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EFFECT OF INDOOR AIR POLLUTION ON POSTURAL BALANCE CONTROL AMONG SCHOOL STUDENTS

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ABSTRACT

Background: To study the effect of indoor air pollution levels on postural balance control among Saudi school students.

Methods: Ninety healthy students (age from 12-16 years) were selected randomly from several preparatory schools representing two areas of different air pollution load and sources in the Eastern Province of Saudi Arabia (group A and B). Levels of carbon monoxide gas (CO), volatile organic compounds (VOCs) and particulate matter less than 10 microns (PM_{10}) were measured at different sites inside the selected schools. The postural control was measured for each participant using Biodex Balance System in bipedal stance with eyes open at the most and least stable levels for 20s.

Results: There was no statistical significant difference for the mean values of overall stability index between both groups A and B at the most stable level ($p=0.17$), while there was a statistical significant difference at the least stable level with mean $\pm$ SD of group A and B 2.01 ± 0.48 and 2.61 ± 0.68 respectively. In addition, there were statistical significant differences between the mean levels of all measured air pollutants and overall stability index at the two stability levels in both groups ($p<0.01$).

Conclusion: Indoor air pollution, particularly exposure of students to VOCs, PM_{10} and CO, has an adverse effect on postural balance control among school students even at low exposure levels.

Key words: Postural stability, indoor air quality, air pollutants, school students.

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INTRODUCTION

Good indoor air quality (IAQ) in schools is a very important factor for healthy, favorable learning environment for all schools staff, particularly students.[1] Students spend a long time of the day inside their schools and they are susceptible to air pollutants that are emitted from different indoor and outdoor sources especially young age in the elementary schools.[2-3] Several studies indicated that levels of air pollutants indoor are similar, or even higher, than those the outdoor air.[4-7] These pollutants include chemical compounds such as particulate matter and biological stressors such as fungal spores and most of them have adverse health impacts.[8-9]

Several published researches proved that there are strong correlations between exposure to indoor air pollutants and the respiratory diseases, allergies, and infectious diseases, particularly between children and adolescents. [10-12] In addition, poor IAQ can adversely affect student performance of mental tasks involving concentration, calculations, and memory.[13] School children, particularly those classrooms are located near heavy traffic or industrialized areas, are the most probable exposed and affected by the poor IAQ because of their higher breathing rate relative to their body size, and continuing growth.[14-15]

Postural balance is a common body function which helps the human to carry out daily living tasks.[16-18] It reaches its adult- like state between the ages of 10 and 12 years in healthy children.[19] Occupational and non-occupational injuries in adulthood may be due to impaired postural balance. [20] Postural sway, stability, equilibrium, standing steadiness and body sway denote terms to maintenance of standing posture which consider part of assessment of nervous system .[21]

The postural balance testing indicated that neuromotor abnormality is a second effect due to exposure to various neurotoxicants.[22] Postural instability has been associated with Mn neurotoxicity in occupational or environmental settings. [23] The influence of chronic non occupational Mn exposure on postural balance has also evaluated by a previous reports. [24] Lead intoxication presented postural sway in children. [25] Worldwide, exposure to chemicals like lead, mercury, organic solvents such as polychlorinated biphenyls (PCBs) and pesticides (particularly organic compounds such as organophosphates) are harmful to children and affect the nervous system as well.[26-27]

One of the most important adverse effects due to exposure of students to indoor air pollution is the developmental disorders, particularly in developing countries where regulations are lax or nonexistent. Several studied proved that lead emitted from leaded gasoline has its effect presents a threat to more than half of urban children. [28] In the United States, a considerable percent of young children have been diagnosed with one or more developmental disability due to the combination of environmental with the children genetic factors.[29]

The present study is aimed to study the effect of indoor air pollution on postural balance control among Saudi school students. It is considered the first scientific work which studied this effect between school students in Arab countries as general, and in Saudi Arabia in particular.

