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IMPROVEMENT IN GUITAR INTONATION

A Statistical Comparison of the Eliasson Adjustable, Compensated Guitar Nut and a Standard Guitar Nut

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INTRODUCTION

There are many reasons why a guitar is not in tune. The spacing of the frets on a guitar is equal tempered, and the distance between the frets is based on a formula that divides the 12- tone octave into 12 logarithmically equal parts (1).

Most guitar fail to achieve equal temperament due to incorrect bridge and nut placement (the bridge supports the strings on the player's right hand side, the nut supports the strings on the neck of the guitar on the players left hand side). Adjusting the bridge for various string gauges and stiffness is called compensating the bridge, and most electric guitars and many acoustic steel string guitars allow for bridge compensation, which allows for better intonation. In this context compensation consist of shortening or lengthening individual strings.

Whereas bridge compensation is common, nut compensation is very infrequently seen. The first commercially produced guitars with as compensated nut were Micro-Frets guitars, designed by Ralph S. Jones, and produced in Frederick, Maryland in the 1960's. Micro-Frets guitars represent a unique and very interesting chapter in the history of American guitar making. Mr. Jones, an engineer by training, noted that the strings were not properly intonated on most guitars. In an effort to compensate for this defect, he created the "Micro-nut", replacing the nut (2).

Luthier Greg Byers published in 1994, in American Luthier , a method on how to compensate the nut on classical guitars. He did work out the physics and the mathematics of nut compensation and published formulas how to calculate string length, and the amount of compensation (3).

At present, the only commercially available system for nut compensation on electric steel string guitars is the patented Buzz Feiten tuning system. It is only available on one guitar brand, Washburn, and involves shortening the fingerboard, and does not fully allow for individual string compensation (4). Recently, Earvana Inc. has begun marketing a compensated replacement nut for steel string guitars, but this is a one size fits all and does not allow for individual string compensation and does not allow for variations in compensation due to different scale length (5 - 7).

Finally, luthier John Gilbert, who is a machinist by training, has produced classical guitars with a compensated nut involving shortening the fingerboard, but again this does not allow for individual string compensation, but is rather based on the law of averages (3).

It is of obvious interest to musicians to have the best-intonated instrument possible, which is also the motivation for the present study. The purpose of this study is to compare the intonation of a guitar with a standard nut with the newly developed, compensated Eliasson adjustable guitar nut. The Eliasson nut differs from previously developed guitar nuts in that each string is individually adjustable, horizontally and vertically.

The hypothesis is that the Eliasson compensated, adjustable guitar nut will result in statistically significant improvement of guitar intonation compared to the intonation of a guitar with a standard nut.

H_0: The intonation of the guitar with the Eliasson nut equals the intonation of the guitar with the standard nut.

H_A: The intonation of the guitar with the Eliasson nut will deviate less from ideal intonation than the guitar with the standard nut.

METHODOLOGY

The data was collected from measurements from a single guitar, a production model of a Fender Squier Jagmaster, before and after the replacement of the guitar's standard Fender nut with the Eliasson compensated, adjustable nut. Measurements consisted of tonally 'mapping' the entire fingerboard of the guitar. Measurements were made after detailed compensation of the bridge. Sound was recorded with the guitars' pick-ups, and processed with a stroboscopic tuner with an accuracy of $1/1000^{th}$ of a semitone (Peterson V-SAM Virtual Strobe Audio Metronome Tuner). For the purpose of the study the unit of measurement was the 'Cent' which is $1/100^{th}$ of a semitone. Measurements were rounded off the nearest cent, mainly as the tuning gears of the guitar did not allow for greater precision.

The Eliasson nut was the 'Lenson Machine' prototype, made of brass, and was retrofitted on the Fender Squier Jagmaster electric guitar, after removal of the original non-compensated nut. The Lenson Machine prototype required a minor design change and manual work prior to fitting.

The fingerboard of the Fender Squier, while still having the original non-compensated nut, was tonally mapped using the stroboscopic tuner after detailed and careful adjustment of intonation using the adjustable bridge saddles, followed by careful tuning of the open strings to E1, B, G, D, A, and E6. Since the Fender Squier had a tremolo-bridge, the tremolo-bridge was blocked to remove the movement of the tremolo as a factor in intonation. The strings used were Peavey Regular Slinky, nickel wound, gauges 10, 13, 17, 26, 36 and 46 respectively. The guitar was placed flat on a table, the

The Fender Squier prior to removal of the original non-compensated nut

The Fender Squier, after removal of the original nut.

The Fender Squier, after installation of the Eliasson adjustable nut.

neck without support. The deviation from ideal intonation of each string at each fret (from fret 1 to 19) was documented. A concerted effort was made not to vary finger pressure from string to string, and from fret to fret.

After installing the Eliasson 'Lenson Machine' prototype, the guitar intonation was verified in a similar manner: First the bridge intonation was verified, and note made that it did not require any change compared to when the guitar had the standard nut. The guitar position was kept the same, strings remained the same, and the guitar's action was confirmed to be the same. Vertical adjustment of the new Eliasson 'Lenson Machine' nut was done on individual saddles to obtain *correct action* (height of strings over the fingerboard). The height of the bridge saddles remained unchanged.

Each string was then tuned with the stroboscopic tuner to E1, B, G, D, A, E6, i.e. standard guitar tuning. The tone on the first fret of each string was then assessed. The nut saddle of each string was then moved horizontally (forward, toward the guitar's bridge) until frequency of the string, fretted at the first fret, matched the stroboscopic tuner as precisely as possible (that is, matched ideal intonation as closely as possible). The nut saddle was moved until optimal frequency was obtained. After intonation adjustment of the nut, the intonation of the bridge was re-verified.

The entire fingerboard was then re-mapped, i.e. the note frequency and its deviation from expected (that is ideal intonation), if present, was documented with the strobe-tuner.

