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THE PHYSIOLOGICAL COST INDEX AND SOME KINEMATIC PARAMETERS OF WALKING AND JOGGING IN BLIND AND SIGHTED STUDENTS

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Abstract
Vision plays an important role in supporting efficient locomotion. The present study aimed to measure the physiological cost index (PCI) and some kinematic parameters of preferred walking and jogging in blind and sighted students. A cross-sectional study was conducted among blind (n=18) and sighted (n=27) students aged 8-16 years. The following parameters were measured during a standard test procedure: step length (meter), cadence (steps/min), mean, speed (meter/min), and the PCI of preferred walking (PCIW) and jogging (PCIJ) over a distance of 100 meters. Univariate linear regression analysis revealed that the weight of an individual as well as the test duration were significant predictors of heart rate (HR) and PCI. Overall, the PCI (beats/meter) of sighted (PCIW=0.22±0.08 and PCIJ=0.24±0.07) and blind students (PCIW=0.27±0.07 and PCIJ=0.31±0.08) were significantly different (all P≤0.05). In addition, the speed of preferred walking (PW) in sighted students was significantly higher than that of the blind students (67±8 versus 62.8±9 m/min; all P≤0.05), while this difference was insignificant in jogging mode (105±9 versus 102±11 m/min). Although the blind students were familiar with the ambient environment and the walking route, they demonstrated a different pattern of PW and jogging modes with respect to kinematic parameters. We also demonstrated that the blind students spent more energy (i.e., PCI) to achieve a lower or equal gait kinematics compared to the sighted students.

Keywords: *Walking, Jogging, Students, Physiological cost index, Kinematic parameters.*

I. INTRODUCTION

Lack of visual feedback results in less efficient and more stressful walking and jogging, which in turn requires increased task-specific energy consumption. The physiological cost index (PCI) and gait kinematics can be utilized to study the efficiency of the locomotor system. While sighted individuals rely solely on visual strategies to accomplish motor tasks, blind individuals rely on hearing, touch, and kinesthetic sense for feedback. Various studies have been conducted on the kinematics of locomotion in individuals with visual impairments. It has been reported that blind people are more susceptible to movement restrictions due to muscle weakness, distorted body image, postural deformities, incorrect orientation, and a balance disorder, which ultimately results in bodily indisposition.

Nakamura compared step time parameters of gait in normally sighted, late blind, and blind from birth individuals. He reported that blind individuals had a slower walking speed, a shorter step length, and a prolonged duration of stance. He suggested that these adaptations arise from a strategy to maintain a more stable posture in the absence of visual feedback. Note that postural control and locomotion are closely related.

Studies have shown that 80% of the blind people suffer from postural deformities, and they lack the visual sense to maintain postural orientation. Skeletal malformations and muscle imbalances in blind people are due to their incorrect body positioning. While the number of blind people worldwide was about 45 million in 1998, a meta-analysis reported an increase in the estimated number of blind people during 1990-2015. In the same period, the number of people with moderate and severe visual impairment also increased worldwide. Hence, research on this topic is of paramount importance.

Any impairment of visual receptors affects spatial orientation, balance, and motor skills. Therefore, a particular focus is needed on the skeleton and the spatial imagination of blind children.9 Since balance disorders and skeletal abnormalities in people with sensory disabilities (e.g., the blind and deaf individuals) are much higher than that in sighted individuals, their movement pattern (walking and jogging) is much more affected. The level of oxygen consumption is one of the parameters commonly used to calculate the energy cost. But, measuring the oxygen consumption requires dedicated instruments, which may not be available in most clinics. MacGregor (1979) proposed a simple and practical method to measure the physiological cost of walking. His method was based on the premise that both heart rate (HR) and walking speed were directly linked to the oxygen consumption. PCI is a simple tool to measure the energy expenditure during walking. HR is an important indicator of physical strain as well as stress and high emotions. According to MacGregor,PCI is defined by dividing the changes in HR (beats/min) by walking speed.

$$PCI\left(\frac{beats}{meter}\right) = \frac{Walking\ HR - Resting\ HR\left(\frac{beats}{\min}\right)}{walking\ speed\ (\frac{meter}{\min})}$$

Since there is a direct relationship between oxygen consumption (VO2) and HR, PCI can be used to estimate the oxygen consumption index.18 Rose and colleagues studied HR and VO during the last 10 seconds of a 2-minute walk at different speeds. They concluded that there was a significant correlation (r=0.99) between HR and VO. Integrating HR changes with physical activity (walking speed) has been proposed as a reliable index for the evaluation of physiological energy consumption.20 This method does not require special training or qualified personnel (technicians, physiotherapists, or physicians) to test and analyze metabolic data. It is an inexpensive method for routine use in clinical environments. The reliability and validity of the PCI have been confirmed in healthy people by a walk test on two different tracks. However, the reproducibility of PCI and its ability to detect small differences in oxygen cost were shown to be moderate.

