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Intellectual and Adaptive Functioning in Sturge-Weber Syndrome

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Abstract

The present study examined the intellectual and adaptive functioning in a sample of children and young adults with Sturge-Weber Syndrome. A total of 80 research participants from a SWS study database underwent full neurological evaluation as part of their participation or concurrent medical care. Twenty-nine of the participants received neuropsychological evaluations. Analyses indicated no significant demographic or neurological differences between those who did and did not receive neuropsychological evaluations. Overall, the neuropsychological evaluation sample displayed significantly lower functioning relative to published normative data across domains of intellectual and adaptive functioning. 32% of the sample displayed impaired performance (standard score 75) in intellectual functioning and 58% displayed impaired performance in adaptive functioning. Hemiparesis status independently predicted overall adaptive functioning while seizure frequency independently predicted overall intellectual functioning. Younger participants displayed significantly higher (more intact) ratings in adaptive functioning compared to older participants, specifically in overall adaptive functioning, motor skills, and community living skills. A composite measure of neurological status (SWS-NRS) incorporating seizure and hemiparesis status effectively distinguished between individuals with impaired or non-impaired adaptive and intellectual functioning, and showed promise as a screening method for identifying individuals with more involved intellectual and/or adaptive needs.

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Keywords

intelligence; adaptive function; sturge-weber syndrome; neuropsychology; neurology

Sturge-Weber Syndrome (SWS) is a rare neurocutaneous syndrome typically characterized by a facial capillary malformation (or port-wine birthmark) in the ophthalmic distribution of the trigeminal nerve, vascular malformations and glaucoma, and a leptomeningeal angioma (Comi, 2007b; Comi, 2011; Comi & Maria, 2008; Kurlemann, 2012; Nabbout & Juhasz, 2013). Exact prevalence rates have not been reported, although it is estimated that SWS incidence rate is 1:20-50,000 live births (Comi, 2007b; Kurlemann, 2012; Nabbout & Juhasz, 2013). SWS is associated with a somatic activating mutation in the GNAQ gene (Shirley et al., 2013), with this mutation contributing to localized abnormal mesodermal and ectodermal formation during the early embryo development, thus resulting in vascular malformations of the skin, eye, and brain (Comi, 2011; Nabbout & Juhasz, 2013; Shirley et al., 2013).

The leptomeningeal angioma in SWS consists of enlarged and tortuous leptomeningeal vessels, along with frequently dilated deep draining veins involving the choroid plexus. It is often ipsilateral to the facial capillary malformation and located most typically within the occipital lobe, although involvement in neighboring temporal and parietal lobes, or the entire hemisphere, can occur (Comi, 2007b; Comi, 2011; Kurlemann, 2012; Nabbout & Juhasz, 2013). Relatedly, the facial capillary malformation involves tortuous and dilated capillaries and venules located in the dermis (Nabbout & Juhasz, 2013), while the eye malformations involve enlarged and tortuous venous vessels that can contribute to glaucoma as well as eyelid, conjunctival and episcleral, and diffuse choroidal vascular malformations (Comi, 2007b; Nabbout & Juhasz, 2013). Underlying the leptomeningeal angiomas, progressive neural damage is often present, including calcification, neuronal loss, gliosis, and cortical dysgenesis (Comi, 2007b; Comi & Maria, 2008; Kurlemann, 2012; Nabbout & Juhasz, 2013). Such damage has been proposed to be a consequence of impaired blood flow and subsequent ischemic injury, potentially due to recurrent seizures and subsequent abnormal vascular compensatory mechanisms, as well as venous stasis (Comi, 2003; Comi, 2007b; Comi, 2011; Nabbout & Juhasz, 2013).

In addition to the main vascular features of SWS, patients with SWS often present with other neurologic symptoms including a clustered pattern of early onset seizures, migraines, hemiparesis, visual field cuts, stroke-like episodes, and other associated abnormalities (Comi, 2003; Comi, 2006; Comi, 2007b; Comi, 2011; Comi & Maria, 2008; Comi, Mehta, Hatfield, & Dowling, 2005; Kossoff, Balasta, Hatfield, Lehmann, & Comi, 2007; Kossoff, Ferenc, & Comi, 2009; Nabbout & Juhasz, 2013). Further, SWS is frequently associated with cognitive involvement, although this can range from subtle attentional and learning disabilities to more severe intellectual impairment (Comi, 2006; Comi, 2011; Comi & Maria, 2008).

