Original Article

Visual Field Changes in Professional Wind versus Non-wind Musical Instrument Players in the Philadelphia Orchestra

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Abstract

Purpose: We compare the prevalence of glaucoma in professional wind versus non-wind instrument players in the Philadelphia Orchestra. Visual field changes in individuals with glaucoma and glaucoma suspects were evaluated, and the results were correlated with cumulative practice time.
Methods: In this cross-sectional, observational study, fifty-one Philadelphia Orchestra musicians were enrolled and categorized as wind or non-wind instrument players. All study participants underwent screening fundus photography. Participants with optic discs suspicious for glaucoma underwent further evaluation, including standard automated visual field perimetry and a comprehensive eye examination by a glaucoma specialist.
Results: Of the 51 musicians enrolled, 9 of the 21 wind instrument players (43%) and 8 of the 30 non-wind instrument players (27%) were suspected of developing glaucoma in at least one eye ($P = 0.25$), with examinations performed on 12 of the 17 returning musicians (71%) for further confirmation. Wind instrument players exhibited significantly higher Octopus visual field mean defect scores (1.08 ± 1.5 dB) than non-wind instrument players (−0.43 ± 0.7 dB; $P < 0.001$). There was a significant association between cumulative hours playing wind instruments and visual field mean defect ($P < 0.001$).
Conclusion: Among members of the Philadelphia Orchestra, the difference in prevalence of glaucoma suspicious optic discs between wind and non-wind instrument players was not significant. The clinical significance of the greater visual field mean defect found in wind instrument players, and the association between the degree of visual field mean defect and the cumulative practice-time of playing wind instruments, needs further investigation.

Keywords: Glaucoma; Visual Field; Wind Instruments

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INTRODUCTION

Glaucoma is a progressive optic neuropathy with corresponding vision loss, and elevated intraocular

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pressure (IOP) is the only modifiable risk factor.[1,2] Previous studies have reported the transient IOP elevations while playing wind instruments.[3-6] Professional wind-instrument players who spend hours practicing daily may be subjected to repeated IOP elevations and the risk of developing glaucoma. Schuman et al found a significantly greater incidence of visual field (VF) loss associated with lifetime practicing hours among high-resistance-wind musicians compared with other musicians.[3]

The prevalence of glaucoma and glaucoma suspects was compared in the professional wind and non-wind instrument players in the Philadelphia Orchestra, and the relationship between the Disc Damage Likelihood Scale (DDLS), the cup-to-disc ratio (CDR), VF mean defect (MD) and cumulative practice time among wind instrument players were assessed.

METHODS

This study was conducted at the Wills Eye Hospital Glaucoma Research Center and the Kimmel Center for the Performing Arts. The study was approved by the Wills Eye Hospital Institutional Review Board, and informed consent was obtained from all participants. Our research adhered to the tenets of the Declaration of Helsinki and regulations of the Health Insurance Portability and Accountability Act.

Study Participants

Any current member of the Philadelphia Orchestra was eligible to participate. Participants were divided into 2 groups: 1) wind-instrument players, and 2) non-wind instrument players (control). Wind instruments were defined as any instrument containing a resonator, a column of air that reverberates as the player blows into a mouthpiece. Non-wind instruments were defined as instruments that do not meet the wind instrument criteria. Participants who played an instrument for ≥1 hour per day for ≥5 years were included. Participants were excluded if they had incisional eye or laser surgery ≤1 month before any study visit.

Visit 1: Baseline Assessment

The Wills Eye Hospital Glaucoma Research team traveled to the Kimmel Center for the Performing Arts in Philadelphia, PA, with all necessary equipment, and eye examinations for participating orchestra members were scheduled between practice sessions. Demographic information (ocular, medical, and family history) was documented, and the mean cumulative practice time was calculated ([hours of practicing/day] x [days of practicing/week] x [number of years of practicing]), which included both practices and performances. Eye examinations included: 1) Snellen visual acuity for best-corrected vision (BCVA) measurement, 2) undilated fundus color photography with a Volk Pictor Digital Retina Camera (Optomed Oy Ltd., Oulu, Finland), and 3) IOP measurement using an iCare tonomete (iCare, Helsinki, Finland). The IOP was measured twice per participant, and the mean value was recorded if the difference between the two measurements was ≤2 mmHg. If the difference between the two measurements was >2 mmHg, a third measurement was obtained, and the median value was recorded.