Methodology –statistics

The 'population' in this study would be defined as all tones from the entire fingerboard of all guitars of the same characteristics as the Fender Squier, that is a scale length of 25.5 inches. The 'sample' would be defined as all tones from the fingerboard of the Fender Squier studied, initially with the standard nut installed, followed by measurements after installation of the Eliasson adjustable nut. Statistics were produced using technology, specifically Minitab 14, and SPSS.

Ideal intonation was defined as zero (0) variation from the note expected in each location as per standard guitar fingerboard definition.

Findings

The variables investigated were the following: 1) Measurement of the deviation from ideal intonation in cents for each string at each fret. 2) Mean deviation from ideal intonation in cents for all strings at each fret (a calculated variable). The first two variables were continuous variables, although the rounding off to the nearest cent may make them appear to be categorical at first glance. 3) Fret location from 0 to 20, a categorical variable. Each measurement was performed initially with the guitar's standard production nut, and again after fitting of the Eliasson adjustable nut.

Figure 1. displays a boxplot of the distribution of deviation from ideal intonation

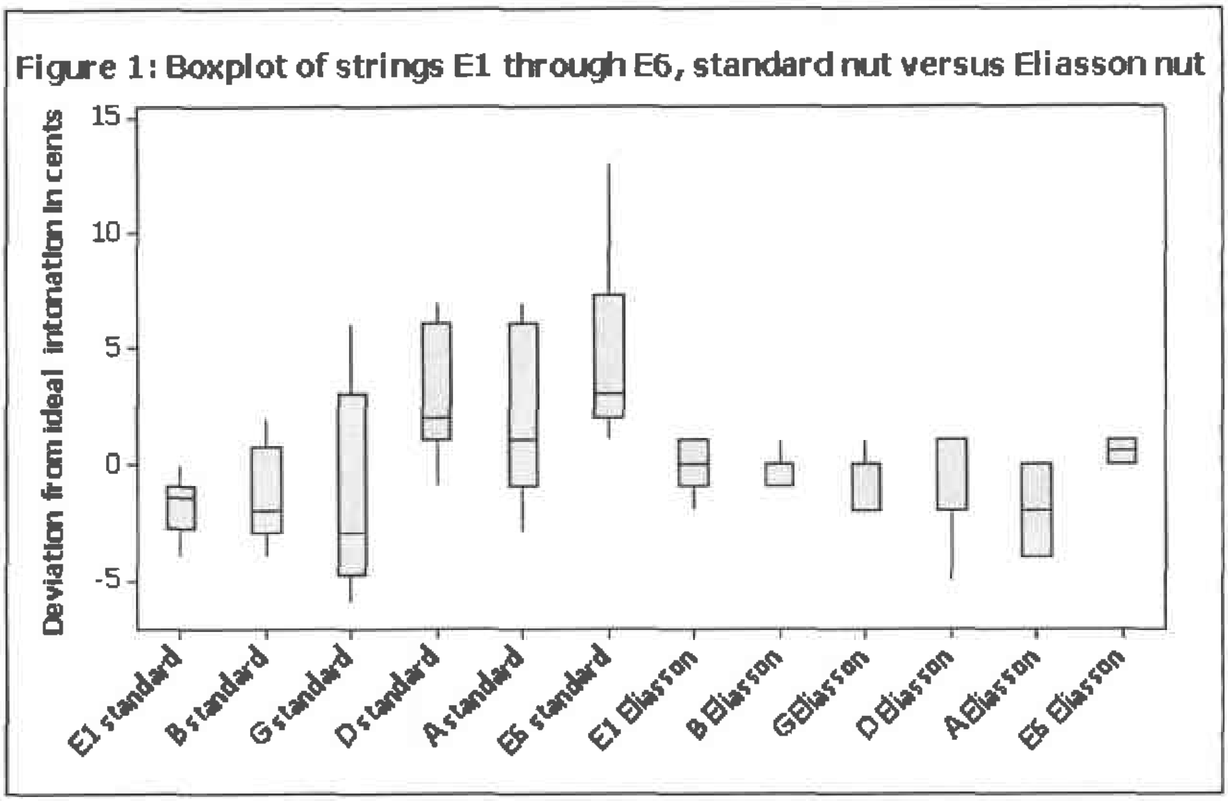

Figure 1: Boxplot of 20 measures (all frets) of 6 strings for the standard versus the Eliasson nut.

in cents for each string for the standard nut and the Eliasson adjustable nut respectively. There are six strings, E1, B, G, D, A and E6 respectively. Figure 2 shows boxplots of mean values per fret (all six strings averaged per fret) for each nut respectively. Figure 3 shows all measured values (all strings, all frets) for the standard nut and the Eliasson nut.

