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Effect of Positive Airway Pressure Therapy in Children with OSAS: Does PAP Use Reduce Pedestrian Injury Risk?

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Abstract

Introduction: Treatment with Positive Airway Pressure (PAP) therapy reduces injury risk among adults with OSAS, but the effect of PAP therapy on children's injury risk is unknown. This study investigated whether treatment of OSAS with PAP reduces children's pedestrian injury risk in a virtual reality pedestrian environment (VRPE).

Methods: 42 children ages 8–16 with OSAS were enrolled upon diagnosis by polysomnography. Children crossed a simulated street several times upon enrollment, prior to PAP treatment, and again after 3 months of PAP therapy. Children underwent sleep studies at both timepoints.

Results: Children adherent with PAP had a significant reduction in hits by a virtual vehicle ($p<.01$) and less time to contact with oncoming vehicles ($p<.01$) following treatment. Those who were non-adherent did not show improved safety. There was no change in attention to oncoming traffic.

Conclusions: OSAS may have significant consequences on children's daytime functioning in a critical domain of personal safety, pedestrian skills. In pedestrian simulation, children with OSAS adherent to PAP therapy showed improvement in pedestrian safety and had fewer collisions with a virtual vehicle following treatment. Results highlight need for heightened awareness of the real-world benefits of treatment for pediatric sleep disorders.

Keywords

pedestrian safety; children; injury risk; obstructive sleep apnea syndrome; PAP

Annually, 6300 American pedestrians are killed and 190,000 others are injured, and a disproportionate number of injured and killed pedestrians are children.[1] Not surprisingly, prevention of pediatric pedestrian injury is targeted as a national public health priority.[2]

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Many factors contribute to unintentional pedestrian injury. Among them are cognitive skills of the pedestrian, including reaction time, impulsivity, risk-taking, attention, and decision-making.[3,5,6] These same characteristics that influence pedestrian safety are negatively influenced by sleepiness, both from sleep deprivation/insufficient sleep and from sleep disorders such as obstructive sleep apnea syndrome (OSAS).[7–13]

OSAS is a common pediatric sleep-related breathing disorder, with estimated prevalence of 1–5% among non-obese children and 25–40% among obese children.[14,15] In adults, OSAS has negative consequences on mood and behavioral regulation and also on neurocognitive functioning, including vigilance, attention, problem solving, and visual and motor functioning.[16,17] Adults with OSAS are at high risk for human error and mental inefficiency, and are more likely to have inattention, risk taking, and daytime sleepiness resulting in motor vehicle crashes and occupational injury.[6–8,16–18]

The standard treatment for adult OSAS is positive airway pressure therapy (PAP).[19–21]PAP consists of patients wearing a mask interface covering the nose or nose and mouth connected to a machine by a tube. The machine blows a determined amount of pressure into the airway functioning as a “stent” to keep the airway patent. There is evidence that treatment of adult OSAS with PAP improves attention, cognitive functioning, sleepiness, and reduces the risk of motor vehicle crashes.[22–25] However, the effect of PAP in children with OSAS who are not yet old enough to drive, and thus engage in traffic primarily as pedestrians, is unknown.

Pedestrian behavior, although enacted subconsciously by most adults, is a highly complex cognitive and perceptual task. A safe pedestrian must simultaneously process several pieces of information, interpret their meaning, and make a decision to cross the street when a safe opportunity arises. These tasks must occur very quickly. Impulse control, attention and reaction time are cognitive skills still developing among children that may impact pedestrian safety,[3–5,26–27] and these same cognitive impairments are reported among children with untreated OSAS who engage in laboratory tasks and questionnaires.[9–12,28] Thus, children with OSAS may have deficits in pedestrian safety. In fact, previous research suggests children with OSAS were at higher risk for pedestrian injury than healthy peers of the same age, race, gender, and estimated household income.[29] The present study was designed to extend that result by testing whether treating OSAS may improve pedestrian safety among children with OSAS.

Specifically, we recruited children with OSAS to engage in a virtual reality pedestrian environment in two conditions: when OSAS was initially diagnosed but untreated and after OSAS was controlled for 3 months using treatment with PAP. We hypothesized children with OSAS would be safer pedestrians after adhering to treatment with PAP versus when untreated or after non-adherent treatment.