There is limited research examining the intellectual functioning of individuals with SWS, with a variety of methodologies utilized to quantify intellectual functioning. Bebin & Gomez (1988) estimated intellectual functioning of patients with SWS via documented

psychometric testing performance or information gathered regarding economic dependence/current employment. A similar mixed method of reporting/estimating intelligence was also utilized by Sujanksy & Conradi (1995) in which intellectual functioning was assessed via available intelligence testing scores or the perception of intelligence based on the opinion of the patient or a caretaker. Several IQ studies have utilized more standardized measures, but the accrual of patients has spanned an extensive period of history, such as Pascual-Castroviejo and colleagues (Pascual-Castroviejo, Diaz-Gonzalez, Garcia-Melian, Gonzalez-Casado, & Munoz-Hirald, 1993; Pascual-Castroviejo, Pascual-Pascual, Velazquez-Fragua, & Viano, 2008) who conducted a chart review of patients receiving medical care in the neurological service between the years of 1965-2004.

More recent research has provided updated data on intellectual functioning in SWS utilizing current standard IQ instruments (Behen et al., 2011; Jagtap, Srinivas, Harsha, Radhakrishnan, & Radhakrishnan, 2012). Behen and colleagues (Behen et al., 2011) prospectively examined the intellectual functioning in 35 children with unilateral SWS under a research protocol. The mean verbal intelligence score for the sample was 82.1 (24.6) and the mean performance intelligence score was 76.4 (21.2). Within verbal intelligence, 34% (n = 12) scored in the impaired range (< 70) and 43% (n = 15) scored in a range characterized by scores greater than or equal to a standard score of 85. Within performance intelligence, 43% (n = 15) scored in the impaired range (< 70) and 37% (n = 13) scored in a range characterized by scores greater than or equal to a standard score of 85. Additionally, Jagtap and colleagues (Jagtap et al., 2012) examined the clinical outcomes of 30 child and adult patients with SWS followed through a clinical care center. Based on psychometric testing, 43.3% (n = 13) of their sample had intelligence scores greater than or equal to a standard score of 70, while 56.6% (n = 17) had intelligence scores less than a standard score of 70.

Several groups have identified associations between intellectual and neurological status. Chapieski and colleagues (Chapieski, Friendman, & Lachar, 2000; Raches, Hiscock, & Chapieski, 2012) have found that children and adolescents with SWS and a history of seizures or hemiparesis had lower ratings of parent/teacher reported developmental and intellectual functioning. In addition to parent/teacher reported difficulties, there is an association between lowered intelligence and greater seizure intensity (Kramer et al., 2000), greater seizure frequency (verbal intelligence; Behen et al., 2011), younger age of seizure onset (Behen et al., 2011; Pascual-Astroviejo et al., 2008), longer duration of epilepsy (Behen et al., 2011), and poor response to medication (Pascual-Astroviejo et al., 2008) in children and adolescents with SWS. Lowered intelligence has also been associated with focal ipsilateral white matter tissue damage (Alkonyi et al., 2011), decreased white matter volume (Juhász et al., 2007), unilateral brain damage (Behen et al., 2011), and the greater severity of the cerebral lesion (Pascual-Astroviejo et al., 2008) in SWS. Further, neural network abnormalities in SWS have been associated with their corresponding verbal cognition, motor, and visual field functions (Jeong, Chugani, Behen, Guy, & Juhász, 2013).

Across these studies, there is significant variability in reported intellectual functioning. More specifically, intact intellectual functioning ("intact" standard score cut-off points = 70-90, depending on the study) ranged from 33-54% of the given samples, while impaired intellectual functioning ("impaired" standard score cut-off points = 70-85, depending on the

study) ranged from 30-57% of the given samples. Intelligence test score means ranged from 74.96 to 82.6, with corresponding standard deviations ranging from 10.4 to 24.6. While methodical limitations of prior research may have contributed to the significant variability in reported intellectual functioning within SWS, variability is also likely due to differences in disease status and associated medical factors (e.g., seizures and brain injury; Zabel et al., 2010), suggesting that there may not be a modal intellectual profile of SWS.

