

Normative psychomotor vigilance task performance in children ages 6 to 11—the Tucson Children's Assessment of Sleep Apnea (TuCASA)

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Abstract Although the psychomotor vigilance task (PVT) is commonly used in sleep and other research settings, normative data for PVT performance in children have not been published. This report presents normal PVT performance measures among children without a sleep disorder participating in the Tucson Children's Assessment of Sleep Apnea (TuCASA) study. TuCASA is a community-based, prospective study of sleep-disordered breathing in Caucasian and Hispanic children ages 6 to 11 years. A standard 10-min PVT trial was completed by 360 participants—48% female and 36% Hispanic; mean age 8.9 years. Detailed analyses were performed for 162 children with respiratory disturbance indices <1 and no parent-reported sleep problems. Mean and median reaction times (RT) decreased with increasing age (p trend < 0.001). Children ages 6 and 11

had median RTs of 544.24 and 325.70 ms, respectively. Standard deviations in RTs also decreased with increasing age (p trend = 0.001), as did lapses (p trend < 0.001), but no trend was apparent in total errors. There were statistically significant ($p=0.006$) differences in the performance of boys and girls. Gender differences were greatest at age 6, where boys had shorter RTs, and decreased with age until performance was approximately equal by age 11. No ethnic differences were detected. Children's PVT performance improves with age and differs by gender. These differences should be considered when the PVT is utilized in pediatric populations.

Keywords Children · Pediatrics · Reaction time · Psychomotor vigilance task

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Introduction

In the 30 years since its development [1], the psychomotor vigilance task (PVT) has been used extensively in sleep research to objectively measure aspects of alertness and sustained attention. The measurement properties and sensitivity of the PVT have been well validated in adults. It has only a 1–3-trial learning curve [2], and performance is independent of aptitude [3]. PVT performance has demonstrated sensitivity to circadian rhythms and to different degrees of sleep deprivation, restriction, and fragmentation in a variety of settings [3]. PVT performance has shown a dose–response relationship with sleep duration and subjective alertness [4], and new technologies such as functional magnetic resonance imaging are being used to identify brain regions active during PVT performance [5]. In occupational research, the PVT has been used to evaluate

alertness among shift workers, the military, and others [6–8]. In clinical research, the PVT has been used to assess the efficacy of treatments for a variety of sleep disorders, including sleep-disordered breathing (SDB) [9–11].

Normal and disordered sleep in pediatric populations is an area of increasing research interest, including the impact that disordered sleep has on daytime function in children [12, 13]. Studies have demonstrated associations between neurocognitive outcomes and snoring or polysomnographic SDB among children [14–16]. Evidence of a relationship between SDB and attention-deficit hyperactivity disorder (ADHD) is also growing [17–20]. Objective, standardized measures of the functional consequences of sleep loss on higher order cognitive processes, including attention, are needed [12]. The PVT may thus prove useful in future research investigating these relationships.

Although the PVT has been commonly used in sleep research and may increasingly be employed in pediatric populations, normative data for PVT performance in children have not been published. This report presents normal PVT performance measures in healthy 6- to 11-year-old children and their relationships with age, gender, and ethnicity. Data were collected as part of the Tucson Children's Assessment of Sleep Apnea Study (TuCASA), a community-based cohort study designed to investigate the prevalence and correlates of SDB in preadolescent children 6 to 11 years of age.

Materials and methods

The design of the TuCASA study specified recruitment of Hispanic and Caucasian children aged 6 through 11 years to undergo an unattended home polysomnogram (PSG), complete a pediatric sleep-habits questionnaire, and have a neurocognitive assessment [21]. The TuCASA protocol was approved by both the University of Arizona Human Subjects and the Tucson Unified School District Research Committees. Subjects were recruited through the Tucson Unified School District, a very large district with an elementary school population representative of children living in southern Arizona. Typically, parents were asked to complete a short sleep-habits screening questionnaire and to provide their contact information if they would allow study personnel to call and schedule a PSG and neurocognitive assessment for their child.