METHODS

Participants and Recruitment.—Using a within-subjects design, forty-two 8- to 16-year-olds with OSAS were enrolled. Diagnosis and recruitment occurred in the Pediatric Sleep Disorders Center at Children’s of Alabama the morning following a diagnostic sleep study. All participating children met International Classification of Sleep Disorders-2 diagnostic criteria for OSAS based on diagnostic assessments that included nocturnal polysomnography (NPSG) using Sandman 9.2 technology software (Embla, Broomfield, CO) and thorough clinical evaluation from one of two attending board-certified sleep specialists early in the morning after the overnight NPSG. Standard polysomnography consisted of electroencephalogram, electromyogram, electrooculogram (right, left), arterial oxygen saturation (Sao2) oximeter pulse wave form, and end-tidal carbon dioxide tension, nasal pressure monitoring, oronasal flow using thermistor, and thoracic and abdominal wall motion. Standard pediatric scoring was used for respiratory events.[30] Diagnosis of OSAS was defined as having an apnea/hypopnea index (AH) I≥1.5 per hour.[31–34] All children were treated with continuous PAP (CPAP) rather than Bilevel PAP (BPAP). Exclusion criteria for the clinical sample included cognitive or physical disabilities that prevented participation in the experimental protocol (e.g., mental retardation, blindness, use of a wheelchair); comorbid medical or neurologic conditions; or antipsychotic medication use. No children were excluded.

General Procedure.—We recruited to the study children diagnosed with OSAS requiring and naïve to PAP therapy. As part of routine care, PAP was prescribed 1) after surgical intervention (tonsillectomy/adenoidectomy), follow-up sleep study determined OSAS was still present or 2) at the diagnostic study when surgical intervention was not an option (i.e., surgery was done at any point prior to initial sleep study and no regrowth of tonsillar/adenoidal tissue has occurred, persistent OSAS likely due to obesity). Following PAP prescription, an initial research visit was scheduled that included informed consent procedures and evaluation in the pedestrian virtual reality environment.

Following the initial research appointment, the family returned to the Pediatric Sleep Disorders Centers for routine care, which consisted of: 1) PAP education, 2) behavioral techniques to aid in adjusting to PAP regimen, and 3) meeting with a home durable equipment representative who fit the child for an appropriate face mask and provided the PAP machine to the family. The child practiced for 1 week to adjust to the new regimen. One week after the baseline visit, children returned to the sleep lab for an overnight sleep study to titrate their PAP to the optimal pressure according to titration manual guidelines. After 3 months of use of PAP at home, the family returned for a post treatment overnight sleep study (conducted while the child was wearing the PAP) to document use of and adequate control of OSAS with PAP and to obtain an objective check of adherence from a downloadable card housed in the machine. The morning following the final overnight visit, the family completed a second research appointment evaluating pedestrian safety in the virtual reality environment; this occurred after 3 months treatment of PAP.

Measures:

Adherence.—Our objective was to evaluate injury outcomes in participants who were adherent. Adherence was monitored with downloadable computerized usage meters in the PAP machine that document hours of usage each night. Following standard practice in the literature, the minimal criterion for category of “adherent” was greater than or equal to average of 4 hours usage per night.[35–36]

Sleepiness.—To verify sleepiness, we sampled level of sleepiness using the Epworth Sleepiness Scale modified for children.[37] The Epworth Sleepiness Scale assesses daytime sleepiness, and is modified for children to rate the propensity to fall asleep in 8 situations in which a child may be likely to fall asleep.[9] Response options are "would never doze," slight chance of dozing," "moderate chance of dozing," and "high chance of dozing." The questionnaire, originally designed for adults, is used in studies with children with OSAS with slight variations in terminology on two questions: (a) the mention of alcohol is removed in question 7 and (b) question 8 was modified to indicate the child is a passenger in a car.[9]

Virtual Reality Pedestrian Environment.—Details of the virtual reality pedestrian environment (VRPE), including validation data demonstrating behavior in the virtual world corresponds with behavior in real pedestrian environments among both children and adults, are available elsewhere.[26] Briefly, the environment has demonstrated convergent, internal, and face validity and has been used in several studies showing impaired pedestrian behavior under a variety of conditions and situations among both children and adults.[3,26,38]

