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ORIGINAL RESEARCH

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Green light exposure in children with autism spectrum disorder: a pilot study

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Abstract

Children with autism spectrum disorder (ASD) are frequently afflicted with sensory processing difficulties, which often impact their ability to cooperate with dental treatment. The objective of this pilot study was to determine the effects of green light exposure on behavior, pain, distress and anxiety in pediatric patients with ASD undergoing a dental prophylaxis. Twelve children diagnosed with ASD, aged 6–17 years, requiring a dental prophylaxis participated in this study. Participants completed two dental prophylaxes, three months apart, one in a standard white light-exposed dental operatory and one in a green light-exposed dental operatory. Behavioral cooperation, pain intensity, physiological stress and anxiety were assessed in all patients. The Wilcoxon matched-pairs signed rank test was used to estimate differences in measured outcomes according to the experimental condition. There was a trend towards reduced uncooperative behavior when children received a dental prophylaxis in the green light-exposed operatory ($p = 0.06$). Similar levels of heart rate variability ($p = 0.41$), salivary alpha amylase ($p = 0.19$), and salivary cortisol ($p = 0.67$) were observed at the start and end of each visit in both conditions. Green light exposure had no significant effect on pain intensity ($p = 0.17$) or behavioral anxiety ($p = 0.31$). These findings suggest a preliminary positive benefit of green light exposure on behavioral outcomes in pediatric patients with ASD and warrants a further, large-scale clinical trial.

Keywords

Autism spectrum disorder; Green light; Anxiety; Pain; Stress

1. Introduction

Children with autism spectrum disorder (ASD) frequently exhibit uncooperative behavior during dental treatment which often impedes access to care. A previous national survey of general dentists demonstrated that patient behavior was the most significant barrier in their willingness to treat patients with special health care needs (SHCN), with over 60% of respondents stating that they would be unwilling to treat patients with developmental disabilities due to uncooperative behavior [1]. The majority of children with ASD exhibit behavior management challenges during dental treatment [2], including hyperactivity, decreased attention span, impulsivity and aggression [3]. Such behaviors may be the determining factor as to whether dental treatment can be rendered in the dental office or requires use of advanced behavioral strategies to facilitate dental work. Notably, advanced behavioral strategies such as general anesthesia have been reported to be utilized in up to 37% of patients with ASD [4].

An additional challenge in the dental management of patients with ASD is their likelihood to experience heightened levels of pain sensitivity. Over 80% of individuals with ASD experience sensory modulating disturbances [5], which are often associated with sensory and pain hypersensitivity to daily stimuli [6]. The sensory stimuli encountered in a standard dental environment, such as bright fluorescent lights, touch in or around the mouth, and taste and smell of dental products have the potential to produce high levels of sensory disturbances in patients with ASD, which may contribute to their heightened pain experiences during dental treatment. In fact, children with ASD who received dental cleanings in a sensory adapted dental environment (SADE) reported lower levels of pain intensity as compared to a regular dental environment [7]. A key feature included in the SADE is a modification to the visual sensory domain, typically in the form of turning off overhead fluorescent lights and applying darkening curtains to windows, in order to reduce sensory over-responsivity in patients with ASD.

Light therapy has been used to treat a variety of medical conditions, including depression [8, 9] and sleep disturbances [10, 11] in both pediatric and adult populations. In particular, green light exposure has been shown to improve pain and quality of life in patients with fibromyalgia [12] and chronic migraine [13]. Furthermore, green color exposure was shown to significantly reduce anxiety and pain during peripheral intravenous cannulation for sedation dentistry in adult patients

[14]. Green light has been shown to alter serotonin levels and stimulate the endogenous opioid system with an increase in enkephalins [15]. In preclinical studies, the effect of green light on the endogenous opioid system has been implicated in antinociception, anti-hyperalgesia and anxiolysis [16]. Therefore, green light exposure may help to reduce the sensory-aversive characteristics of a standard dental environment to improve behavior during dental care in children with ASD. This pilot study was designed to determine the effects of green light exposure during a dental prophylaxis in pediatric patients with ASD. We compared children's behavioral cooperation (the primary study outcome) in two conditions: a standard white light-exposed dental operatory and a green light-exposed dental operatory. Secondary outcomes included physiological stress, anxiety and pain. The null hypothesis was that there would be no difference in behavioral cooperation, physiological stress, anxiety, or pain when children with ASD underwent a dental prophylaxis in a green light-exposed dental operatory as compared to a standard white light-exposed dental operatory.

2. Materials and methods

2.1 Informed Consent

The details of the study, the procedures involved, and the risks and benefits associated with it were explained to the patient's parent/legal guardian. Electronic informed consent was obtained from each participant prior to participation. Upon completion of both study visits, participating families were provided a $100.00 compensation.

