



Protective equipment and health education program could benefit students from dust pollution

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Abstract

In recent years, children living in the downstream of the Choshui River in Taiwan have been exposed to violent dust episodes. For the sake of the health of these children, we aimed to investigate the effectiveness of protective equipment (sand-proof plastic cover and air purifier) installed outside/inside the classrooms on students' pulmonary function and evaluate the health education program for preventing the adverse consequences of exposure to river-dust episodes. Public elementary school students in Yunlin County, which was severely affected by river-dust, were selected as the participants. Study 1 consisted of three-wave follow-up data (801 person-times) in high-/low-dust exposure regions to examine pulmonary function. Study 2 used 147 and 73 students in the high-/low-dust exposure regions, respectively, to establish our health education intervention. Paired *t* tests, repeated measures ANOVA, and generalized estimating equation were used to analyze the short- and long-term effects. The results showed that the students' pulmonary function in schools that installed protective equipment was improved. The health education (such as the usage of correct masks and our designed PM_{2.5} full-cover sand-proof clothing) improved the students' cognition and behaviors related to river-dust episodes and yielded both short- and long-term effects. Therefore, we suggest more schools with high-dust exposure to adopt protective equipment and health education program. Our designed PM_{2.5} full-cover sand-proof clothing can prevent from not only haze but also droplet transmission by infectious diseases such as COVID-19.

Keywords Protective equipment · Health education · River-dust episodes · Students · Pulmonary function

Introduction

Vast expanses of bare riverbed often exist in the lower river reaches of central Taiwan. When a strong northeastern

monsoon strikes, it immediately causes short-term deterioration of air quality. During the dry seasons (especially in winter), exsiccation of the sand and mud of riverbeds often causes severe river-dust episodes (i.e., river-dust air pollution). The

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Choshui River is the longest river in Taiwan. Because of the extreme steepness of the riverbed in the upstream segment of the river, the sediment yields of fine sludge in the downstream segments of the river are significant each year (Kuo et al. 2010). In recent years, due to expansion of the exposed area of the riverbed of the Choshui River, exposure of the gravel at the main deep-groove portion of the riverbed is obvious, and this gravel exposes children who live near the south bank of the downstream river to violent dust episodes. According to Kuo et al. (2014), the concentrations of particulate matter 10 (PM₁₀) at high-exposure sites during river-dust episodes (RDEs) were substantially higher than those during non-river-dust episodes (NRDEs), and both the PM₁₀ and metal concentrations were higher at high-exposure sites than those at low-exposure and control sites both during and after RDEs. The concentrations of toxic metals (Ni, Cr, As, and Cd) at high-exposure sites were approximately 11.3 times higher during RDEs (189 ng/m³) than those during NRDEs (16.7 ng/m³) and approximately 8.9 times higher than those during the same periods at a control site (21.3 ng/m³). Based on these findings, the decreased air quality caused by dust episodes can no longer be ignored.

Suspended particles from river-dust episodes enter the respiratory tract during inhalation, causing respiratory system-related diseases and affecting other systems of the body. Many epidemiological studies suggest that elevated levels of atmospheric PM₁₀ result in increased adverse health effects in susceptible individuals (Stone et al. 2003), especially children (Chiang et al. 2017). Studies have indicated that the increase in PM₁₀ was associated with increases in systolic and diastolic blood pressures in Chinese children, especially in overweight children (Li et al. 2018). People who experience long-term exposure to higher concentrations of suspended particulates are prone to respiratory disease (Pope et al. 2002). Sofer et al. (2013) reported that exposure to elevated PM₁₀ levels caused an approximate 3 to 6% decline in lung function, and Kozusznik et al. (2017) formulated the hypothesis that PM₁₀ levels were positively correlated with health symptoms. The increased prevalence of symptoms, including lower respiratory symptoms, asthma, and cough, is also associated with PM₁₀ levels (WHO 2006). The damage to pulmonary function caused by suspended particles is reflected by reductions in the forced expiratory volume at the first second (FEV1) and the peak expiratory flow rate (PEFR) (Studnicka et al. 1995; Tam et al. 2016). This damage is particularly significant in the age group spanning children through adolescents. For example, children exposed to higher concentrations of fine particulates showed poorer pulmonary development (Gauderman et al. 2004). The Lunbei Township of Yunlin County in Taiwan is close to the river area where the occurrence of river-dust episodes with a high concentration of PM₁₀ has been increasing over time, and the PM₁₀ concentration consistently increases during school hours, which might affect the

pulmonary functions of the students. Therefore, for these children living near environmental hazards, reductions in exposure are a priority (Zierold et al. 2016), including improvements in air filtration and surface cleaning for the classrooms (Chen et al. 2020). Of course, a more in-depth investigation is also necessary.