METHODS

Selection of Schools & Target population

For the present study, two areas with different numbers of air pollution sources were selected in the Eastern Province of Saudi Arabia. Al Doha residential district (group A) was selected as an area with low number of air pollution sources, while Al Rakah commercial district (group B) was selected as an area with slightly higher or moderate number of air pollution sources. From each area, two preparatory schools were randomly selected. Inside each school, five different classrooms were selected as sampling points for measuring of air pollution levels. Some of these classrooms were located adjacent to the outside streets while other was located directly to the school playground. The parents of 350 children from the four selected schools were notified by a letter to give the permission for their child to participate in this study. Only 250 of them gave their acceptance and a total of 250 students were initially screened and evaluated to determine age, inclusion and exclusion criteria. The inclusion criteria included his residence within a 5 km around the selected schools, and his age ranged from 12-16 year with normal body mass index. The exclusion criteria included a history of vertigo or dizziness, vestibular or neurologic disorders, uncorrected visual problems, sustained lower extremity injuries, use of medications influencing the balance system, hearing loss, and acute/chronic ear infections. The above criteria were evaluated by a prepared questionnaire given to the applicant's parent to fill it, and the applicant who didn't match with these criteria was excluded from participation in the study. Accordingly, only 90 students were eligible to conduct this study, (45 from each group A and B). The selected students were transported to the physiotherapy labs in the University of Dammam for conducting the postural stability measurements. The ethical approval to achieve this study was confirmed from the human research ethics committee in the University of Dammam.

Dynamic Balance Measurements (Biodex Balance System BBS):

Prior to perform the balance tests, basic anthropometrical data for every child were registered by a comfortable digital weight and height scale (Detecto / PD300DHR / USA). The body height was recorded in cm, the body mass was measured to the nearest 0.1 kg for the participant with his school uniforms but without shoes. Consequently, the Body mass index (BMI) was calculated (kg/m^2) was calculated from the formula: BMI = Weight (W) in kg / [Height (H) in meter]2. (kg/m^2).[30] Measurements of BMI were transformed into percentiles using the anthropometric standards developed by the World Health Organization, Center for Disease Control and Prevention (CDC/WHO) as reference. To classify obesity, overweight, healthy weight......etc., the international standards published by Cole et al. (2000) were used as follows: Obesity (>95th); Overweight (>85th to 95); Healthy weight (5th to 85th); Underweight (<5th).[31]

The Balance tests of all selected students were performed by the Biodex Stability System (BSS) (Biodex, Shirley, NY) which was used for assessment of the postural balance control from standing position by evaluating of dynamic bilateral postural stability for each participant. This system consists of a support rail, platform, display and printer. It has 12 levels of platform stability; level 1, which represents the least stable platform, and level 12, which represents the most stable platform. Before the evaluation process, each participant was given an explanatory session to stand his bare feet on the centre of platform while his both arms should be adjusted at the side of body, to look straight and to focus on visually feedback screen. He was tested on the two stability levels, 1 and 12 with three trials for each level and the average of these trials was confirmed as a final result.

For dynamic bilateral postural stability test, the participant was asked to do his best to maintain the cursor in the middle of bull's-eye on the screen. The test duration was 20 seconds. The test includes measurement of the overall stability index which represents the variance of foot platform displacement in degrees, from level, in all motions during a test. The overall stability score is believed to be the best indicator of the overall ability of the subject to balance the platform.[32] The obtained high values represent a lot of platform movement, refers to less stability and means that the participant has a difficulty in balance control. In contrary, the lower values are indicative of a better balance control.

Indoor Air Quality Measurements

Inside each one of the participant's schools, levels of particulate matter less than 10 microns (PM_{10}), carbon monoxide (CO), and volatile organic compounds (VOCs) were measured through a period from 8 – 11 am during three days per week and three months of the academic year 2013.

Levels of PM_{10} were determined gravimetrically (ref) in milligram of dust per cubic meter of air (mg/m^3) using the Staplex® PST-2X Personal Air Sampler. Each sample of dust was collected on a membrane filter carried in a filter holder assembly and transferred to the labs of Dammam university for further analysis and calculations. Thirty five samples were collected from the two selected schools in each area and a total of 70 PM_{10} samples were collected during this study.

The pre-calibrated MIRAN 205B Series SapphIRe-XL Portable Ambient Air Analyzer was used for the direct assessment of the other two gaseous air pollutants levels (CO and VOCs) from the environment of the selected classrooms. At each measuring point, a reading was recorded for each pollutant in parts per million (ppm) every 15 minutes, and an average concentration was computed for every day. Similarly, a total of 70 daily average levels were calculated for each pollutant during the total period of this study from the two selected areas.