2.2 Setting and eligibility criteria

Inclusion criteria included children between the ages of 6 and 17, a documented American Society of Anesthesiologists (ASA) Classification of I or II, and a diagnosis of ASD by the patient's pediatrician and/or medical specialist. Children must have been registered patients at NYU Dentistry's Oral Health Center for People with Disabilities (OHCPD) on a three-month recall schedule. Thus, all eligible participants had previously received a dental prophylaxis at NYU Dentistry's OHCPD, and the research visit was not the child's first visit to the dentist. Excluded were children with an ASA Classification of III or higher, colorblindness, children with active carious lesions or children in active dental pain at the time of enrollment.

2.3 Study Design

This pilot study used a randomized counterbalanced study design (Fig. 1). Each child participated in two dental prophylaxes three months apart, per the child's regular dental recall schedule. Participants were randomized to their first assigned condition, either the white light-exposed dental operatory or the green light-exposed dental operatory. Both visits, each one hour in length, consisted of an oral examination, dental cleaning, and application of topical fluoride varnish. A single pediatric dentistry resident was the only practitioner providing the exam, cleaning, and application of fluoride varnish for both dental visits. An additional observing dentist was present throughout the entire study visit as an additional examiner for behavior and anxiety assessments. All study procedures were able to be completed in all participants with basic behavior guidance techniques (*e.g.*, distraction) without the need for advanced behavior guidance methods (*e.g.*, sedation, protective stabilization).

2.4 Treatment condition

All dental operatories located within NYU Dentistry's OHCPD feature color-tuned dimmable lighting, thus giving providers the ability to fully adjust the color of each operatory to green for the entire duration of the appointment (**Supplementary Fig. 1**). Therefore, all participants were exposed to green light for the full duration of the one-hour research visit. Each dental operatory is enclosed with a sliding door, thus preventing additional light from shining into the operatory.

2.5 Physiological stress measurements

A pulse oximeter (Handheld type, Aleshon America, Chino, CA, USA) was used to evaluate participants' heart rate as a proxy of physiological anxiety [17, 18]. The pulse oximeter was attached to the participants' left index finger and the pulse rate was recorded at the beginning and end of each visit. In order to assess physiological stress in participants [19], saliva was collected at the beginning and end of each visit and salivary cortisol and amylase (AMY1) levels were measured by enzyme-linked immunosorbent assay (ELISA). Salivary cortisol and AMY1 levels have previously been utilized to measure the stress responses of children with ASD [20].

2.6 Saliva collection

Approximately 500 microliters of saliva were collected from the buccal vestibule of all participants at the start and end of each visit using disposable graduated transfer pipettes (Thermo Fisher Scientific, Waltham, MA, USA). Saliva was collected into 15 mL conical sterile polypropylene centrifuge tubes (Thermo Fisher Scientific, Waltham, MA, USA) and placed immediately on ice.

2.7 Saliva sample preparation

Saliva samples were stored at −80 °C. On the day of the assay, samples were thawed, and centrifuged for five minutes at 10,000×g. The supernatant was recovered and assayed immediately or aliquoted and stored at −20 °C.

2.8 Salivary cortisol ELISA and analysis

Cortisol concentration in saliva was measured by ELISA (Abnova, Taipei City, Taiwan) following the original users' manual. Briefly, the microplate wells of the kit are pre-coated with a polyclonal rabbit antibody directed against cortisol (PA1-85347, Thermo Fisher Scientific, Waltham, MA, USA). Standards and samples are added with cortisol conjugated to horseradish peroxidase (31490, HRP, Thermo Fisher Scientific, Waltham, MA, USA). The competitive inhibition reaction is launched between cortisol conjugate and cortisol present in the samples. Unbound conjugate and sample are washed

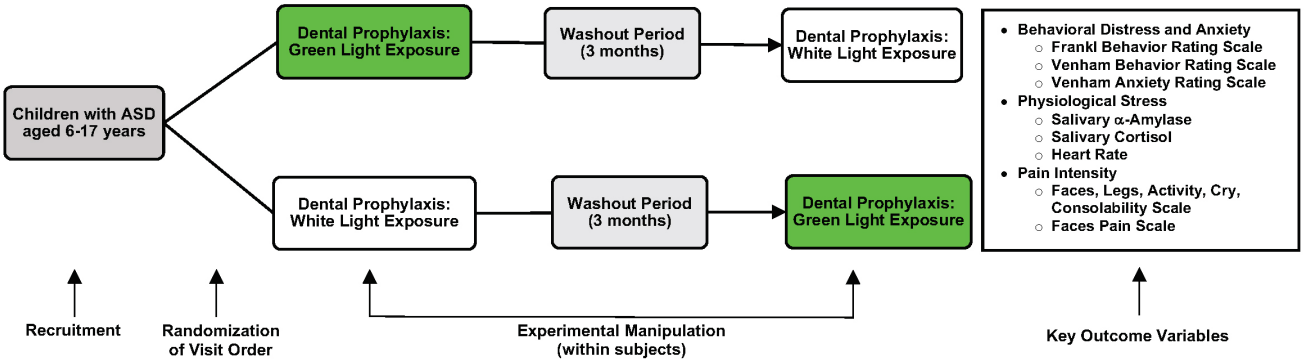

FIGURE 1. Overview of study design. ASD: autism spectrum disorder.

