Influence of Age on Effort Required to Complete Spirometry in Children and Adolescents

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ABSTRACT

Although effort required to complete spirometry is known to differ by age, no studies have addressed this issue. The present study aimed to identify the difference in the effort required to complete spirometry by age in children and adolescents. Data from 707 children (mean age, 10.2 years; range, 4–25 years) from 6 medical centers were analyzed. In addition to demographics, we obtained information on the time required for as well as the number of demonstrations and spirometry demonstrations and trials from the patients’ electronic medical records. A total of 398 (56.3%) male participants were included, and 300 (42.4%) participants had no prior experience receiving spirometry. The mean time required for spirometry demonstration was 2.7 minutes (standard deviation [SD], 2.1 minutes), whereas that for spirometry trial was 5.9 minutes (SD, 5.1 minutes). The total mean time required for spirometry was 8.6 minutes (SD, 6.5 minutes). Significant negative associations were observed between age and effort required to complete spirometry with respect to the time and number of demonstrations and trials. The results of the present study suggest that age may affect the degree of effort required to complete spirometry, with a pattern of increasing effort with decreasing age. This finding provides important evidence for the establishment of health care policies especially regarding lung diseases that can benefit from spirometry.

Keywords: Adolescent; children; age; effort; preschooler; spirometry; lung disease

INTRODUCTION

Spirometry, one of the most widely used lung function assessment methods, measures the volume of air during exhalation,¹ which can aid the diagnosis of diverse respiratory diseases and in monitoring of treatment responses.²,³ Whereas it has long been assumed that children
aged 6 years can reliably undergo spirometry, more recent studies have confirmed that younger children (e.g., 2–5 years of age) can also perform these maneuvers.4,8

Unlike adults, children inevitably face a number of special challenges when undergoing pulmonary function tests (PFTs).6 For technicians for pediatric PFTs, special attention should be paid to ensuring the following aspects: child-friendly environment, age-appropriate instructions, sufficient training time, and patience.3,10 Therefore, additional time and effort are required to meet the specific needs of children undergoing spirometry. Some studies with a small sample size showed that the time required for a reliable spirometry result was approximately 15 minutes for adults and 15–30 minutes for children.11,12 Furthermore, older children showed higher spirometry success rates than preschoolers.13–15 Thus, it is presumed that more resources should be dedicated to obtaining acceptable spirometry results in younger children. However, no studies have quantified resources required for children to complete spirometry or explored age-based effort differences. Therefore, here we aimed to investigate the influence of age on effort required for children and adolescents to complete spirometry.

MATERIALS AND METHODS

Study population
To ensure the quality of PFT data, 2 research groups, including the 1) Research on Pulmonary Function and the 2) Healthcare Informatics Clinical Application in the Korean Academy of Pediatric Allergy and Respiratory Disease, held a campaign to encourage each institution to focus more on quality control in PFTs. The campaign recommended the following items: 1) laboratory technicians should manage equipment calibrated before the session, explain maneuvers thoroughly with good demonstrations, and give sufficient time to practice; 2) maximal efforts should be encouraged to obtain an appropriate flow-volume curve. Pulmonary laboratory technicians from each hospital accurately followed the general principles of quality control when evaluating PFTs.13 To formally quantify their efforts, we recorded the information on the time taken for and the number of demonstrations required before performing PFT as well as the time taken for and the number of trials required to perform PFT.

This study was performed between July 1 and September 30 of 2021 at 6 hospitals (Chonnam National University Hospital, Myongji Hospital, Chungnam National University Hospital, Pusan National University Children’s Hospital, Soonchunhyang University Seoul Hospital, and Seoul National University Hospital). Individuals (age range, 4–25 years) who visited pediatric allergy and respiratory disease outpatient clinics with diverse respiratory diseases, including chronic cough and asthma, were enrolled. If a participant had multiple clinic visits and several spirometry results, only the first spirometry session completed during the study period was included.

Measurement of spirometry
Spirometry was performed using the Vmax Encore system (CareFusion, San Diego, CA, USA) according to the 2007 American Thoracic Society/European Respiratory Society guidelines.14 Experienced technicians in the pulmonary function laboratories demonstrated the appropriate method to the participants prior to their sessions. If a participant did not fully understand the spirometry process and methods, the technicians repeated the instructions and demonstrations if needed (Supplementary Data S1).
Statistical analysis

Spearman's rank correlation analysis was used to assess the correlation between age and the time and number of spirometry demonstrations and trials. Since the time and number of spirometry trials did not satisfy the parametric assumption for the age groups, the Kruskal-Wallis rank test was performed to compare variables among the age groups, followed by the pairwise Mann–Whitney test with Bonferroni correction as a post hoc test. As the distribution of the time and number of demonstrations and trials of spirometry showed a bimodal pattern, a mixture of Gaussian density estimation was used. Continuous variables were converted into binary variables based on the intersection points. The transformed binary variable was 1, indicating that the group required more time as well as more demonstrations and trials to successfully complete the spirometry; otherwise, those below individual intersection points were defined as 0. The multiple logistic regression model was employed to identify the effect of age on the time and number of demonstrations and trials for complete spirometry, whereas adjusted odds ratios were used to examine the estimated effects of the variables. All statistical analyses were performed using R software version 4.1.3 (R Statistical Foundation of Computing, Vienna, Austria). P values of <0.05 were considered statistically significant.