Recruitment has been described in detail previously [21]. Briefly, a one-page, 13-item screening questionnaire designed to assess the severity of SDB-related symptoms in children was utilized. Questions such as “how often does your child snore loudly,” “is your child sleepy during the daytime,” “does your child stop breathing during sleep,” and “does your child have learning problems” were

evaluated by the parent on the scale of “never,” “rarely,” “occasionally,” “frequently,” “almost always,” or “don't know.” The overall response rate on the screening questionnaire was 30.6%. The return rate was similar for boys and girls (49.7 and 49.4%), and was higher for Hispanics than for Caucasians (45.4 and 38.1%, respectively). Other ethnicities comprised 16.6% of the surveys. We encouraged maximum participation through recruitment incentives for the school and also allowed parents to return the survey anonymously. Parents were called regarding the possibility of a PSG for their child if they indicated their willingness to participate further. Children were excluded if they had a history of asthma, SDB, tonsillectomy, ADHD, other chronic respiratory problems, or mental retardation. The profile of children who participated in the sleep study was similar to that of nonparticipants in terms of symptoms; however, Hispanic parents were more likely than Caucasian parents to complete the survey but opt out of having a PSG for their child.

An unattended home PSG was scheduled as soon as possible after recruitment. Methods for obtaining and scoring PSG data have been described previously [21]. Briefly, a two-person, mixed-sex team arrived at the home approximately 1 h prior to the child's normal bedtime. Informed consent was obtained from the parent, and an Institutional Review Board-approved assent form was obtained from the child. Questionnaires were administered, and anthropometric and other physiologic measurements were completed. Unattended overnight PSGs were obtained using the Compumedics PS-2 system (Abbotsford, Victoria, Australia). The following signals were acquired as part of the TuCASA montage: C3/A2 and C4/A1 electroencephalogram, right and left electrooculogram, a bipolar submental electromyogram, thoracic and abdominal displacement (inductive plethysmography bands), airflow (nasal/oral thermister), nasal pressure cannula, finger pulse oximetry, electrocardiogram to detect major arrhythmias (single bipolar lead), snoring microphone, body position (mercury gauge sensor), and ambient light to determine sleep-period time (sensor attached to the vest to record on/off). Studies were done on both weekdays and weekends depending upon parent preference. Using the Compumedics software system to process the PSG data, apneas and hypopneas were identified as described previously [21], and the respiratory disturbance index (RDI) was calculated as the number of apneas and hypopneas associated with at least a 3% oxygen desaturation per hour of total sleep time [22].

Questionnaires on the night of the PSG included a more extensive parentally completed sleep-habits questionnaire. Using these data, several composite variables were created based on a combination of selected survey items. Subjects were classified as having excessive daytime sleepiness (EDS) if the parents reported that their child had any of the

following frequently or almost always: child was sleepy in the daytime, fell asleep while watching TV or in school, or had problems falling asleep during the day. Snoring was defined as occurring if parents reported that their child snored loudly frequently or almost always. Insomnia (difficulty initiating and maintaining sleep) was present if the parents reported that their child had trouble falling asleep or staying asleep, had not enough sleep, or was troubled by waking up too early and not being able to get back to sleep.

A neurocognitive assessment was scheduled as soon as possible following successful completion of a PSG. The median interval between PSG and neurocognitive assessment was 38 days (interquartile range = 61). Neurocognitive assessments were administered by trained technicians under the supervision of a licensed pediatric neuropsychologist, all unaware of PSG results. The 3-h assessment battery consisted of a series of standardized neurocognitive measures completed in a fixed order and ending with a single standard 10-min visual PVT trial. The PVT-192 (Ambulatory Monitoring, Ardsley, NY, USA) is a simple task administered on a handheld device. Participants were asked to press a button as quickly as possible each time they saw a visual stimulus appear (a small red LED-digital counter). The stimulus was presented approximately 100 times during the 10-min task, with the interstimulus interval varying randomly from 2 to 10 s. During administration of the PVT, children sat in a quiet room and could not see the technician. PVT data were downloaded to a computer and processed using REACT software (Ambulatory Monitoring) to produce summary statistics for each child's performance. Summary reaction time (RT) measures utilized in this analysis include mean and median RT, standard deviation RT, and mean reciprocal RT. Other summary measures considered include number of lapses (defined as RT > 500 ms based on convention and adult data) and total number of errors (wrong keys and false starts).