All optic disc photos were exported to a research computer following removal of identifying information. The two glaucoma specialists reviewing the images (LJK, AVM) were masked to participant information. The optic disc was classified as: 1) glaucoma suspect: characteristic optic nerve damage with suspicious findings including a vertical CDR >0.65 in discs >2.0 mm, or >0.5 in discs ≤2.0 mm; CDR asymmetry (>0.2); presence of disc hemorrhage with increased CDR, or a definite notch in neuroretinal rim or 2) normal. The DDLS was used to evaluate the extent of optic disc damage caused by glaucoma through an assignment of a score from 1 to 10 based on the rim-to-disc ratio and the size of the optic nerve.[7,8] Participants with IOP >21 mmHg and normal disc appearance were diagnosed with ocular hypertension. In cases with a discrepancy, the final diagnosis was provided by a committee of three glaucoma specialists (LJK, AVM, MW).

Visit 2: Comprehensive Eye Examination

Participants were notified to schedule a comprehensive eye examination at the Kimmel Center for the Performing Arts (visit 2) when they were diagnosed as glaucoma suspects, ocular hypertension, any other eye pathology or having poor quality of optic disc photos from visit 1. Comprehensive eye examinations included: 1) Snellen BCVA measurement, 2) central corneal thickness measurement using an iPac Handheld Pachymeter (Reichert Inc, Depew, NY, USA), and 3) VF testing using Octopus 300 Static Perimetry (Haag-Streit Inc, Bern, Switzerland). A glaucoma specialist performed the following: 1) slit lamp examination of the anterior segment, 2) gonioscopy, 3) IOP measurement using Goldmann applanation tonometry, and 4) undilated fundus examination. If deemed medically necessary and permitted by the study participant, dilation was performed using tropicamide 1% (Bausch and Lomb Inc., Tampa, FL, USA) and phenylephrine 2.5% (Akorn Inc., Lake Forest, IL, USA). Glaucoma was considered present if the participant exhibited glaucomatous optic neuropathy and characteristic VF loss in either eye. Participants were diagnosed with glaucoma, suspicion of glaucoma, ocular hypertension, or no glaucomatous findings in either eye. If treatment

or follow-up was needed, participants were referred to an ophthalmologist locally or at Wills Eye Hospital.

Statistical Analyses

Data were analyzed using the R 3.4.0 (R core team, Vienna, Austria). The two-sample *t*-test or Wilcoxon test was used to compare continuous variables, and a Chi-squared or Fisher's exact test was used to compare categorical variables between wind and non-wind instrument players. Relationships between DDLS, CDR, VF MD, and cumulative practice-time were analyzed using generalized estimating equation (GEE) models to account for inter-eye dependencies. Another multivariable GEE model was used to analyze the relationship between cumulative practice time and VF MD among wind and non-wind musicians following adjustment for BCVA and lens status.

RESULTS

Fifty-one musicians from the Philadelphia Orchestra were enrolled and completed the first visit. The mean age was 52.9 ± 11.5 years (mean ± standard deviation), and 20 participants (39%) were female, and there were 21 wind and 30 non-wind instrument players [Table 1]. Overall, the musicians practiced an average of 42.7 ± 11.6 years, 6.2 ± 0.7 days/week, and 3.1 ± 1.3 hours/day. The mean cumulative practice-time was 43,600 ± 25,400 hours. Non-wind instrument players had longer cumulative practicing hours compared to wind instrument players ($P = 0.005$).

There were 6 participants with self-reported glaucoma ($n = 3$) or suspicion of glaucoma ($n = 3$), and they all were using at least 1 glaucoma medication. There were more musicians with self-reported glaucoma in the wind-instrument group ($n = 3$) compared to the non-wind instrument group ($n = 0$; $P = 0.08$). Wind instrument players had a relatively higher resting IOP (15.6 ± 2.8 mmHg) compared to the controls (14.4 ± 3.3 mmHg) ($P = 0.06$). There were no differences in the CDR and DDLS between the two groups in both eyes ($P = 0.63$ and $P = 0.62$, respectively).

