# Afgestudeerd

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## Design of an ergonomic electric guitar

An investigation of existing literature reveals that guitar players are most prone to musculoskeletal injuries amongst all musicians. In the light of recent injuries to prominent guitar players such as Eddie Van Halen, this article explores ergonomics of electric guitars. By means of surveys, user observations, biomechanical analysis and laboratory measurements, the root of the problem has been determined. Bad posture while playing and high wrist flexion seem to be the two prominent issues that are omnipresent. The article culminates with the design of an electric guitar that presents a solution to the ergonomic issues associated with the existing design.

### Introduction

A musician is a unique form of an athlete. The physical demands on the muscles and tendons of a guitarist may not be far from those of a sportsman. The difference is that playing music usually involves smaller muscles which are more prone to repetitive strain injuries. Although professional athletes constantly train with physiotherapists, most musicians do not even realize the amount of strain they put on their bodies, until they are down with injury. Lead-ing guitar manufacturers continue to produce models that were designed in the '50s, even though musculoskeletal injuries amongst guitarists have become common.

Playing a musical instrument may be second only to computer use in terms of population exposure to a risk factor for MS I or Musculoskeletal Injury (Morse e.a., 2000). Some studies have shown that approximately half of professional musicians and music students experience significant symptoms (Chong e.a., 1989; Fry, 1986; Norris, 1993; Zaza, 1998). Although MSI is common across the entire industry, the risk of MSI is apparently greater for string players (such as guitar) and keyboardists (such as piano) than other musicians (Zaza & Farewell, 1997). In a study done by University of North Texas Musician Health Survey, out of 520 electric guitar players, 74% experienced one or more musculoskeletal problems (Fjellman-Wiklund e.a., 2006). In another survey with 261 professional and student guitars, most common reported location was the fretting hand (40%) followed by back and neck (17% and 14%) (Rigg e.a., 2003).

Postures that require flexion at the elbow and wrist together with rotation and upward turning of the palm (supination) – for example, the left hand position while playing the violin or guitar – present a risk of cubital tunnel syndrome (Chong e.a., 1989). Musicians are also likely to develop epicondylitis when playing instruments, like the guitar, because of complex postures with rotation of forearms, bending of wrist and independent finger movements. (Fry, 1986; Chong e.a., 1989). Carpel Tunnel Syndrome is common amongst guitar players, not only because of playing excessively, but also a cumulative effect of poor posture combined with other activities that employ using the hands excessively with little movement of the body (Sternbach, 1991).
MSI has become common in the music industry. Some of the top players of the era, such as Eddie Van Halen and Dave Mustaine, have been diagnosed with MSI multiple times putting their entire careers at risk. It can be concluded that guitar players are pushing the limits of physical ability, but putting more strain on their body. A new design of an electric guitar that not only compliments a musician's ever growing repertoire but also aids in his development while minimizing the risk of injuries is needed.

### Goal

The focus of the project was on understanding why guitar players get injuries and device a solution for prevention of MSI. Based on the analysis of probably injury causes, an ergonomic guitar design with the aim to reduce discomfort while playing and prevent musculoskeletal injuries is described in this paper.

## Analysis

To determine the requirements for an ergonomic electric guitar, various techniques were used. These include user surveys and discussions, observations and laboratory study.

### User survey

A questionnaire was sent to a number of guitar players, both amateur and professional, with varied experience to determine the complaints of a sample population. They were asked to describe their playing habits and introspect on their experience with the instrument through both open and close ended questions. 25 guitarists from different parts of the world responded to the questionnaire. The list included amateur hobbyists, music students (including PhD candidates) and professional musicians with upto 25 years of experience.

Most experienced guitarists practice about two hours a day. 80% of the time, users prefer to play in a sitting position. Most users concurred practicing while sitting causes back pain, whereas practicing while standing leads to neck pain, after prolonged playing. Almost 75% reported one or more of lower back pain, left wrist ache and pain in shoulder and neck.