A total of 360 Hispanic and Caucasian children completed both a PSG and cognitive evaluation. Descriptive statistics were calculated for the whole sample to establish demographic characteristics. Among TuCASA participants, an RDI of at least one event/hour associated with a 3% oxygen desaturation corresponded to a higher prevalence of clinical symptoms [22]. This threshold was used in the present analysis to objectively define the presence of SDB. Parent-reported sleep problems included EDS, snoring, and insomnia. Descriptive statistics for selected domains of PVT performance were calculated in a subsample restricted to children with RDI < 1 and no parent-reported sleep problems ($n=162$) to determine normal PVT performance measures in children ages 6 to 11. Multiple linear regression techniques were used to test relationships of age, gender, and ethnicity with PVT

performance in this subsample. Both main effects and interactions were evaluated. Because the distribution of mean RTs was positively skewed, with many more observations of faster mean RTs and relatively few slower mean RTs, mean reciprocal RT scores were used in regression analyses. No adjustments were made for multiple comparisons. All analyses were conducted using Stata 9.2 (StataCorp, College Station, TX, USA).

Results

Demographic characteristics for TuCASA participants completing a PVT trial ($N=360$) are presented in Table 1. Approximately 48% of participants were female and 36% Hispanic. Mean age was 8.9 years (SD 1.6 years). Table 2 presents the age and sex distribution for children included in the normative analysis ($n=162$).

Normal PVT performance measures are presented in Table 3. Mean and median RT in milliseconds (ms) decreased with increasing age (p for trend < 0.001). Children 6 years of age had mean and median RTs of 721.15 and 544.24 ms, respectively, while children 11 years

Table 1 Baseline characteristics of 360 children completing a PVT trial in the TuCASA study

Characteristic	Frequency (n)	Percent (%)
Gender		
Male	188	52.2
Female	172	47.8
Ethnicity		
Caucasian	229	63.6
Hispanic	131	36.4
Age (years)		
6	65	18.1
7	45	12.5
8	71	19.7
9	72	20.0
10	75	20.8
11	32	8.9
RDI ≥ 1		
No	276	76.7
Yes	84	23.3
Snoring		
No	310	86.1
Yes	50	13.9
Insomnia (DIMS)		
No	257	71.4
Yes	103	28.6
EDS		
No	305	84.7
Yes	55	15.3

DIMS = difficulty initiating and maintaining sleep

Table 2 Participant distribution by age and sex for 162 children included in the normative analysis

Age (years)	Boys (%)	Girls (%)	Total (%)
6	14 (8.6)	13 (8.0)	27 (16.7)
7	12 (7.4)	8 (4.9)	20 (12.4)
8	16 (9.9)	23 (14.2)	39 (24.1)
9	18 (11.1)	13 (8.0)	31 (19.1)
10	13 (8.0)	17 (10.5)	30 (18.5)
11	6 (3.7)	9 (5.6)	15 (9.3)
Total	79 (48.8)	83 (51.2)	162 (100)

of age had mean and median RTs of 396.35 and 325.70 ms, respectively. Figure 1 shows observed median RTs by age and gender. Standard deviations in RTs also decreased with increasing age (p for trend = 0.001), although the trend was not as consistent as with mean and median RTs. Similarly, the number of lapses decreased as age increased (p for trend < 0.001), but no such trend was apparent in the number of total errors.