According to social cognition theory (SCT), the interaction among personal factors (especially cognition), environmental factors, and behavior is a dynamic process characterized by high interdependence. These three factors affect each other and serve as causes and results of one another, and this interdependence is known as “triadic reciprocal determinism” (Bandura 1978). A health education intervention program in Canada confirmed that tailored health interventions for different circumstances could improve knowledge and then change health beliefs consistent with behavior change (Jones et al. 2015). Schools can be considered important health promotion settings because school plays an essential role in the development of adolescents, who spend more than one-third of their waking hours in school (Rutter et al. 1979). Patton et al. (2003) believed that the implementation of a school health intervention program, school environmental improvements, and health education for students are indispensable. In Yunlin County, Taiwan, river-dust episodes start every November. Accordingly, we not only installed protective equipment (sand-proof plastic cover and air purifier) outside or inside the classrooms of local public elementary schools to reduce students’ inhalation of suspended particles during river-dust episodes but also deepened students’ self-protection awareness through different forms of health education, including the use of proper self-protection behaviors. Therefore, this study aims to investigate (1) the effect of the protective equipment installed outside or inside the classrooms on the pulmonary function of students and (2) the effectiveness of health education activities aimed at preventing and controlling the health consequences of exposure to river-dust episodes to improve the students’ awareness, confidence, attitudes, and response behavior.

Methods

Participants

The health education intervention was carried out in Yunlin County, which is severely affected by river-dust. Based on the goals of public health, i.e., prevention is better than cures, and because primary school is a critical period for adolescent health and behavioral development, we selected third and fourth graders from local public elementary schools as the participants. To examine pulmonary function, this study selected six classes from seven public elementary schools in a high-dust exposure region for the experimental group, which

was taught how to use protective equipment, and eleven adjacent classes in the schools were selected as the control group. Three classes from one public elementary school in a low-exposure region were selected as the control group outside of the experimental schools. Three evaluations were completed in 1 year. The first evaluation involved 271 people, the second evaluation involved 269 people 4 months later, and the third evaluation involved 261 people 6 months after the first evaluation. This study included a total of 801 person-times.

In addition, for the health education intervention, this study selected another five public elementary schools in the high-dust exposure region to establish health education intervention classes, with fourth graders serving as the experimental group and third graders (at the same school) serving as the inside-school control group. Furthermore, the fourth graders of two public elementary schools in a region where river-dust episodes have a lower impact were selected as the outside-school control group. After the schoolteachers and parents/guardians provided written informed consent, 73 students agreed to participate in the experimental group, 74 students were included in the inside-school control group, and 73 students were included in the outside-school control group.

Study design and procedure

In this study, for the experimental group, air purifiers were installed in the classrooms, and sand-proof plastic covers were installed outside the classrooms (Fig. 1). During the health education intervention classes, the students were taught how to use the indoor air purifiers and were reminded

to turn them on and to pull the outdoor sand-proof plastic covers down during the dust episode period between November and March. In this study, the first pulmonary function examinations were conducted before the protective equipment was installed. The examinations were conducted again at 4 and 6 months after installation of the protective equipment. During the three pulmonary function examinations, each participant assumed a standing position, and a peak expiratory flow meter was used to measure the PEFr three times, while a Flowscreen spirometer (Jaeger) was used to measure the airflow of various vital capacities. Before every test, standard calibrations were performed using the Flowscreen spirometer, and all procedures were performed in accordance with the norms developed by the American Thoracic Society. When analyzing the pulmonary indicators, the influences of age, gender, height, and body weight were taken into account.

