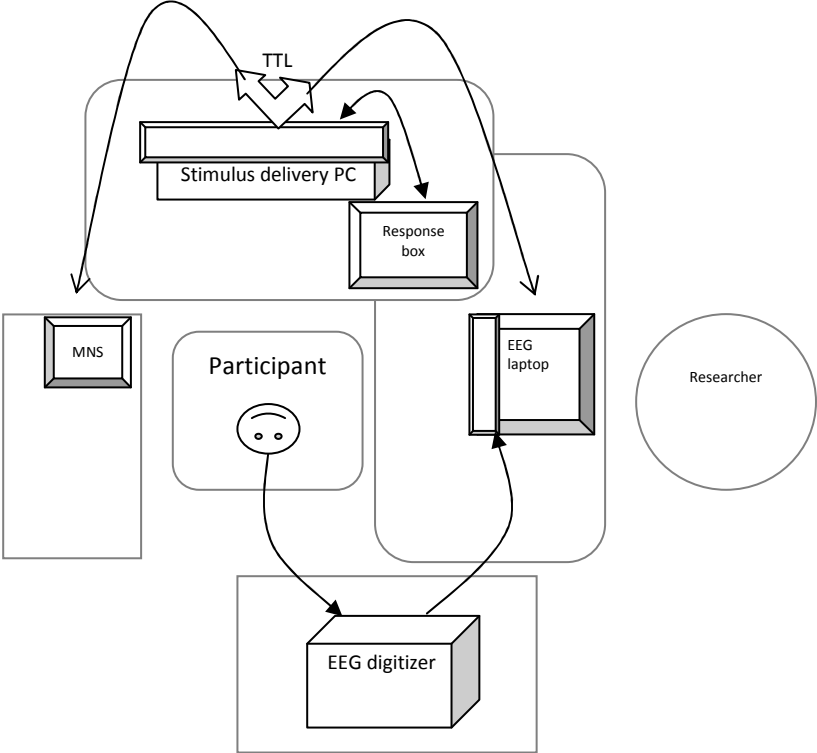


Figure 2 Participation flow chart

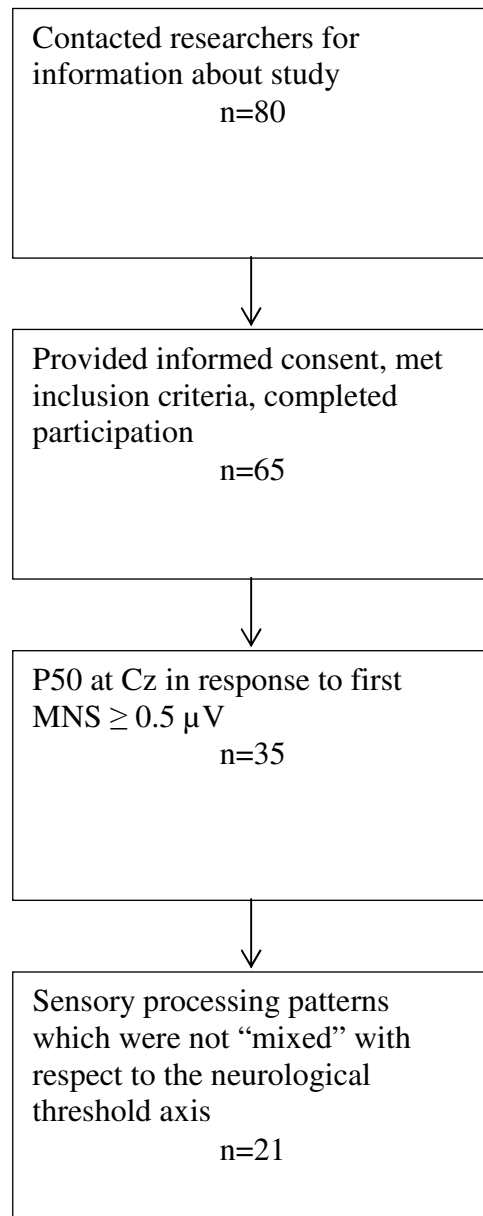
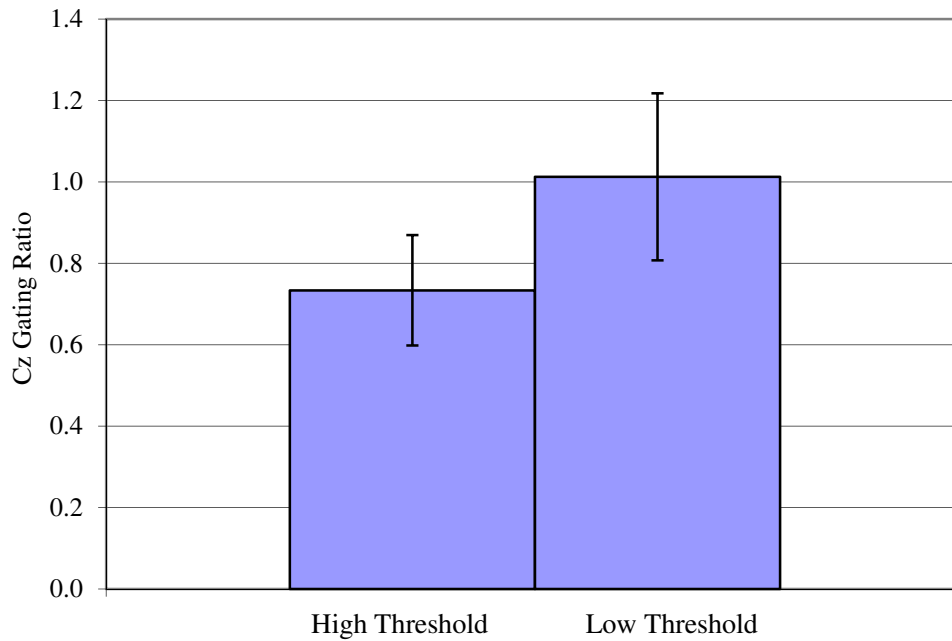