Table 2 shows the type and number of instruments for members of the wind instrument group. Among 21 musicians, there were 12 high-resistance-instrument players (French horn, trumpet, bassoon, and oboe) and 9 low-resistance-instrument players (trombone, tuba, clarinet, and flute).[3] Following visit 1, 17 out of 51 musicians (33%) were considered glaucoma suspects in at least one eye: 9 wind instrument players (43%) and 8 non-wind instrument (26.7%) ($P = 0.25$) [Figure 1].

Overall, older age was associated with higher odds of having a glaucoma-suspicious disc (60.5 ± 8.0 versus 51.8 ± 9.8 years; odds ratio [OR] 1.05, 95% confidence interval [CI] 1.00–1.11]). Other measures, including gender, family history of glaucoma, IOP, cumulative practice hours, and type of instrument were not associated with increased risk for glaucoma suspect ($P > 0.05$ for all).

Table 1. Demographic and clinical characteristics of wind and non-wind instrument players from the Philadelphia Orchestra who were enrolled in the study

	Wind, *n*=21	Non-wind, *n*=30	*P*
Age, years (SD)	55.3 (9.9)	51.1 (12.5)	0.23
Gender, female, no. (%)	5 (23.8)	15 (50.0)	0.08
Race, no. (%)			
Caucasian	18 (85.7)	13 (43.3)	0.02
Asian	2 (9.5)	9 (30)	
African American	0 (0)	4 (13.3)	
Others	1 (4.8)	4 (13.3)	
Time of practicing the instrument, mean (SD)			
Years	42.3 (10.1)	42.9 (11.9)	0.87
Numbers of days per week	6.1 (0.7)	6.2 (0.6)	0.28
Numbers of hours per day	2.4 (0.9)	3.5 (1.3)	<0.001
Cumulative practice-time, hours (per thousand)	32.8 (15.3)	51.0 (28.5)	0.005
Family history of glaucoma, no. (%)	7 (35.0)	7 (25.0)	0.45
Self-reported glaucoma, no. (%)	3 (14.3)	0 (0)	0.08
Self-reported glaucoma suspect, no. (%)	1 (4.8)	2 (6.7)	0.78
Receiving glaucoma treatment, no. (%)	4 (19.0)	2 (6.7)	0.20
BCVA, LogMAR mean (SD)	−0.01 (0.09)	−0.04 (0.08)	0.113
IOP, mmHg (SD)*	15.6 (2.8)	14.4 (3.3)	0.06
DDLS, mean (SD)	2.2 (1.3)	2.0 (1.2)	0.62
Vertical cup-to-disc ratio, mean (%)	0.35 (0.2)	0.33 (0.2)	0.63

BCVA, best-corrected visual acuity; IOP, intraocular pressure; DDLS, Disc Damage Likelihood Scale; SD, standard deviation; no, number
Data from both eyes were included for analyses of clinical exam data (BCVA, IOP, DDLS, and cup-to-disc ratio) *iCare tonometer

Table 2. Number of musicians (*N*=21) playing each type of wind instrument

	N (%)*
Type of wind instruments	
Brass	
Horn (French, English) (H)	6 (28.6)
Trumpets (H)	1 (4.8)
Trombones (L)	2 (9.5)
Tuba (L)	1 (4.8)
Woodwind	
Bassoon (H)	6 (28.6)
Clarinet (L)	2 (9.5)
Flute (L)	4 (19.0)
Oboe (H)	2 (9.5)
Piccolo (L)	3 (14.3)
Resistance of instruments (by person)†	
High	12 (57.1)
Low	9 (42.9)

H, high-resistance instrument; L, low-resistance instrument *The sum may be more than 100% as each musician may play more than one instrument †Based on the highest resistance instrument type for each musician

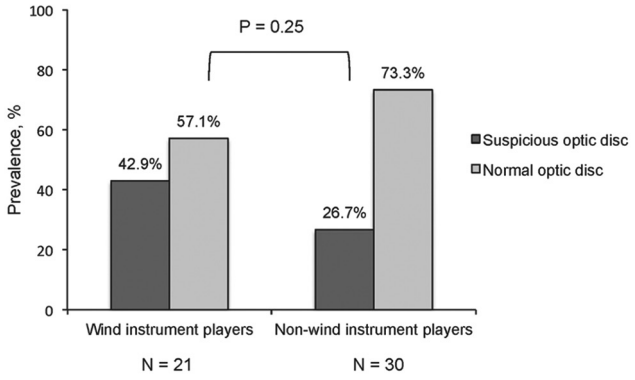

Figure 1. Prevalence of glaucoma-suspicious optic discs among wind and non-wind instrument players at visit 1 (*N* = 51).