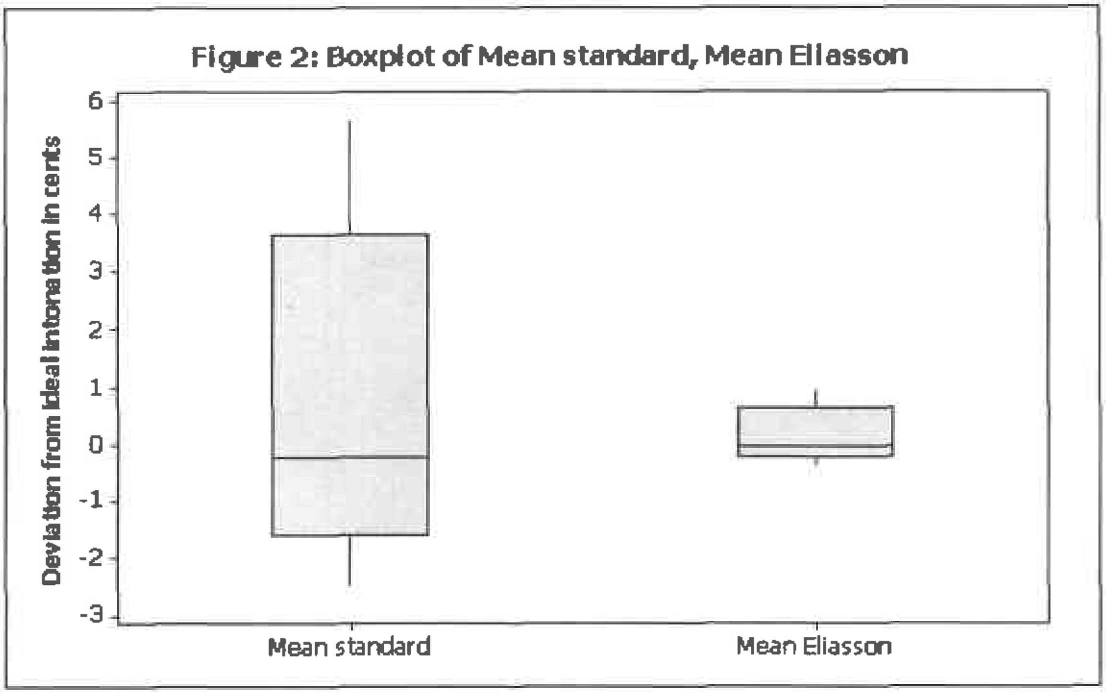

Figure 2: Boxplot of deviation of the mean deviation from ideal intonation (0) of 6 strings per fret for the standard nut vs. the Eliasson nut (20 measures per nut, that is 20 frets)

Inspection of the boxplots for individual strings (Figure 1) reveals that the means for each string using the standard nut appear different from zero (ideal intonation) and the spread of the values is substantial, particularly for the G string. Conversely, the means for each string using the Eliasson nut seem to cluster around zero and the spread of the distribution is less. In figure 2 it is evident that when the values are averaged by fret, a similar pattern appears, and also when all 120 measures (6 strings x

20 frets, Figure 3) are plotted individually. Averaging values such as seen in figure 2 obviously will reduce scatter, that is the standard deviation.

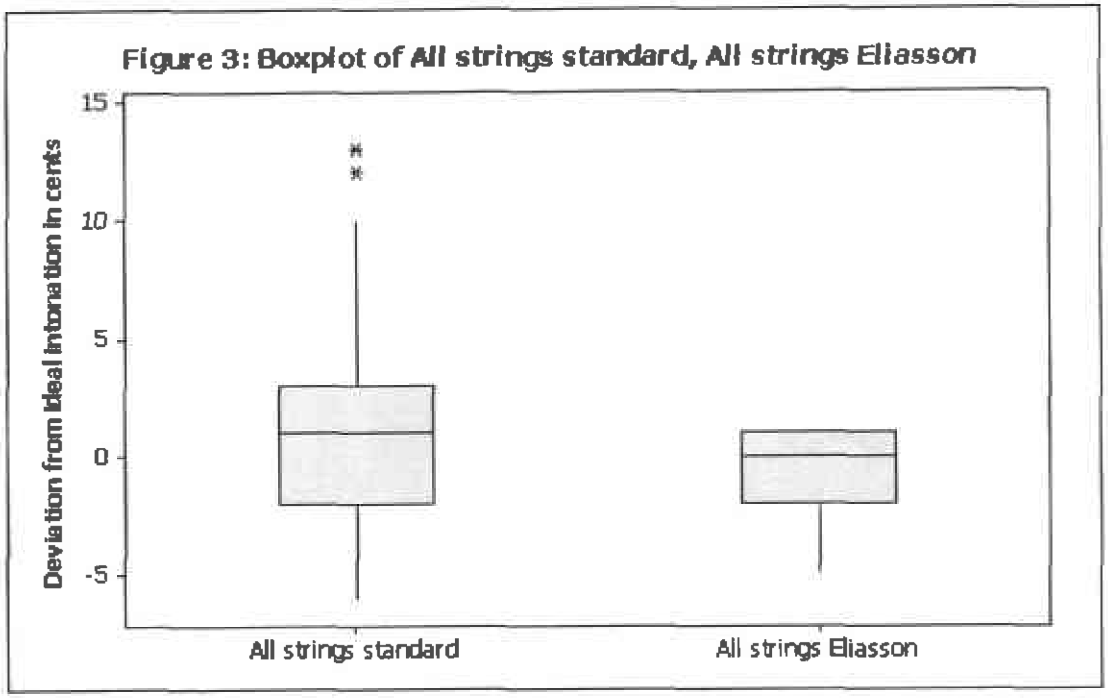

Figure 3: Boxplot of deviation from ideal intonation (0) of all measurements per nut, (6 strings measured on 20 frets = 120 measures per nut), standard nut versus Eliasson nut.

Figure 4 shows a summary of side-by-side histograms using identical x-scale for all strings, both nuts. These histograms demonstrate greater spread of the distribution for individual strings using the standard nut, as compared to the Eliasson nut.

Figure 5 shows histograms of the mean values of the six strings per fret for the standard nut and the Eliasson nut respectively. Individual string measurements per fret are shown in Figure 6, which reveals a normal distribution of the measures for the standard nut, slightly skewed to the right due to outliers caused by the E6 and G strings. There are no major gaps in the distribution. Figure 6 also shows all individual string

