The Role of Computer Games in Measuring Spirometry in Healthy and “Asthmatic” Preschool Children*

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Study objectives: To explore the role of respiratory interactive computer games in teaching spirometry to preschool children, and to examine whether the spirometry data achieved are compatible with acceptable criteria for adults and with published data for healthy preschool children, and whether spirometry at this age can assess airway obstruction.

Design: Feasibility study.

Settings: Community kindergartens around Israel and a tertiary pediatric pulmonary clinic.

Participants: Healthy and asthmatic preschool children (age range, 2.0 to 6.5 years).

Intervention: Multitarget interactive spirometry games including three targets: full inspiration before expiration, instant forced expiration, and long expiration to residual volume.

Measurements and results: One hundred nine healthy and 157 asthmatic children succeeded in performing adequate spirometry using a multitarget interactive spirometry game. American Thoracic Society (ATS)/European Respiratory Society spirometry criteria for adults for the start of the test, and repeatability were met. Expiration time increased with age (1.3 ± 0.3 s at 3 years to 1.9 ± 0.3 s at 6 years [± SD], p < 0.05). FVC and flow rates increased with age, while FEV1/FVC decreased. Healthy children had FVC and FEV1 values similar to those of previous preschool studies, but flows were significantly higher (> 1.5 SD for forced expiratory flow at 50% of vital capacity [FEF50] and forced expiratory flow at 75% of vital capacity [FEF75], p < 0.005). The descending part of the flow/volume curve was convex in 2.5- to 3.5-year-old patients, resembling that of infants, while in 5- to 6-year-old patients, there was linear decay. Asthma severity by Global Initiative for Asthma guidelines correlated with longer expiration time (1.7 ± 0.4 s; p < 0.03) and lower FEF50 (32 to 63%; p < 0.001) compared to healthy children. Bronchodilators improved FEV1 by 10 to 13% and FEF50 by 38 to 56% of baseline.

Conclusions: Interactive respiratory games can facilitate spirometry in very young children, yielding results that conform to most of the ATS criteria established for adults and published data for healthy preschool children. Spirometric indexes correlated with degree of asthma severity.

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Key words: asthma; preschool children; respiratory interactive computer games; spirometry

Abbreviations: ATS = American Thoracic Society; ERS = European Respiratory Society; FEF50 = forced expiratory flow at 50% of vital capacity; FEF75 = forced expiratory flow at 75% of vital capacity; FEV1 = forced expiratory flow volume; FEV0.5 = forced expiratory volume in 0.5 s; GINA = Global Initiative for Asthma; PEFR = peak expiratory flow rate; RV = residual volume; TLC = total lung capacity; Vbe = back-extrapolated volume

Respiratory disorders are very common in preschool children, and their prevalence in this age group is increasing.1 Spirometry is a standardized and common test for evaluating airway obstruction in adults and older children,2–4 whereas in young children, reliable spirometry measurements have traditionally been difficult to achieve. However, in recent years, several studies5–13 have demonstrated that the majority of preschool children can produce repro-

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ducible forced expiratory flow volume (FEFV) curves with proper coaching techniques.

Spirometry is generally taught to adults and children by verbal coaching. Since games play an important role in the learning processes of the preschool child, several manufacturers have integrated computer games into their commercially available spirometry software. These games teach the child to blow out forcefully using a visual incentive such as blowing out candles, moving clouds, or popping balloons with arrows. These incentives are based on a single target, usually peak expiratory flow rate (PEFR). Taking a deep breath to total lung capacity (TLC) may be “instinct dependent,” but expiration to residual volume (RV) is not.

The effectiveness of these games as an aid for teaching spirometry is controversial. Studies showed that children cooperated with single-target games and achieved acceptable reproducibility criteria, but FVC and FEV₁ were underestimated. It was concluded that teaching spirometry using games did not yield superior results to verbal coaching. Other studies examined teaching spirometry via several games and targets, one being PEFR and the other FVC, and found this to be helpful in the learning process of spirometry in young children. We developed and assessed an animated program for teaching spirometry to young children. This program teaches a full FVC maneuver with proper coaching techniques.