In the case of this study's health education courses, a pre-test questionnaire was distributed before establishing the experimental classes. One week later, the students in the experimental group participated in the health education intervention activities for 4 weeks (one unit each week). Unit one was a cognition-promoting course that introduced the evolution of Choshui River, the cause and timing of river-dust episodes, and the bodily harm caused by the dust episodes. Unit two taught the students about the use of personal protection (e.g., the usage of correct masks and our designed PM_{2.5} full-cover sand-proof clothing for participants, as shown in Fig. 2) and indoor and outdoor protection equipment. Unit three promoted the students' confidence via metanoia and sentence composition. Unit four taught the importance of loving one's

Fig. 1 The design of the sand-proof plastic cover outside the classroom

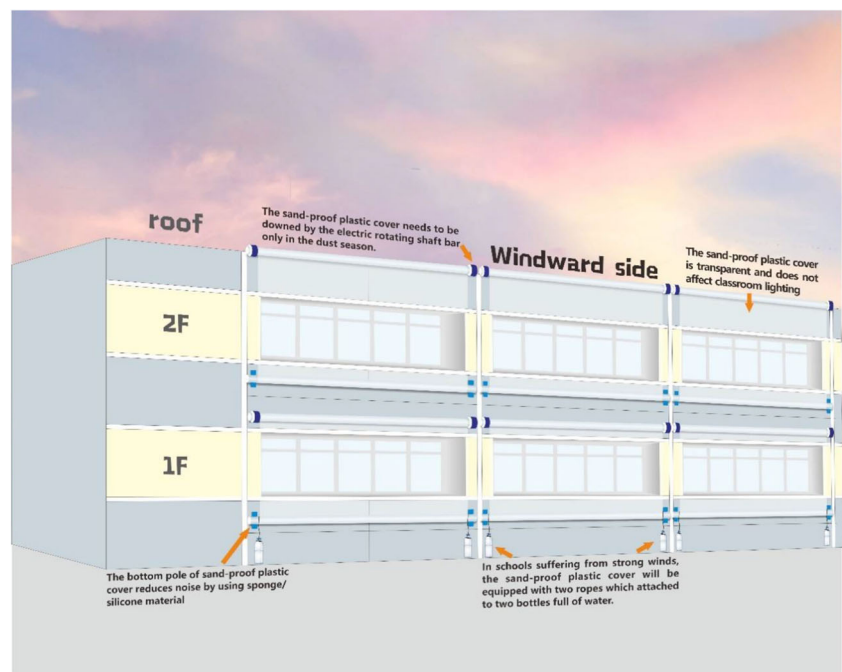




Fig. 2 The students wore our designed PM_{2.5} full-cover sand-proof clothing in the classroom

hometown and environmental protection. We used collective teaching for the entire health education course provided to the experimental group of students from the high-exposure region. We conducted posttest surveys of the students in the experimental and control groups to understand the effectiveness of implementing the intervention activities within 1 week and 3 months after the intervention activities were completed to examine the immediate and delayed effects of the intervention.

Research instrument

Study 1: Pulmonary function examination

After the students inhaled as much air as they could into their lungs, they fully exhaled fast and hard, and the air volume exhaled was considered the forced vital capacity (FVC). This indicator demonstrates the strength of the respiratory muscles and the ventilation/storage capability. An FVC% \geq 80% suggested normal pulmonary function (although this value does not necessarily reflect a disease-free status). An FVC% $<$ 80% indicated abnormal pulmonary function. Therefore, the pulmonary function indicators were reclassified into two categories: “0 = normal” and “1 = abnormal.”

Study 2: Health education intervention experiment

This study was conducted using a self-report questionnaire. The questionnaire was divided into four parts, and each part had five questions. The first part addressed cognition related to river-dust episodes (RDEs), and one answer was selected from among three choices. The students earned one point for choosing the correct answer and zero points for choosing an incorrect answer. The total score ranged from zero to five, where higher scores denoted more accurate knowledge regarding RDEs. The remaining items were rated using a five-point scale ranging from “not very confident/highly disagree/never” to “very confident/highly agree/every time.” The total score for each of the other three parts ranged from five to twenty-five. The second part of the questionnaire addressed confidence regarding dust exposure prevention, and higher scores denoted greater confidence in preventing the negative consequences of RDEs. The third part addressed attitudes towards dust exposure control, and higher scores denoted better attitudes towards prevention of the negative consequences of RDEs. The last part addressed behaviors corresponding to dust exposure prevention, and higher scores indicated that the students were better equipped with appropriate behaviors.

Control variables

In this study, “days with dust episodes (whether any dust episodes occurred on the day of the pulmonary function test),” “pulmonary function-related diseases (the presence of a cold/cough/wheezing/shortness of breath/pneumonia/asthma/runny nose/nasal congestion),” and “the number of tests (whether the test was performed more than four times)” were regarded as control variables.