While participating in the virtual environment task, children stood on a wooden simulated curb and viewed the virtual pedestrian environment on three consecutive monitors arranged in a semicircle in front of them. Children were immersed in the virtual environment as they watched vehicles pass bidirectionally on the screens and heard environmental and traffic noise through speakers in the room. After deciding it was safe to cross, they stepped off the curb onto a pressure plate connected to the computer and a gender-matched avatar was then activated to cross the street. The avatar's walking speed in the VRPE matched children's walking speed, which was evaluated prior to the VPRE task in a separate location. If the avatar safely reached the other side, children heard one of two positive messages such as "Yes! Great job!" If the child made it across safely but was close to being hit by a car, the child heard, "Whoa! That was close!" If the child was struck by one of the cars, they heard, "Uh oh, you should try that again." Thus, the child was immersed into a virtual world while deciding when it was safe to cross. After choosing to cross, the world became third-person, and the child witnessed the safety (or danger) of the crossing. During the experimental visits, children performed 10 practice trials to reduce learning effects and then engaged in 12 virtual street crossings. Behavior in the 12 crossings was used for analysis.

Measures of Crossing Behavior.—We considered three pedestrian outcome measures. First, we looked at overall risk of simulated injury. We also considered two aspects of crossing behavior: looking at traffic and time to contact by an oncoming vehicle after entering a traffic gap.

1. **Simulated Injury (Collisions with Virtual Vehicles):** "Hits" were any direct collisions between the virtual pedestrian and a vehicle.

2. **Looking at traffic.** To evaluate attention to traffic, looks toward traffic were tallied by head-tracking equipment (Trackir4:Pro, NaturalPoint Inc, Corvallis, OR) that monitored participants' visual attention to traffic from the left and right. We summed the number of times participants looked left plus the number of times they looked right while waiting to cross, divided by the average wait time in seconds.

3. **Time to contact by an oncoming vehicle:** The time to contact by an oncoming vehicle was the shortest latency (in seconds) between the child and an oncoming vehicle during the time the child was in the crosswalk. Shorter time to contact by an oncoming vehicle indicates selection of a riskier traffic gap to cross within.

Data Analysis Plan.—Descriptive statistics were considered first to examine the distribution of scores and insure assumptions of inferential analyses were met. We also examined descriptively the number of children who were adherent and non-adherent to the PAP treatment. To address the primary hypothesis, that children with OSAS would engage more safely as pedestrians after adhering to treatment with PAP versus when untreated or after non-adherent treatment, we constructed mixed-model, ordinal logistic regressions run using the Generalized Estimating Equations procedure to compare pre- and post-treatment hits by simulated traffic in a stratified manner, with one model constructed among children who were adherent to PAP and a second among children who were non-adherent. Given our results that the regression was statistically significant among adherent children but not among non-adherent children, we proceeded to evaluate secondary pedestrian behavior outcomes, time to contact and attention to traffic, among only the adherent group. Paired sample t-tests compared behavior pre and post treatment among those children. All analyses were conducted using SPSS, version 22 (IBM Corp, Armonk, NY). Significance was ascribed at $p < 0.05$.

RESULTS

Study Group

Forty-two children with OSAS were enrolled. One child was excluded who could not be provided with a machine due to inadequate insurance coverage and 12 children were lost to follow-up over the 3-month time period. Analyses comparing those lost to follow-up to those who completed the study found that children lost to follow-up were more likely to be male (92% vs 59%), but otherwise were similar on demographic, BMI, and baseline sleep measures.

Table 1 presents data for the sample of 29 children who completed the study, both overall and divided into adherent and non-adherent subgroups. Of the 29 participants, 20 children were evaluated at both visits, had usable data, and did not have persisting OSAS. One child was excluded because the downloadable card malfunctioned and eight children had persisting OSAS greater than 1.5 AHI so were categorized as inadequately treated due to poor titration. Based on the criteria of PAP usage for an average of greater than 4 hours a night, 11 of the 20 included children were adherent to the PAP therapy and 9 were non-adherent. The non-adherent group was somewhat older than the adherent group, but otherwise the two groups were similar on all variables tested.

To test the primary hypothesis, stratified mixed model, ordinal logistic regression analyses indicated that following treatment, children adherent and adequately treated with PAP experienced a significant reduction in hits by simulated vehicles in the VRPE (Wald $\chi^2(1) = 6.86$, p=.009, Figure 1) but children not adherent to treatment with PAP did not experience a significant reduction in hits by simulated vehicles (Wald $\chi^2(1) = 1.47$, p=.23). A follow-up mixed binomial regression indicated that, when untreated, children were 12 times more likely to have a simulated hit by a virtual vehicle than when adherent to PAP (Wald $\chi^2(1) = 5.61$, OR 12.00, 95% CI 1.12 – 128.84, p=.018).