away. Then, the substrate is added, and the color develops in opposition to the unknown amount of cortisol present in the sample. The color development was stopped, and the absorbance was measured with CLARIOstar Plus microplate reader (BMG LABTECH, Ortenberg, Germany) at 450 nm. The calibration curve was derived based on standards. The detectable range was between 0.1 and 30 ng/mL. The assay sensitivity was 0.019 ng/mL, and the assay dynamic range was 0.1–30 ng/mL. An average of duplicate readings for each standard and sample was used for the analysis. The standard curve was generated using a sigmoidal four parameter logistic (4-PL) curve-fit, and cortisol concentration of samples was interpolated. Data is reported as ng/mL.

2.9 Salivary AMY1 ELISA and analysis

Salivary AMY1 concentration in saliva was measured by ELISA (Novus Biologicals, Centennial, CO, USA) following the original users' manual. Briefly, the microplate wells of the kit are pre-coated with an antibody specific to human AMY1 (PA1-85176, Thermo Fisher Scientific, Waltham, MA, USA). Standards and samples are added. Then, a biotinylated detection antibody specific for human AMY1 and avidin conjugated HRP were added. Unbound antibody, conjugate and sample are washed away. Substrate solution is added, and the color develops proportionally to the unknown amount of human AMY1 present in the sample. The color development was stopped, and the absorbance was measured with CLARIOstar Plus microplate reader (BMG LABTECH, Ortenberg, Germany) at 450 nm. The calibration curve was derived based on standards. The detectable range was between 1.56 and 100 ng/mL. The assay sensitivity was 0.94 ng/mL, and the intra-assay coefficient of variation was $<10\%$. An average of duplicate readings for each standard and sample was used for the analysis. The standard curve was generated using a 4-PL curve-fit, and AMY1 concentration of samples was interpolated. Data is reported as μg/mL.

2.10 Behavior and anxiety assessments

The Frankl Behavior Rating Scale (FBRS), Venham Behavior Rating Scale (VBRS), and Venham Anxiety Rating Scale (VARS) were completed at the end of each visit by the treating pediatric dentistry resident and an additional observing dentist who was present in the operatory throughout the exam, cleaning, and application of fluoride varnish. Both the pediatric dentistry resident and the additional observing dentist were calibrated for consistent scoring of the FBRS, VBRS and VARS prior to initiation of the study. The final score used in analysis for each assessment was the average of both scores recorded by the pediatric dentistry resident and the additional observing dentist. Both the FBRS and VBRS were used to measure behavioral cooperation in participants. The FBRS is a one-item Likert Scale ranges from 1 (definitely negative) to 2 (negative) to 3 (positive) to 4 (definitely positive) [21]. The VBRS is a measure of uncooperative behavior designed to assess children's response to dental stress [22]. The VBRS is a five-level scale ranging from "total cooperation" (score of 0) to "general protest, no compliance, or cooperation" (score of 5). Participants' anxiety was assessed by the VARS, a validated instrument that assigns numerical values to observable behaviors associated with anxiety [23]. The scale consists of five behaviorally defined categories ranked by severity ranging from 0 (relaxed) to 5 (out of contact). The FBRS [24], VBRS [25] and VARS [25] all have high inter-rater reliability and have been used to measure behavior and anxiety of children with ASD.

2.11 Pain assessment

The Faces Pain Scale-Revised (FPS-R) was completed by the parent to evaluate pain in their child and the Revised-Face, Legs, Activity, Cry and Consolability Scale (r-FLACC) was completed by both the treating pediatric dentistry resident and the observing dentist to evaluate pain in the patient. The FPS-R is a validated self-report tool for children measuring pain intensity [26], but it also has been previously adapted for parental use as an observational pain measurement tool [27]. The FPS-R consists of six horizontally positioned faces, representing increasing levels of pain from left ("no pain") to right ("very much pain"), scored as 0–2–4–6–8–10. Parents were asked to point out the face that best reflects their child's pain at the end of each visit. The r-FLACC is tailored to assess pain in patients with developmental delays, intellectual disabilities, and cognitive impairments [28]. Pain intensity with the r-

FLACC is measured on a 3-point ordinal scale (0–2) for five categories; each category includes a description of behaviors to guide scoring the category from 0 to 2 (*i.e.*, no cry = 0, moans = 1 and screams = 2). With the r-FLACC, the evaluator can add unique, descriptive behaviors that represent moderate to severe pain in the subject; these added descriptions are scored as "2" within the 0–2 scoring range. The pediatric dentistry resident and the additional observing dentist completed the r-FLACC at the end of each visit to measure pain intensity in all participants. Both the pediatric dentistry resident and the additional observing dentist were calibrated for consistent scoring of the r-FLACC prior to initiation of the study. The final score used in analysis for the r-FLACC was the average of both scores recorded by the pediatric dentistry resident and the additional observing dentist.