**Materials and Methods**

**Study Subjects**

Preschool children were recruited to this study between January 2001 and December 2003. Age inclusion criteria were from 2.0 to 6.5 years. Two groups of subjects were studied, and none of the children had former experience with spirometry maneuvers.

**Healthy Group:** Children were recruited to the study from a number of public kindergartens. An initial screening questionnaire addressing the child’s birth, past and present health status, parental smoking habits, and asthma or allergies within the immediate family was completed by the parents. The questionnaire was based on the ATS-DLD-78-A questionnaire for adults, adapted for children and translated into Hebrew. Each patient underwent a physical examination on the day of test.

Exclusion criteria included previous symptoms or treatment for asthma of the child, his or her parents, or siblings; any respiratory symptoms (cough, postnasal drip, pneumonia, allergic rhinitis) within the preceding 4 weeks; history of respiratory syncytial virus bronchiolitis, prematurity, oxygen administration or mechanical ventilation; any chronic respiratory illness (ie, cystic fibrosis, bronchopulmonary dysplasia, or chest deformation). Children with allergic rhinitis, atopic dermatitis, gastroesophageal reflux, and extensive passive tobacco exposure were also excluded.

**Asthmatic Group:** This group included children with asthma diagnosed by pediatric pulmonary physicians prior to the study. Children in the asthmatic group were considered to have asthma if they exhibited the following symptoms: repeated episodes of shortness of breath, wheezing and/or nocturnal cough with clinical response to inhaled bronchodilators (Global Initiative for Asthma [GINA]). These children had all been referred to the Pediatric Pulmonary Unit. A detailed history (including comorbidity factors such as passive smoking, allergic rhinitis, allergic conjunctivitis, and atopic dermatitis) was obtained, and a physical examination was performed. Asthma severity was classified clinically according to GINA guidelines, as mild intermittent, mild persistent, moderate persistent, and severe persistent. Exclusion criteria were current acute respiratory illness (common cold, pneumonia), use of bronchodilators within the past 12 h, any other chronic respiratory illnesses (cystic fibrosis, bronchopulmonary dysplasia, or chest deformation), history of prematurity, oxygen administration or mechanical ventilation, gastroesophageal reflux disease, and other nonrespiratory chronic illnesses.

Written informed consent was obtained from each parent or legal guardian. The Helsinki Board at the Sheba Medical Center approved the study.

**Spirometry**

Spirometry was performed with a commercial spirometer (ZAN100; ZAN Messgeraete GmbH; Oberthulba, Germany). Calibration was performed before each testing session. The spirometer software includes on-line analysis of the FEFV curves. The curves were monitored on the computer screen to ensure best effort. Results were corrected to body temperature and barometric pressure, saturated. The software also included SpiroGame (patented by Dr. Vilzome, 2003), an interactive animated computer game set by targets of the FEFV maneuver, combining maximal inhalation before forced expiration, PEFR, and FVC, with emphasis on prolonged expiration. The targets were the extrapolated values derived from comparative data from older children, corrected for height. Target values were increased by 10% if the flows exceeded the target or decreased by 10% if despite an optimal effort the child could not reach the target. The SpiroGame is comprehensively described in a previous publication and briefly in the Appendix.

**Procedure**

**Healthy Children:** Tests were performed in a designated room in the kindergarten. One parent or teacher was present during the test. We allowed up to two additional children in the room for learning purposes.

**Asthmatic Group:** Tests were performed in the Pediatric Pulmonary Function Laboratory. As with the healthy children, parents were present during the test. Children were asked to refrain from using bronchodilators 12 h before the test.
Spirometry Measurements: Tests were performed in a standing position without a nose clip. An experienced pulmonary technician instructed each child how to operate the game. Emphasis was placed on full inspiration before expiration, without breath holding, and on forced expiration to RV according to the game targets. Maneuvers were repeated to obtain best possible efforts on at least three technically acceptable FEFV curves. Sessions lasted on average 15 min per child, but were shorter if three repetitive, technically acceptable curves were achieved. These curves were stored, and the three curves with the maximal repetitive, technically acceptable curves were achieved. These lasted on average 15 min per child, but were shorter if three technically acceptable curves could not be chosen off-line. Off-line, the curves were inspected for acceptability criteria and common spirometric parameters (FVC, FEV₁, FEV₆₅, PEFR, forced expiratory flow at 25% of vital capacity [FEF₂₅], and forced expiratory flow at 50% of vital capacity [FEF₅₀]). These curves were analyzed.