There is also limited research examining adaptive functioning in SWS. To our knowledge, a prior study conducted on a subsample of the current research sample (Reesman et al., 2009) is the only study that has examined adaptive functioning in SWS. Reesman and colleagues (Reesman et al., 2009) evaluated the neurologic correlates of adaptive dysfunction in 18 children and adolescents with SWS. The presence of hemiparesis was the only individual neurological variable that differentiated between individuals with nonimpaired and impaired adaptive functioning. Given the potential for adaptive dysfunction in this population due to neurological and intellectual weaknesses, it was deemed important to build on this prior study (Reesman et al., 2009) and further examine the potential contributors to adaptive functioning in SWS.

Given the significant variability in prior intellectual studies and the dearth of adaptive functioning studies, the present study examined the intellectual and adaptive functioning in a sample of children and young adults with SWS. The objective was to provide clarity on the intellectual and adaptive functioning in individuals with SWS and the role of neurological involvement. These individuals were treated with a standard approach to care, including the aggressive treatment of seizures and the use of low-dose aspirin (Comi, 2007a; Lance et al., 2013), with a portion of the sample receiving neuropsychological evaluations. Given a review of prior research, it was hypothesized that intellectual and adaptive functioning of the current sample would be lower (poorer) than published normative data and greater neurological involvement (e.g., seizures, hemiparesis) would be associated with lower overall intellectual and adaptive functioning.

Methods

Sample

This study received approval from the Johns Hopkins University School of Medicine Institutional Review Board. Participants were children and young adults with confirmed Sturge-Weber syndrome brain involvement who were recruited for an observational research study during a routine visit to the Hunter Nelson Sturge-Weber Center at the Kennedy Krieger Institute and who consented to participate in a multidisciplinary study of SWS. All participants or their parents signed informed consent forms. A total of 80 research participants from a large SWS study database were identified for this study between the years of 2005-2012. All participants underwent full neurological evaluations as part of their participation or concurrent medical care. Twenty-nine of the participants received neuropsychological (NP) evaluations, either as part of their care within the Hunter Nelson Sturge-Weber Center or from a community based neuropsychologist. Of the 29 participants who received neuropsychological evaluations, 2 participants did not have reportable standard intelligence scores or standard adaptive functioning scores, 2 participants had standard

adaptive functioning scores but not intelligence scores, and 2 participants had intelligence scores but not standard adaptive functioning scores. Lack of intelligence scores was due to limited functioning of the participants (potentially administered a developmental assessment tool [e.g., Mullen Scales of Early Learning] in lieu of an intelligence test) or language differences (e.g., Spanish speaking). A lack of scores on measures of adaptive functioning occurred in two instances due to parents/guardians not completing the adaptive functioning questionnaire or completing a measure of adaptive functioning that was not utilized in the present study.

Results of adaptive and intellectual assessment from the neuropsychological evaluation were used for the present study. Intellectual functioning was assessed based on age-appropriate psychometric IQ tests, while adaptive functioning was assessed via a parent-completed adaptive functioning questionnaire. Clinical ratings of seizure frequency, hemiparesis, visual field cut, and cognitive function were assigned by a neurologist via the Sturge-Weber Syndrome Neurological Rating Score (SWS-NRS; Kelley, Hatfield, Lin, & Comi, 2005), which is described below.

Measures

Intellectual functioning was assessed through age-appropriate psychometric measures of intelligence (i.e., the Wechsler Preschool and Primary Scale of Intelligence-Third Edition [Wechsler, 2002], Wechsler Intelligence Scale for Children-Third Edition [Wechsler, 1991], Wechsler Intelligence Scale for Children-Fourth Edition [Wechsler, 2003], Wechsler Adult Intelligence Scale-Third Edition [Wechsler, 1997], the Stanford-Binet Intelligence Scale-Fifth Edition [Roid, 2003], or the Differential Ability Scales [Elliott, 1990]). As stated previously, a large minority of cases obtained neuropsychological evaluation from community based neuropsychologists for clinical purposes, thus contributing to the range of instruments used to measure intellectual functioning. Due to the range of intellectual quotients obtained from clinical evaluations, the present study utilized estimates of verbal intelligence (e.g., Verbal Comprehension Index, Verbal IQ) and performance or nonverbal intelligence (e.g., Perceptual Reasoning Index, Nonverbal IQ, Performance IQ) to assess functioning in these domains. In order to estimate overall intelligence, a “Computed IQ” score was obtained from the average of the verbal and performance intelligence domains.