2.12 Statistical analysis

Sample size was determined using the G*Power software (Version 3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). The required sample size to achieve power of 80% in a 2-tailed *t*-test with a type 1 error rate of 5% was 11. Thus, the obtained final sample size of 12 in the current pilot study was adequate to test the study hypothesis. Statistical analysis was performed using GraphPad Prism (Version 10.0.2, Boston, MA, USA). Descriptive statistics including means with standard deviations (SD), medians, ranges and percentages were calculated. All data were tested for normal distribution and for homogeneity of the variances. For data recorded on a continuous scale (*e.g.,* heart rate, salivary cortisol and salivary AMY1), mean ± SD was calculated, and groups were compared using a two-way repeated measures analysis of variance to assess the effects of treatment and time. For ordinal data obtained *via* assessment forms, median anxiety, behavior and pain scores (with the interquartile ranges) were calculated, and the Wilcoxon matched-pairs signed rank test was used to estimate differences in anxiety, behavior, and pain scores according to the experimental condition. All statistical outcomes are summarized in **Supplementary Tables 1,2**. A p-value < 0.05 was considered statistically significant.

3. Results

3.1 Patient characteristics

16 children were recruited into the study, but four (25%) did not return for the second visit and thus were not included in the analysis. Table 1 shows the demographic characteristics of the participants. The final sample consisted of 12 children, 11 (91.7%) of whom were male. Enrolled participants ranged in age from 7 to 14 years with a mean (SD) of 10.5 (2.2) years. Most participants identified as Black (41.7%) or White (16.7%). Another 8.3% identified as Asian or Pacific Islander, but many (33.3%) identified as Other or Unknown. The majority identified as non-Hispanic (75%). Although participants were randomly allocated into treatment arms using the randomization module in REDCap, an uneven distribution into the treatment arms resulted in three participants receiving the control condition first and nine participants receiving the treatment condition first. Results were visually inspected for evidence of carryover effect and period effect; none of the results demonstrated any overt carryover effect.

TABLE 1. Demographic characteristics of study participants.

Age (Mean (SD))	
10.5 (2.2)	
Demographic	Frequency n (%)
Sex	
Male	11 (91.7)
Female	1 (8.3)
Ethnicity	
Hispanic	3 (25.0)
Non-Hispanic	9 (75.0)
Race	
Black	5 (41.7)
White	2 (16.7)
Asian or Pacific Islander	1 (8.3)

SD: standard deviation.

3.2 Physiological stress measurements

Fig. 2 shows the results of physiological stress parameters measured in all participants at the start (*i.e.*, pre- dental prophylaxis) and end (*i.e.*, post- dental prophylaxis) of each visit. Heart rate was similar at the start and end of each visit in both conditions in all participants (Fig. 2A), and was not modified by treatment (p = 0.41). Similarly, there was no significant difference in the concentration of salivary cortisol (Fig. 2B, time p = 0.20) or salivary AMY1 (Fig. 2C, time p = 0.21) in participants at the start and end of each visit, and this was not modified by the treatment condition (cortisol, p = 0.67; AMY1, p = 0.19). Descriptive statistics and results are presented in **Supplementary Table 1**.

3.3 Behavioral cooperation and anxiety assessments

Fig. 3 shows the behavior and anxiety scores of all participants as measured by the FBRS (Fig. 3A), VBRS (Fig. 3B), and VARS (Fig. 3C). No statistically significant effects of treatment condition were observed on behavior scores as measured by the FBRS (p = 0.18). There was a trend towards reduced uncooperative behavior by the VBRS when children received a dental prophylaxis in the green light-exposed dental operatory (p = 0.06). Although statistically significant differences were not detected between control and treatment scores, the difference plots suggest that the majority of participants showed improved behavior during a dental prophylaxis in the treatment condition compared to the control setting (FBRS, 58.3%; VBRS, 41.7%). Notably, when receiving a dental prophylaxis in the green light condition, only two participants (16.7%) received lower behavior scores on the FBRS and zero participants received higher behavior scores on the VBRS,