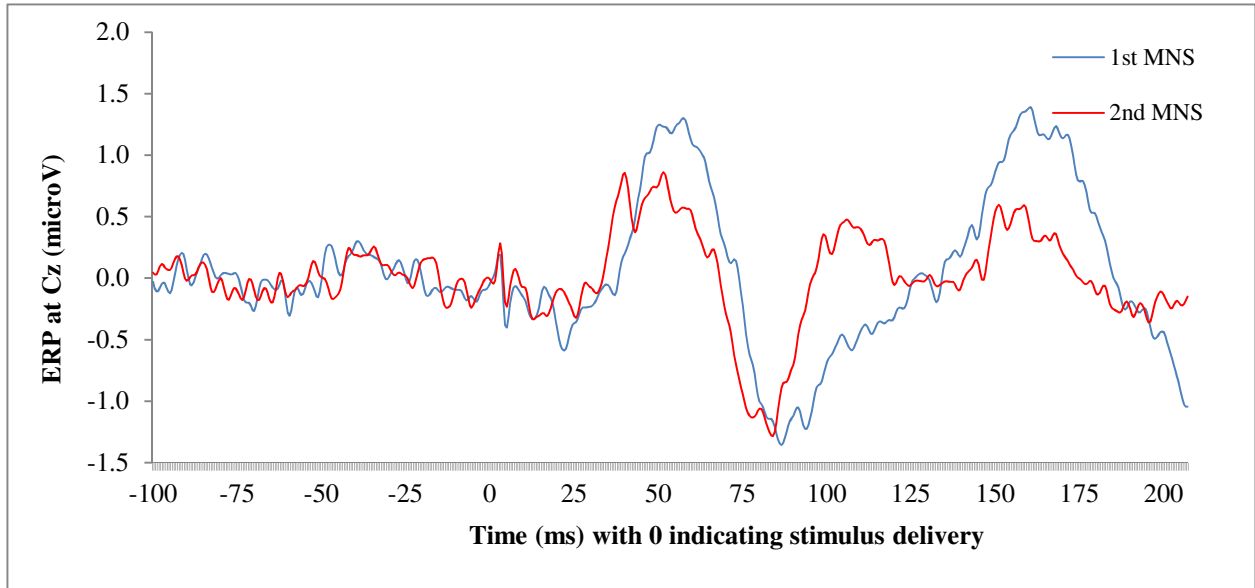
Figure 3



Mean gating ratio at Cz for participants with sensory processing patterns indicative of high and low thresholds compared to participants with thresholds similar to most people ($n= 5$ for High Threshold, 8 for Similar, and 8 for Low Threshold, $F(2,18)=0.743$, $p=0.49$)