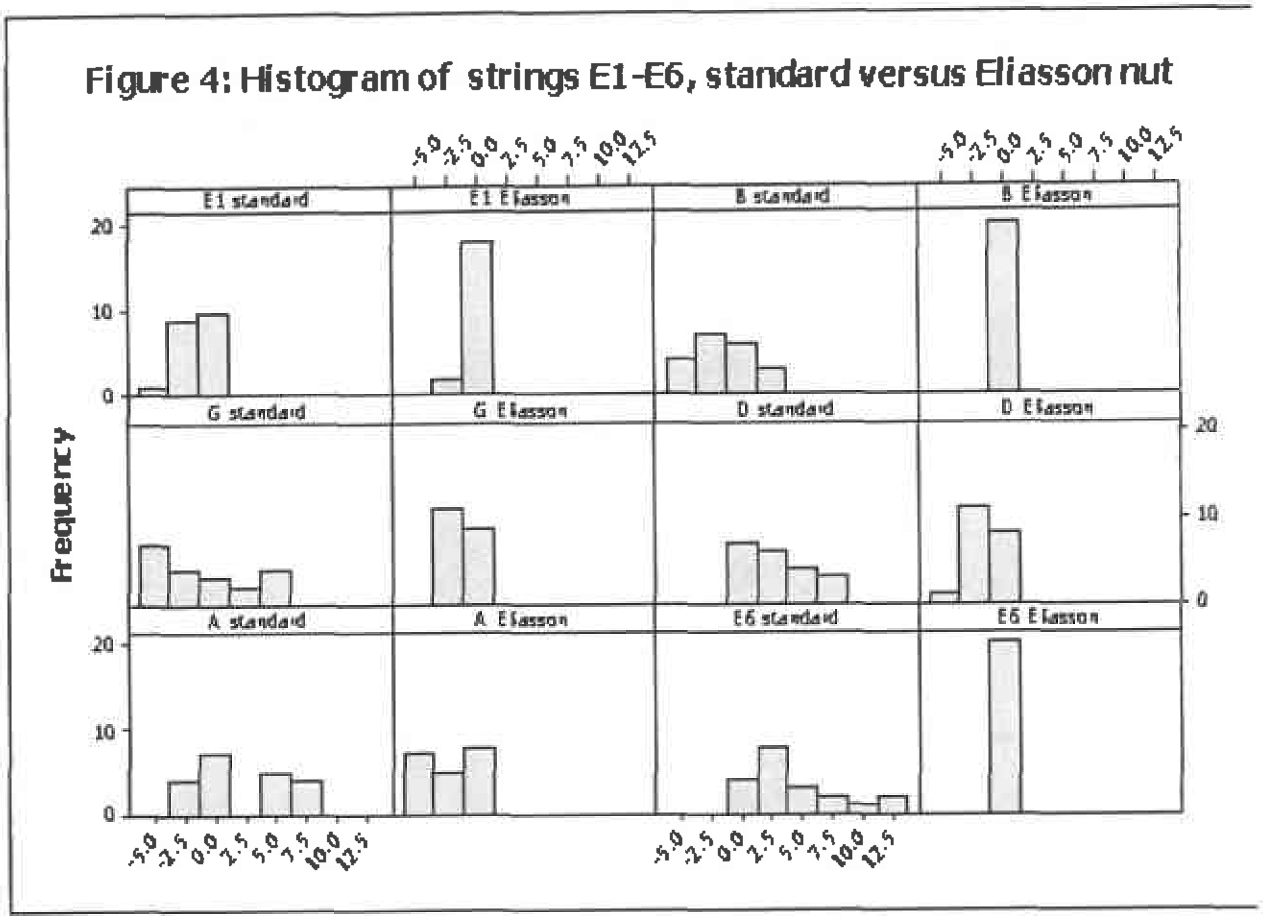

Figure 4: Histogram of all measures of deviation from ideal intonation (0) (x co-ordinates) of each string E1, B, G, D, A and E6 (20 measures per string). Comparison of the standard nut with the Eliasson adjustable nut.

measurements per fret for the Eliasson nut, confirming much narrower distribution, than that for the standard nut. The distribution can be assumed to approximate normal, a little skewed to the left. One gap at –3 cents was noted. For the Eliasson nut there were no values above 1 (range –5 to 1) whereas for the standard nut a large number of measurements fell above 1 (range –6 to 13). Histograms shown in Figures 5 and 6 demonstrate a fairly similar pattern.

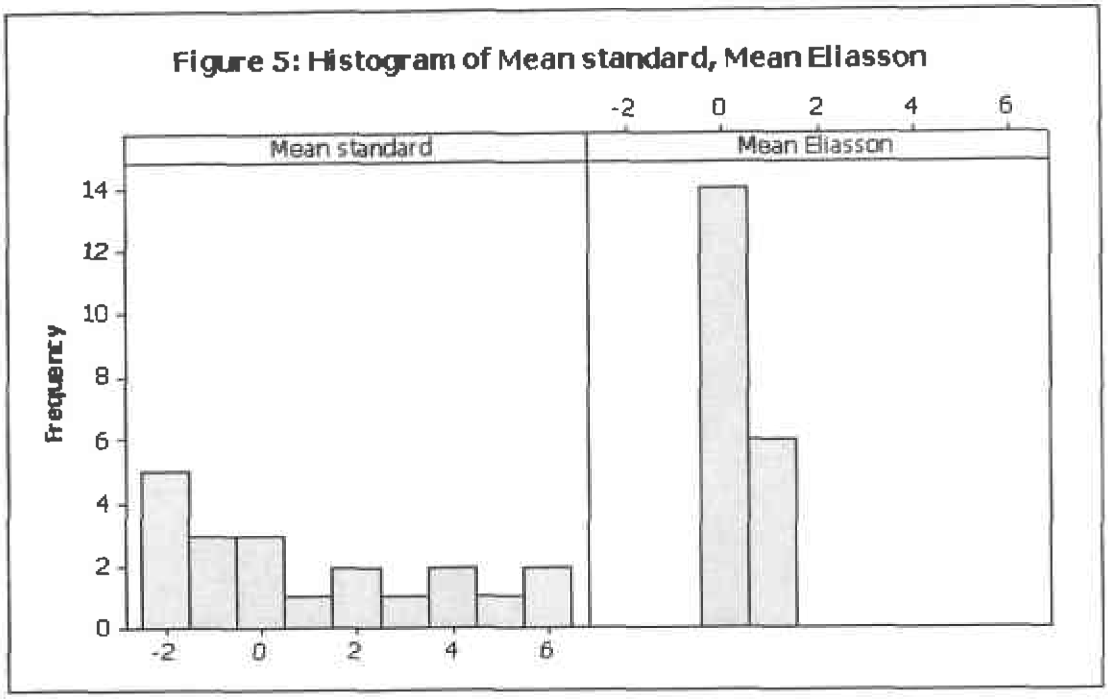

Figure 5: Distribution by histogram of <u>mean</u> deviation from ideal intonation (0) (x co-ordinates) per fret (average of all 6 strings) for the standard nut versus the Eliasson nut.