Ethics statement

This study was approved by the institutional review board and research ethics committee of each of the participating hospitals (SCHUH 2022-03-007, SNUH 2201-066-1290, CNUH [Chonnam National University Hospital] 2021-177, MJH 2022-01-025, CNUH [Chungnam National University Hospital] 202140-002, and PNUCH 05-2021-2021).

RESULTS

Characteristics of the study population

A total of 707 participants, who completed the spirometry, were enrolled in the present study (Table 1). The mean age of the participants was 10.2 years (standard deviation [SD], 3.8 years; range, 4–25 years) and 57.6% of the study population were male. The mean time required for the spirometry demonstration was 2.7 minutes (SD, 2.1 minutes), whereas that for the spirometry trial was 5.9 minutes (SD, 5.1 minutes). The total mean time required for the spirometry was 8.6 minutes (SD, 6.5 minutes).

Effort required to complete spirometry according to age

We investigated effort required for the completion of spirometry with respect to the time for as well as the number of demonstrations and trials of spirometry. The time required

| Variables                                             | Values                          |
|-------------------------------------------------------|---------------------------------|
| Number                                                | 707                             |
| Age (y)                                               | 10.2 ± 3.8 (range, 4–25 yrs)    |
| Sex, male/female                                      | 398/309 (56.3/43.7)             |
| Participants with prior experience with spirometry    | 300 (42.4)                      |
| Total duration of pulmonary function from demonstration to completion, min | 8.6 ± 6.5                       |
| Time for demonstration of spirometry, min             | 2.7 ± 2.1                       |
| Time for trial of spirometry, min                     | 5.9 ± 5.1                       |
| Number of demonstrations of spirometry                | 2.8 ± 2.6                       |
| Number of trials for spirometry                       | 6.1 ± 3.4                       |

Values are presented as mean ± SD or number (%).
for the demonstrations and trials for the completion of spirometry showed a significantly reverse correlation and a decreasing linear trend with increasing age (Figure). The number of demonstrations and trials required for the completion of spirometry also showed a significant reverse correlation to age with similar trends. When the participants were classified into 4 groups according to age as preschoolers, school-aged children, adolescents, and young adults, similar patterns between age groups and effort required for the completion of spirometry were observed (Supplementary Table S1).

**Effect of age on effort required to complete spirometry**

Based on each interception point, the time and number of demonstrations and trials required for the completion of spirometry were dichotomized and logistic regression analyses were performed to identify the association between age and effort required for the completion of spirometry. Based on each interception point, younger age was significantly associated with the requirement of more than 2.60 minutes for demonstrations, more than 4.59 minutes for trials, and more than 7.26 minutes for the completion of the spirometry (Table 2). In addition, younger age was significantly associated with the requirement more than 3.13 demonstrations of spirometry and more than 4.14 trials of spirometry.

**DISCUSSION**

In the present study, we identified that spirometry can be performed even on younger children, although the effort required for the completion of spirometry is influenced by age albeit a decreasing effort with age. Compared to older children, younger children require
additional effort in terms of time and number of demonstrations and trials for spirometry. In addition, the quality of spirometry in younger children was relatively acceptable, although the proportion of good quality spirometry showed increasing trends with age. The results of the present study can provide fundamental data for understanding effort required to complete spirometry and improve the quality of spirometry in children. Furthermore, the results of the present study would be helpful for the establishment of diagnostic and therapeutic strategies in children with diverse pulmonary diseases.

Although the experience on the performance of spirometry may affect the degree of effort required for its completion in instrument handling, there was no significant association between the first spirometry attempt and greater effort required for its completion in the multiple logistic regression analysis. However, we identified that the first attempt was negatively associated with good quality results of spirometry. These findings suggest that repeated experience with spirometry in different time intervals may help improve the quality of spirometry. The increased effort required to complete spirometry might affect the inter-trial reproducibility, an important factor in monitoring a patient’s disease status and treatment response. Therefore, it is necessary to consider these aspects during the follow-up period, especially in younger children.

Compared to older children, younger children have physiologically smaller absolute lung volume and larger airway size relative to lung volume. The latter is associated with increased airway dead space in younger children. Thus, we need to evaluate whether instruments designed for adults are suitable for younger children requires evaluation, as minimizing the dead space in younger children is required to decrease effort required for complete spirometry. Regardless of these physiologic differences, younger children have difficulty in making consistent flow-volume curves, partially due to their inability to consistently inspire to their total lung capacity and exhale completely and with consistent maximal effort to zero flow. Although it is unclear whether this was partially related to the effort required, the results of this study suggest that effort can affect the ability of younger children to meet acceptability criteria. In addition, factors associated with the differences in acceptability criteria between adults and younger children and/or adolescents subsequently affect spirometry quality. Nonetheless, most flow-volume curves in preschoolers and school-aged children can be useful for interpretation, although not all experienced children met spirometry acceptability criteria.