Curves had to show a rapid rise to peak flow, and gradual, smooth decline of flow to RV. On-line rejection of curves based on visual inspection for “noncooperation” errors included duration of expiration of < 0.5 s, poor effort, incomplete expiration, cough, and glottis closure. The entire examination of a child was rejected if three technically acceptable curves could not be chosen off-line. Curves had to show a rapid rise to peak flow, and gradual, smooth decline of flow to RV. On-line rejection of curves based on visual inspection for “noncooperation” errors included duration of expiration of < 0.5 s, poor effort, incomplete expiration, cough, and glottis closure. The entire examination of a child was rejected if three technically acceptable curves could not be chosen off-line. Off-line, the curves were inspected for acceptability criteria and common spirometric parameters (FVC, FEV₁, FEV₆₅, PEFR, forced expiratory flow at 25% of vital capacity [FEF₂₅], and forced expiratory flow at 75% of vital capacity [FEF₇₅]). These were analyzed.

Analysis and Statistics

Acceptability of Curves: Three authors of this study reviewed the spirometry curves visually for acceptability, blinded as to name, sex, age, and height of the children. Accepted curves were further analyzed in relation to ATS/ERS criteria for adults³⁴ and to preschool measurements as measured using verbal coaching techniques or a single-target game.⁶⁹¹⁰¹³ These included the following: (1) “start-of-test” criteria: time to peak expiratory flow and backward extrapolated volume (Vbe); (2) “end-of-test” criteria: forced expiratory time of 6 s, and the ratio between the “time of no change in expiratory volume” to total expiratory time; and (3) repeatability: the differences between the three best FEFV curves of each parameter (SD/mean × 100) for each child. In all statistical analyses, p < 0.05 was considered significant.

Further Analysis

Healthy Subjects: Children were grouped by age: 2.5 to 3.5 years old (age 3), 3.6 to 4.5 years old (age 4), 4.6 to 5.5 years old (age 5), and 5.6 to 6.5 years old (age 6). Correlations between each parameter and height (age) were calculated for the healthy children using the Pearson correlation. Parameters between groups were compared using unpaired t tests and χ² analysis. Spirometric values were then compared by paired t test to the extrapolated values of height parameters published previously for preschool children⁶⁹¹⁰

Asthmatic Children: Asthma severity was classified clinically according to GINA guidelines² as mild intermittent, mild persistent, moderate persistent, and severe persistent. Bronchodilators were administered only when airway obstruction was evident. Bronchodilator, 200 μg salbutamol, was delivered via an air-holding chamber with a facemask sealed gently to the face around the nose and mouth. The child was asked to breathe the medication for 40 s. Spirometric values of each child were compared to the extrapolated values for height of our healthy children by paired t test. Postbronchodilator values were compared as percentage change to the baseline values; p < 0.05 was considered significant.

Results

Of 341 children who participated in the study (both healthy and asthmatic), 266 patients (75%) performed technically acceptable triplicate spirometry. Of the 266 children, 109 were healthy and 157 were asthmatics. When broken down according to age, there were 64 3-year-olds, 79 4-year-olds, 75 5-year-olds, and 44 6-year-olds. The main cause for rejection of spirometry was lack of comprehension of the breathing tasks of the game or the FEFV maneuver (n = 57). Five “healthy” children had spirometry findings that strongly suggested obstructive airways disease and were excluded from analysis. Only a small number of children refused to play the games (n = 13). The success rate for each age group and anthropometric data for 109 healthy and 157 asthmatic children are presented in Table 1. Healthy children did not differ from asthmatic children in their mean ± SD of height or weight. The overall success rate increased with age and was significantly higher in the asthmatic group.