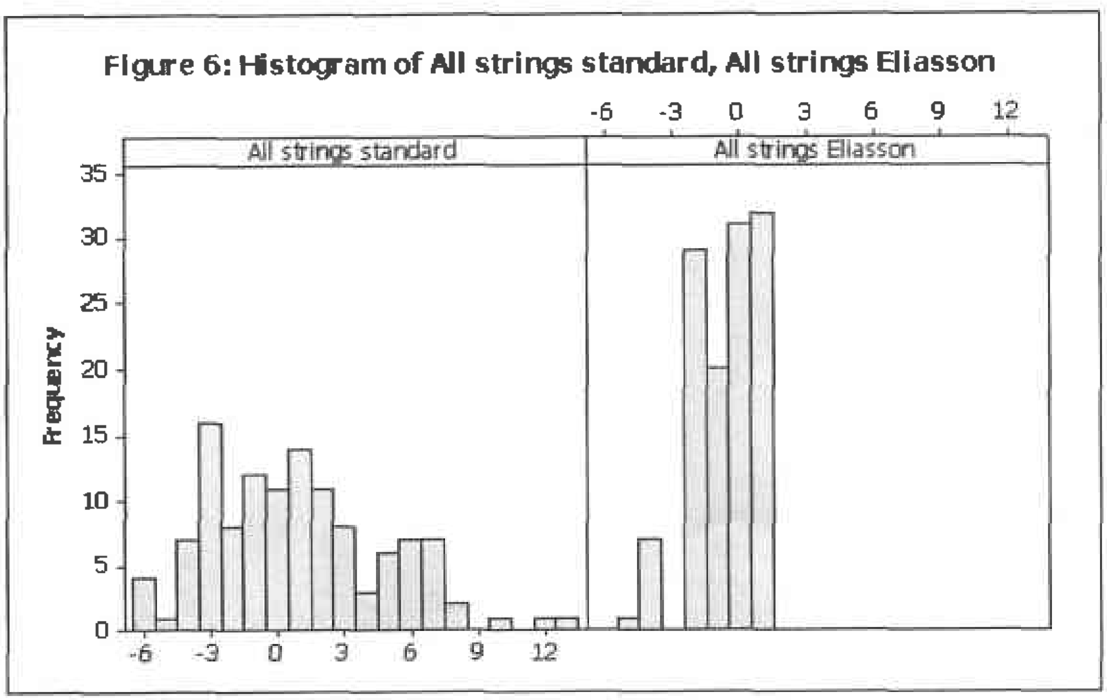

Figure 6: Distribution by histogram of all strings on all frets (6 * 20 measures per nut) of deviation from ideal intonation (0) (x co-ordinates) in cents for the standard nut versus the Eliasson adjustable nut.

A scatterplot of mean deviation from ideal intonation per fret, standard nut versus Eliasson nut is shown in Figure 7. A distinct pattern is evident. Using the standard nut, the strings on the average (these are mean values per fret) became immediately sharp (above ideal intonation), at the first fret. Going up the fretboard, this deviation decreased in a linear manner, crossed 0 at or around the 12^{th} fret, and the notes became flat (below ideal intonation) at the upper frets. A plot of the mean values per fret versus fret location for the Eliasson nut indicated a straight line relationship, minimally sharp (above ideal intonation) at the lower frets and minimally flat (below ideal intonation) in the upper frets.

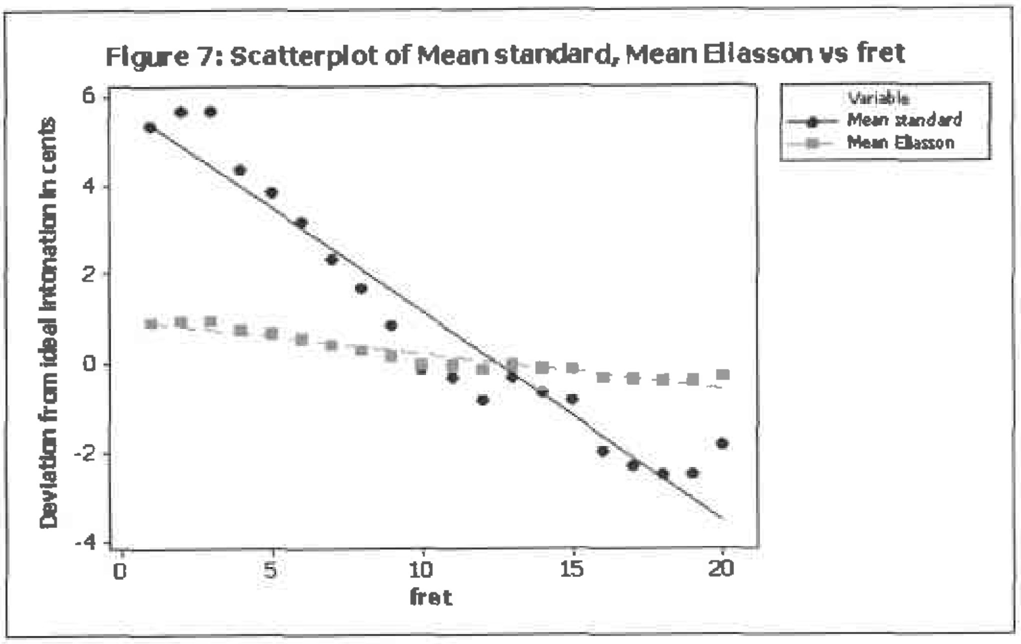

Figure 7: Scatterplot of mean deviation per fret (average of 6 strings) from ideal intonation (0) in cents for the standard nut versus the Eliasson adjustable nut.

