INTRODUCTION
The chinrest is a thin oval-shaped wood or plastic piece attached to a violin or viola near the tail piece for the player to position his/her jaw. It plays an important role in stabilizing the instrument. This study examined the force acting on the chinrest due to the violinist’s jaw while playing music. Habitual and prolonged application of this force to the left mandible has been considered a major cause of craniomandibular dysfunction (CMD) and muscular-skeletal problems in the adjacent neck and shoulders [1, 2]. Detailed information on chin force under different playing conditions can help in understanding the etiology of these dental and medical problems. Information on chin force is also important for understanding the force balance related to an efficient and optimal playing technique, which is a common goal of the players. Chin force/pressure was evaluated by Okner et al. [3]. They used the Pedar system, a 2.5 mm-thick mat equipped with 150 1-cm square capacitance sensors, to record distributed pressure over the surface of commercially-available chinrests. In their study, chin force was estimated by dividing the measured pressure value by the area of contact. Because the force and spatial resolution of their pressure sensor were relatively low (20 kPa and 1 cm$^2$), the precision and accuracy of force measurements were suspect.

The purposes of the present study were to design and develop a chinrest which permitted the direct and accurate measurement of chin force during violin performance, and to provide base-line data for the chin force obtained from elite players.

METHODS
A force transducer-mounted chinrest (Wt = 60 g) was designed and built by the present authors Figure 1. It consisted of three miniature strain-gauge load cells sandwiched by thin duralumin plates, and a wooden chin cup. The force transducer could measure the maximum force of 100 N within 0.5% error of linearity, and its resolution was 0.02 N. The chin-cups, with three types of curvature (shallow, medium, and deep), were prepared based on the dimensions of commercially available chinrests for the player’s to select from. The chin cup was attached to the transducer plate using an adhesive tape, and the transducer was then firmly attached to the top panel of a 4/4 Suzuki violin. Chin force data were obtained from 11 young violinists (Age = 25.6 ± 4.5 (SD) yrs.) while they performed sets of scale and melody tasks. After an adequate practice period using an experimental violin with the force transducer-mounted chinrest, three sets of experimental tasks were performed by each subject.

These were static hold, scale, and melody tasks. In the static-hold task, the subject held the violin with and without left hand support. The scale task between the A4 and A5 tones was performed at different dynamics (70 – 72, 75-77, and 80 - 82 dB, representing piano (p), mezzo forte (mf), and forte (f) dynamics, respectively) and tempi (1, 4, and 8 Hz) at the 1$^{st}$ hand position without a vibrato technique. The effect of vibrato was also tested at 1-Hz tempo at f. Rapid position shifts (“jumps”) between the 1$^{st}$ and 8$^{th}$ hand positions were tested while playing a scale at f dynamics. The melody task was to play the initial 40 measures of Max Bruch’s violin concerto G minor. In all tasks, the subjects used their own bow and shoulder rest. At the end of the experiment, each subject was interviewed with questions related to playing career, weekly practice duration, chinrest, experimental violin and chinrest, functional problems in the craniomanibular, or and neck/shoulder joints and muscles along with a few clinical tests. A soundproof and shielded-chamber with an ambient noise of around 38 dB was used for the entire experiment. The chin force data were sampled at 1 kHz, and the corresponding radiated sound data sampled at 40 kHz were stored in PCs. Peak and average forces were subsequently evaluated. Peak and mean force were computed from the data obtained from each test condition for each subject (Figure 2). One-way or two-way ANOVA with repeated measures was used to test the effect(s) of test condition(s) on the variable(s) of interest.