### User Observation

It was observed that playing the electric guitar in a neutral sitting posture poses certain challenges. The guitar is usually supported on the user's lap and has a natural tendency to rotate in the coronal plane known as 'neck dive' (figure 1a). As a result, the user needs to hold the guitar in his preferred position using his arms even while playing (figure 1b).

Neck dive is an issue while standing as well. A strap is used to fasten the guitar around the neck and torso. The guitar neck tends to become horizontal to keep its balance. The effect is strongest for bass guitars where the neck is longer and heavier, and extended range guitars that have more than 6 strings.

**Figure 1a. Guitar neck tends to 'dive' down**

**Figure 1b. Guitar neck needs to be held in position while playing**

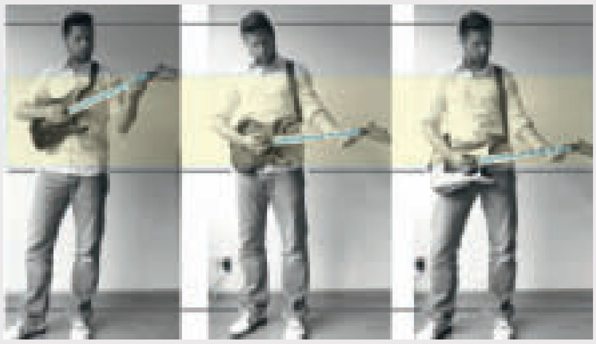

**Figure 2. User standing with the guitar in three different positions according to strap length; the tendency to neck dive increases as the strap length increases**

Most users were in spinal kyphosis while playing in the sitting posture. This allowed them to see the guitar neck when it rests horizontally in the normal sitting posture (figure 3). Neck flexion and spinal kyphosis result in unfavorable loads on the musculoskeletal structure. Even slight neck flexion creates a bending moment three times greater than the neutral position in the C7T1 joint (Harms-Ringdahl, 1986). The existing design of the guitar body does not take into consideration size of the user. For most users, guitar neck was too low and some users prefer to use a guitar strap

**Figure 3. Most users can be seen in a 'drooping' posture which allows them to see the fretboard (neck) while playing**

even while sitting to allow for height adjustment of the neck as per their preference.

However, the conventional C shaped profile is inherently unstable as can be seen in the figure 5. When a force is applied to fret the string, the thumb tends to rotate about the curvature requiring constant adjustment in the direction of applied thumb force.

Another aspect of observation was the grip. It was observed that the grip is not constant, but keeps changing as one plays different passages at various locations of the fretboard. Most players predominantly use one of the following three grips : (a) classical, (b) pinch and (c) thumb around (figure 4).

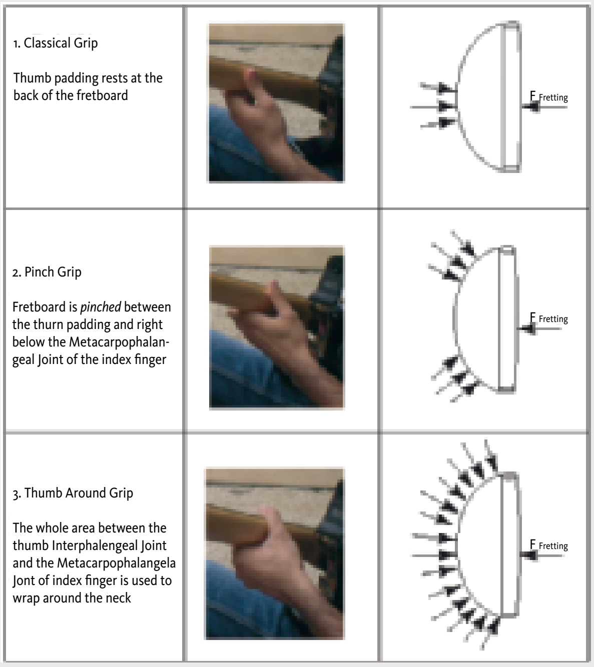


**Figure 4. Various grips and interaction of forces. These grips are not constant but vary dynamically during the act of playing. Images are extracted from a video of user playing his favorite piece**