Data analysis

This study used the KOKO Legend Portable Spirometer (FERRARIS) to perform three pulmonary tests, and we used a generalized estimating equation (GEE) to perform a multivariate analysis. For the health education classes, the frequency, percentage, mean, and standard deviation were used for the descriptive statistical analysis, and a paired-samples *t* test and repeated measures analysis of variance (ANOVA) were used to explore the effectiveness of the intervention.

Results

Study 1: Protective effect of river-dust prevention equipment (sand-proof plastic cover and air purifier)

This study used two models to control for different variables. In Model 1, all the samples were divided into four groups

according to the exposure region and protective equipment use. Model 2 only contained the schools in the high-exposure regions, which were divided into three groups according to the use of protective equipment.

Model 1 revealed that when the low-exposure region without protective equipment was used as the control group, the risk ratios of the three high-exposure groups (i.e., without protective equipment, low protective equipment application compliance, and high protective equipment application compliance) were 1.75, 1.23, and 1.11, respectively. Although the risk ratios of the three groups were not significant, the odds ratios (ORs) showed a dose-effect relationship, suggesting that the number of students with abnormal FVC% values from schools that frequently used protective equipment was lower than the number of students from schools with high exposure but with no protective equipment or with low protective equipment application compliance. Moreover, in the high-exposure group, all of the risk ratios of the exposure groups were higher than that of the control group. Model 2 revealed that the risk of an abnormal FVC% in the high exposure without protective equipment group was 2.47-fold higher than that in the high exposure with high protective equipment application compliance group ($p < 0.05$), suggesting that the use of the equipment had a protective effect on the pulmonary function of the students (Table 1).

Study 2: Effectiveness of the health education course

The cognition of the students significantly improved after the intervention. As shown in Table 2, in terms of cognition, the average differences in the scores between the 1-week posttest and the pretest and between the 3-month posttest and the pretest were statistically significant (both $p < 0.001$). In addition, the average score increase between the posttest and the postposttest in the experimental group was higher than that in the outside-school control group (-0.17 and -0.38 , respectively) and the inside-school control group (0.01 and -0.01 ,

respectively), demonstrating that the river-dust episode education course was effective.

After the teaching intervention, the cognition and protection behaviors of the students showed both immediate and delayed effects, as shown in Table 3. The average pretest cognition score of the students in the experimental group was only 1.99, which significantly improved on the 1-week and 3-month posttests (3.88 and 3.67, respectively), demonstrating both an immediate effect ($p < 0.001$) and a delayed effect ($p < 0.001$). The pretest behavior score of the students in the experimental group was 15.18, which slightly increased on the 1-week and 3-month posttests (15.84 and 15.25, respectively), demonstrating an immediate effect ($p < 0.05$) and a delayed effect ($p < 0.05$). The results indicated that the education course had short- and long-term effects on improving river-dust episode protection cognition and behaviors among the students.

The assessment of the class format by the students and the effectiveness of the course content are shown in Table 4. On the 1-week and 3-month posttests, 68.49% of the students indicated that the class format with pictures was “fairly helpful to very helpful,” followed by video watching and a quick-answer game. On the 1-week posttest, 72.60% of the students indicated that learning about dust episodes was the most helpful, followed by the lessons concerning changing attitudes about dust episode protection. After 3 months, 68.49% of the students still thought that having knowledge about dust episodes was “fairly helpful to very helpful.” In general, the course format involving pictures was the most helpful in terms of learning, whereas the lessons on dust episode cognition were the most helpful with respect to the course content.

Discussion

Although many studies have been conducted on the effects of suspended particulates on human health (Schwartz et al. 1993;

Table 1 Results of the abnormal FVC analysis using a GEE model

	FVC% (normal/abnormal)	
	OR	95% CI
Model 1: Using the low-exposure group without protective equipment as the control		
High exposure without protective equipment	1.75	(0.73, 4.18)
High exposure with low protective equipment application compliance	1.23	(0.43, 3.64)
High exposure with high protective equipment application compliance	1.11	(0.42, 2.90)
Model 2: Using the high-exposure group with high protective equipment application compliance as the control		
High exposure without protective equipment	2.47	(1.22, 4.97) *
High exposure with low protective equipment application compliance	1.54	(0.63, 3.81)