Figure 8 reveals a scatterplot of mean deviation from ideal intonation for all measures, reaveling a similar pattern as Figure 7. An important difference between the plots is that the variation in deviation from ideal intonation for the Eliasson adjustable nut is minimal at the lower frets, indicating very good intonation, whereas the variation increases at the upper frets.

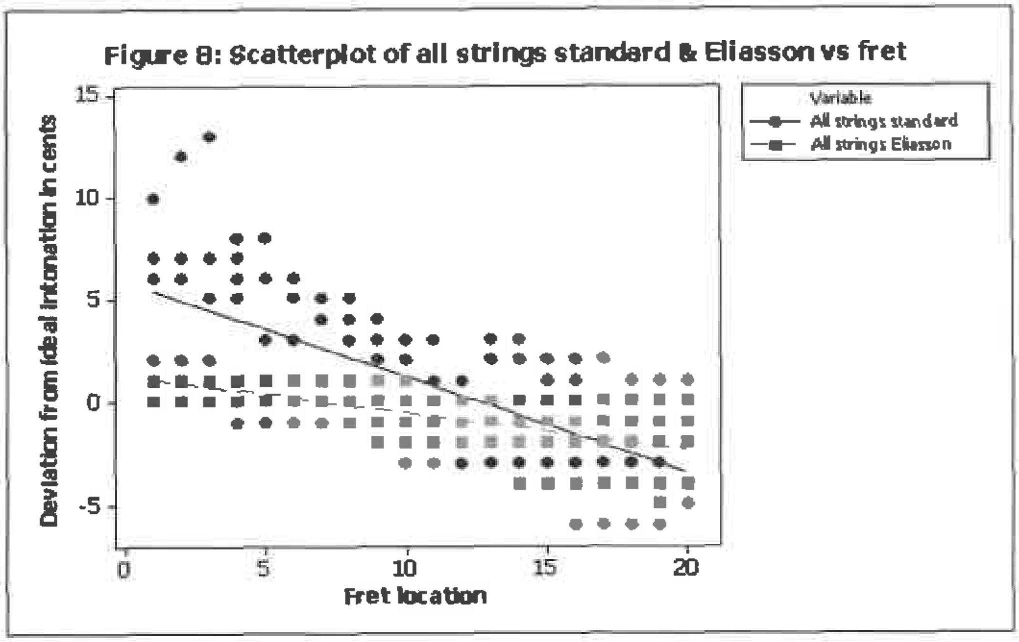

Figure 8: Scatterplot of deviation from ideal intonation (0) of all measures (6 strings per fret, 20 frets) for the standard nut versus the Eliasson adjustable nut.

Table I lists the descriptive statistics for all variables, that is mean, standard deviation, range, median and the quartiles. It is obvious, however, from the scatterplot shown in Figure 7 that the deviation from ideal intonation behaves differently depending on fret location. Using the standard nut the fretted strings went sharp (above ideal intonation, positive values) in the lower frets whereas the opposite happened in the upper frets (below ideal intonation, negative values). Averaging the values per string would therefore tend to mask the difference between the nuts. Since the Eliasson nut was intended to improve intonation in the lower frets, analysis was performed per fret, to sort out this confounder, in addition to analysis per individual string.

TABLE I: Descriptive statistics, standard nut versus Eliason adjustable nuts.

Variable	N	Mean	Standard deviation	Min	Q1	Median	Q3	Max
STANDARD NUT:								
E1	20	-1.6	1.2	-4.0	-2.8	-1.5	-1	0
B	20	-1.4	0.5	-4.0	-3.0	-2.0	0.8	2.0
G	20	-1.1	4.3	-6.0	-4.8	-3.0	3.0	6.0
D	20	3.0	2.7	-1.0	1.0	2.0	6.0	7.0
A	20	2.1	3.8	-3.0	-1.0	1.0	6.0	7.0
E6	20	4.6	3.7	1.0	2.0	3.0	7.3	13.0
Mean Stand	20	0.9	2.9	-2.5	-1.6	-0.3	3.7	5.7
All Stand	120	0.9	3.9	-6.0	-2.0	1.0	3.0	13.0
ELIASSON ADJUSTABLE NUT:								
E1	20	-0.1	1.0	-2.0	-1.0	0.0	1.0	1.0
B	20	-0.4	0.8	-1.0	-1.0	-1.0	0.0	1.0
G	20	-1.0	1.3	-2.0	-2.0	-2.0	0.0	1.0
D	20	-1.0	1.7	-5.0	-2.0	-2.0	1.0	1.0
A	20	-2.0	1.7	-4.0	-4.0	-2.0	0.0	0.0
E6	20	0.5	0.5	0.0	0.0	0.5	1.0	1.0
Mean Elias	20	0.2	0.5	-0.4	-0.3	-0.0	0.6	0.9
All Elias	120	-0.7	1.5	-5.0	-2.0	0.0	1.0	1.0

Table I: Descriptive statistics for the Squier Jagmaster with the standard nut and after installation of the Eliasson adjustable nut. *E1, B, G, D, A, E6 refers to the strings.* Mean stand and mean Elias are mean values per fret of all six strings for the standard and Eliasson nuts respectively. All stand and all Elias are all values (all strings, all frets) for each nut respectively.

Linear regression analysis was performed, using the fret as a predictor variable (independent variable - x) and the mean (of 6 strings) deviation from ideal intonation as a response variable (dependent variable - y). Linear regression assumes normal distribution, which these variables approximated as shown above, as well as no major outliers. Linear regression similarly assumes independent y variables for each x variable. Residual plots were generated to verify fit and indicated that the residuals were normally distributed, and scattered around zero without an obvious pattern. The regression formulas were as follows (calculations of 95% confidence intervals are shown below (8)):

Standard nut $Y = -0.467\,X + 5.357$, $p < 0.0001$, $r^2 = 93.2\%$

95% confidence interval for the slope (-0.467): -0.529 to -0.404.