Table 1—Success Rate for Each Age Group and Anthropometric Data for 109 Healthy and 156 Asthmatic Children

<table>
<thead>
<tr>
<th>Age range, yr</th>
<th>Male/Female Gender, No.</th>
<th>Median Height (Range), cm</th>
<th>Median Weight (Range), kg</th>
<th>Success Rate, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 to 3.5</td>
<td>12/11</td>
<td>95 (85–108)</td>
<td>14 (11–17)</td>
<td>62</td>
</tr>
<tr>
<td>3.6 to 4.5</td>
<td>15/17</td>
<td>102 (93–114)</td>
<td>16 (12–21)</td>
<td>69</td>
</tr>
<tr>
<td>4.6 to 5.5</td>
<td>14/16</td>
<td>110 (99–118)</td>
<td>18 (15–26)</td>
<td>75</td>
</tr>
<tr>
<td>5.6 to 6.5</td>
<td>9/15</td>
<td>116 (109–126)</td>
<td>20 (17–27)</td>
<td>78</td>
</tr>
<tr>
<td>All (age 4.5)*</td>
<td>50/59</td>
<td>106</td>
<td>17</td>
<td>71</td>
</tr>
<tr>
<td>Asthmatic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 to 3.5</td>
<td>23/20</td>
<td>97 (81–114)</td>
<td>15 (10–24)</td>
<td>65</td>
</tr>
<tr>
<td>3.6 to 4.5</td>
<td>32/15</td>
<td>104 (93–117)</td>
<td>18 (12–26)</td>
<td>75</td>
</tr>
<tr>
<td>4.6 to 5.5</td>
<td>28/18</td>
<td>109 (97–123)</td>
<td>18 (15–26)</td>
<td>82</td>
</tr>
<tr>
<td>5.6 to 6.5</td>
<td>9/9</td>
<td>112 (104–125)</td>
<td>20 (17–27)</td>
<td>88</td>
</tr>
<tr>
<td>All (age 4.1)*</td>
<td>94/62</td>
<td>104</td>
<td>17.9</td>
<td>76</td>
</tr>
</tbody>
</table>

*Median value only.
Spirometry Curves Yielded From the Games in Healthy Children

Examples of technically accepted flow/volume curves for the four age groups are presented in Figure 1. The configurations of the curves are typical for all accepted curves obtained at the different ages. Curves are related to reference values offered by Eigen et al.6 (verbal coaching). Mean spirometry parameters for the different age groups are presented in Table 2. Both flow rates and FVC increased significantly with age (p < 0.01), while the \( \text{FEV}_1/	ext{FVC} \) ratio decreased significantly with age (p < 0.02).

Acceptability Criteria

Acceptability criteria of start of test and repeatability were not affected by age and were similar in healthy and asthmatic children.

Start of Test: PEFRs were achieved within 92 ± 8 ms, and mean Vbe was 2.2 ± 1.5% of FVC.

Repeatability: The differences between three measurements were 3.54 ± 2.66% for FVC; 2.95 ± 2.01% for \( \text{FEV}_{0.5} \); 3.43 ± 2.34% for \( \text{FEV}_1 \); 4.66 ± 3.01% for PEFR; 5.98 ± 4.89% for \( \text{FEF}_{50} \) and 8.99 ± 7.93% for \( \text{FEF}_{75} \).

End of Test: The time of “no change in expiratory volume” at the end of expiration was similar in healthy and asthmatic children (0.33 ± 0.05 s).

Expiratory Time: In healthy children, expiratory time increased with age. Mean values for healthy 3-year-old children were 1.34 ± 0.45 s, increasing to 1.56 ± 0.62 s in 6-year-old children (p < 0.05), with mean for the total healthy group of 1.56 ± 0.45 s. The correlation between height (age) and expiratory time is presented in Figure 2. The ratio of no change in expiratory volume to “total expiration time” was 0.19 ± 0.05 for the healthy children. In asthmatic children, the mean expiration time for the mild group was 1.45 ± 0.41 s, as in healthy preschool children.Expiration time was significantly longer in the moderate and severe groups (1.7 ± 0.4 s and 1.7 ± 0.5 s, respectively), compared with healthy children (p < 0.03).