Statistical analysis:

Descriptive statistics were calculated for participants' demographic characteristics. The data were analyzed and reported as dynamic bilateral overall stability index for each participant using Biodex stability system and three measured air pollutants in two different areas. Independent t-test was used to compare between groups and a paired t-test was used to assess the effect of air pollutants on postural stability in each group. A probability of $P<0.05$ was considered to be statistically significant.

RESULTS:

Table 1 indicates the demographic characteristic of the 90 participants. The mean ± standard deviation (SD) of the age, weights, heights and BMI were 13.94 ± 1.24, 47.49 ± 4.42, 155.19 ± 6.79 and 19.69 ± 0.77 respectively. There is no statistical significant differences between both groups in the above four factors (P = 0.78, 0.13, 0.13 and 0.79 respectively).

Table 1: Demographic characteristic of participants

Variables	AlDoha group (A), $n = 45$ Mean $\pm$ SD	AlRakah group (B), $n = 45$ Mean $\pm$ SD
Age, years	13.90 $\pm$ 1.21	13.98 $\pm$ 1.27
Height, cm	154.12 $\pm$ 7.57	156.28 $\pm$ 5.79
Weight, kg	46.79 $\pm$ 4.56	48.20 $\pm$ 4.22
Body mass index (BMI) (kg/m^2)	19.67 $\pm$ 0.81	19.71 $\pm$ 0.74

SD = Standard deviation.

Regarding the results of overall stability index between both groups, there is no statistical significant difference between the mean values at level 12 (i.e. most stable level) between both groups with t = -1.38 and P = 0.17, while, there is a statistical significant difference between the mean values at level 1 (i.e. least stable level) between both groups with t = 4.81 and p = 0.001 as shown in table 2.

Table (3) represents mean $\pm$ SD for the measured three pollutants in both of the selected two areas. The mean levels of CO, VOCs and PM_{10} in AlDoha district were 1.31 $\pm$ 0.28 ppm, 0.22 $\pm$ 0.10 ppm and 1.79 $\pm$ 0.21 mg/m^3 respectively; while in AlRakah district they were 1.82 $\pm$ 0.58 ppm, 0.37 $\pm$ 0.17 ppm and 2.9 $\pm$ 1.79 mg/m^3 respectively. Statistically, there were very strong significant differences as shown in the table ($p < 0.001$).

Table 2: Mean values of the overall stability index at two stability levels

Items	Overall stability index	
	Most stable level (level 12)	Least stable level (level 1)
Al-Doha group (A)	0.74 $\pm$ 0.25	2.01 $\pm$ 0.48
Al-Rakah group (B)	0.82 $\pm$ 0.28	2.61 $\pm$ 0.68
t-value	1.38	4.81
p-value	0.17	0.001*

* Statistical significant.

Table 3: Mean levels of the measured air pollutants in the selected areas

Air pollutants	Al-Doha district area (mean $\pm$ SD)	Al-Rakah district area (mean $\pm$ SD)	t-value	p-value
CO (ppm)	1.31 $\pm$ 0.28	1.82 $\pm$ 0.58	-6.64	0.0001*
VCOs (ppm)	0.22 $\pm$ 0.10	0.37 $\pm$ 0.17	-6.26	0.0001*
PM_{10} (mg/m^3)	1.79 $\pm$ 0.21	2.9 $\pm$ 1.79	-5.13	0.0001*

* Statistical significant. SD = standard deviation.
CO = carbon monoxide gas VOCs = volatile organic compounds.
PM_{10} = particulate matter less than 10 microns.

Correlating the overall stability index values with mean levels of the three air pollutants using the t-test revealed that there were statistical significant differences with overall stability index of bilateral dynamic balance at two stability levels (12 and 1) in both groups (A and B) with ($P < 0.01$) as shown in table 4.