Scales of Independent Behavior-Revised (SIB-R; Bruininks, Woodcock, Weatherman, & Hill, 1996)—The SIB-R is a parent-report questionnaire assessing adaptive functioning. The SIB-R divides adaptive functioning into broad domains of motor skills, social interaction and communication skills, personal living skills, and community living skills. The Broad Independence scale is the global rating of overall independence. The internal consistencies between the various subscales of the SIB-R are strong (.70-.90 for all subscales; Bruininks et al., 1996).

The Sturge-Weber Syndrome-Neurological Rating Score (SWS-NRS; Kelley et al., 2005)—The SWS-NRS provides a clinically derived rating of visual field cut (Visual Field-Cut Score; 0 = none, 1 = partial, or 2 = full homonymous hemianopsia), frequency of seizures (Seizure Score; 0 = none ever, 1 = one or more controlled, 2 = breakthrough, 3 =

monthly, or 4 = weekly to regular), and hemiparesis (Hemiparesis Score; 0 = normal, 1 = slight [postures intermittently], 2 = mild [impaired fine motor], 3 = moderate [impaired gross and fine motor], 4 = severe [little fine motor control and severe gross motor impairment, poor helper arm function, walks with difficulty or not at all]). The final component of the SWS-NRS is a rating of cognitive functioning (Cognitive Function Score; possible score ranging from 0 to 5) assigned by the neurologist based on self-report or parent report of developmental, academic, and/or vocational functioning. Of note, the Cognitive Function Score was significantly correlated with Computed IQ ($r = -.637, p < .001$) in the present sample. The final cumulative score (SWS-NRS Total Score) can range from 0 to 15 and is calculated by adding the clinician's ratings of the domains of visual field cut, hemiparesis, seizures, and cognitive functioning. A lower score equals better overall neurological functioning and fewer neurological indicators of SWS severity. In this study, the SWS-NRS was assigned by the neurologist (A.M.C.) in accordance with the published rating criteria (Kelley et al., 2005).

Analysis Plan: Participants were grouped based on neuropsychological evaluation status. Those individuals who received neuropsychological evaluation were grouped into the *Neuropsychological Evaluation Group (NP Group, n = 29)* and those who did not receive neuropsychological evaluation grouped into *Clinic Comparison Group (CC Group, n = 51)*. Prior to examining intellectual and adaptive functioning within the *NP Group*, analyses of variance (ANOVA) were conducted to examine the group differences in demographic and neurological variables. A lack of group differences was hypothesized to reflect demographic and neurological similarities between groups, with subsequent findings within the *NP Group* potentially reflecting the functioning in the whole sample, and more broadly in the general SWS population.

In order to assess the intellectual and adaptive functioning of the sample, independent samples *t*-tests were conducted to compare the intellectual and adaptive functioning of the sample to normative data (presumed mean = 100; standard deviation = 15). Impaired intellectual functioning was classified as a Computed IQ ≤ 75 , in order to identify impairment and the associated margin for measurement error (~ 5 points). Based upon the methodology of previous research studies (Behen et al., 2011; Pascual-Castroviejo et al., 2008), a standard score ≤ 85 cut-point (SS; 1 standard deviation below the mean) was used to identify intact intellectual functioning. Impaired adaptive functioning was classified as an impaired standard score (≤ 75) on at least one domain of adaptive functioning via the SIB-R. Given the motor difficulties of this population, motor impairments assessed via the SIB-R did not count towards adaptive functioning impairment.