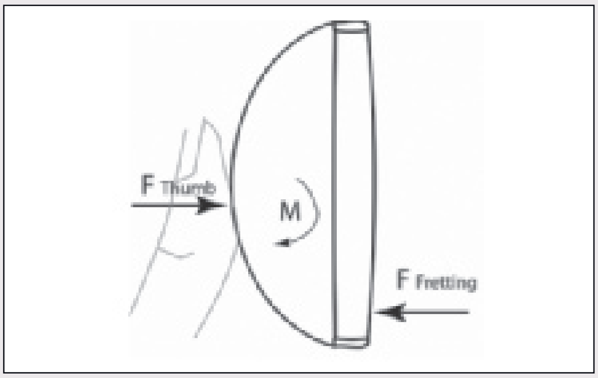


**Figure 5. Balance of forces when a lower string is fretted on a conventional guitar neck**

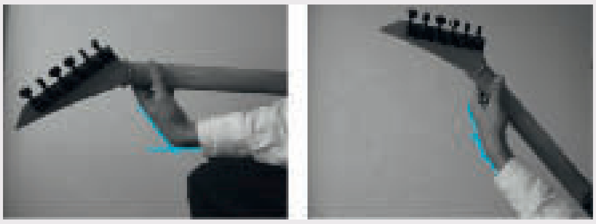

**Figure 6. Wrist flexion when the guitar neck is a) horizontal b) at 45 degree elevation, while holding the same chord**

Wrist flexion was commonly observed in electric guitar players. It was observed that there are some instances during the act of playing where wrist flexion was really high.

## Laboratory Study

High wrist flexion observed during playing was considered an important factor that contributes to MSI in guitar players. Further analysis was carried out to study the range of wrist flexion and device means to reduce it.
One hypothesis is that wrist flexion can be reduced by allowing the neck to be oriented at an angle to the horizontal (figure 6).

A goniometric study was done in which wrist flexion and ulnar deviation were measured using a Biometrics MWX8 kit on three subjects who are amateur guitar players. The experiment was carried out in the laboratory of Department of Design Engineering, Faculty of Industrial Design, Delft University of Technology. The objective of this study was to measure wrist flexion for extreme scenarios and compare the same while using an ergonomic aid. The aid

**Figure 7. User during the goniometric evaluation with the ergonomic aid**

allowed users to position the instrument as per their preference by adjusting the height and orientation of the guitar neck.

The maximum wrist flexion at one instance was as high as 68.5 degrees. Mean wrist flexion for all three subjects while playing two different chords was 47.5 degrees. A mean reduction of 13 degrees was observed in wrist flexion by orienting the guitar neck according to the user's preference with the ergonomic aid.

Mean wrist flexion values for three subjects are compared with and without the ergonomic aid in the graph (figure 8).

Maximum ulnar deviation was 41 degrees. Mean ulnar deviation for three subjects was 30.5 degrees. A mean reduction of 6.5 degrees in ulnar deviation was observed using the ergonomic aid.

## Design criteria

Based on user surveys and observations, it can be concluded that most users prefer to play while sitting (upto 80% of the time), but the existing design does not compliment the sitting posture. This is apparent in the drooping posture that most guitar players can be seen in while sitting which allows them to see the fretboard while playing. Pain in the neck and back can be attributed to this. Moreover, the arms need to hold the instrument in place which puts more constraint on the body.

The conventional C shaped neck profile puts more stress on the wrist based on biomechanical analysis. The neck profile should provide stability to the wrist and minimize grip forces.

Wrist flexion while gripping can result in high moments on the wrist that can cause inflammation or even misalignment of carpal bones in the long run as per literature research. These instances can contribute to musucloskeletal injuries in the wrist and explains why almost half of guitar players experience pain in the area. By positioning the neck at an angle, wrist flexion can be reduced based on laboratory experiments. The design should:

- have the guitar neck at an angle rather than horizontal;
- provide adjustability of the neck orientation according to user preference and size;
- provide optimum balance to support the instrument without having to hold it;
- minimize grip forces;
- fit the context of playing music and be aesthetically pleasing.