Table 4: T-test values for the relation between mean levels of the measured air pollutants and overall stability index values of both groups

items	CO		VCOs		PM_{10}	
Location	t-value	p-value	t-value	p-value	t-value	p-value
AlDoha OASI at most stable level	15.59	0.0001*	13.97	0.0001*	32.91	0.0001*
AlDoha OASI at least stable level	9.59	0.0001*	25.22	0.0001*	2.97	0.0001*
AlRakah OASI at most stable level	23.74	0.0001*	10.76	0.0001*	51.81	0.0001*
AlRakah OASI at least stable level	7.76	0.0001*	22.06	0.0001*	3.88	0.0001*

* Statistical significant
OASI = overall stability index
CO = carbon monoxide gas VOCs = volatile organic compounds.
PM_{10} = particulate matter less than 10 microns.

DISCUSSION AND CONCLUSIONS

Postural balance is a complex task that is controlled by both the central and peripheral nervous systems. Maintaining upright posture requires integration of brain sensory inputs and motor outputs controlling the body musculature to achieve appropriate coordination. Under eye opening conditions, visual, proprioceptive, and vestibular pathways yield sensory information relevant to maintain the postural balance.[33] At a cortical level, the ability to integrate a number of afferent signals is a prerequisite for static and dynamic balance.[34] Also, posterolateral thalamus regarded as a structure basically involved in our control of upright body posture. [35]

Results of this study presented in this paper provide evidence that low to moderate indoor air pollutants levels exposure has a measurable and statistically significant impact on the control of postural balance in school students. Indoor air pollutants may have influenced the basal ganglia to brain stem level centers' ability to properly integrate the proprioceptive afferents needed for postural control.[36]Our results are in accordance with the conclusions of several previous studies [36-38] that postural balance testing has proven useful in identifying subtle neuromotor abnormalities secondary to exposures to jet fuel, solvents, alcohol and lead. Other studies [39-42] also concluded that posturography is a useful technique to assess the toxicity of solvents on the CNS.

Outdoor air pollutants are able to penetrate inside the buildings, influencing indoor concentration levels.[43] Traffic is one of the most important sources of air pollution in schools.[44] This fact is confirmed by our study, where a very strong statistical difference ($p < 0.001$) was found between the mean levels of all measured air pollutants inside schools of the two selected areas (AlDoha and AlRakah) due to the difference in outdoor traffic activity. Our study results are in accordance with the results of study which was conducted to investigate outdoor and indoor sources of PM measured at 39 primary schools in Barcelona during 2012 revealed that on average 47% of indoor particulate matter (PM) level was found to be generated indoors due to continuous resuspension of ground particles, skin flakes, clothes fibers, chalk and building deterioration; while the outdoor sources, particularly traffic movement, was responsible for the remaining 53% of measured PM indoors. It was also found that, traffic contributions were significantly higher (more than twofold) for classrooms with windows oriented directly to the street, rather than to the interior of the block or to playgrounds.[45-47] Other studies were achieved in several schools in the Kingdom of Saudi Arabia (KSA) and United Arab Emirates (UAE) showed high levels of VOC, CO and PM in elementary schools' classrooms, especially those located directly on the outside traffic streets. [48-49]

As reported by Mejía et al. (2011) [50], the school environment could be a major contributor to children exposure to air pollutants. Although, there are numerous studies in the literature relating indoor air quality and student's health [51-53], no studies have been fulfilled to study the effect of indoor air pollutants on the student's postural stability; and based on our knowledge, this study is considered the first one in this field. We found very strong statistical significant differences between mean levels of the three measured air pollutants (VOCs, CO and PM_{10}) and the mean values of overall stability index during bilateral dynamic balance at two stability levels (12 and 1) in schools of the two selected areas, as shown in table 4.

Among the most important categories of chemicals that occur in the indoor air are volatile organic compounds (VOCs). The reasons for the broad occurrence of these chemicals are their volatile character and the fact that they have been used widely in a big number of household products. [54-55] They are emitted from various outdoor sources such as industrial processes and transportation and from indoor sources such as environmental tobacco smoke and cleaning products. [56-57] In an experimental study, Otto et al. [58] noted that subjects exposed to a low concentration of VOCs (25 μg/m^3) reported symptoms of headache, drowsiness, fatigue, and confusion. At fairly high concentration (188 μg/m^3), VOCs may cause symptoms of lethargy, dizziness, and confusion. At high concentrations, many VOCs are potent narcotics, and can depress the central nervous system. At extreme concentrations, some VOCs may result in impaired neurobehavioral function. [59] In our study, the mean level of VOCs in AlRakah, which is a moderate polluted area (0.32 ppm), was higher than the 0.24 ppm air quality guideline (AQG) for this pollutant as recommended by the World Health Organization (WHO); [60-61] while the mean level in AlDoha, which is a light polluted area (0.22), was near the AQG value. All of these results indicate that exposure of school students to VOCs can lead to a bad postural stability control, particularly in high air polluted areas.