Multiple linear regression analysis revealed statistically significant ($p=0.006$) differences in the mean reciprocal RTs of boys and girls. In addition, the age trend for boys was different from the age trend for girls (p for interaction = 0.029). Gender differences in mean reciprocal RTs were greatest at age 6, where boys had shorter mean RTs, and decreased with age until performance was approximately equal regardless of gender at age 11. The regression constant was 0.921 s^{-1} , and the regression coefficients were 0.191 s^{-1} for age, -0.950 s^{-1} for female gender, and 0.0834 s^{-1} for the age–gender interaction. Thus, for boys, mean reciprocal RT is expected to be 2.06 s^{-1} at age 6, and expected to increase by 0.191 s^{-1} with each additional year of age. For girls, mean reciprocal RT is expected to be 1.61 s^{-1} at age 6, and

expected to increase by 0.274 s^{-1} with each additional year of age. Figure 2 illustrates predicted mean reciprocal RTs by age and gender. No differences based on Hispanic or Caucasian ethnicity were detected.

Similar gender differences were observed in median RTs and lapses. Boys and girls had statistically significantly different median RTs ($p<0.001$) and age trends in median RTs (p for interaction = 0.004). For both genders, the relationship between median RT and age was best described by a quadratic model (p for age² < 0.001). There were statistically significant gender differences in lapses ($p<0.001$) as well, and the age trend for boys was again different from that of girls (p for interaction = 0.001). As with median RT, the relationship between lapses and age was best described by a quadratic model (p for age² = 0.002). Boys had shorter median RTs and fewer lapses at age 6, and performance on both measures was approximately equal by age 11. Figures 3 and 4 show age and gender differences in predicted median RTs and lapses, respectively.

Although no relationship between age and total errors was observed, a Mann–Whitney U test revealed statistically significant gender differences ($p<0.001$). The median number of total errors was lower for girls (median = 4; interquartile range = 9) than for boys (median = 9; interquartile range = 14). No ethnic differences in performance were detected in this analysis.

Discussion

Among TuCASA participants with RDI < 1 and no parent-reported sleep problems, PVT performance differed by age and gender. Speed and accuracy improved with increasing age. Although boys were faster and had fewer lapses than

Table 3 Means and SDs for PVT performance measures in the normative sample ($n=162$) by age and gender

Age	Gender (n)	Mean RT ^a		SD RT ^b		Median RT ^a		Lapses ^a		Total errors	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
6	Girls (13)	787.65	252.17	631.71	515.38	602.50	144.87	58.23	17.35	6.85	6.24
	Boys (14)	659.41	303.14	537.80	581.32	490.14	104.98	39.00	15.67	19.64	24.98
7	Girls (8)	622.47	144.88	411.73	278.54	505.88	109.76	42.38	21.00	4.50	3.46
	Boys (12)	515.00	114.00	357.51	241.52	420.38	66.46	30.42	11.35	11.67	11.61
8	Girls (23)	554.97	133.89	486.65	473.11	439.46	61.84	31.35	11.76	11.43	19.53
	Boys (16)	567.87	254.81	736.41	1,028.82	392.91	62.69	24.69	11.28	19.81	21.07
9	Girls (13)	465.20	103.32	436.29	432.79	373.92	57.58	18.31	12.45	10.62	15.19
	Boys (18)	444.92	107.71	529.67	629.75	355.25	28.79	14.56	6.14	11.17	14.70
10	Girls (17)	452.99	165.93	396.77	470.25	356.79	67.88	15.35	10.34	5.71	5.49
	Boys (13)	557.98	355.96	680.47	1,061.14	338.81	28.79	15.25	7.50	11.54	11.82
11	Girls (9)	393.45	107.71	255.81	214.59	333.28	71.38	12.56	13.38	5.33	5.74
	Boys (6)	400.71	121.91	397.49	326.51	314.33	46.37	10.83	10.67	17.17	17.61