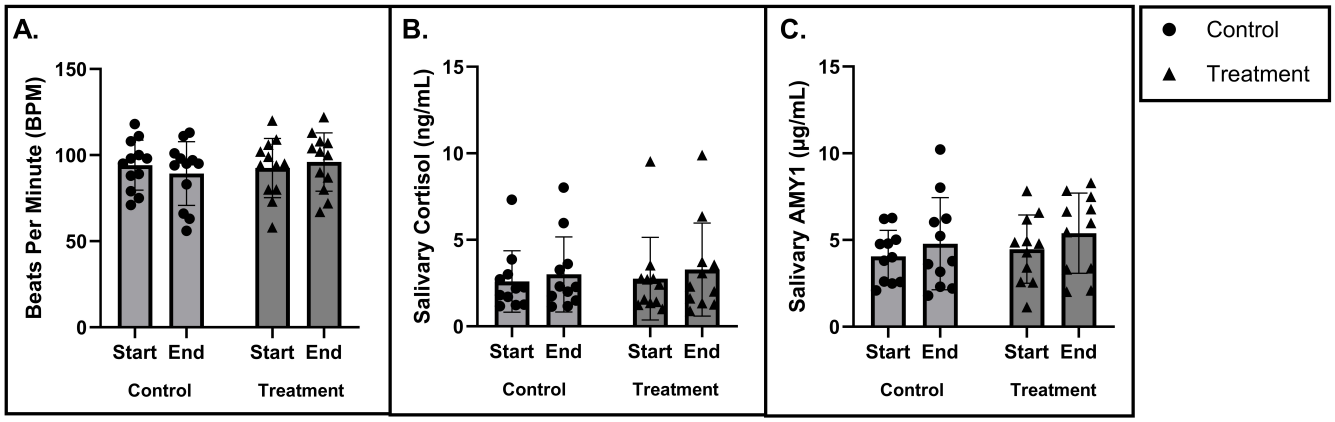

FIGURE 2. Physiological stress measurements taken at the start (*i.e.*, prior to dental prophylaxis) and end (*i.e.*, after dental prophylaxis) of each visit. (A) represents heart rate as measured by pulse oximetry in all participants. Concentration of salivary cortisol (B) and salivary amylase (C) as measured by enzyme-linked immunosorbent assay are shown. N = 12. Bars represent mean and standard deviation.

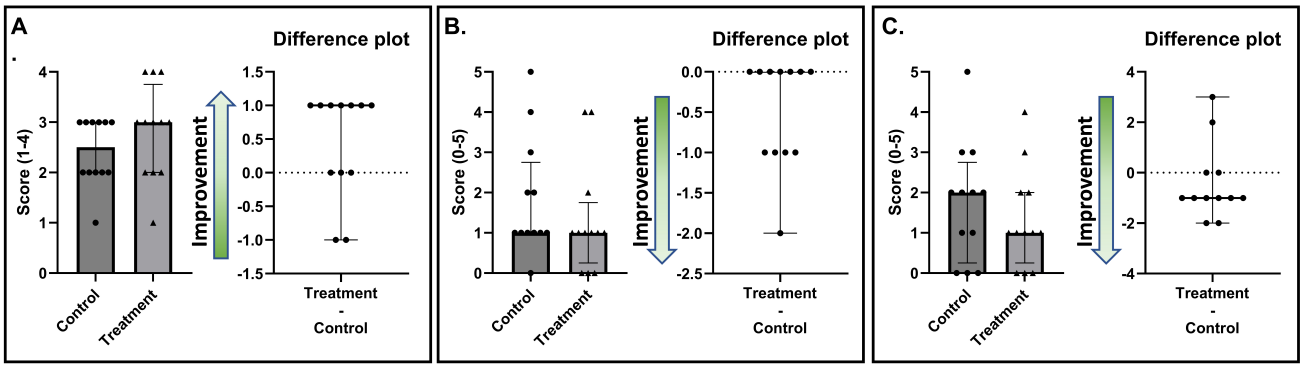

FIGURE 3. Behavioral cooperation and anxiety measured in all participants when receiving a prophylaxis in the control condition (*i.e.*, white light-exposed dental operatory) and treatment condition (*i.e.*, green light-exposed dental operatory). (A) represents behavior scores as measured by the Frankl Behavior Rating Scale. Behavioral cooperation (B) and anxiety (C) were assessed using the Venham Behavior Rating Scale and the Venham Anxiety Rating Scale, respectively. Difference plots suggest the difference in score for an individual participant under treatment versus control conditions, where the line at 0 suggests no change in score. Bars suggest median and interquartile range. N = 12. *p*-values suggest results from the Wilcoxon matched-pairs signed rank test. Direction of arrow indicates improvement in behavior or anxiety score.

suggesting a worsening in behavior. The VARS did not detect any significant differences between the control and treatment conditions ($p = 0.31$). However, the majority of participants (66.7%) showed less anxiety when receiving a dental prophylaxis in the green light condition. Descriptive statistics and results are presented in **Supplementary Table 2**.