### Table 2. Multiple logistic regression analysis for a group requiring higher efforts

| Outcome                        | Parameter                     | Estimate | P value  | Adjusted odds ratio | 95% confidence interval |
|--------------------------------|-------------------------------|----------|----------|---------------------|-------------------------|
| Time for demonstrations        | Age                           | −0.0537  | 0.0159'  | 0.95                | 0.91–0.99               |
|                                | Male                          | 0.1537   | 0.3411   | 1.17                | 0.85–1.60               |
|                                | No previous spirometry experience | −0.0389 | 0.8115   | 0.96                | 0.70–1.32               |
| Time for trials                | Age                           | −0.0805  | < 0.001' | 0.92                | 0.89–0.96               |
|                                | Male                          | −0.0688  | 0.6549   | 0.93                | 0.69–1.26               |
|                                | No previous spirometry experience | 0.1282 | 0.4096   | 1.14                | 0.84–1.54               |
| Total time for spirometry      | Age                           | −0.0544  | 0.0089'  | 0.95                | 0.91–0.99               |
|                                | Male                          | −0.0168  | 0.9135   | 0.98                | 0.73–1.33               |
|                                | No previous spirometry experience | 0.1929 | 0.2191   | 1.21                | 0.90–1.65               |
| Number of demonstrations       | Age                           | −0.1526  | < 0.001' | 0.86                | 0.81–0.91               |
|                                | Male                          | 0.2090   | 0.267    | 1.23                | 0.85–1.78               |
|                                | No previous spirometry experience | 0.8347 | 0.001    | 2.30                | 1.55–3.42               |
| Number of trials               | Age                           | −0.0850  | < 0.001' | 0.92                | 0.88–0.96               |
|                                | Male                          | −0.1576  | 0.317    | 0.85                | 0.63–1.16               |
|                                | No previous spirometry experience | −0.1000 | 0.529    | 0.90                | 0.66–1.24               |

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For clinical usefulness, we suggest 2 prediction models for obtaining good quality of spirometry in the supplementary file (Supplementary Figs. S1 and S2); one includes age, sex, and number of demonstrations and trials required to complete spirometry, whereas the other includes the aforementioned variables with the first experience of spirometry, considering the learning effect. Although sex was not significantly associated with good quality of spirometry results, we included this variable in the prediction models because of physiological differences in the lungs, such as lung volume, that can affect the degree of forced expiratory flow. The constructed prediction models enable us to earlier recognize the probability of obtaining good quality spirometry results, especially among younger children.

In terms of strengths, the present study is the first to have investigated the efforts required for the completion of spirometry in children and adolescents, especially stratified by age. However, our study had some limitations. The number of sample in the present study was relatively small and the distribution of age was disproportionate as a preliminary study to identify the influence of age on effort required for the completion of spirometry. Future large-scale multi-center studies are required to validate our results. Although spirometry was performed by trained and experienced pediatric pulmonary function technicians, the quality and effort required to complete spirometry might have been affected by the involvement of different pulmonary function technicians. However, we did not consider the effect of the involvement of technicians from different institutions, partially in an effort to reveal the effect of real clinical situations on spirometry performance. Further prospective studies on these issues might confirm our results. In the present study, we included data from participants who had technically acceptable and reproducible spirometry results. Data on the required efforts from those who failed to complete spirometry were excluded, which may have imposed medical burden, especially in children. Although other factors, such as disease status, might affect the effort required to complete spirometry, we mainly focused on participant age rather than disease status. Further studies are needed to identify diverse factors that might affect the effort required to complete spirometry.

In conclusion, the results of the present study suggest that age may affect the time and effort required to complete spirometry; specifically, younger children require more effort and time. These findings provide definitive evidence for the establishment of health care policies, especially those for pulmonary diseases whose pulmonary function measurements are important for the diagnosis, follow-up, and improvements in disease burden in children and adolescents.

SUPPLEMENTARY MATERIALS

Supplementary Data S1
Methods and results

Click here to view

Supplementary Table S1
Effort required to complete spirometry by age group

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Supplementary Fig. S1
Prediction of satisfactory lung function test performance based on age, sex, and number of spirometry demonstrations and trials. (A) Nomogram for predicting good quality spirometry performance in children and adolescents. (B) Calibration plot of the actual and predicted probabilities in the train and test sets. (C) Receiver operating characteristic curve of the nomogram.

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Supplementary Fig. S2
Prediction of satisfactory spirometry performance based on age, sex, pulmonary function test experience, and number of demonstrations and trials of spirometry. (A) Nomogram for predicting good quality of spirometry results in children and adolescents. (B) Calibration plot of the actual and predicted probabilities in the train and test sets. (C) Receiver operating characteristic curve of the nomogram.

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