^a Statistically significant effect of age, p for trend < 0.001

^b Statistically significant effect of age, p for trend = 0.001

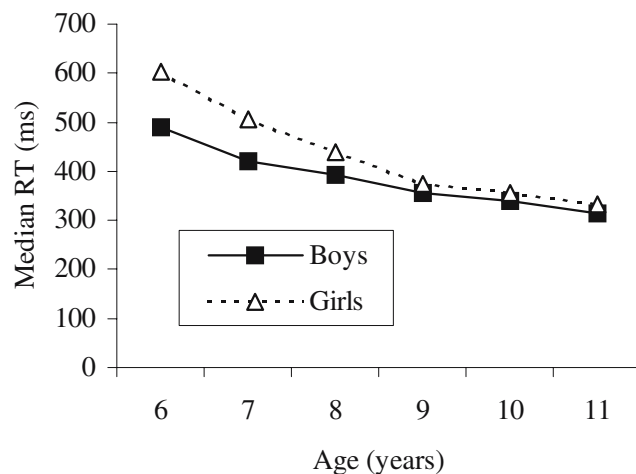


Fig. 1 Median RT by age and gender for children in the normative sample ($n=162$)

girls at age 6, performance was approximately equal by age 11, and girls had fewer total errors than boys at all ages. No statistically significant differences in performance based on ethnicity were detected. The descriptive statistics presented in this report may serve as preliminary normative comparison data for both normal and clinical samples in future pediatric sleep research studies.

Our study in children is consistent with PVT studies in adults that have found performance differences based on age. However, in contradistinction to children, slower performance is observed among older vs younger adults [23, 24]. In a large study, simple RT was evaluated in a sample of 5,325 adults and children using a task similar to the PVT [25]. RTs were fastest among individuals in their 20s, with declines in performance beginning in the third decade of life and increasing progressively up to age 60. In the same study, RTs were slowest among children age 10 and younger, with progressive improvements in performance through the teenage years. Gender differences in psychomotor and PVT performance have also been

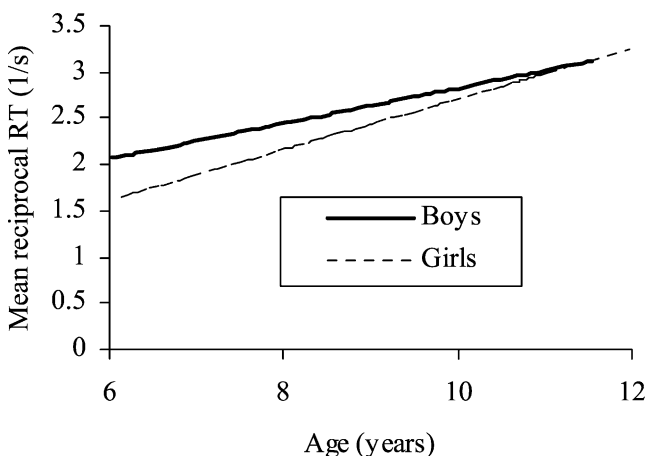


Fig. 2 Estimated differences in mean reciprocal RT by age and gender for children in the normative sample ($n=162$)

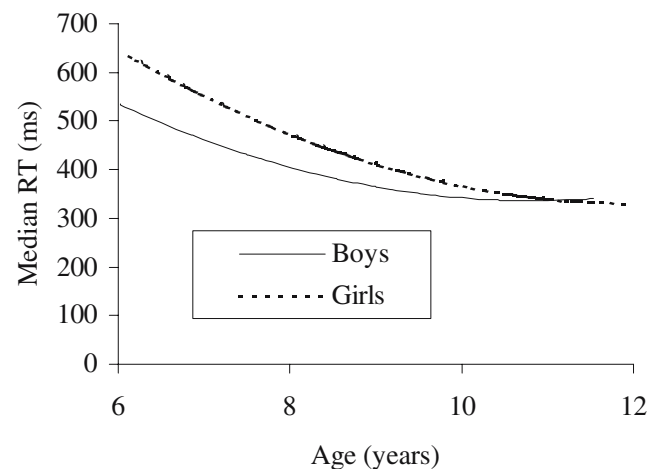


Fig. 3 Estimated differences in median RT by age and gender for children in the normative sample ($n=162$)

reported in adults, with slower RTs in women than in men, although the effect is independent of age [26, 27]. In our study, gender differences in RTs disappeared as children approached adolescence, but gender differences are present in young adulthood [26], indicating that differences may reemerge during adolescence. Evidence in adults also shows that women make fewer errors of commission (false starts) than men [26], again consistent with our findings in children. Girls in our study made fewer total errors, including errors of commission and wrong key hits, than boys.