3.4 Pain intensity measurements

Fig. 4 shows the pain intensity scores of all participants as measured by the R-FLACC (Fig. 4A) and the FPS-R (Fig. 4B). Statistical analysis detected no significant differences in pain intensity between the two treatment conditions when evaluated by the treating pediatric dentistry resident and additional observing dentist with the R-FLACC ($p = 0.17$) or when assessed by the parent with the FPS-R ($p = 0.50$) at the end of each visit. The difference plots for R-FLACC, assessing the difference for the two treatment settings for the individual participants, suggest that most children (66.7%) exhibited lower pain intensity after receiving a dental prophylaxis in the green light condition as compared to the control condition.

4. Discussion

The results of this randomized, counterbalanced clinical pilot study showed a trend towards reduced uncooperative behavior when children received a dental prophylaxis in a green light-exposed dental operatory, compared to a standard dental environment (*i.e.*, white light-exposed dental operatory). Green light exposure had no statistically significant effect on physiological distress, anxiety or pain intensity in children with ASD undergoing a dental prophylaxis. Accordingly, the null hypothesis was partially rejected because a trend towards reduced uncooperative behavior was observed in the treatment condition.

Children with ASD often present with impairments in com-

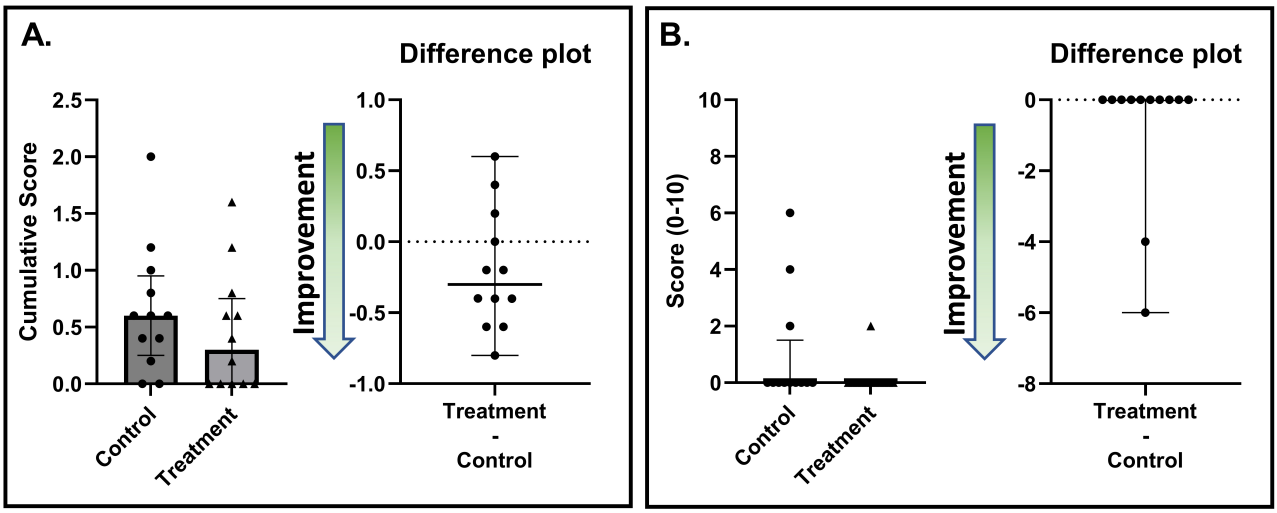

FIGURE 4. Pain intensity scores evaluated by the dentist and the parent in all participants when receiving a dental prophylaxis in the control condition (*i.e.*, white light-exposed dental operatory) and treatment condition (*i.e.*, green light-exposed dental operatory). (A) represents pain intensity scores evaluated by the treating pediatric dentistry resident and an additional observing dentist with the Revised-Faces, Legs, Activity, Cry and Consolability Scale. (B) shows pain intensity scores assessed by the parent with the Faces Pain Scale-Revised. Difference plots suggest the difference in score for an individual participant under treatment versus control conditions, where the line at 0 suggests no change in score. N = 12. Bars suggest median and interquartile range. *p*-values suggest results from the Wilcoxon matched-pairs signed rank test. Direction of arrow indicates improvement in pain score.