Given these results, we next examined secondary pedestrian safety outcomes at baseline and post-treatment among children adherent to treatment. As shown in Table 2, children adherent to treatment showed a significant improvement in time to contact with oncoming vehicles post-treatment ($t(10) = 4.05$, $p < 0.01$), indicating they had left more time between themselves and oncoming traffic following treatment. There was not a significant change post-treatment in looking at oncoming traffic ($t(10) = -.63$, $p = 0.55$).

DISCUSSION

Our results suggest children with OSAS who were treated with PAP therapy experienced significant improvement in their pedestrian safety, as measured in a virtual pedestrian environment, following adherence to PAP therapy. In contrast to children who were not adherent, we found adherent children experienced a significant reduction in collisions with virtual vehicles. We also saw an improvement in leaving more time before contact with oncoming traffic among adherent children.

Results reinforce the fact that pediatric OSAS causes significant cognitive impairment that manifests itself in multiple applied domains, including pedestrian safety, and that adherent treatment with PAP therapy can produce positive change in functioning. Crossing streets safely requires simultaneous processing of several pieces of information, and therefore is a highly complex cognitive and perceptual task. OSAS may impair relevant cognitive components.[28] When children with OSAS were adherent to PAP, they seemed to re-gain cognitive capacity and engaged more safely in the virtual street environment, functioning closer to what their age and development status would predict. When they were untreated at baseline, their pedestrian safety was compromised.

Consistent with other research, we did not find that looking at traffic was impaired or improved with PAP therapy.[29,39] A possible explanation for this finding is that when they are sleepy, children are still able to follow simple and rote rules learned when they were young, such as looking both ways before crossing, but they may not fully process cognitively the complex environment they perceive or select safe traffic gaps to cross within. This hypothesis corresponds with results from research investigating pedestrian safety in untreated pediatric sleep disorders of central hypersomnia and untreated OSAS, in which children looked both ways at traffic but did not process the crossing properly and were struck by virtual vehicles.[29,39]

Our findings have implications for clinical practice. While a few pediatric studies have documented cognitive improvement on laboratory tasks following PAP therapy,[40–42] this study extends findings to the applied outcome of unintentional pedestrian injury risk. In adults with OSAS, PAP therapy improves occupational safety, driving performance, and injury risk following PAP therapy.[22–24] This study offers initial evidence that pediatric functioning concords with that of adults and PAP therapy has the potential to reduce injury risk among children engaging in what is perhaps the most common mode of transportation where children influence their own safety, pedestrian injury.

We note several study limitations. First, we recruited children with OSAS from a clinically referred group of children that may represent a group with more severe symptoms that prompt a referral than the larger community sample of children with OSAS. Second, while we chose 3 months as an outcome point based on prior research,[41–42] the minimal amount of daily PAP use required for improvement in safety and the length of time needed to wear PAP before safety improvement is observed remain unknown. Third, our study suffered from attrition over the three-month time period. Fourth, we used a non-counter-balanced within-subjects research design. Ethical considerations prohibited counterbalancing or inclusion of a clinical control group, but future research might consider alternative research designs to control for the possibility of practice effects and the simple cognitive-perceptual development that occurs in children over a 3-month time period and might influence pedestrian behavior and skill. Finally, the findings are limited to pedestrian injury. Future research should consider other aspects of health and safety among children with OSAS, other treatments that might reduce injury risk in children with OSAS, and possible countermeasures that could be implemented to promote increased safety.

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Abbreviations:

OSAS	obstructive sleep apnea syndrome
PAP	positive airway pressure
VRPE	virtual reality pedestrian environment