Eliasson nut $Y = -0.177\,X + 1.031$, $p < 0.0001$, $r^2 = 93.2\%$

95% confidence interval for the slope (-0.177): -0.206 to -0.148

$$b \pm t_{n-2,1-\alpha/2}\,se(b)$$

$$-0.177 \pm 2.101(.014) = (-.206, -.148)$$
$$-0.467 \pm 2.101(.030) = (-.529, -.404)$$

The probability values listed with the regression formulas indicate that both slopes are significantly different from zero. The slope of the Eliasson nut data clearly falls outside of the 95% confidence limit of the slope of the standard nut data, indicating a statistically significant difference. Since the slope of the Eliasson nut data was closer to zero than that of the standard nut, the Eliasson nut clearly improved intonation. The regression proceedure was repeated using all strings per all frets i.e. 120 measures per nut, and remained statistically significant.

The difference per fret of deviation from ideal intonation was compared using a matched-pair t-procedure. This test was chosen since the measurements are a before and after measure after a change had been made. The assumption of this test is that the data are a simple random sample from the population of interest (all guitars) and that the

Table II: Paired samples t-test, standard nut – (minus) Eliasson nut (19 degrees of freedom):

String	**Mean difference**	**Standard deviation**	**t-value**	**one-tailed p-value**
E1	**-1.5 Cents**	**0.8**	**-8.816**	**0.000**
B	**-1.0 Cents**	**1.5**	**-3.082**	**0.003**
G	**-0.1 Cents**	**3.2**	**-.071**	**0.472**
D	**4.0 Cents**	**1.4**	**12.667**	**0.000**
A	**4.0 Cents**	**2.3**	**7.797**	**0.000**
E	**4.1 Cents**	**3.4**	**5.385**	**0.000**
Mean per fret				
	1.6 Cents	**1.8**	**3.888**	**0.000**
All strings, all frets				
	1.6 Cents	**3.3**	**5.210**	**0.000**

Table II: Paired sample t-test of the standard nut versus the Eliasson adjustable nut per string. E1, B, G, D, A, E6 refers to the individual strings. Mean per fret refers to mean of all 6 strings per fret, whereas all strings, all frets, refers to all measurements. Means and standard deviations were rounded off.

population distribution is normal, and that there are no major outliers. The normality assumption seems to have been met as outlined above. However, the sample size was by definition small, that is only 6 strings per fret. For that reason, a nonparametric test, which does not assume normal distribution was used as a confirmatory test.

TABLE IIA: Paired sample t-test, standard nut –(minus) Eliasson nut (19 degrees of freedom)

$$t=\frac{x-0}{s/\sqrt{n}}=\frac{-1.5-0}{0.7609/\sqrt{20}}=-8.816$$

$$t=\frac{x-0}{s/\sqrt{n}}=\frac{-1.0-0}{1.4510/\sqrt{20}}=-3.082$$

$$t=\frac{x-0}{s/\sqrt{n}}=\frac{-0.05-0}{3.1368/\sqrt{20}}=-0.71$$

$$t=\frac{x-0}{s/\sqrt{n}}=\frac{3.95-0}{1.3945/\sqrt{20}}=12.667$$

$$t=\frac{x-0}{s/\sqrt{n}}=\frac{4.00-0}{2.2942/\sqrt{20}}=7.797$$

$$t=\frac{x-0}{s/\sqrt{n}}=\frac{4.05-0}{3.3635/\sqrt{20}}=5.385$$

Table IIA: Paired sample t-test of the standard nut versus the adjustable Eliasson nut per string, in order from top to bottom E1, B, G, D, A, E6.

Table II lists the results of a paired t-test comparing each string between the standard nut and the Eliasson nut. There was a statistically significant difference for all strings, except for the G string with a one-tailed p-value being less than 0.003 for all. When the strings were grouped per fret (nut summary) the comparison revealed a statistically significant difference with the Eliasson nut lowering intonation by 1.6 +/- 1.8 Cents on the average (one-tailed p = 0.0005). However, as outlined above, comparing means per string will mask differences between the nuts due to averaging of positive and negative values that is lower frets versus the upper frets.

Table III shows the findings of a paired t-test comparing the standard nut to the Eliasson nut per fret, for frets 1 through 4, and is summarized below:

Table III:

Paired samples t-test, standard nut – (minus) Eliasson nut (5 degrees of freedom):

	Mean difference	**Standard deviation**	**t-value**	**one-tailed p-value**
Fret 1	**4.5 Cents**	**3.8**	**2.915**	**0.017**
Fret 2	**4.8 Cents**	**4.3**	**2.748**	**0.020**
Fret 3	**4.8 Cents**	**4.6**	**2.561**	**0.026**
Fret 4	**3.5 Cents**	**3.7**	**2.300**	**0.035**

Table III: Paired samples t-test of the standard nut and the Eliasson adjustable nut per fret, for the first 4 frets, that is the lower end of the fret board. Means and standard deviations have been rounded off.

Table IIIA:

Paired samples t-test, standard nut – (minus) Eliasson nut (5 degrees of freedom):

$$t = \frac{x-0}{s/\sqrt{n}} = \frac{4.5000-0}{3.7815/\sqrt{6}} = 2.915$$

$$t = \frac{x-0}{s/\sqrt{n}} = \frac{4.8333-0}{4.3089/\sqrt{6}} = 2.748$$

$$t = \frac{x-0}{s/\sqrt{n}} = \frac{4.8333-0}{4.6224/\sqrt{6}} = 2.561$$

$$t = \frac{x-0}{s/\sqrt{n}} = \frac{3.500-0}{3.7283/\sqrt{6}} = 2.300$$

Table IIIA: Paired samples t-test calculations. Comparison of the standard nut versus the Eliasson nut per fret, for from top to bottom, fret 1, fret2, fret 3 and fret 4.