Of the 17 participants diagnosed as glaucoma suspect during visit 1, 12 (71%) returned for visit 2 (6 wind and 6 non-wind) [Table 3]. The mean age of the wind instrument players was older ($P = 0.01$), and there were more participants with self-reported glaucoma in the wind instrument group compared to the controls (3 and 0 respectively), and 2 of them had a confirmed diagnosis of primary open-angle glaucoma (POAG) (the third person lost to follow-up). None of the non-wind instrument players were diagnosed with POAG. There were 3 out of 6 players (50%) in the wind instrument group versus 5 out of 6 players (83.3%) in the non-wind instrument group who were diagnosed as glaucoma suspects.

The VF MD was higher in wind musicians compared with non-wind musicians in both eyes (1.08 ± 1.5 dB versus -0.43 ± 0.7 dB, $P = 0.006$). Multivariable GEE models showed VF MD was significantly associated with cumulative practice hours among wind instrument players. After adjusting for BCVA and lens status, every 1000 hour increase in cumulative practice hours was associated with a 0.07-dB increase in VF MD ($P < 0.001$) [Figure 2]. There was no significant association between the DDLS or vertical CDR with cumulative practice-time in wind musicians ($P = 0.89$ and 0.96, respectively). There was also no difference between wind and non-wind musicians regarding central corneal thickness ($P = 0.86$), resting IOP ($P = 0.95$), vertical CDR ($P = 0.28$), and DDLS ($P = 0.36$).

DISCUSSION

In this study, the prevalence of glaucoma and glaucoma suspects was compared in the professional wind and non-wind instrument players in the Philadelphia Orchestra. It was discovered that the prevalence of glaucoma-suspicious discs among wind instrument players was higher compared to non-wind instrument players (43% versus 26.7%); however, this difference was statistically insignificant. Two wind instrument players were diagnosed with POAG, while no cases were detected in non-wind instrument players.

The findings from this study did not show significant structural differences in CDR and DDLS between the two groups based on clinical examination and fundus color photography. However, among 12 participants with suspicious glaucomatous optic discs, results showed a significant functional difference (greater mean VF MD) among wind instrument players compared to non-wind instrument players. Although the difference between groups may not reach clinical significance, these findings are in agreement with Schuman et al, who found that playing high-resistance wind instruments was more likely to associate with an abnormal VF, with nosignificant optic nerve head changes between high-resistance wind, low-resistance wind, and non-wind instruments.[3] They also reported a 0.009 dB increase in VF corrected pattern standard deviation for every 1000 life-hours of practicing wind instruments (univariable analysis, $P = 0.02$). In the multivariable model from this study adjusting for BCVA and lens status, a significant association between cumulative playing time and VF MD among wind instrument players was discovered, with a 0.07 dB increase in VF MD for every 1000 hour increase in cumulative practice and performing time ($P < 0.001$).

Professional wind instrument players have been subjected to transient IOP elevations during practice. Schuman et al suggested that these long-term intermittent IOP elevations may result in cumulative functional damage to the eye, causing "intermittent high pressure glaucoma."[3] Prior studies also found significant elevations in IOP immediately after playing a wind instrument.[4,5] The mechanism of IOP elevation is controversial. Studies have suggested

Table 3. Demographic and clinical characteristics of wind and non-wind instrument players who returned for a confirmation examination (visit 2)