## Design

As per the criteria set earlier, the design of the body should allow the neck to be at an angle to the horizontal and should also be adjustable as per user preference and size in order to minimize wrist flexion. The body should be balanced minimizing the need to hold the instrument while playing. The design of the neck should minimize grip forces and provide stability to the wrist.

### Design of the body

The design shown in figure 10 resolves these issues. The body is supported between both legs, keeping the instrument more stable while playing. This configuration also allows the guitar neck to be at an angle rather than horizontal.

The guitar body also needs be adaptable to different sizes and preferences of users. Hence, instead of using a solid block of wood for the lower half of the body, a hollow plastic shape was chosen. The plastic shape can pivot about the

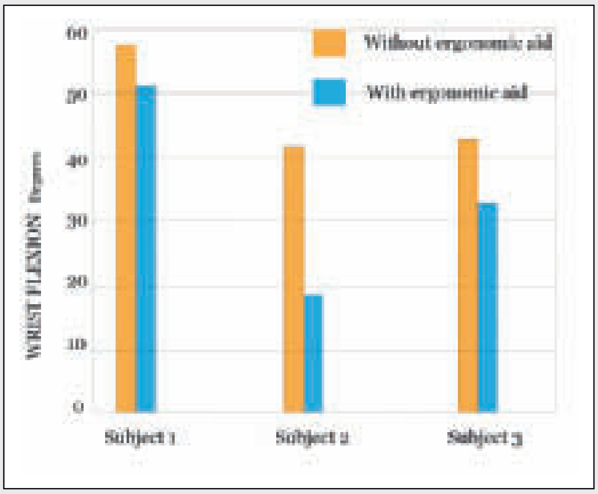


**Figure 8. Wrist Flexion of three subjects using goniometry; positioning the guitar neck at an angle reduces flexion of the wrist**

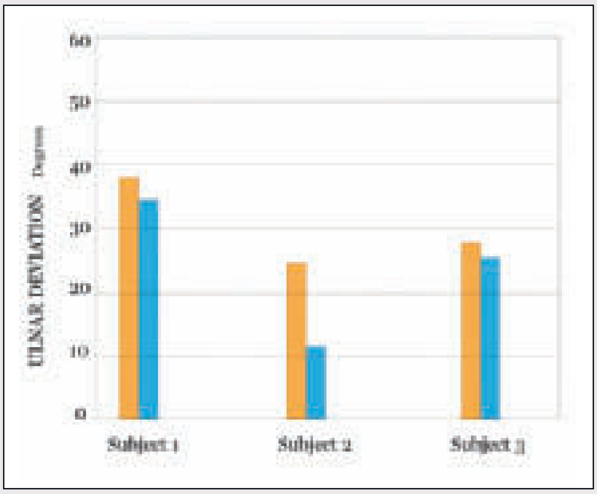


**Figure 9. Ulnar Deviation of three subjects using goniometry; positioning the guitar neck showed reduction in ulnar deviation in subjects**

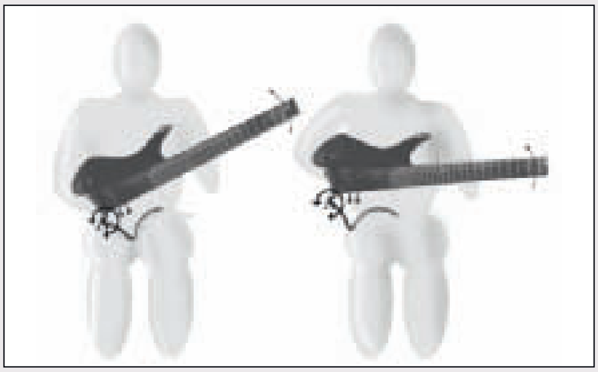

**Figure 10. Users can position the guitar in different ways; the lower body can pivot about A allowing adjustable orientation of the neck**

body providing adjustability in the coronal plane. Users can orient the guitar neck, and adjust its height and position as per their preference and body size.