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Spirometry Yielded by Respiratory Games in Comparison With Published Reference Data for Preschool Children Yielded by Verbal Coaching Techniques or Single-Target Games

Values are presented in Table 3. FVC and \( \text{FEV}_1 \) values were similar to those published by Eigen et al.,6 but significantly higher than those of Zapletal and Chalupova.9 \( \text{FEV}_{0.5} \) values were similar to those of Nystad et al.10 PEFR values were similar to those of Nystad et al.10 and significantly higher than those of Eigen et al.,6 but the differences were < 0.5 SD. Flow-related volumes measured in our study were significantly higher compared to the results published by Eigen et al.6 and Zapletal and Chalupova.9 Equations for each parameter of the \( \text{FEF}_{V} \) parameters in correlation to height used to calculate healthy spirometric data are presented in Table 4.

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Asthmatic Group

The anthropometric data of the asthmatic children (93 boys, 62 girls) are presented according to disease

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Table 2—Lung Function Measurements in Healthy Subjects*

<table>
<thead>
<tr>
<th>Age Group</th>
<th>FVC, L</th>
<th>( \text{FEV}_1 ), L</th>
<th>( \text{FEV}_{0.5} ), L</th>
<th>( \text{FEV}_1/	ext{FVC} )</th>
<th>PEFR, L/s</th>
<th>( \text{FEF}_{25-75} ), L/s</th>
<th>( \text{FEF}_{50} ), L/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.81 ± 0.14</td>
<td>0.77 ± 0.15</td>
<td>0.64 ± 0.13</td>
<td>0.97 ± 0.04</td>
<td>1.90 ± 0.37</td>
<td>1.41 ± 0.29</td>
<td>1.45 ± 0.28</td>
</tr>
<tr>
<td>4</td>
<td>1.00 ± 0.16</td>
<td>0.92 ± 0.16</td>
<td>0.84 ± 0.32</td>
<td>0.96 ± 0.05</td>
<td>2.39 ± 0.40</td>
<td>1.75 ± 0.30</td>
<td>1.77 ± 0.29</td>
</tr>
<tr>
<td>5</td>
<td>1.23 ± 0.21</td>
<td>1.09 ± 0.18</td>
<td>0.93 ± 0.13</td>
<td>0.94 ± 0.05</td>
<td>2.85 ± 0.44</td>
<td>1.93 ± 0.31</td>
<td>2.07 ± 0.30</td>
</tr>
<tr>
<td>6</td>
<td>1.43 ± 0.25</td>
<td>1.27 ± 0.17</td>
<td>1.07 ± 0.16</td>
<td>0.93 ± 0.06</td>
<td>3.31 ± 0.40</td>
<td>1.97 ± 0.29</td>
<td>2.21 ± 0.29</td>
</tr>
</tbody>
</table>

*Data are presented as mean ± SD. \( \text{FEF}_{25-75} \) = forced expiratory flow between 25% and 75% of expiratory vital capacity.

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severity in Table 5. There were more boys then girls, but there were no significant differences among the groups in respect to age, height, or weight. A representative FEFV curve yielded by the games for each group is presented in Figure 3. Mean values of the FEFV indexes are presented as percentage of healthy subject values for the groups in Table 6 and Figure 4. Children in the mild group had spirometric indexes and FEFV curve shapes similar to the healthy subjects. Children with moderate asthma had FVC and FEV1 values within the healthy range, but flows at low lung volumes (FEF50 and FEF75) were significantly lower (\( p < 0.05 \))2 SD. In children with severe asthma, all parameters were significantly reduced. All children in the moderate and severe asthma groups, regardless of age, expired \( \geq 1 \) s, ie, were able to produce FEV1.