No study has reported PVT performance differences by age and gender in children, but other measures of psychomotor performance and sustained attention show similar trends for age and gender differences among children [28–31]. Performance on virtually all psychomotor and cognitive measures improves with age among school-aged children, consistent with the neurocognitive and physiological development taking place during these years

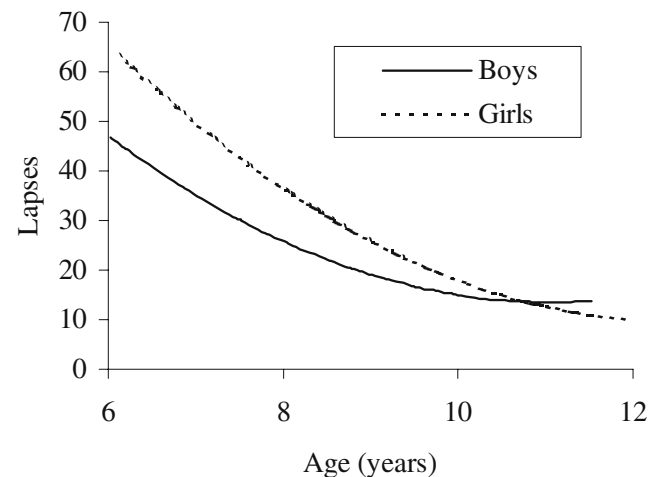


Fig. 4 Estimated differences in lapses by age and gender for children in the normative sample ($n=162$)

[32, 33]. Gender differences in performance are also commonly reported, although the direction of the difference depends on the task. For other measures of RT, reported gender differences are generally consistent with our findings, but no publication has described an interaction between gender and age trends. Among other measures of vigilance and psychomotor performance, continuous performance tests (CPTs) are most similar to the PVT. Unlike the simple RT task utilized in the PVT, CPTs measure vigilance and RT using a choice RT task. CPTs are commonly used in pediatric populations in both clinical and experimental settings [30]. Several versions of the CPT have been published; among the most common are the Conners' CPT [34], the test of variables of attention [35], and the Gordon diagnostic system [36]. Most versions of the CPT require subjects to press a key in response to a rare target, similar to the original paradigm described by Rosvold et al. [37]. However, nontarget stimuli are also presented and subjects must discriminate and only respond to the target. The Conner's CPT is most like the PVT, with a frequently occurring target stimulus producing a greater number of responses to use when calculating RT [30]. The increased probability of the target also increases occurrence of errors of commission, again making the Conners' CPT most similar to the PVT. Recently published normative data for Conners' CPT performance in children ages 9 to 17 demonstrated robust age effects like those found in our study, with improved performance on all measures as age increased [30]. Gender differences consistent with our study were also reported. Females in the Conners' CPT study had longer mean RTs and lower errors of commission than males. However, no interactions between age and gender were detected. This discrepancy may reflect the older age of the sample compared to our study, or a difference between the processes measured by the Conners' CPT and the PVT. Additional research directly comparing the PVT and Conners' CPT in a pediatric population is needed to investigate this difference. As in our study, no ethnic differences in Conners' CPT performance were found.