A headless design was chosen as it allows better balance and reduces the tendency to neck dive. A headless design is one in which the tuners, usually located at the headstock, are placed on the body rather than the neck (figure 15).

## Design of the neck

Guitar neck is the main interface between the player and the instrument. The neck cross-section (or neck profile) plays an important role in determining grip force. A neck profile that provides stability to the hand while allowing enough flexibility to the fingers for movement is desirable. Various concepts were generated to determine the ideal mating surface for the grip. This would minimize grip forces and provide more stability to the wrist while playing.

The first concept consists of a neck cross section with flat surfaces forming a trapezoid (figure 12 (ii)) in comparison with the usual C shaped cross section (figure 10 (i)). The thumb rests on a flat surface providing more stability to the grip compared to the conventional C profile (figure 13 (i)).

The second concept (figure 12 (iii)) uses an asymmetrical trapezoidal cross section which varies along the neck, leaning towards the thumb at the headstock end and towards the palm at the body end. This varying section acts as a guide to help the user straighten his wrist when playing at different areas of the neck.

The third concept (figure 12 (iv)) consists of a concave mating surface for the thumb and flat top and bottom surfaces. The concave surface not only follows the curvature of thumb to maximize contact area, but also cancels out moments naturally so that the thumb muscles do not have to make constant adjustments in the direction of force.

## Evaluation

In order to determine the ideal neck profile, four prototypes were made and tested on users. First a foam model of the profile was made, which was then vacuum formed to

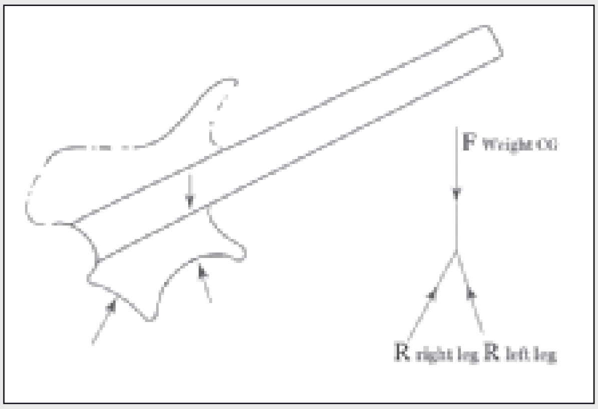


**Figure 11. Design with two cutaways on the lower half allows the instrument to rest between the legs of the user. Equilibrium of forces is also shown**

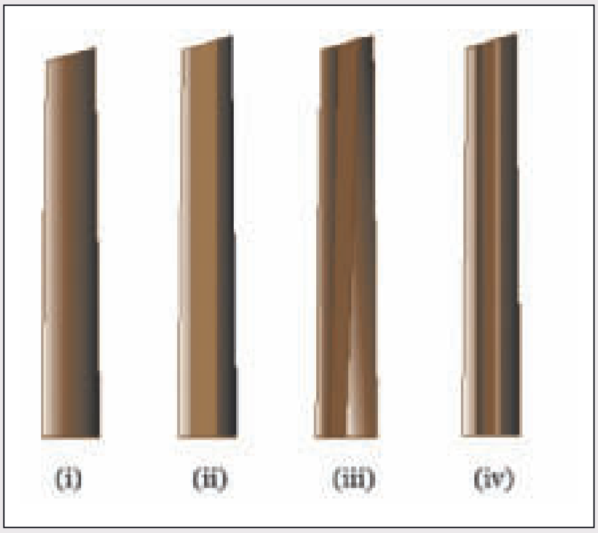


**Figure 12. Various concepts for the neck profiles (rear view). (i) Conventional C shape profile (ii) concept 1 - trapezoidal profile (iii) concept 2- assymetrical trapezoidal profile (iv) concept 3-concave profile**