**Bronchodilator Effect**

Ninety-eight children from the moderate and severe asthma groups were tested after bronchodilator administration. Results of the effect of bronchodilators are presented in Table 7. Bronchodilators improved most spirometry indexes. FVC and flow-related time values were improved by a smaller magnitude than PEFR and flow-related volume parameters. FEV1/FVC ratio and FEV0.5/FVC ratio did not significantly improve in either of the groups. We found that the magnitude of response of flow-related volumes was three times higher than volume-related time values.

**Discussion**

We found that the interactive respiratory games teaching technique can be a useful method to facilitate spirometry in very young children. Our study demonstrated that with such aid, many children aged \( > 2.5 \) years can perform reliable FEFV curves, which conform to most of the ATS criteria that were established for older children and adults. In addition, spirometry obtained at the preschool age can detect airway obstruction and discriminate the degree of severity of respiratory symptoms. However, it should be reminded that we aimed to evaluate whether teaching games with multiple targets will yield spirometry measurements that are compatible with published data using verbal coaching techniques, and not to argue teaching methodologies. It should also be noted that our target games did not include forced inspiratory capacity after forced expiration, and therefore inspiration was not assessed.

It is interesting to note a small gap between parental perceptions of “healthy” and past respiratory diseases. We found that, for 5 of the 153...
Meeting ATS/ERS Criteria

Overall, most start-of-test, end-of-test, and repeatability criteria were met, and results were similar to those reported previously for adults, school children, and healthy preschool children. Repeatability was also similar to values reported by Nystad et al, who taught spirometry using games. Specific differences in acceptability of curves found in our study.

Start-of-Test Criteria: The volume exhaled during the first 100 ms overlapped 25% of the expiratory volume in some of the younger healthy children. We rejected curves if PEFR was reached after 25% of the expiratory volume (defined as slow starts), but this rejection may have to be reconsidered since the younger children may not be able to reach their peak expiratory flow within 100 ms. Vbe ≤ 5% of FVC found in our study is tighter than reported, as we have rejected in advance curves with Vbe > 5% of FVC at the expense of success rate. The value of 100 to 150 mL, also cited for differences between curves, is a relatively high percentage of the FVC in young children (>18% of FVC in healthy 3 year olds and/or 10% of FVC at age 6). Therefore, rejecting curves on this basis may be inappropriate.

End-of-Test Criteria: We found that expiratory time was age related. Thus, it is suggested that age-related rather than a fixed expiratory time may be more appropriate to define end-of-test criteria at the preschool ages. A positive correlation between expiratory time and age has been documented in infants; therefore, our finding may insinuate continuation of lung growth. The change in shape from convex to linear in the pre-school age reflects a continuation of the developmental processes of lung maturation. The significant decline of spirometric indexes in relation to FVC found in our study and by Zapletal and Chalupova supports our assumption of continued developmental processes of lung volume in preschool age.

Compatibility of Measurements in Healthy Preschool Children With Published Data

We found that volume-related time values in our study were similar to those yielded by verbal coaching. The main outcome differences between the teaching methods are in the flow values. We found that PEFR values and flow-related volumes were significantly higher compared to the results in verbal coaching. PEFRs produced by the children in our study were in close agreement with PEFRs reported by Nystad et al, who used a single target (PEFR) game. Gracchi et al also reported that PEFRs yielded by a single-target game were higher than those yielded by verbal instructions only. Apparently, the “single-target games” based on PEFR could not yield sufficient FVC values to establish correct flow-related volume values. The higher flow-related volume found in our study may be due to the use of several targets, which clarify the spirometry maneu-

Table 5—Anthropometric Data of the Asthmatic Group According to Respiratory Symptoms*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mild Asthma</th>
<th>Moderate Asthma</th>
<th>Severe Asthma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>44</td>
<td>74</td>
<td>37</td>
</tr>
<tr>
<td>Male/female gender</td>
<td>27/17</td>
<td>45/29</td>
<td>21/16</td>
</tr>
<tr>
<td>Age, yr</td>
<td>4.4 (2.8–5.8)</td>
<td>4.3 (2.3–5.9)</td>
<td>4.0 (2.3–5.8)</td>
</tr>
<tr>
<td>Height, cm</td>
<td>105 (90–123)</td>
<td>105 (85–121)</td>
<td>103 (81–117)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>18 (14–23)</td>
<td>18 (10–29)</td>
<td>17 (10–24)</td>
</tr>
</tbody>
</table>

*Data are presented as No. or median (range).
ver both audibly and visually, and thus enable the child to recruit greater effort.