Particulate matters (PM) are solid or liquid matter with aerodynamic diameters ranging from 0.005 to 100 mm. Dusts, fumes, smoke, and organisms such as viruses, pollen grains, bacteria, and fungal spores are solid PM, whereas mists and fog are liquid PM. [62] Small particles (such as PM_{10} and $PM_{2.5}$) are likely to be more dangerous, since they can be inhaled deeply into the lungs and settle in areas where natural clearance mechanisms, like coughing, cannot remove them. [63] PM exposures are linked to cognitive deficits, oxidative stress, neuroinflammation and neurodegeneration.[64] Several individual metals including aluminum, arsenic, cadmium, lead, manganese, and mercury have been demonstrated to affect the neurological system [65], and general accumulation of metal ions in the brain contributes to heightened oxidative stress and neuronal damage.[66] Several studies [67-68] reported that low level lead exposure during early childhood is associated with neuromotor dysfunction such as unsteadiness, clumsiness and fine motor deficits. In addition, suglia et al. 2008 reported a relationship between exposure to black carbon (the major component of particles from traffic) and reduced neurocognitive functioning in urban 8-11-year-old children. [69] The mean levels of PM_{10} during this in schools of AlRakah and AlDoha were 2.9 and 1.79 mg/m^3 respectively (2900 and 1790 μg/m^3 respectively). All the recorded PM_{10} levels were much higher than the recommended AQG values (150 μg/m^3) as recommended by the US Environmental Protection Agency (USEPA). [70] Our results were in accordance with the study that was conducted in the elementary schools of the UAE, where the mean level of PM was 1730 μg/m^3. Consequently, Exposure of students to high levels of PM_{10} is another cause of the bad postural stability control.

Carbon monoxide (CO), the largest constituent of incomplete combustion, is a neurotoxicant at high exposure levels among adults and children. The developing nervous system is especially vulnerable to environmental insults. CO has the ability to cross the blood brain barrier and impair neuronal function, membrane metabolism, and anaerobic energy metabolism (targeting the globus pallidus, a subcortical structure involved in motor and postural control). [71-72] In utero CO exposure may interrupt sensitive oxygen-dependent neurodevelopmental processes such as myelination, neural packing, and neuronal migration. Various symptoms of neuropsychological impairment have been associated with acute low level exposures. Amitai et al. (1998) [73] found that subjects exposed to CO from residential stoves for up to 2.5 h showed declines in their learning and planning abilities, as well as a drop in their attention and concentration spans. In our study, the mean levels of CO in schools of AlRakah and AlDoha (1.82 and 1.31 ppm respectively) were lower than the AQG of 9 ppm as recommended by the USEPA and near from the mean level of CO inside the elementary schools of the UAE (1.16 ppm). These results indicate that exposure of students to CO inside the studied schools may affect their postural stability control in a low degree when compared with the other two measured pollutants (VOCs and PM_{10}).

The overall stability index of bilateral dynamic balance at the least and most stability levels of school students is adversely affected due to the exposure to indoor VOCs, PM10 and CO pollutants, particularly in high air polluted areas. Indoor air quality in schools is greatly affected by the outdoor sources of air pollution, particularly traffic activity. Further and future researches in the same field are required for other types of air pollutants and a wide number of school students

STUDY LIMITATION

Small sample size doesn't allow for generalization of the present findings. As human exposure to pollutants takes place in a long period of time and in places with different levels of pollution, it still difficult to estimate the individual exposure. Participants' postural balance control was measured during quiet bilateral stance using a natural base of support. This less challenging foot position might explain the absence of marked group differences in postural balance control in static conditions or in most stable condition (level 12). In addition, learning abilities, attention and concentration spans are not measured in this study.

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