* $p < 0.05$

Table 2 The effectiveness of the education training courses: paired-samples *t* test

	d1 = differences between posttest and pretest			d2 = differences between post-posttest and pretest		
	Outside-school control group	Inside-school control group	Experimental group	Outside-school control group	Inside-school control group	Experimental group
Cognition	− 0.17	0.01	1.89***	− 0.38*	− 0.01	1.68***
Confidence	0.30	0.93	0.59	− 0.11	0.34	0.10
Attitude	− 0.57	0.13	0.44	− 1.17*	− 0.52	0.25
Behavior	0.03	− 0.72	0.63	− 0.11	− 1.31**	0.04
Sustainability	− 0.26	− 0.24	− 0.11	− 0.37	− 1.23**	− 0.41

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Seaton et al. 1995; Jerrett et al. 2005), the emission characteristics of the suspended particles from river-dust episodes (RDEs) differ from those of other air pollutants. We must first understand the emission characteristics and hazard statuses to create effective protection measures and increase public awareness. The PM₁₀ generated by RDEs is not easily recognized by the defense mechanisms of the human body, which especially affects the lungs and other parts of the respiratory tract. This study proved that the pulmonary function of students in schools that installed protective equipment improved to a certain extent. Therefore, we recommend that this protective equipment should be installed in areas prone to RDEs to protect the health of students. In addition to installing the relevant protective equipment, an appropriate degree of compliance and cooperation can more readily lead to long-term protective effects for students. SCT proposes that an interdependent relationship exists among the environment, personal behaviors, and cognition (Bandura 1978). The current study further confirmed that the interplay among these three dimensions is important to ensure that students benefit from complete health protection. Therefore, we suggest that in addition to providing protection against environmental elements, schools and parents must strengthen their instruction of the

use of protective measures and the concepts of protective behavior (Laza et al. 2009). When both environmental factors are controlled and students can defend themselves against pollution, students' long-term stable pulmonary health can be assured.

The implementation of health education improved the students' cognition related to RDEs, and their confidence and attitudes towards RDEs also improved slightly. Notably, environmental education (EE) not only aims to improve students' knowledge but also encourages the implementation of new behaviors. Most studies have suggested that the effectiveness of EE and sustainable development education should focus on "action competence" (Tsevreni 2011; Kater-Wettstädt 2017; Mansilla and Jackson 2011; Mogensen and Schnack 2010; Ceaser 2012), and the effectiveness of a school curriculum should help students to develop proper knowledge, attitudes, skills, and responsible environmental behaviors (Cincera and Krajhanzl 2013). In fact, this education and training course was able to improve the protective behaviors of students with regard to dust episodes and had both short- and long-term effects. In terms of the sustainable concept of RDEs, however, certain questions on the survey were rhetorical and might have been too

Table 3 Repeated measures ANOVA

	Inside-school control group			Experimental group			Immediate effect ^a <i>F</i> value	Delayed effect ^b <i>F</i> value
	Pretest Mean	Posttest Mean	Post-posttest Mean	Pretest Mean	Posttest Mean	Post-posttest Mean		
Cognition	2.03	1.99	2.01	1.99	3.88	3.67	45.18***	46.60***
Confidence	16.85	17.58	17.22	16.94	17.62	16.99	0.20	0.09
Attitude	18.68	18.81	18.18	19.99	20.46	20.22	0.25	1.22
Behavior	17.06	16.35	15.69	15.18	15.84	15.25	5.20*	4.85*
Sustainability	17.20	16.80	15.82	17.40	17.32	17.01	0.03	2.71

* $p < 0.05$; *** $p < 0.001$

^a Immediate effect: Comparison of the experimental group (the average value of the posttest–the average value of the pretest) with the inside-school control group (the average value of posttest–the average value of pretest)

^b Delayed effect: Comparison of the experimental group (the average value of the post-posttest–the average value of the pretest) with the inside-school control group (the average value of the post-posttest–the average value of the pretest)

Table 4 Assessment of the class format by the students in the experimental group and the effectiveness of the course content ($n = 73$)