The PVT has several advantages that make it attractive for future studies in children, especially those related to sleep disorders. As previously discussed, in adults, the PVT has a minimal learning curve and performance is independent of aptitude [2, 3], making the PVT ideal for repeated testing and both intraindividual and interindividual comparisons. Other measures of sustained attention currently utilized in children are not as free from these influences. In addition, the simple RT task of the PVT differs from choice RT tasks (such as the CPT) in that it requires no decision making and less language ability. This reduces confounding from these domains at all ages and may make the PVT more appropriate for use in younger children in particular. Furthermore, the standard PVT is administered

with a portable device rather than requiring a desktop or laptop computer for administration. A palm-pilot-administered, 5-min PVT task has recently been developed [38] that may improve on this convenience if it proves comparable to the PVT-192. Although we did not evaluate this new device, it has the potential to permit on-demand testing in nonclinical situations. The PVT has proven sensitive to a variety of sleep problems in adults [3]. If this sensitivity can be demonstrated in children, the PVT's desirable measurement properties make it preferable to other measures of sustained attention currently used in children, and may result in it becoming a useful instrument for sleep research in children.

One strength of our study is the large, population-based sample. Findings are based on data collected as part of a prospective, community-based study. In addition, children with objective or subjective sleep problems were excluded from the analysis, reducing the likelihood that poor or inadequate sleep might influence the results. The remaining sample was still large enough to evaluate PVT performance and relationships with age, gender, and ethnicity with adequate statistical power. Although larger sample sizes are always desirable for normative analyses, our sample is consistent with normative sample sizes commonly used in neurocognitive research [32].

Interpretations of our results are subject to several caveats. The exclusion of children with parent-reported EDS, snoring, or insomnia is subjective by definition, and children with parent-reported symptoms but no objectively measured sleep problems may represent a group within the healthy population excluded from this analysis. Furthermore, generalizability of these findings may be reduced by potential response bias in the recruitment of the TuCASA cohort [22]. Unfortunately, this type of bias is possible in any prospective study. If parents of children with sleep problems preferentially returned the screening questionnaire, participants may have been more likely to have symptomatic SDB than those who did not participate. This analysis is less affected by this potential bias given the exclusion of children with sleep problems. Another limitation related to recruitment is the absence of participants with races/ethnicities other than Caucasian or Hispanic. The demographic characteristics of the community from which TuCASA participants were recruited should be considered when evaluating the generalizability of our findings. These types of limitations to generalizability are possible in any normative analysis using data from a larger population-based study. The intent of this report is introduce a reference point for future studies using the PVT in children, rather than a definitive description of PVT performance in this age group.

The nature of the PVT itself and the timing of PVT testing in this study may introduce bias affecting these

results. A few TuCASA participants who completed both a PSG and neurocognitive assessment were unable to complete the PVT because they could not sit still for 10 min without interruption. While it is possible that these children would have had systematically different PVT performance from children who completed the task and were included in the analysis, there were fewer than five such children. Thus, it is unlikely that their performance would have altered the results of the normative analysis significantly. Conceivably, PVT performance in this sample may also have been affected by the placement of the PVT at the end of the 3-h cognitive testing battery, or individual factors such as IQ. We believe this is unlikely because the PVT has proven robust to these types of influence in adults [3].

Finally, although we selected children without sleep symptoms or PSG evidence of SDB, we did not assess whether they slept normally on the night prior to PVT testing. Thus, it is possible that some children were sleep-deprived on the day of testing. However, even if this were to have occurred in some children, it is unlikely that this would have produced a systematic error in our analyses.

Despite some limitations, this is the first study to report normal PVT performance measures in children ages 6 to 11. Our findings are consistent with normative data for other vigilance and psychomotor measures in this age group, and with theories of cognitive and physiological development. Researchers using the PVT in pediatric populations need to be conscious of the impact of age and gender on performance.

Acknowledgements The authors wish to thank Charles Wynstra, MBA, RRT; Marty Ukockis, RPSGT, RRT; Marissa Carey, Ph.D.; Fernanda Martinez, Ph.D.; and Mary Frances Miller, BA, for their diligence in data collection and scoring. We also thank the principals, teachers, parents, and students from the Tucson Unified School District for their ongoing support of this research. This document is a portion of a thesis submitted in partial completion of the requirements for a Master of Science degree at the University of Arizona. This work was supported by HL 62373 from the National Heart, Lung, and Blood Institute.

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