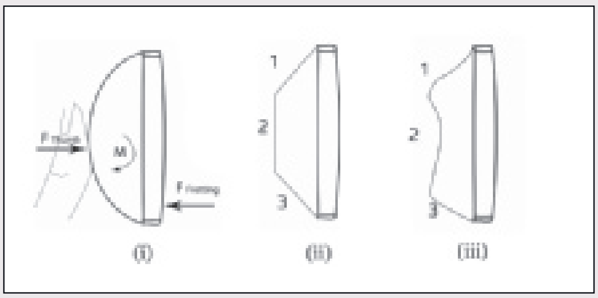


**Figure 13. Various concepts for neck profiles (cross sections shown) were generated ranging from convex to concave to optimize the cross section; (i) Conventional convex shaped neck is inherently unstable; (ii) trapezoidal section with flat surfaces (concept 1 &2) & (iii) concave section (concept 3) provide more stable alternatives**

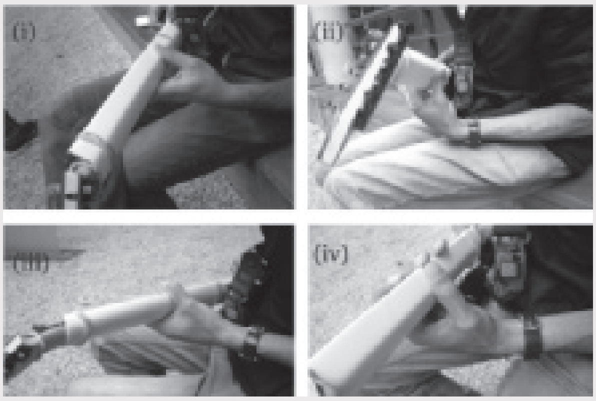


**Figure 14. Users testing four different neck profiles for comfort; concepts with flat surfaces ((i) & (iv)) seem more comfortable compared to (ii) & (iii)**

create a hollow plastic neck. These were then fastened to an actual guitar neck and tested with users.

Two amateur players were asked to evaluate the designs. Both users agree that flat mating surfaces seem a lot more comfortable to the standard 'C' shaped profile, but a bigger radius was needed between the top (1), middle(2) and bottom(3) surfaces (figure 13). Not much difference was felt between Concept 1 & Concept 2. Concept 3 was also taken positively, but during some instances, the 'bump' between surfaces 1 & 2 was not seen positively (figure 13 (iii)). The conventional 'C' shaped profile (figure 13 (i)) was taken least positively. Both users concurred that a trapezoidal profile feels the most comfortable but all surfaces should have a large rounding between them. Hence, concept 1 was finally selected as it provides optimization between all possible solutions for neck profile.

## Final Design ERG

The final design is aesthetically pleasing and fits within the context of playing music. A clear wood finish is chosen for the body taking inspiration from classical instruments such as violin and cello. The choice of wood is based on tone and sustain. In electric guitars, the weight of the instrument is directly proportional to the duration a note is sutained. A longer sustain is a desirable quality. Since only half the body is made of solid wood, heavy wood such as Mahogany is chosen as the material to optimize sustain while still keeping the instrument lightweight. The final weight of the instrument is around 2 kgs. Dark soft touch plastic is used to create contrast with natural wood.

Stowing an electric guitar away is sometimes a problem due to its bulky shape. The ERG design has a hole on the headstock which allows it to be hung on a wall using just a peg. This eliminates the need for buying a 'guitar stand' or a 'wall hanger'.

The instrument fits within 0.9 m case which makes it highly portable and acceptable on most flight cabins. Although the design is applicable to 6 string guitars, it is especially relevant for 7 & 8 string guitars. This is due to the fact that wider necks and higher string tensions make extended range guitars more difficult to play. This makes ergonomic designs more useful. 7 & 8 string electric guitars are gaining popularity and this design aims to alleviate problems of future generations of instrumentalists.

## Conclusions

Musculoskeletal pain and injuries are common amongst guitar players. Almost 75% of musicians report having discomfort in one or more of the following body regions lower back, fretting hand, neck and shoulder based on literature survey and user research. Discomfort experienced in lower back, neck and shoulders can be attributed to poor posture, as these are not directly involved in playing but allowing the user to see the guitar neck while playing. Discomfort in the tendons and joints of fingers, wrist and elbow are a result of repetitive strains experienced during the act of playing, and can be attributed to the grip when wrist is in flexion.