Various studies have shown a significant relationship between walking difficulties and increased energy cost of walking. It has been reported that disabilities lead to an increased energy cost of locomotion in children. It has also been reported that HR increases significantly in blind individuals depending on their walking mode. Visual impairments can have a major impact on the acquisition and development of motor skill.

Previous studies have shown that step length is associated with the severity of physical abnormalities. Similarly, we considered step length as a kinematic variable to study the walking and jogging modes in blind and sighted individuals. Studies on the biomechanics of gait and the PCI of locomotion in visually impaired people will improve our knowledge of the visual control of locomotion. We hypothesized that PCI and kinematic parameters of the preferred pattern of walking and jogging would differ between the blind and sighted individuals. Consequently, the present study aimed to determine some spatial and temporal parameters (kinematics) and PCI as well as the corresponding indices.

PARTICIPATE AND METHODS

A cross-sectional study was conducted among blind (n=18) and sighted (n=27) students aged 8-16 years. The blind students were recruited from the Shoorideh Shirazi School for the blinds (Ahvaz, Iran); all officially diagnosed as blinds. The sighted students were recruited from the Navab Safavi School and the Daneshgah School (Ahvaz, Iran). The mean age of the students was 11.5±2.46 years. The inclusion criterion for both the blind and sighted students was no apparent disability or abnormality, particularly heart problems, which could affect their normal performance. The blind students had to meet additional criteria for participation in the trial. These inclusion criteria were: officially diagnosed as blind, permission from a physician to participate in the study, and the ability to walk safely and continuously without a white cane at a sensible and constant speed. The exclusion criterion was the inability to fully complete the test procedure. The study procedure was approved by the Deputy of Research and Development as well as the Ethics Committee of Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran (number: IR.AJUMS. REC.1397.062). A written informed consent was obtained from the parents of the students prior to the study.

After completion of baseline evaluations, the participants were requested to perform the test procedure. The time and sequences of all tests were the same for each participant and their bodies were in a post-absorptive state. The participants were encouraged to wear comfortable shoes to avoid unnecessary introduction of an additional variable. The test procedure was performed on a large oval-shaped indoor walk track (100×1.55 m). An auditory system was used to provide the blind participants with verbal instructions to guide them through the walking track. The ambient environmental conditions were: average relative temperature 22-24 °C, average relative humidity 35-40%, and the test were performed between 10-12 a.m. The measured kinematic variables of PW and jogging were walking distance, duration, and the number of steps. In addition, telemetric measurement of the HR during PW, jogging, and resting was recorded. The primary outcome measures were the step length, cadence, mean speed, PCIW, and PCIJ. The instruments utilized for the test procedure were a polar telemetry HR measurement device with an accuracy of 1% (model RC3 GPS; Polar, Finland), a 200 kg digital calibrated scale with an accuracy of 1% (model EF921; Camry, China), a Stopstar-2 stopwatch (Hanhart, Germany), a measuring tape, a tally counter, and a standard chair. The procedural standard for the test was reviewed and the participants were familiarized with the instrumentations. During data recording, the participants were asked not to think about any stressful and/or emotional issues that could adversely affect their HR. A full test cycle consisted of three phases, namely resting (sitting on a standard chair for 5 minutes), walking, and jogging periods. Each participant completed the full test cycle three times and their HR was recorded using the Polar device. The data were telemetrically transmitted to a computer for further analysis using the Polar software.

II. STATISTICAL ANALYSIS

Data analysis was performed using the STATA software, version 14.0 (StataCorp LLC, Texas, USA). HR values during the resting, walking, and jogging periods (excluding the extreme values) were averaged and the PCI was calculated. The skewed variables were logarithmically (Ln) transformed. The mean of the kinematic and physiological variables was adjusted with respect to important predictors (i.e., the weight of a participant and the test duration). The mean of the differences between the blind and sighted students was determined using the independent sample t test. Data were presented as mean±SD and $P<0.05$ was considered statistically significant.