**Spirometry in Asthmatic Children as Compared With Healthy Children**

The correct spirometry reference values for preschool children are still controversial and are currently being standardized. The present study examined spirometry in preschool children who were thought to have asthma, with varying degrees of respiratory symptom severity (Tables 1, 5) in relation to a healthy population. A difficulty related to this study exists in the definition of asthma at this young age, particularly since there are a number of other entities, such as transient wheezing or viral-associated wheezing, that may overlap, and can cause repeated wheezing in young infants. Their exact definition and nomenclature are still the subject of research and debate.

In our study, children with repeated episodes of wheezing and shortness of breath responding to bronchodilators were considered as having asthma. Their diagnosis of asthma and its severity were based on GINA criteria, which do not include pulmonary function at this age. GINA guidelines state that there have been no well-conducted clinical trials to provide scientific evidence for the proper treatment of asthma at each step of severity in the preschool age, and no objective lung function measurement in the preschool age. This may increase intergroup SDs. The overlap between the groups may also be due to the inclusion of "silent asthmatic" patients in the healthy group. Spirometry indexes of children with asthma from the "mild groups" did not significantly differ from those of our healthy control children. Our findings did not agree with Zapletal and Chalupova, who suggested that both PEFR and FEF$_{50}$ in mildly asthmatic children should be reduced by 2 to 3 SDs. The inclusion of mild intermit-

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mild Asthma</th>
<th>Moderate Asthma</th>
<th>Severe Asthma</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC</td>
<td>98 ± 13</td>
<td>83 ± 13</td>
<td>63 ± 12</td>
</tr>
<tr>
<td>FEV$_{1}$/FVC</td>
<td>103 ± 18</td>
<td>78 ± 13</td>
<td>58 ± 12</td>
</tr>
<tr>
<td>FEV$_{1}$</td>
<td>108 ± 13</td>
<td>86 ± 12</td>
<td>63 ± 10</td>
</tr>
<tr>
<td>PEFR</td>
<td>97 ± 14</td>
<td>68 ± 13</td>
<td>51 ± 17</td>
</tr>
<tr>
<td>FEF$_{50}$</td>
<td>88 ± 14</td>
<td>59 ± 15</td>
<td>45 ± 11</td>
</tr>
<tr>
<td>FEF$_{25}$</td>
<td>75 ± 16</td>
<td>56 ± 17</td>
<td>37 ± 13</td>
</tr>
<tr>
<td>FEF$_{25-75}$</td>
<td>95 ± 18</td>
<td>63 ± 16</td>
<td>46 ± 12</td>
</tr>
<tr>
<td>Expiratory time</td>
<td>1.29 ± 0.37</td>
<td>1.65 ± 0.53</td>
<td>1.66 ± 0.62</td>
</tr>
</tbody>
</table>

*Data are presented as mean ± SD percentage of healthy children. See Table 2 for definition of abbreviation not used in text.

![Figure 3](image-url) Representative flow volume curves for children with respiratory symptoms. Curves are aligned to TLC; actual, backward extrapolated from healthy children of this study.
tent asthma in the mild group may explain the normal values found in our study in mild asthma.

Spirometry was sensitive in detecting moderate and severe symptoms. Airway obstruction increased with increasing severity of symptoms according to the groups, but indexes differed in their sensitivity and $\text{FEF}_{50}$ was reduced more than $\text{FEV}_1$. We found that $\text{FEV}_1/\text{FVC}$ deteriorated with severity of symptoms in a similar degree to $\text{FEF}_{50}$. This finding may counter the considerable doubt over whether $\text{FEV}_1/\text{FVC}$ is sensitive enough to reveal airway obstruction in preschool age children since some young children are not able to expire for > 1 s. In light of our findings, the decision regarding which of the parameters is best for determining airway obstruction may require additional investigation.