In order to best assess for the potential influence of neurological variables on intellectual and adaptive functioning, Pearson correlation and multiple regression analyses were conducted with neurological and intellectual/adaptive variables. Those neurological variables that displayed a statistically significant linear relationship (i.e., Pearson correlation) to intellectual/adaptive variables were then entered into linear regression analyses with intellectual and adaptive functioning serving as dependent variables. The SWS-NRS variables of Cognitive Function and Total Score were not included in regression analyses, given that an estimate of intellectual functioning is contained within these scores (as

opposed to neurological status). The SWS-NRS Total Score contains all variables throughout all analyses.

Given the significant variability in age within the sample, a comparison of neurological and intellectual and adaptive functioning of younger versus older participants was conducted. A cut-score was set at 6 years old, given increased stability of cognitive functioning during school aged years and commonly used intellectual tests for children (as opposed to infants/toddlers; e.g., WISC-IV) have an age-range starting at age 6. Those participants younger than 6 years old at the time of neuropsychological evaluation grouped into the *Younger NP Group* ($n = 9$) and those participants at least 6 years old at the time of neuropsychological evaluation grouped into the *Older NP Group* ($n = 20$). ANOVAs assessed group differences on demographic, neurological, and intellectual/adaptive variables. Finally, Receiver Operating Characteristic (ROC) analysis was used to determine if the SWS-NRS Total Score could distinguish between individuals with and without intellectual and adaptive impairment. Significance was set at $p < .05$ to appropriately capture important findings in the context of a limited sample size.

Results

The distribution of the intellectual and adaptive scores did not have significant skew or kurtosis. ANOVAs were conducted to determine if there were demographic and neurological differences between the *NP Group* (those individuals who received neuropsychological evaluations) and the *CC Group* (those individuals who did not receive neuropsychological evaluations). There were no statistically significant differences between groups based on age, gender, or neurological status (SWS-NRS; Table 1). To further characterize the total sample, the percentage was reported of those individuals who had partial neurological involvement based on the SWS-NRS (i.e., scoring at least “1” for the given variable; Table 1).

The remaining analyses were restricted to the group of participants who received neuropsychological evaluations (*NP Group*). Independent samples *t*-tests identified significant mean standard score differences between the *NP Group* and published normative data (presumed mean = 100 and standard deviation = 15) across all assessed domains of intellectual and adaptive functioning (Table 2). Rate calculations of impaired intellectual and adaptive functioning identified 32% of the sample as displaying impaired performance in intellectual functioning (Computed IQ standard score ≤ 75) and identified 58.3% of the sample as displaying impaired performance in adaptive functioning (1+ adaptive functioning domain standard score ≤ 75). Based upon the methodology of previous research studies (Behen et al., 2011; Pascual-Castroviejo et al., 2008), a standard score ≤ 85 cut-point (SS; 1 standard deviation below the mean) was used to identify intact intellectual functioning. Based on this criterion, 36% of the sample displayed intact intellectual functioning (with the remaining 64% falling below that range). The final third (32%) performed in a “borderline/low average” range.

The next analyses sought to examine the association between neurological status and intellectual and adaptive functioning. Correlation analyses were first conducted to identify

significant associations between SWS-NRS scores and overall intellectual (Computed IQ) and adaptive (SIB-R Broad Independence) functioning. Overall intellectual functioning was negatively correlated with SWS-NRS Total Score, SWS-NRS Cognitive Function Score, and SWS-NRS Seizure Score. Overall adaptive functioning was negatively correlated with SWS-NRS Total Score, SWS-NRS Cognitive Function Score, and SWS-NRS Hemiparesis Score. SWS-NRS Seizure Score and Hemiparesis Score were both entered as potential predictor variables into multiple regression analyses (Tables 4 & 5). Both multiple regression models were statistically significant ($p < .05$), with SWS-NRS Seizure Score and Hemiparesis Score accounting for a significant proportion of variance in overall intellectual functioning (23%) and adaptive functioning (34%). Within the respective models, SWS-NRS Seizure Score was independently associated with overall intellectual functioning while SWS-NRS Hemiparesis Score was independently associated with overall adaptive functioning.

ANOVAs were then conducted to assess differences on demographic, neurological, and intellectual/adaptive variables between the *Younger NP Group* and *Older NP Group*. No significant group differences were identified based on gender, neurological, or intellectual functioning (Table 3). However, significant group differences were identified based on SIB-R Broad Independence, $F(1, 22) = 5.52, p = .028$; SIB-R Motor Skills, $F(1, 23) = 4.72, p = .04$; SIB-R Community Living Skills, $F(1, 23) = 5.01, p = .035$, with the *Younger NP Group* displaying higher (i.e., more intact) scores in these three domains.