	Wind, *n*=6	Non-wind, *n*=6	*P*-values
Age, years (SD)	63.5 (4.9)	51 (8.9)	0.01
Gender, female, no. (%)	1 (16.7)	1 (16.7)	0.77
Race, no. (%)			
Caucasian	5 (83.3)	3 (50.0)	
Asian	1 (16.7)	1 (16.7)	
African American	0	1 (16.7)	0.24
Others	0	1 (16.7)	
Cumulative lifetime practice time, thousand hours, mean (SD)	35.1 (15.0)	39.6 (14.7)	0.61
BCVA, LogMAR, mean (SD)	0.03 (0.05)	0.02 (0.04)	0.67
Lens status			
Clear	2 (16.7)	10 (83.3)	0.003
Mild cataract	9 (75.0)	2 (16.7)	
IOL	1 (8.3)	0 (0)	
IOP, mmHg (SD)*	14.4 (3.4)	14.3 (3.3)	0.95
Vertical cup-to-disc ratio, mean (%)	0.54 (0.2)	0.43 (0.2)	0.25
DDLS, mean (SD)	3.9 (1.9)	3.3 (1.4)	0.36
DDLS ≥5, no (%)	4 (33.3)	2 (16.7)	0.21
Visual field mean defect, dB (SD)	1.08 (1.5)	−0.43 (0.7)	0.006
Central corneal thickness, μm (SD)	578.5 (38.8)	575.3 (53.4)	0.86
Diagnosis, no (%)			
Primary open-angle glaucoma	2 (33.3)	0 (0)	0.7
Glaucoma suspect	3 (50.0)	5 (83.3)	
Normal	1 (16.7)	1 (16.7)	

BCVA, best-corrected visual acuity; IOP, intraocular pressure; DDLS, Disc Damage Likelihood Scale; SD, standard deviation Data from both eyes were included for analyses of clinical exam data (BCVA, IOP, DDLS and cup-to-disc ratio); *P* values were calculated by using GEE model
*Goldmann tonometer

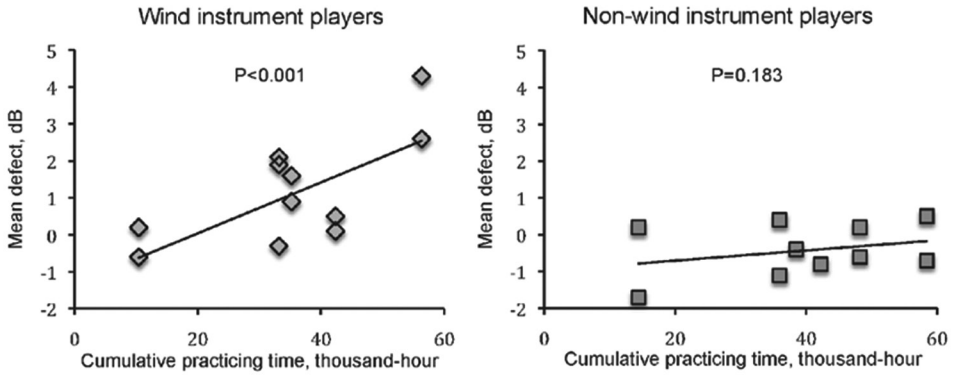

Figure 2. Multivariable linear regression between cumulative practice time and visual field mean defect among wind and non-wind instrument players in visit 2, after adjusting for best-corrected visual acuity and lens status.

that playing high resistance wind instruments utilizes the Valsalva maneuver, which comprises forcible exhalation against a closed glottis, creating a sudden increase in intrathoracic and abdominal pressures.[3,9-11] Subsequently, increased episcleral venous pressure reduces aqueous outflow, which is transmitted to the choroid, causing choroidal expansion.[3,12] The engorged choroidal vessels may produce a small increase in total ocular volume against the relatively rigid eye wall, ultimately increasing IOP.[13]

Compressions of the thoracic vena cava and spinal dura also lead to reduction of jugular venous return, and upward motion of CSF into the cranial cavity.[14] Both processes occur synchronously, leading to elevation in both CSF and cerebral parenchymal pressures.[15] It has been proposed that the trans-laminar cribrosa pressure difference (TLCPD; TLCPD [mmHg] = IOP [mmHg] - CSF Pressure [mmHg]) is an important determinant of the strain placed on the optic nerve head resulting in glaucoma.[16,17] Zhang et al found that during the

Valsalva maneuver, the elevation in CSF pressure (by 10.5 ± 2.7 mmHg) was higher than the increase in IOP (by 1.9 ± 2.4 mmHg) ($P < 0.001$) in 20 neurological patients, leading to changes in TLCPD.[18] However, the extent of IOP and CSF pressure change in healthy wind instrument players is unknown. Furthermore, we did not find a greater optic nerve structural damage corresponding to the greater VF MD changes in wind instrument players compared to the controls. Future prospective, longitudinal studies with advanced non-invasive monitoring techniques are needed to shed light on this dynamic interaction between CSF pressure and IOP changes during wind instrument playing.