III. RESULTS

The characteristics of the participants are shown in table 1. A total of 45 students (blind: 18, sighted: 27) with practically equal sex distribution and an average age of 12 years (range: 8-12) participated in the study. The HR, PCI, and kinematic parameters of both groups were calculated based on the average of the three test cycles; each comprising of walking/jogging a 100-meter distance on an oval-shaped walk track (table 2). Since some of these variables were important determinants of locomotion characteristics, a univariate linear regression analysis was performed to investigate significant predictors of the locomotion parameters. The results showed that age, sex, and height were not the predictors of HR and PCI, while weight and test duration were significantly associated. Therefore, the adjusted mean of kinematic parameters and PCI (for weight and test duration) in both types of locomotion (PW and jogging) was calculated to determine group differences. However, after removing the effect of group differences (weight and test duration), these differences were persistent (table 2).

The test duration of the walking mode (not jogging) in the blind students was significantly higher than that of the sighted students. It was observed that the step length (both walking and jogging) in the sighted students was significantly longer than that of the blind students (28% and 17%, respectively). The PW speed in the sighted students was significantly higher than that of the blind students, while the difference in the jogging speed was not significant. The cadence of PW and jogging modes in the blind students were significantly higher than that of the sighted students. The HR of the participants during PW, jogging, and resting periods are shown in table 2. There was no statistically significant difference.

Table 1: Characteristics of the sighted and blind students Variables Sex Sighted students Blind students N (%)

Number of students	Male Female	14 (64)	8 (36)
	Total	13 (56)	10 (44)
		27 (60)	18 (40)
			Mean±SD
Age (year)	Male	12.5±2.8	13.13±2.5
	Female	10.5±1.7	11.2±3.12
	Total	11.5±2.5	12.06±2.96
Height (m)	Male	1.52±0.2	1.54±0.12
	Female	1.43±0.1	1.41±0.14
	Total	1.46±0.15	1.47±0.15
Weight (kg)	Male	50.42±25.26	59.71±25.37
	Female	39.38±10.21	42.34±18.11
	Total	44.1±19.77	50.06±22.75

Table 2: Mean PCI and kinematic parameters in blind and sighted students during walking and jogging a 100-meter distance on a walking track

Variables	Locomotion mode	Blind (n=18)	Sighted (n=27)	P value
		Mean±SD		
Test duration (min)	Walking	1.63±0.23	1.50±0.20	<0.001
	Jogging	1.00±0.12	0.95±0.12	0.300
Step length (m)	Walking	0.45±0.08	0.58±0.05	<0.001
	Jogging	0.60±0.11	0.70±0.06	0.002
Speed (m/min)	Walking	62.8±9	67±8	0.010
	Jogging	102±11	105±9	0.346
Cadence (steps/min)	Walking	140.92±30.63	115.76±11.42	0.001
	Jogging	172.13±21.8	150.90±8.90	<0.001
Resting heart rate (beat/min)	Walking	102±16	107±13	0.229

	Jogging	114±19	110±13	0.410
Locomotion heart rate (beat/min)	Walking	119±14	121±12	0.567
	Jogging	144±14	134±13	0.020
PCI	Walking	0.27±0.07	0.22±0.08	<0.001
	Jogging	0.31±0.08	0.24±0.07	0.007

All kinematic and physiological variables were adjusted for important predictors (weight and test duration). In HR during the resting period between the groups. The HR during PW in both groups did not differ significantly. However, during the jogging period, HR in the blind students was higher than that of the sighted students.

Details of the PCIW and PCIJ are shown in table 2. Since the PCI was not normally distributed, logarithmic (Ln) transformation was applied to obtain a normal distribution. The results showed that the PCI in the blind participants, during walking and jogging periods, was significantly higher than that of the sighted students.

IV. DISCUSSION

Significantly higher test duration in walking mode (but not in jogging) and a higher number of steps in both walking and jogging modes were observed in the blind students compared to those of the sighted students. This was probably due to the fact that the blind students took a shorter step length to overcome gait uncertainty caused by blindness. In line with previous studies, we observed that walking and jogging step length of the sighted students was 28% and 17% longer than that of the blind students, respectively. In addition, Hallemans and colleagues reported that blind individuals walked at a slower speed ($P<0.001$), with a shorter step length ($P<0.001$), and a prolonged duration of stance ($P<0.001$) compared to both the control and low vision groups. This was attributed to the vestibular and proprioceptive information that could not fully compensate for vision loss.