ROC analysis revealed that the SWS-NRS Total Score was useful for discriminating participants with impaired adaptive and intellectual functioning from those without impairment. Specifically, the area under the curve suggests adequate discrimination for intellectual functioning (Computed IQ: area under the curve, .79, $p < .05$) and adaptive functioning (SIB-R Broad Independence: area under the curve, .84, $p < .01$). With regard to intellectual functioning, sensitivity and specificity of the SWS-Total Score were maximized for screening purposes using a cut-score of SWS-NRS Total Score 4, with 75% sensitivity and 65% specificity. With regard to adaptive functioning, SWS-NRS Total Score sensitivity/specificity were maximized for screening purposes also using a cut-score of SWS-NRS Total Score 4, with 78% sensitivity and 73% specificity.

Discussion

The present study examined the intellectual and adaptive functioning in a sample of children and young adults with Sturge-Weber Syndrome (SWS). Questions regarding the intellectual and adaptive skill impact of SWS have been previously approached by way of a number of recruitment approaches, assessment methodologies, and historical time periods. The present study built upon the pre-existing SWS knowledge base, and sampled a cohort of individuals with SWS who received current and standard medical care. Much like previous studies of SWS and intellectual/adaptive skill functioning, the current study relied largely upon a sample that was clinically referred for neuropsychological evaluation. However, this study included a clinical comparison group receiving standard SWS medical care, with no identified demographic or neurological differences between those patients who did and did not receive a neuropsychological evaluation. As such, relative to previous studies, the current findings may be more representative of the current SWS population as a whole.

Within this context, approximately one third of the present sample displayed impaired intellectual functioning (32%), while another one third displayed intact intellectual functioning (36%), with the final third (32%) performing in a “borderline/low average” range. These findings are consistent with lower estimates from the range of impaired intellectual functioning documented in previous research (30-57%; Behan et al., 2011; Jagtap et al., 2012; Pascual-Castroviejo et al., 1993; Pascual-Castroviejo et al., 2008; Kramer et al., 2000). Similarly, the current findings are consistent with lower estimates from the range of intact intellectual functioning documented in past studies (33-54%; Behan et al., 2011; Jagtap et al., 2012; Pascual-Castroviejo et al., 1993; Pascual-Castroviejo et al., 2008; Kramer et al., 2000). In short, these data suggest a more conservative estimate of intellectual impairment in individuals with SWS (~one third), but also highlight a potentially expanding population of individuals with SWS who fall in the “borderline” and low-average ranges of intellectual ability.

In addition to the risks for intellectual difficulties, current findings suggest that the majority of individuals with SWS may display adaptive functioning difficulties. Specifically, parent report suggested evidence of adaptive impairment in 58% of this sample. Excluding a prior study performed on a subsample of the current research sample (Reesman et al., 2009), no other studies to our knowledge have evaluated adaptive functioning in this population. Thus, there is a limited context in which to place our findings, and future research studies will need to replicate current findings. Generally, current findings suggest that individuals with SWS may display intellectual and adaptive impairments, although adaptive impairments may be more prevalent. As demonstrated by Papazoglou and colleagues (2013), adaptive dysfunction has been linked with a variety of different potential underpinnings (e.g., executive dysfunction, externalizing and internalizing behavioral disorders, borderline intellectual functioning), over and above intellectual impairment. As such, it is not unexpected that estimates of adaptive dysfunction exceed those of intellectual impairment in this SWS sample. That said, parent report suggests adaptive dysfunction in close to 60% of the individuals with SWS included in this study. Early and periodic screening of adaptive functioning is critical in order to identify areas of difficulty and guide the implementation of subsequent accommodations (e.g., checklists/reminders for daily task completion, extra supports in school, vocational/career assistance) and interventions (e.g., occupational therapy, daily living skills training, cognitive rehabilitation).