A greater increase in IOP by playing higher resistance instruments and higher note-frequencies has also been reported, and possibly results in greater VF abnormalities. Grewal et al[19] measured IOP in musicians after 1 minute of blowing sustained notes at certain frequencies, and found that IOP increased dramatically during high notes, but did not significantly change while playing low or middle tones.[19] Another study found that brass players had increases in IOP after playing high and middle frequency notes, whereas woodwind players only had an increase in IOP while playing high frequency notes.[5] However, after stratifying subjects by the resistance of instruments, there appeared to be no difference in the prevalence of suspicious optic discs among high or low resistance wind, and non-wind instrument groups (data not shown), due to the small sample size.

This study has several limitations. First, the sample size is small. Nevertheless, the largest possible number of professional musicians were included. Although having enrolled more than 50% of Philadelphia Orchestra members, recruitment was limited by the specialized population. In addition, the multivariable GEE model was used, with both eyes included, to adjust for the potential confounding factors, and results were in agreement with the previous study reported by Schuman et al[3] Second, this study only included a resting IOP measured at a single time point, which may not reflect the dynamics of IOP. It was found that wind instrument players had a higher mean IOP (15.6 ± 2.8 mmHg) compared to non-wind instrument players (14.4 ± 3.3 mmHg), although this difference was small and did not reach statistical significance. Study participants had their IOP measured at any time during their practice session, but never immediately after playing their instrument. As a result, the IOP may have returned to baseline by the time their IOP was measured. Third, most participants were first-time VF test takers, which may have limited the reliability of the VF results. Previous VF studies have shown that abnormalities on a reliable test were not seen during repeated testing.[20] Therefore, further testing is warranted to confirm the reliability of our VF results. Additionally, we did not perform optical coherence tomography (OCT) to further quantify the optic disc changes. However, this study followed the protocol of the Philadelphia Glaucoma Detection and Treatment Project, as well as the Philadelphia Telemedicine Glaucoma Detection and Follow-up Study, which have both shown the reliable detected rates of optic nerve pathology.[21,22] Furthermore, Philadelphia Orchestra musicians already diagnosed with glaucoma may not have participated, possibly leading to an underestimation of glaucoma prevalence in this population. Finally, the mean age of wind instrumentalists was greater than that of non-wind instrumentalists, and the wind instrument group also included more individuals with mild cataracts. Notably, since VF MD is calculated by comparing to an age-matched population, this was not considered a significant confounding factor in our analysis. Moreover, multivariable analysis showed a significant association between VF MD and cumulative practice hours after adjusting for lens status and BCVA. However, even with 33% of participants being diagnosed as glaucoma suspects at visit 1, there was still no increase in the prevalence of glaucoma among wind instrument players compared with non-wind instrument players. It must be acknowledged that our cross-sectional study simply demonstrates an association between cumulative practice hours and VF changes in wind instrument players without examining the causality. Future investigation with a larger sample size and all potential risk factors for glaucoma included as covariates (such as body mass index and refractive status) is required.

In conclusion, among members of the Philadelphia Orchestra, the difference in prevalence of glaucoma-suspicious optic discs between wind and non-wind instrument players was not significant. The clinical significance of the greater VF MD in wind instrument players, and the association between the degree of VF MD and the cumulative wind instrument practice time needs further investigation.

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Conflicts of Interest

There are no conflicts of interest.

REFERENCES

1. Sultan MB, Mansberger SL, Lee PP. Understanding the importance of IOP variables in glaucoma: A systematic review. *Surv Ophthalmol* 2009;54:643-662.
2. Nassr MA, Morris CL, Netland PA, Karcioglu ZA. Intraocular pressure change in orbital disease. *Surv Ophthalmol* 2009;54:519-544.
3. Schuman JS, Massicotte EC, Connolly S, Hertzmark E, Mukherji B, Kunen MZ. Increased intraocular pressure and visual field

defects in high resistance wind instrument players. *Ophthalmology* 2000;107:127-133.