Unexpectedly, we found that both FVC and PEFR decreased with severity of symptoms. This finding may indicate elevation of functional residual capacity as a strategy of breathing or elevation of RV due to air trapping.23–27

The Effect of Bronchodilators on Spirometry indexes in the Moderate and Severe Groups

Bronchodilators were administrated only to those children showing airways obstruction, ie, the moderate and severe groups. In the moderate and severe groups, we found that use of bronchodilators improved most spirometry indexes $> 15\%$. The sensitivity of reversibility testing based on spirometry seems to be comparable to that found in asthmatic school children.28

The magnitude of response of flow-related volumes was three times higher than volume-related

![Figure 4: Z-score deviation of the spirometry parameters of asthmatic children from those of healthy children. See Table 2 for definition of abbreviation not used in text.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/22030/)

![Figure 5: The descending part of the curve in relation to age; ages of 3 years and 6 years are presented for simplicity.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/22030/)
time values. Interestingly, PEFs were improved ≥ 22%. The ratios of $FEV_1/FVC$ (or $FEV_{0.5}/FVC$) were insensitive indexes for measuring airway responsiveness, as they did not significantly improve in either of the groups, probably due to simultaneous improvement of flow and volume.

**The Role of Games in Teaching Spirometry to Young Children**

We strongly believe in the value of games for teaching spirometry in preschool-age children, particularly the younger ones. In addition to the elements of fun and pleasure, games engage the children passionately and intensely, offering motivation and ego gratification. But games need rules, structure, goals, and feedback to regulate the learning process. It is only then that a game can have measurable outcomes. Achieving successful goals cannot rely on the instinct of the child to take a deep breath to TLC, nor the voluntary effort to blow out down to RV. Thus, a game with multiple targets to teach all of the steps needed to achieve successful curves seems justified. The use of several games, each teaching a single step of the maneuver to incorporate a full maneuver, may also be appropriate. The relatively small number of healthy children participating in our study may not be sufficient to establish global reference values. Larger study groups evaluating different teaching methods in other institutions may establish solid reference values.

We conclude that many children > 2.5 years of age can perform reliable FEFV curves. The incentive teaching technique with computer games can facilitate spirometry in these very young children, but incentive programs should include all steps of spirometry. Spirometry obtained at the preschool age can detect airway obstruction and correlates with degree of asthma severity. Among the routine indexes used to quantify spirometry, flow-related volumes were better than timed expiratory volume in detecting abnormal airway function. Our results emphasize the need for standardization of suitable teaching techniques, and outcome parameters of spirometry measurements in healthy children, and in revealing airway obstruction in preschool children.

**APPENDIX**

The SpiroGame program was previously published and includes two games. The first game teaches the child to differentiate between inhalation and exhalation by simulating a caterpillar crawling on a window to an apple over a period of 30s of tidal breathing. During inhalation, the back of the caterpillar rises, and during exhalation it flattens. Tidal volume and breathing rate targets are preset at 7 to 10 mL/kg and 20 ± 7 breaths/min, respectively. If the child exceeds either frequency or depth of breathing, the caterpillar falls off the window.

The second game teaches the FVC maneuver. A caterpillar is crawling (tidal breathing) in a field with flowers situated at different locations on the screen. A bee is sitting on the first flower that the caterpillar reaches. On reaching the first flower, the bee flies to another one according to the forced expiratory maneuver targets (inspiratory capacity, PEF, FVC, with emphasis on long expiration). To produce a PEF, the bee has to fly over a fence; to produce FVC, the last flower is within a visual distance from the others. On completion of the FEFV maneuver, a new picture rewards the child for success. The targets are calculated from extrapolated predicted values for height, and the game has several levels of difficulties.

**REFERENCES**

16. Ranganathen SC, Hoo AF, Lum SY. Exploring the relation-