The significant increase in test duration for PW in the blind students led to a significantly lower mean PW speed than that of the sighted students, while the difference in the jogging speed mode was not significant. This was due to the fact that the blind students could better follow the verbal instructions; in line with their accustomed gait pattern. However, they did not have the same feed-forward pattern in jogging mode. Knutzen and colleagues conducted a study to measure the three-dimensional kinetics of walking in blind, blindfolded, and sighted groups. They reported significant differences in the maximum braking force and maximum propelling force of the sagittal plane, while the results of the vertical and mediolateral ground-reaction force parameters did not differ significantly. Their findings further confirmed our results on a relatively high jogging speed and cadence of the blind students.

In the present study, a significant increase in the test duration, short step length, and lower mean PW speed was observed in the blind students. This could be due to their compensatory safety measures to overcome possible postural instability or other deficits related to the lack of vision. It could also be the result of their gait pattern adaptation to prevent the risk of a fall and relying on their accustomed safe gait pattern. In this regard, Hallemans indicated that although individuals with a visual impairment performed rather well during overground locomotion, a prolonged duration of the double support phase was observed. In other words, they spent more time keeping their two feet firmly on the ground and took smaller steps which in turn caused a slower walking speed. In blind individuals, alterations in gait pattern were more pronounced than in those with a low vision. By comparing the PW cadence of the blind students to that of the sighted students, it became clear that the blind students walked at a significantly higher cadence. This result was expected since the sighted students walked with a significantly longer step length than the blind students. As shown in table 2, although there was no significant difference between the jogging speed in the sighted and blind students, the jogging cadence in the blind students was significantly higher. This indicated that the blind students struggled with the short step mode of locomotion. A previous study also reported a lower efficiency of motion in blind individuals compared to that of sighted individuals. There was no significant relationship between some of the kinematic variables of the PW and jogging in the sighted and blind students. This could be attributed to the familiarity of the blind students with the ambient environment of the test track (i.e., previous experiences as well as our safety training program), which compensated for their lack of visual strategies to control motor performance.

Higher jogging HR in the blind students compared to the sighted students (7.5%) might have been associated with a higher jogging cadence of the blind students (14.1%). The observed differences in the HR between the blind and sighted students during PW and resting periods were not statistically significant. However, as shown in table 2, a significant difference in PCI was observed after combining the changes in the walking HR and resting HR with the performance of the participants (PW speed). The PCIW and PCIJ were significantly higher in the blind participants compared to that of the sighted participants. The difference persisted even after adjusting for other confounding variables such as weight and test duration (table 2). A significant PCIW increase in the blind students (42.1%) and a significant walking speed increase in the sighted students indicated that the blind students allocated a higher level of PCI to achieve a lower level of PW speed. Moreover, a significant PCIJ increase in the blind students (22.6%) and insignificant difference of jogging speed between the two groups indicated that the blind students spent more energy (PCI) to achieve the same level of PW speed. In line with a previous study,1 the effect of visual acuity on locomotion was confirmed since the PCI and the speed of walking (r=-0.49, P=0.020) and jogging (r=0.57, P=0.012) of the blind students were correlated.

The main limitation of the present study was due to the limited participation of blind students. However, this limitation was outweighed by the fact that there has been no investigation at all on PCI in blind people, while there are a few studies on kinematics variables. Additionally, the field measurement (indoor test track) was not fully representative of laboratory conditions with a controlled ambient environment. Therefore, the results should be viewed as an estimate of the actual performance. Further studies should include a larger sample size and random sampling. In addition, the test protocol should be performed in a more realistic environment to determine the actual performance. The findings of the present study can be utilized by healthcare services to better understand the PCI and gait kinematics of locomotion in the blind people and, subsequently, to provide more suitable intervention programs.

V. CONCLUSION

The results of the present study showed that the blind students spent more energy (PCI) to achieve a lower or equal gait kinematics compared to the sighted students. It is recommended to conduct combined laboratory and field measurements to obtain reliable indices for the evaluation of kinematic variables and PCI.

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