munication, difficulties or irregularities in social interactions, and repetitive behaviors, which can create significant barriers to tolerating in-office dental care. Despite the remarkable increase in the prevalence of ASD (1 in 36 children) over the past decade [29], there are few clinical dental protocols designed specifically to meet the unique needs of pediatric patients with ASD [30]. Although a dental prophylaxis is not considered to be an anxiety- or pain-provoking procedure in neurotypical populations, it still stimulates sensory stimuli across all sensory modalities (touch, oral, light, taste, smell, movement, sound and vibration) [7]. As a result, these stimuli often produce high levels of sensory disturbances in children with ASD, which has been associated with behavioral and physiological distress, pain and anxiety [7]. Therefore, the current study chose to focus on a dental prophylaxis due to procedure's previously reported effects on behavior, pain, distress, and anxiety in children with ASD. Furthermore, the majority of children with ASD are unable to tolerate more invasive (*i.e.*, operative) dental procedures in-office due to developmental and/or behavioral impairments [31], thus limiting the nature of the procedure type that could be utilized in the current study.

One of the biggest challenges for dentists when treating pediatric patients, especially those with SHCN such as ASD, is managing behavior and anxiety. The American Academy of Pediatric Dentistry offers recommendations on behavior guidance to inform healthcare providers, parents, and others with information for predicting and guiding behavior in children during dental procedures [32]. However, many of the basic behavior guidance techniques, such as tell-show-do and ask-tell-ask, are based on communication and communicative guidance. Due to impairments with language and expression, these behavior guidance strategies often have limited efficacy for children with ASD. Therefore, alternative methods of managing behavior in patients with ASD are necessary to facilitate effective dental treatment in-office without employing advanced behavioral guidance strategies (*e.g.*, general anesthesia). A notable finding in the current study was that children who received a dental prophylaxis in a green light-exposed dental operatory showed a trend toward reduced uncooperative behavior when assessed by the VBRS. The lack of significant changes in behavior when measured by the FBRS may be due to a lack of sensitivity of this measure to assess change. The VBRS is a validated clinical instrument for assessing children's behavioral responses to dental stress, and the behavioral definitions used in the VBRS more accurately capture the essence and variable manifestations of "uncooperative behavior" in pediatric patients compared to the FBRS [22]. Despite a lack of statistical significance between treatment and control conditions for behavior and anxiety, the improvements in behavioral cooperation and anxiety scores for the individual patients still suggest that green light exposure may have beneficial effects for the majority of pediatric patients with ASD.

From a clinical standpoint, the trend toward reduced uncooperative behavior when children received a dental prophylaxis in the green-light exposed operatory has significant potential implications. Because patient behavior is cited as the greatest barrier in dentists' willingness to treat patients with SHCN [1], improved cooperative behavior through green light exposure may increase access to care for pediatric dental patients with ASD. Furthermore, dental treatment may become safer for children if there is a reduction in the use of general anesthesia, which is used more frequently when children are

not cooperative for dental treatment [4]. Additionally, the need for restraint (*i.e.*, protective stabilization) during dental treatment may also be reduced if children exhibit more cooperative behavior. Notably, restraint is used in children with ASD 18–33% of the time [7], and the majority of parents of children with ASD do not consider restraint to be an acceptable behavior guidance technique [24]. When interpreting the behavior results and their implications, a natural limitation to consider is the small sample size due to the pilot nature of the study. A larger sample size of adequate power in future studies will allow researchers to better understand the effects of green light exposure on behavioral cooperation, and which subgroups of children with ASD will benefit best from such intervention.

Although overt behavioral displays of distress have been previously assessed in children with SHCN, few studies have investigated the physiological stress and anxiety experienced by pediatric patients with ASD during dental treatment. Since many children with ASD have impairments in social communication and limited expressive language skills, it is especially difficult for healthcare providers to assess stress and anxiety in this population due to their difficulty describing their feelings and emotions. Therefore, it is clinically useful to utilize an objective tool to measure children's physiological experience as an alternative way of recognizing stress and anxiety in this population. In the current study, physiological stress was measured at the start and end of each visit by salivary AMY1 and heart rate, markers for sympathetic nervous system (SNS) activity, and salivary cortisol, a measure for activity of the hypothalamic-pituitary-adrenal (HPA) axis. Although there were no significant differences in the physiologic parameters measured in the current study, previous clinical reports have suggested that children with sensory processing difficulties are physiologically different than neurotypically-developing children on measures of SNS activity [33] and HPA axis regulation [34]. Thus, conventionally used clinical tools for measuring physiological stress and anxiety may not accurately reflect the physiological differences inherent in children with ASD. Moreover, previous studies suggest that individuals with ASD have difficulty modulating their physiological responses accordingly to a stressful event [35]; therefore, failure to adapt physiological responsiveness may explain the lack of statistical significance in the stress measurements observed in the current study. An alternative explanation for the lack of difference in physiological stress parameters is that the length of green light exposure was not adequate enough to elicit a neuroendocrine response that could be measured by the current methods. Therefore, future research should focus on optimizing the length of the intervention's exposure along with identifying additional clinical tools to better measure physiological stress and anxiety specifically in patients with ASD and other sensory processing disorders.