The Eliasson nut clearly resulted in statistically significant improvement of intonation in the lower frets. It should be noted that the difference between the E1 strings was fairly minimal, and the difference between the other five strings was therefore probably greater than indicated by the means above. An issue in this approach to the data is multiple comparisons, but the testing was generated by the hypothesis. Correction for multiple testing goes beyond the scope of this paper.

In view of concerns about assumptions about normal distribution, statistical consultation was obtained. The consultant performed a nonparametric test, the Wilcoxon rank-sum test on the mean data from frets 1-4. This test does not require normal distribution. The differences between the nuts were still statistically significant. The results of the Wilcoxon signed ranks test are shown in the appendix.

To summarize; the null hypothesis was rejected as the Eliasson Adjustable Guitar Nut caused a statistically significant improvement in the guitar's intonation.

DISCUSSION - CONCLUSIONS

The present study demonstrates that an adjustable compensated guitar nut can result in statistically significant improvement in guitar intonation as compared to a standard guitar nut. Are these results meaningful from a musical standpoint? In fact, the improvement in intonation was clearly audible particularly when using guitar fingerings that used both open and fretted strings. The human ear can distinguish a difference of two cents. The improvement in the lower frets averaged 3 to 4 cents, but the improvement was much greater concerning individual strings.

Sources of error and difficulties in data collection were as follows:

1. Strings (strings were new, and the same for both nuts).
   - Scale length (Length between nut and the bridge, which will vary depending on the type of guitar.)
   - String elasticity (An elastic string will have greater intonation problems as opposed to a stiffer string.)
   - String gauge (heavier gauge strings appeared to have worse intonation than lighter gauge strings, possibly due to the fact that they are wound.)
   - Use of old strings in the experiment (Strings stretch over time to a variable degree, which prompted the use of new strings in this experiment.)
2. Frets
   - High (tall) frets cause intonation problems, more so than low frets, (This is the very reason why the nut has to be adjustable, so it may accommodate different fret heights.)
   - Poorly leveled frets affect intonation of the guitar, (the 14th fret on the Squier Jagmaster was too high and required filing prior to the conduction of the experiment.)
3. Guitar Action (Height of strings above the fingerboard.)
   - High action causes intonation problems as compared to low action as higher action requires the guitar player to press the string further down. In this study, the

action was set a low level and was kept constant and probably did not affect the results.

4. Bridge Intonation

   - Improper bridge saddle position will affect the intonation of a guitar. Prior to the conduction of the experiment, the guitar's bridge was properly intonated and subsequently, bridge saddle placement was kept constant.

5. Tuning Gears

   - Different tuning gears will affect guitar intonation to various degrees based on their gear ratios, (The Squier Jagmaster had stock tuning gears that did not allow for the full use of the capabilities of the Strobe tuner.) Since this study consisted of before and after measurements on the same instrument, this was not an issue but certainly did affect measurement precision.

6. Finger Pressure of the Fretting Hand

   - When greater pressure is applied to the strings, it will result in greater deviation from ideal intonation than when lighter pressure is applied. In this study, an attempt was made to keep finger pressure constant.

7. String Plucking Pressure

   - Greater force applied to the string when it is plucked will result in greater intonation problems than if the string were plucked lightly. In the present study an attempt was made to apply equal, light force when strings were plucked.

8 Reading of the Strobe Tuner

   - The strobe has rapidly scrolling bars that show the tuning of the string. When the string becomes more in tune, the scrolling bars begin to stabilize and settle once the string being tuned is in tune. This can affect the precision by which tuning results are read. In this study, the findings were probably not affected by this factor.

Sources of error in data analysis were as follows:

1. This investigation was a before and after experiment. The statistical procedures used assume that the experimental subjects area simple random sample (SRS) of the population being investigated. In this study, only one guitar was examined, which hardly can be considered a SRS. However, the production of these guitars is highly standardized and there is no reason to believe that the Squier Jagmaster used for the study was any different from any other guitar of this brand, and other brands built in a similar manner. For this reason, the results of this investigation are probably applicable to all guitars of this type.

2. The statistical methods used assume normal distribution and no major outliers. In view of the relatively few measurements, normal distribution was difficult to ascertain in all instances. However, statistical methods not requiring normal distribution confirmed the findings of the study, validating the methodology used.
3. Some of the analysis involved using mean or average values, which by definition will reduce scatter, narrow down the distribution and reduce the standard deviation. The means very used in order to perform analysis per fret. This is a relevant approach from a musical standpoint as certain chord voicings involve fretting of all strings at a certain fret, or fretting of several strings at a certain fret.

In order to validate this approach, analysis was also performed using all values (that is not averaged). Both approaches yielded similar results.

The main limitation of this study is that is involves only one guitar. It would of course be of interest to repeat these measurements using several guitars of different types. In this manner, one could investigate the effect of different scale lengths (distance between the nut and the bridge) which is a major factor in how a guitar plays and sounds. Furthermore, the guitar examined was a standard (tenor) guitar, and the results can not be immediately extended to baritone or bass guitars or the smaller soprano guitar.

However, the Eliasson adjustable nut is designed in a manner to allow for adjustment for various scale lengths. The author believes that the Eliasson adjustable guitar nut will be equally effective in correcting intonation of other tenor guitars with a different scale length, but that a slightly different design (allowing for greater horizontal adjustment) would be required for a baritone or a bass guitar.

As stated in the introduction, the intonation problems of a standard guitar nut have been recognized in the past. In fact, the deviation from ideal intonation of a standard guitar nut, such as documented in this study, has been investigated in the past. However, the author was unable to locate similar data on a compensated nut, and certainly none on an adjustable compensated nut. This study represents the first attempt of a statistical comparison of a standard guitar nut with a adjustable compensated guitar nut.

Statistics are one thing, the actual sound is another. In this study, hearing was believing!

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