In order to improve posture and reduce wrist flexion while playing, a new design of an electric guitar is presented. The new shape of the guitar body allows the guitar neck to be oriented at an angle. As a result, wrist flexion is reduced as deduced from laboratory experiments. The guitar body is adjustable so users can orient the neck as per their preference and body size. Since the guitar rests between the two legs, it is more stable minimizing the need for support while playing. The new shape of the guitar also allows the user to sit straight and reduces neck flexion since the fretboard is closer to the head.

A trapezoidal cross section profile of the guitar neck provides optimum support for the grip and stabilizes the wrist based on user tests. More research on this topic, such as EMG measurements on the muscles of the forearm while playing on different neck profiles, can provide conclusive evidence. A wooden prototype of the instrument is underway to test the findings on a playable instrument, preferably on a larger sample group (n>= 10).

The design presented in this article is part of the research to design a guitar of the future. It has been sixty years since Leo Fender took the last giant step from converting an acoustic guitar to an electric one. And it is about time to climb the next one – from an electric guitar to an electronic one. If you would like to contribute to this project, or would like more details on the design, kindly contact the author through his website : www.golden-ratio.nl

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**Figure 15. Author with a virtual prototype of the instrument**

**Figure 16. Realistic rendering of the new electric guitar design**

## References


Chong, J., M. Lynden, D. Harvey, and M. Peebles (1989). Occupational health problems of musicians. *Canadian Family Physician 35*:2341-2348.

Fjellman-Wiklund, A. & Chesky K. (2006). Musculoskeletal and General Health Problems of Acoustic Guitar, Electric Guitar, Electric Bass, and Banjo Players; *Medical Problems of Performing Artists* (2), 1, 4: 169.

Fry, H. (1986a). Incidence of overuse syndrome in the symphony orchestra. *Medical Problems of Performing Artists (June)*: 51-55.

Fry, H. (1986b). Overuse syndrome of the upper limb in musicians. *The Medical Journal of Australia 144*:182-185.

Harms-Ringdahl, K. On assessment of shoulder exercise and load-elicited pain in the cervical spine. Biomechanical analysis of load –EMG – methodological studies of pain provoked b extreme position. *Thesis*, Karolinska Institute, University of Stockholm, Sweden.

Marmaras, N., Zarboutis, N. (1997). Ergonomic redesign of the electric guitar, *Applied ErgonomicsVolume 28*, 1, 59-67.

Matheson, A.B., Sinclair, D.C. and Skene, W.G. (1970). The range and power of ulnar and radial deviation of the fingers. *Journal of Anatomy 107*(Pt 3): 439-458.

Morse, T., Ro, J. e.a. (2000). A pilot population study of musculoskeletal disorders in musicians. *Medical Problems of Performing Artists Journal 15*(2): 85.

Nordin, M., Frankel, V.H. (2001). Basic Biomechanics of the Musculoskeletal System, (3rd edition). Lippincott Williams & Wilkins, ISBN 978-0683302479.

Norris, R. (1993). *The musician's survival manual: A guide to preventing and treating injuries in instrumentalists*. St. Louis: MMB Music Inc.

Rigg, J.L., Marrinan, R., Thomas, M.A. (2003). Playing-related injury in guitarists playing popular music. *Medical Problems of Performing Artists* (18), 4: 150.

Sternbach, D. (1991). Carpal tunnel syndrome: What to know about it, what to do about it. *International Musician* (July): 8-9.

Volz, R.G., Lieb, M., and Benjamin, J. (1980). Biomechanics of the wrist. *Clin. Orthop., 149*:112-117.

Zaza, C. (1998). Playing-related musculoskeletal disorders in musicians: A systematic review of incidence and prevalence. *Canadian Medical Association Journal 158*(8): 1019-1025.

Zaza, C., and Farewell, V. (1997). Musicians' playing-related musculoskeletal disorders: An examination of risk factors. *America Journal of Industrial Medicine 32*:292-300.



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