Despite previous clinical reports suggesting that exposure to green light reduces pain intensity in patients [12, 13], the current study's findings demonstrated similar pain scores in patients when receiving a dental prophylaxis in either the control or treatment condition. It is important to note that patients in the previous studies were exposed to green light emitting diodes for 1–2 hours daily for 10 weeks [12, 13]; therefore, it is possible that the length of time patients were exposed to green light in the current study was not sufficient to elicit a reduction in pain intensity. Additionally, a lack of sensitivity associated with the FPS-R tool for assessing pain may have contributed to the lack of significant differences between control and treatment conditions, which is supported by previous studies [36]. Therefore, it would be beneficial for future studies to utilize alternative methods of evaluating pain intensity in children with ASD, such as utilization of pain drawings. Although not statistically significant, it is important to note that the majority of patients in the current study exhibited lower pain intensity after receiving a dental prophylaxis in the green light-exposed dental operatory as compared to the control setting. Therefore, future studies with a larger sample size may have adequate enough power to detect a statistically significant difference between the control and treatment conditions.

There are several primary areas to investigate in future research of green light exposure. First, it will be important to examine whether green light exposure may also be helpful for children with other SHCN that exhibit sensory over-responsivity, such as Fragile X Syndrome [37], attention deficit hyperactivity disorder [38], and developmental coordination disorder [39], in addition to typically developing children with sensory sensitivities. Second, more reliable objective measures of physiological stress and anxiety, such as electrodermal activity (EDA), should be included when evaluating the efficacy of green light exposure. EDA reflects the skin conductance of the palmar sweat glands controlled by the SNS, and EDA readings are known to increase in stressful or painful situations [7]. Due to the non-invasive nature of the technique, EDA could feasibly be utilized in ASD populations and has successfully been used in prior studies [7]. Last, it will be essential to examine additional relevant clinical outcomes for patients with sensory processing difficulties, such as level of sensory discomfort.

The present study had several limitations. 16 participants were enrolled in the study but only 12 children completed both visits. Although trends were evident within the data, a larger sample size would allow for more discernable differences between the control and treatment conditions. Therefore, the current study's results are not reliable enough to draw definitive conclusions. Future clinical studies with a larger, appropriately powered sample size could address this limitation. Additionally, due to the nature of the study, it was not possible to blind the raters to the green light for the treatment condition. Moreover, the patient population in this study was confined to those receiving a dental prophylaxis, which limits the generalizability of the findings to other types of dental treatment which may be more invasive. To address this, future studies should focus on additional dental procedures that could feasibly be completed in office on children with ASD, such as sealant placement. Lastly, this study was limited to the population treated at NYU Dentistry's OHCPD and did not capture patients who received dental care at other external sites, where the clinical management of patients, especially those with SHCN, may be different. Future studies may consider implementing the green light intervention into multiple types of clinical practice modalities (*e.g.,* academia, private practice, state health department) in order to examine

its effects. Despite these limitations, the study's findings suggest that green light exposure has the potential to reduce uncooperative behaviors in children with ASD, which may increase access to care and lead to the facilitation of improved healthcare outcomes.

5. Conclusions

Green light exposure during a dental prophylaxis may help to reduce uncooperative behavior in children with ASD. As uncooperative behavior is the most commonly reported barrier for treating children with ASD [1, 31], the use of green light exposure during dental treatment is a potential technique to increase successful outcomes for this vulnerable patient population, thus increasing access to care. Despite the pilot nature of this study, the current findings made it possible to examine trends, draw potential clinical implications, and support future studies with an appropriately powered sample size.

ABBREVIATIONS

AMY1, amylase-1; ASA, American Society of Anesthesiologists; ASD, autism spectrum disorder; ELISA, enzyme-linked immunosorbent assay; FBRS, Frankl Behavior Rating Scale; FPS-R, Faces Pain Scale-Revised; HPA, hypothalamic-pituitary-adrenal; NYU, New York University; OHCPD, Oral Health Center for People with Disabilities; R-FLACC, Revised-Faces, Legs, Activity, Cry and Consolability Scale; SADE, sensory adapted dental environment; SHCN, special health care needs; SD, standard deviation; SNS, sympathetic nervous system; VARS, Venham Anxiety Rating Scale; VBRS, Venham Behavior Rating Scale.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

CMS, RK and SDW—designed the research study. CMS and SDW—performed the research. CMS, PD and SH—analyzed the data. CMS—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of New York University (s21-01589, 01 January 2023). Informed consent was obtained from the legal guardian of all subjects involved in the study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jocpd.com/files/article/1808369158223478784/attachment/Supplementary%20material.docx.

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