Current findings identified the expected association between neurological and intellectual and adaptive functioning, reflecting the importance of understanding brain-behavior relationships in SWS. Specifically, both hemiparesis and seizure frequency together were associated with intellectual and adaptive functioning in this sample. Further, seizure frequency was independently associated with intellectual functioning while hemiparesis status was independently associated with adaptive functioning, consistent with prior research (Behan et al., 2011; Kramer et al., 2000; Reesman et al., 2009). It is hypothesized that seizure frequency may be predictive of intellectual functioning due to disruption posed to consistency of access to academic instruction as well as the shared underlying neurobiologic pathogenic mechanisms of seizures and intellectual abnormalities (Kanner et al., 2012; Lin et al., 2012). Similarly, it is hypothesized that hemiparesis may be predictive of adaptive functioning due to the disruption posed to day-to-day functional tasks as well as the

quantitatively significant brain insult (causing hemiparesis) in potentially qualitatively important neural regions for adaptive functioning (e.g., frontal lobes; Reesman et al., 2009).

Interestingly, younger individuals (< 6 years old) displayed significantly higher adaptive functioning than older individuals (≥ 6 years old) despite no apparent differences in neurological or cognitive functioning. As previously stated, there is not a research context for these findings. In our opinion, these findings may reflect multiple processes, such as the more attenuated functional expectations for children younger than 6 years old and/or the difficulty inherent in accurately assessing adaptive functioning in this younger group of individuals. Moreover, these findings may suggest a progressively revealed pattern of adaptive dysfunction that becomes more apparent over time as individuals with SWS fall “off track” with regard to adaptive functioning at some point in childhood. This may be due to increasing adaptive skill expectations presented over time, progressive deterioration of medical/neurological status, or a combination of both. Finally, it is possible that younger individuals have benefitted from advances in SWS-related medical care (e.g., introduction of aspirin into routine care), and have related preservation of adaptive functioning. However, these hypotheses are purely speculative and longitudinal research studies will provide clarity regarding the utility of current treatment approaches in preserving intellectual and adaptive functioning throughout the course of neurodevelopment.

Finally, we identified a SWS-NRS-Total Score of 4 as a cut-score with adequate sensitivity and specificity for discriminating impaired and non-impaired individuals with regard to both intellectual and adaptive functioning. From a clinical perspective, this finding holds potential utility for neurologists and others providing “front line care” of individuals with SWS, as it provides research support for the use of the SWS-NRS in predicting developmental outcomes and identifying individuals who may require additional and more specialized assessment and intervention.

This study had several notable limitations. The present study has a small sample size without a healthy control group to compare findings. Moreover, the age range of individuals included in the present sample was broad, including young children through adults. While both these limitations reflect the rarity of the condition, they limit the extent of conclusions that can be drawn. Emotional and behavioral functioning was not assessed in the current study and can have notable influences on intellectual test performance and adaptive rating scale scores. A lack of additional neuropsychological variables (e.g., memory) provides a limited understanding of the abilities of this population. Potential variability between verbal and performance intellectual scores may also limit the utility of interpreting overall intellectual findings. Future studies are encouraged to assess broader domains neuropsychological functioning in SWS while utilizing larger sample sizes and more constricted age ranges.

In conclusion, this study supports the following: Approximately 1/3 of patients with Sturge-Weber syndrome in this sample had impaired intellectual functioning (32%), with the overall mean for the sample in the “borderline impaired” range (mean IQ = 78.8). This is comparable to what has been recently reported in the literature, particularly compared to older studies. This suggests that in addition to improvements in overall medical outcomes, modern care and standard treatments for SWS (i.e., aggressive seizure management plus

low-dose aspirin) may have contributed to improved cognitive outcomes. Furthermore, these results support the use of the SWS-NRS as an effective screening tool in determining which individuals with SWS would be appropriate for neuropsychological evaluation. There appears to be a need to refer most of these patients for early neuropsychological evaluations in order to identify neuropsychological impairments and guide the implementation of appropriate accommodations and interventions.