	Posttest			Post-posttest		
	Very unhelpful to unhelpful (%)	Fair (%)	Fairly helpful to very helpful (%)	Very unhelpful to unhelpful (%)	Fair (%)	Fairly helpful to very helpful (%)
Class format						
Watch a video	9.59	23.29	67.12	13.70	19.18	67.12
Group discussion	13.70	21.92	21.92	10.96	21.92	67.12
Quick-answer game	12.33	20.55	67.12	10.96	21.92	67.12
Draw	18.06	27.70	54.17	16.44	24.66	58.90
Tell stories	11.11	36.11	52.78	16.44	27.40	56.16
Compose sentences	12.50	25.00	62.50	19.18	23.29	57.53
View pictures	10.96	20.55	68.49	12.33	19.18	68.49
Course content						
Knowledge of dust episodes	13.70	13.70	72.60	17.81	13.70	68.49
Protective behavior when dust episodes occur	12.33	20.55	67.12	9.59	23.29	67.12
Improve confidence in dust episodes protection	15.07	27.40	57.53	16.44	20.55	63.01
Change attitudes towards dust episodes protection	9.59	21.92	68.49	15.07	19.18	65.75
Environmental protection methods	17.81	17.81	64.38	8.22	24.66	67.12

difficult for third and fourth graders to answer. As a result, some students were unable to answer correctly because they misunderstood the question. This study corrected this problem in subsequent questionnaires by adjusting to questions to be consistent with the reading abilities of the students to avoid invalid evaluations of the effectiveness of the course due to our overoptimistic questionnaire design. Furthermore, the sustainable development concept regarding RDEs is a broad, long-term issue, and this project will continuously strengthen the teaching activities concerning the concept of sustainably developing the environment in subsequent education/training courses.

Compared with a teacher unilaterally imparting knowledge, the interactive teaching activities adopted in this study might improve learning effectiveness because combining education with entertainment is more acceptable to students (Zhang et al. 2011). Knowledge becomes internalized by stimulating learning achievement in the classroom, oral expression, or writing down opinions about a course (Weiss 2013). Previous studies have indicated that multiple teaching formats (e.g., combining text, pictures, sounds, and cartoons) presented via multimedia computer-assisted instruction (MCAI) are highly knowledge-intensive and powerfully expressive, stimulating students' interest and improving their learning efficiency (Tee and Lee 2011). In this study, the activity leader used diverse teaching aids (e.g., videos, games, drawings, stories, pictures, posters, and handbooks) to create an interesting and vivid atmosphere to encourage the students to practice independent thinking, engage in interactive group discussions, and actively express their opinions. For example,

before each class, the activity leader asked the students to share what they had learned in the previous week through interactive games to deepen their understanding, and before the end of each class, the leader summarized the class focus to facilitate the students' knowledge internalization and their ability to reflect the knowledge in their behaviors. Interactive teaching can not only promote interactions and sharing between students and leaders but also facilitate students' deeper understanding of the implications of the teaching content. The results revealed that more than half of the students assessed this teaching format as "helpful to very helpful," and we speculate that this teaching method of reviewing and summarizing the focus of each class enhanced the learning effectiveness.

According to confirmation from international studies, exposures to dust particles (e.g., under 10 μm) may result in the following conditions: ophthalmic diseases (e.g., conjunctivitis or red-eye syndrome), upper respiratory tract inflammation, abnormal lung function, cardiovascular diseases (e.g., arrhythmia or myocardial infarction), and heavy metal residues in the body. Moreover, children and teenagers are especially vulnerable groups, and long-term exposure to a large number of dust particles can seriously increase the incidence of uncomfortable symptoms. Our previous study observed that the concentrations of PM_{10} at the high-exposure schools during RDEs were approximately 7.3 times higher than concentrations at the same exposure sites during the periods of NRDEs (Kuo et al. 2014). In particular, the time period of the occurrence of high PM_{10} concentrations during the RDEs frequently occurred at the time in which schoolchildren were in elementary

school. Based on this, the students in our experimental classes were suggested to bring the PM_{2.5} full-cover sand-proof clothing with them during RDEs, in case they needed to wear the clothing inside/outside of the classroom or in traffic. The laboratory test results of this clothing in Taiwan (Fig. 3) demonstrated that particles larger than 1 µm can be 100% filtered (Wang et al. 2013). In other words, the wearing of this clothing is equivalent to being protected by the use of a large mask. Furthermore, during the RDEs, the teachers in our experimental classes would drop the sand-proof plastic cover outside of the classroom (Fig. 1), and they would also use the air purifier inside of the classroom. Thus, the students' degrees of consciousness would become enhanced after the health education courses, and they would act to automatically protect themselves. With the use of this multipronged approach, the abnormal pulmonary functions of the schoolchildren can be decreased to the greatest extent.