RESULTS
The mean chin force for holding the violin on the shoulder without left hand support was 22.2 ± 5.7 N, and that with left hand support was 14.1 ± 4.9 N for all subjects. During the scale tasks, the mean chin force was 13.5 ± 3.8 N at p, 14.8 ± 4.6 N at mf, and 17.4 ± 6.1 N at f at the 1-Hz playing tempo in the 1$^{st}$ position.
Peak forces observed during the corresponding test conditions were $17.6 \pm 5.1$ N, $19.3 \pm 5.6$ N, and $24.3 \pm 8.0$ N, respectively. ANOVA revealed no dynamics x tempo interaction, but significant dynamics ($F_{2,20} = 26.44$, $p=0.000$) and tempo main ($F_{2,20} = 9.63$, $p =0.001$) effects for the peak force. Both mean and peak chin forces during vibrato at 1 Hz and f were $24.3 \pm 8.0$ N, and $32.8 \pm 11.4$ N, respectively, which were significantly larger that those of the no-vibrato performance (mean, $F_{1,10} = 37.86$, $p=0.000$, and peak, $F_{1,10} =25.48$, $p <0.0001$). Chin force during a jump had a distinct peak slightly at the moment of hand movement (Figure 3). The mean peak force during jumps for all subjects was $41.3 \pm 11.1$ N. While playing Bruch’s concerto, a mean force of $24.7 \pm 8.5$ N, and a peak force of $53.7 \pm 13.8$ N (range: 31 – 82 N) were measured. The SD value and the range of peak force indicated a relatively large inter-violinist variation.

**DISCUSSION**

A force-sensing chinrest was developed to assess mechanical stress to the left mandible of violin players during musical performance. Okner et al. [3] earlier used 150 pieces of small capacitance sensors to measure pressure distributed over the surface of the chinrest. These sensors had a relatively low resolution of pressure measurement ($>20$ kPa), as well as the area of each sensor being 1-cm squared, indicating a low resolution of force (around 2 N). The present sensor resolved these problems by measuring force directly at high resolution (0.02 N). Sampling of the force data was also made at a much higher rate (1 kHz) and thus a more accurate evaluation of moment-by-moment changes in chin force compared to the 50 Hz in the study by Okner et al were obtained. The findings indicated the feasibility of a force-sensor mounted chinrest to assess stress to the mandible, as well as for biofeedback training to safely hold of violins and violas.

Using this chinrest, we provided basic information about the chin force while playing the violin. Typical chin force during ordinary violin playing was within 30 N. The chin force became greater when producing tones with stronger dynamics and a slower fingering tempo, or when using vibrato or jump techniques. Jumps in particular demonstrated distinct force peaks due to freeing of left hand support during the hand shift. Clearly, actions causing destabilization of the violin led to increased chin force. The mean peak chin force for all players was 55 N, but this force exhibited relatively large inter-player variation. Review of the time history force curve revealed that peaks appeared when the players produced tones with multiple stops or jumps with strong dynamics. Okner et al. [3] also investigated chin force and pressure when 10 professional violinists played the same concerto. They found that the mean peak chinrest force of these violinists was 44 N, while one violinist had the highest value of 67 N. Their mean value was therefore 10 N (23%) smaller than ours. This difference may be attributed to the fact that our subjects were 12 years younger and thus less experienced in stabilizing control of the violin than their subjects (mean age = 36 yrs). However, it can be more likely attributed to underestimating force when using a mat of pressure sensors with a relatively low pressure detection resolution.

The present study confirmed that players were constantly receiving an unusual level of mechanical stress to their mandible whenever they played the violin. Such a load is a potential cause of CMD and pain in their neck, shoulders, and upper extremities [4, 5, and 6]. The use of oral splints has been suggested as a preventive measures or treatment for these problems [2]. The finding that there was a large inter-player variability of peak force when playing the same piece of music, on the other hand, suggests that a reduction in the force is possible for those who use an unnecessarily large force to stabilize the instrument.

**CONCLUSIONS**

A relatively accurate measurement of chin force during actual violin performance was achieved by using a chin-rest force sensor developed in this study. Typical chin force to stabilize the violin during an ordinary musical performance was less than 30 N, but it exceeded 50 N when subjects performed technically demanding musical pieces.

**REFERENCES**