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Table 1
Demographics and Mean Scores of SWS-NRS

Domain	Clinic Group (n = 51) Mean (SD)	NP Group (n = 29) Mean (SD)	% With Condition (n = 80)
% Female	49% (n = 25)	31% (n = 9)	-
Age at SWS-NRS	11.71 (9.167)	11.95 (8.86)	-
SWS-NRS			
Total	4.86 (3.08)	4.45 (2.90)	-
Seizures	1.76 (1.18)	1.45 (1.06)	91.2% (n = 73)
Hemiparesis	1.08 (1.25)	1.17 (1.23)	51.2% (n = 41)
Visual Field Cut	.61 (.83)	.28 (.59)	32.5% (n = 26)
Cognitive Function	1.41 (1.30)	1.55 (1.35)	66.2% (n = 53)

Note. NP = Neuropsychological Evaluation; SWS-NRS: Sturge-Weber Syndrome-Neurological Rating Score.

None significant at $p < .05$.

Table 2
Mean Scores of Intellectual and Adaptive Functioning

Domain	n	Standard Score Mean (SD)	Range (min-max)
Intelligence			
VIQ/VCI	25	80.76 (14.28) **	54-104
PIQ/PRI	27	76.22 (14.45) **	47-101
Computed IQ	25	78.80 (13.47) **	50-102
Adaptive Functioning			
SIB-R Broad Independence	24	79.75 (20.03) **	31-110
SIB-R Motor Skills	25	78.32 (18.46) **	43-111
SIB-R Social & Communication Skills	25	88.60 (21.69) *	23-126
SIB-R Personal Living Skills	25	87.92 (19.39) **	51-117
SIB-R Community Living Skills	25	78.40 (21.11) **	35-126

Note. VIQ/VCI = Verbal Intelligence; PIQ/PRI = Perceptual/Performance Intelligence; Computed IQ = Computed Overall Intelligence; SIB-R = Scales of Independent Behavior – Revised.

* $p < .05$;

** $p < .01$

Table 3
Group Demographic, Neurological, Intellectual, and Adaptive Differences Based on Age Group

Domain	n	< 6 Years (n = 9) Mean (SD)	6 Years (n = 20) Mean (SD)
% Female	29	56% (n = 5)	20% (n = 4)
Age at NPT	29	4.67 (.90)	15.94 (10.32) **
SWS-NRS			
Total	29	3.56 (2.13)	4.85 (3.15)
Seizures	29	1.44 (.53)	1.45 (1.23)
Hemiparesis	29	.89 (1.17)	1.30 (1.26)
Visual Field Cut	29	.00 (.00)	.40 (.68)
Cognitive Function	29	1.22 (1.20)	1.70 (1.42)
Intelligence			
VIQ/VCI	25	80.75 (12.65)	80.76 (15.36)
PIQ/PRI	27	76.63 (12.99)	76.05 (15.35)
Computed IQ	25	78.69 (11.38)	78.85 (14.68)
Adaptive Functioning			
SIB-R Broad Independence	24	93.43 (18.96)	74.12 (18.06) *
SIB-R Motor Skills	25	90.29 (14.21)	73.67 (18.11) *
SIB-R Social & Communication Skills	25	97.43 (19.79)	85.17 (21.94)
SIB-R Personal Living Skills	25	95.00 (25.45)	85.17 (16.54)
SIB-R Community Living Skills	25	92.43 (14.28)	72.94 (21.08) *

Note. NPT = Neuropsychological Testing; Sturge-Weber Syndrome-Neurological Rating Score. VIQ/VCI = Verbal Intelligence; PIQ/PRI = Perceptual/Performance Intelligence; Computed IQ = Computed Overall Intelligence; SIB-R = Scales of Independent Behavior – Revised.

*
p < .05;

**
p < .01.

Table 4
The Influence of Neurological Status on Intellectual Functioning

	R	Adjusted R²	β	<i>p</i>
Model	.539	.226		.023
SWS-NRS Seizure			-.388	.043
SWS-NRS Hemiparesis			-.334	.078

Note. SWS-NRS: Sturge-Weber Syndrome-Neurological Rating Score.

Table 5
The Influence of Neurological Status on Adaptive Functioning

	R	Adjusted R²	β	p
Model	.631	.341		.005
SWS-NRS Hemiparesis			-.557	.004
SWS-NRS Seizure			-.194	.278

Note. SWS-NRS: Sturge-Weber Syndrome-Neurological Rating Score.