Limitations and future research

Inspired by SCT, this study explored the measures taken by schools in a high-dust exposure region to improve the class environment, enhance students' cognition and protective behaviors, and protect students from harmful conditions. However, limitations should be considered. First, some students' parents/guardians refused to sign the consent forms, possibly because the forms did not conform to local conventions; the consent form for environmental sampling and physical examination and the consent form for the questionnaires were signed separately, and the consent forms included an overwhelming amount of content and number of pages. We tried to increase the consent rate using many different strategies: the research group members contacted the students' parents/guardians to acquire their consent, we invited

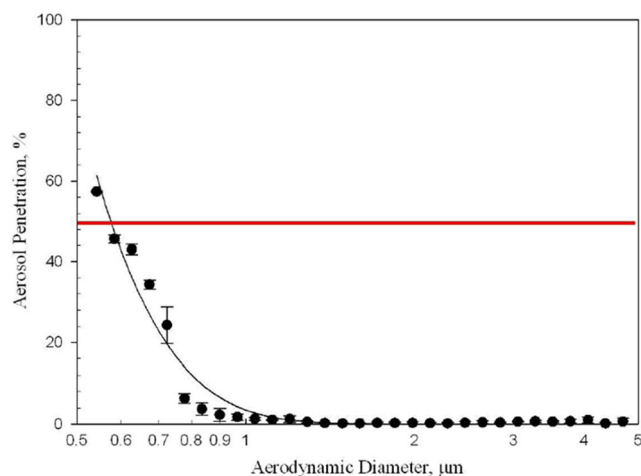


Fig. 3 The penetration of the main filter area of the head of the PM_{2.5} full-cover sand-proof clothing when simulating heavy work (Wang et al. 2013)

the head of the village or the presidents of the parent associations and other local personnel to accompany the research group members when visiting the students' homes, and we invited the school staff (e.g., school guards and school workers familiar with the students' parents) to make phone calls, visit families, and help contact the parents. As a result, the consent rate improved slightly. Second, few schools are seriously polluted by dust in Yunlin County, and the number of students studying in each school is not very large. In addition, third and fourth graders show stable learning abilities, cognitive abilities, language expression, and thinking abilities, and they are well adapted to school life. Therefore, the third graders in the same school served as the inside-school control group for the fourth graders. To reduce bias, we also selected fourth-grade students from schools in a low-dust exposure region as the outside-school control group. Finally, because of the ethical issues associated with intervention studies, the control group in our study was offered the same intervention program after the completion of the 6-month assessment.

In this study, our designed PM_{2.5} full-cover sand-proof clothing has been patented and applied in the health education courses to teach students to use it during the dust season, in order to avoid the invasion of suspended particles. In addition, future research can focus on the comfort level of students wearing sand-proof clothing, the willingness to wear sand-proof clothing and the awareness of individual protection, and the feasibility and protective power of wearing sand-proof clothing inside and outside the classroom all day (including traveling between family and school) under students' high-dust exposure at school. Finally, future researchers can compare the sand-proof clothing with other equipment to further examine its ability of preventing from infectious disease transmitted by droplet (such as COVID-19).

Conclusions

In conclusion, the use of protective equipment showed a protective effect on the pulmonary function of students during river-dust episodes. In addition, the health education intervention also had a positive effect, which was related to the teaching format and course content. More specifically, the intervention improved students' cognitive ability and protection behaviors. We suggest that more schools in high-dust exposure regions should adopt the protective equipment and health education program introduced in this research to increase attention to students' health in relation to dust pollution.

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Authors' contributions All authors contributed to the study conception and design. Yi-Chen Chiang, Xian Li, and Chun-Yang Lee (three first authors) carried out the data analysis, conducted the manuscript writing, and have made major modifications and improvements to the article. Jia Rui, Chiung-Wen Hu, Hao-Jan Yang, Szu-Chieh Chen, Tianmu Chen, Yanhua Su, Chung-Yih Kuo, and Shao-Chieh Hsueh reviewed and further edited the article. Yi-Chen Chiang and Shao-Chieh Hsueh provide funding acquisition during the research process. All the authors have read and approved the final version.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This project was approved by the Institutional Review Board in Chung Shan Medical University (No. CS11053).

Informed consent Written informed consent was obtained from the schoolteachers and parents/guardians of the students before survey.

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