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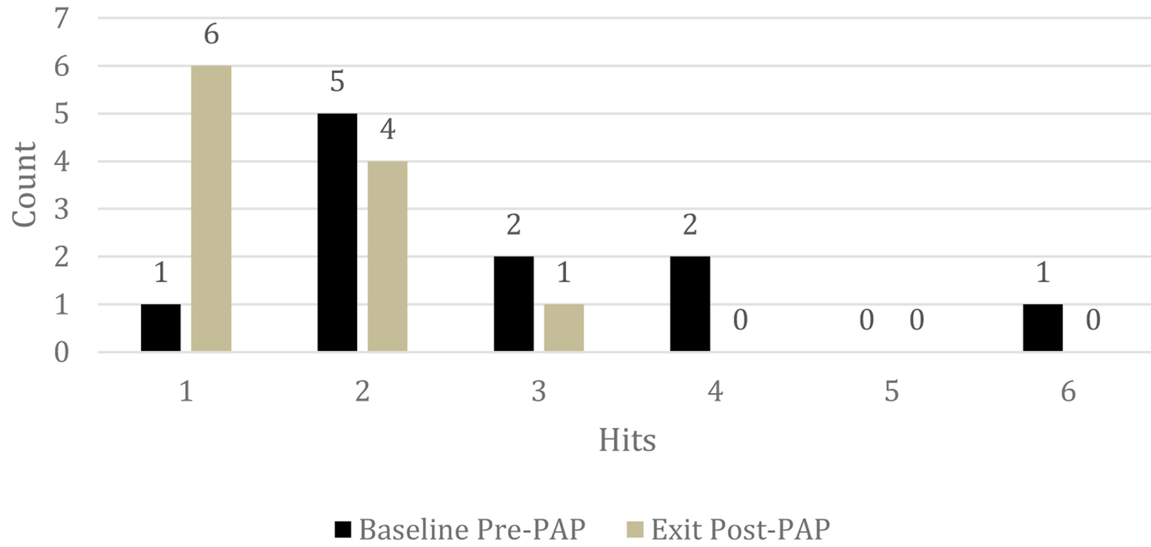

Figure 1.
Reduction in Hits by a Virtual Vehicle in Children with OSAS Adherent to PAP

Table 1.

Demographic, BMI, and Sleep Characteristics of Sample at Baseline

Characteristic	Completers (*N* = 29)	Adherent (*N* = 11)	Non Adherent (*N* = 9)	Test Statistic[1]
Sex: % male	58.6	54.5	55.6	$p = 0.658$
Age: mean (SD), in years	11.9 (2.7)	10.7 (2.2)	14.7 (1.1)	$t = 5.1^{**}$
Ethnicity: % white	42.9	54.5	50.0	$p = 0.605$
Household Income: % Below $20,000	30.8	45.5	42.9	$p = 0.648$
ESS Total, mean (SD)[2]	12.7 (5.4)	13.2 (5.1)	16.4 (4.6)	$t = 1.4$
BMI: mean (SD) (age and gender adjusted)	36.1 (11.9)	37.7 (11.1)	38.4 (14.3)	$F(1,16) = 0.01$
BMI z-score mean (SD)	2.29 (0.16)	MED = 2.5	MED = 2.9	U = 26.0
Polysomnography Data				
Total Sleep Time (min; mean (SD))	445.3 (54.2)	455.0 (51.1)	445.2 (27.9)	$t = 0.544$
Sleep Efficiency % mean (SD)	85.4 (10.6)	MED=93.6	MED=89.9	U = 53.5
Sleep Latency (min; mean (SD))	16.4 (15.2)	MED=12.5	MED=7.0	U = 67.0
Awakenings (count mean (SD))	24.0 (11.4)	21.0(11.5)	28.2 (11.7)	$t = 1.4$
Stage 1 Sleep (%mean (SD))	8.0 (5.0)	6.5 (3.9)	10.9 (5.5)	$t = 2.1$
Stage 2 Sleep (%mean (SD))	49.4 (10.0)	48.0 (11.1)	50.4 (10.1)	$t = 0.5$
Stage 3 Sleep (%mean (SD))	23.6 (9.3)	25.2 (10.3)	19.7 (8.2)	$t = 1.3$
REM sleep % mean (SD)	18.9 (6.4)	20.3 (6.2)	19.0 (6.8)	$t = 0.4$
AHI mean (SD)	10.7 (15.0)	MED=3.0	MED=5.7	U = 35.5

Note: ESS = Epworth Sleepiness Scale; BMI=Body Mass Index; MED=Median; AHI=Apnea-Hypopnea Index.

[1] Test statistic compares adherent to non-adherent groups. Fisher's exact test *p* values presented for categorical variables. Independent samples *t* or Mann Whitney U statistics presented for continuous variables, depending on distribution of outcome variable. ANCOVA used for BMI in order to covary age and gender.

[2] N=10 for adherent group and N=8 for non-adherent group on this variable due to missing data.

* $p < .05$.

** $p < .01$.

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Table 2.

Pedestrian Outcome Measures in Children with OSAS adherent to PAP

Pedestrian Risk Outcome Measure	Pre M (SD)	Post M (SD)	*t*	*df*	*p*
Time To Contact	3.45 (0.61)	4.43 (0.68)	4.05	10	0.002
Looking At Traffic	27.60 (9.97)	30.27 (8.54)	0.63	10	0.546