Figure 4

A. ERPs for a representative participant in the High Threshold Category



B. ERPs for a representative participant in the Low Threshold Category

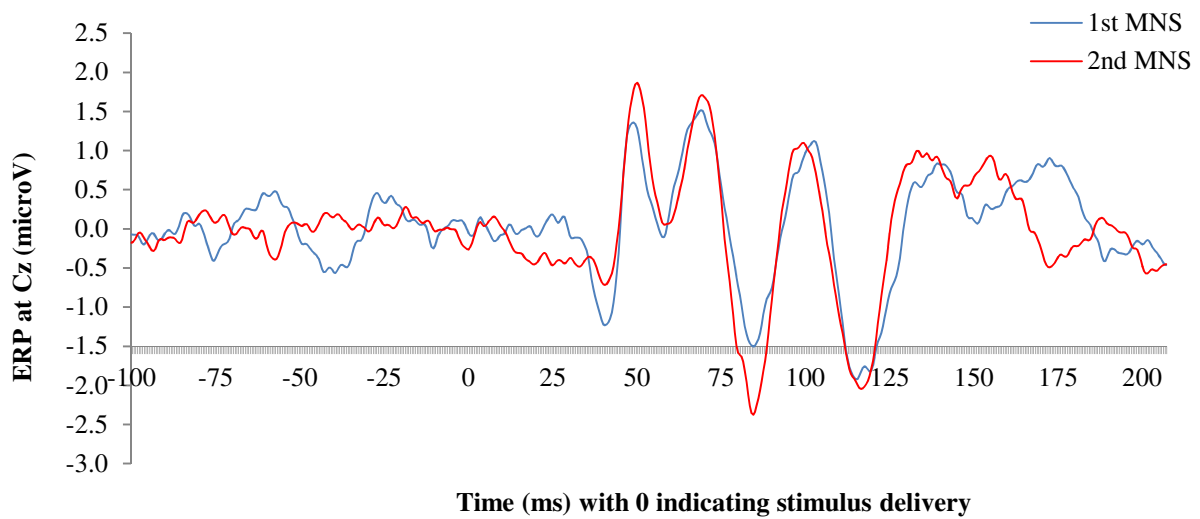
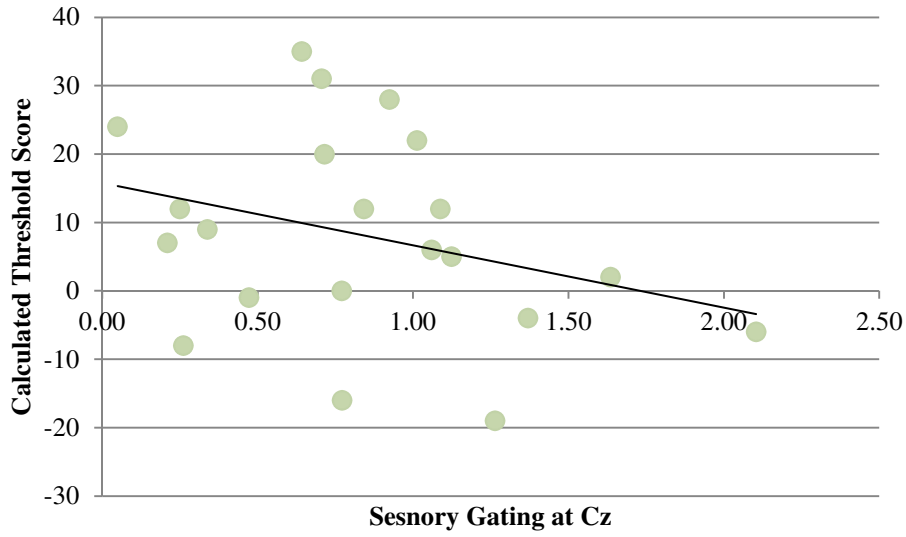


Figure 5. Scatterplot for Gating Ratio and Calculated Threshold for participants with sensory processing patterns “similar to most” or indicative of high or low threshold (n=21, R=-0.310, $r^2=0.1$, p=0.172).



Appendix A

Screening Data Sheet

Screening Data Sheet

Participant number: _____

1. Age: _____

 18-65

2. Gender: _____

3. Smoking:

 not a regular smoker?

4. General health:

 no current major medical diagnoses? no current or past neurological diagnoses?

5. MMSE score: _____

 ≥ 25

6. Visual acuity at 14'': _____

 $\geq 40/20$

7. Hand dominance: _____

8. Regular medications:

EEG session:

 Refrained from caffeine for at least 8 hours? Refrained from smoking for at least 8 hours?