4. Aydin P, Oram O, Akman A, Dursun D. Effect of wind instrument playing on intraocular pressure. *J Glaucoma* 2000;9:322-324.
5. Schmidtmann G, Jahnke S, Seidel EJ, Sickenberger W, Grein HJ. Intraocular pressure fluctuations in professional brass and woodwind musicians during common playing conditions. *Graefes Arch Clin Exp Ophthalmol* 2011;249:895-901.
6. Lanzl IM, Kappmeyer K, Kotliar KE. Intraocular pressure during wind instrument playing. *Invest Ophthalmol Vis Sci* 2012;53:4174.
7. Bayer A, Harasymowycz P, Henderer JD, Steinmann WG, Spaeth GL. Validity of a new disk grading scale for estimating glaucomatous damage: Correlation with visual field damage. *Am J Ophthalmol* 2002;133:758-763.
8. Spaeth GL, Henderer J, Liu C, Kesen M, Altangerel U, Bayer A, et al. The disc damage likelihood scale: Reproducibility of a new method of estimating the amount of optic nerve damage caused by glaucoma. *Trans Am Ophthalmol Soc* 2002;100:181-185; discussion 185-6.
9. Dimsdale JE, Nelesen RA. French-horn hypertension. *N Engl J Med* 1995;333:326-327.
10. Larger E, Ledoux S. Cardiovascular effects of French horn playing. *Lancet* 1996;348:1528.
11. Harris LR. Horn playing and blood pressure. *Lancet* 1996;348:1042.
12. Rosen DA, Johnston VC. Ocular pressure patterns in the Valsalva maneuver. *Arch Ophthalmol* 1959;62:810-816.
13. Khan JC, Hughes EH, Tom BD, Diamond JP. Pulsatile ocular blood flow: The effect of the Valsalva manoeuvre in open angle and normal tension glaucoma: A case report and prospective study. *Br J Ophthalmol* 2002;86:1089-1092.
14. Wostyn P, Audenaert K, De Deyn PP. The Valsalva maneuver and Alzheimer's disease: Is there a link? *Curr Alzheimer Res* 2009;6:59-68.
15. Mousavi SR, Fehlner A, Streitberger KJ, Braun J, Samani A, Sack I. Measurement of *in vivo* cerebral volumetric strain induced by the Valsalva maneuver. *J Biomech* 2014;47:1652-1657.
16. Jonas JB, Berenshtein E, Holbach L. Anatomic relationship between lamina cribrosa, intraocular space, and cerebrospinal fluid space. *Invest Ophthalmol Vis Sci* 2003;44:5189-5195.
17. Ren R, Wang N, Zhang X, Cui T, Jonas JB. Trans-lamina cribrosa pressure difference correlated with neuroretinal rim area in glaucoma. *Graefes Arch Clin Exp Ophthalmol* 2011;249:1057-1063.
18. Zhang Z, Wang X, Jonas JB, Wang H, Zhang X, Peng X, et al. Valsalva manoeuver, intra-ocular pressure, cerebrospinal fluid pressure, optic disc topography: Beijing intracranial and intra-ocular pressure study. *Acta Ophthalmol* 2014;92:e475-480.
19. Grewal KS, Karakekas D, Kraff C, Hawkinson D, Krupin T. Intraocular pressure change with increased pulmonary outflow. *Investig Ophthalmol Vis Sci* 1995;36:295-387.
20. Keltner JL, Johnson CA, Quigg JM, Cello KE, Kass MA, Gordon MO. Confirmation of visual field abnormalities in the Ocular Hypertension Treatment Study. Ocular Hypertension Treatment Study Group. *Arch Ophthalmol* 2000;118:1187-1194.
21. Waisbourd M, Pruzan NL, Johnson D, Ugorets A, Crews JE, Saaddine JB, et al. The Philadelphia Glaucoma Detection and Treatment Project: Detection rates and initial management. *Ophthalmology* 2016;123:1667-164.
22. Hark LA, Katz LJ, Myers JS, Waisbourd M, Johnson D, Pizzi LT, et al. Philadelphia telemedicine glaucoma detection and follow-up study: Methods and screening results. *Am J Ophthalmol* 2017;181:114-124.