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STUDY OF TWO STROKE TECHNIQUES WITH TRANSVERSE MOVEMENT OF THE RIGHT HAND ON CLASSICAL GUITAR USING SURFACE EMG

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ABSTRACT

The purpose of this study is to examine expert playing patterns involving the index and middle fingers of the right hand of two professional classical guitar players using surface electromyographic (EMG) to analyse two different stroke techniques, rest stroke and free stroke, during the performance of a musical composition.

In the area of instrumental technique analysis, there are few studies that use EMG technology. The current study provides an empirical basis to help understand underlying motor control processes in classical guitar performance technique. Further it establishes a process for exploration of instrument technique during music performance.

Two case studies were conducted with professional guitarists who performed the classical guitar piece Estudio No. 5 by Francisco Tárrega (1993). Execution of the piece was recorded using EMG equipment and two video cameras. Subsequent analysis of the fingers involved the synchronisation of EMG data with each of the finger movements made during the performance of technically challenging sections of the music (e.g., transverse movement of the right hand or string crossing).

Results indicated a high degree of stability and consistency in terms of muscular activation, which demonstrated the excellent motor control of the expert guitarists. It is important to note that, each performer showed consistent patterns of motor control for each of the two repetitions of the musical passage even though a comparison of the two performers reveals different surface EMG patterns. These results indicate a measure of technique individualization during the performance of the technically challenging section (transverse movement or string crossing) for the fingers (index and middle) and strokes (rest stroke and free stroke).

Keywords: Music performance, instrumental technique, guitar, surface EMG, rest stroke, free stroke

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INTRODUCTION

Technical skills are required to perform any musical piece correctly. Expert-level technique serves to free the interpreter from physical constraints in order to allow for greater freedom of musical expression. Thus, technique should be considered a creative element instead of an end unto itself. It is a means of gaining confidence and control, and, through this, magnifying musical effects and improving performance outcomes (Deschaussées, 2002).

Typically, different master teachers have varying approaches to teaching guitar technique, resulting in considerable motor control differences, especially for right hand stroke techniques. Russell (1993) states that although the left hand movements of most advanced guitarists are generally standardised and some diversity exists in terms of different fingerings which may be used to reduce difficulty or for different musical preferences, there are considerable differences in the way the right hand is used. Each performer tends to adopt a personalized posture and technique. However, when discussing technique it is common to refer to the type of positioning of the hands, while what is truly and fundamentally important lies in coordinating multiple seemingly insignificant movements.

Consequentially, based on this, successful execution on the guitar can be accomplished in many ways and strings can be plucked in a variety of different manners. Decision-making with regard to the kind of stroke to employ is a primary methodological resource in teaching the instrument. Further, the manner in which a stroke is executed provides the means to develop proper technique and to facilitate the interpretation of musical compositions from different eras and styles. The two methods of plucking the string are: 1) the rest stroke, which involves resting the finger on the neighbouring string after a finger plucks a string, and 2) the free stroke, in which the finger does not rest anywhere, the finger only flexes (De Contreras, 1998; Duncan, 1980; Pujol, 1956; Schneider, 1985).

In general, musical technique and interpretation are founded on teaching methods governed by tradition and pedagogy which are commonly determined by the teacher's own artistic preferences (Visentin and Shan, 2011). In accordance with this, it is noteworthy that current pedagogical methods, which substantively focus on learning technique, are normally based on a series of practical tips which are either generally accepted because they are based on common sense or they have been proposed by teachers of recognised prestige. This reality and the small number of existing empirical studies on guitar technique underscore the relevance of the current study. The results of the study contribute objective information about how to play the guitar and motor control characteristics during performance.

In the field of guitar, one study comparing plucking techniques which did not employ EMG was conducted by Marques, Rosset-Llobet, Fonseca Marques, Gurgel and Augusto (2003). The study indicated rest stroke technique to primarily involve flexion and extension of the proximal phalanges of the three middle fingers. This distinguishes it from the free stroke technique, which involved incomplete flexion of the middle phalanges of the same digits. One of the conclusions reached by the authors was that rest stroke technique requires greater tension of the flexor muscles, because, after plucking a string, the finger then rests on the neighbouring string.

An additional study of classical guitar plucking techniques (rest stroke and free stroke) conducted by Granda, Barbero and Diaz (2006) examined the degree of muscle involvement using EMG recording for both expert and novice players. The results of the study showed

differences in EMG activity between the index and middle fingers of the right hand and significant differences in muscle voltage levels between novices and experts.

In continuation to the work above, Granda, Barbero and Diaz (2007) conducted a study with guitar students at the Professional Music Conservatory of Melilla which determined levels of muscle voltage using surface EMG recording of the right hand. The rest stroke method was confirmed to involve lower levels of muscle voltage, allowing for better development at the beginner and intermediate guitar technique levels, both in terms of skill acquisition and retention.

EMG has also enabled researchers to examine specific techniques used with musical instruments other than the guitar. For example, Bejjani, Ferrara, Xu, Tomaino, Pavlidis, Wu, and Dommerholt (1989) published a research paper which compared three different techniques for playing the piano, confirming the utility of EMG as a means of distinguishing muscle activity for each of the techniques. The results of a study by Moore (1992) on the execution of trills on the piano showed that finger acceleration and EMG activity are presented as phases characteristic of the trill cycle. Furthermore, magnitude and coordination are dependent on speed of the execution of the trill, the dynamic level, and place where the finger hits the key. Another study with professional pianists to complement teaching techniques for piano was conducted by Montes, Bedmar and Sol Martin (1993). The study examined changes in EMG activity by measuring the short abductor muscle of the thumb. The results were used for continued study of the various execution techniques for this instrument. In the same vein, a study examining alternatives to help improve the quality of piano teaching was conducted by Granda, Barbero and Rodriguez (2004). Their results indicated that implementing a program based on information limitation appears to provide significant improvement in the motor control of hand actions, which results in a decreased voltage levels in the thumb extensor muscle and increased values for the little finger extensor, supported by kinaesthetic and proprioceptive information processes.

In terms of bowed string instrument technique, Moore, Hary and Naill (1988) analysed trills executed on the cello to determine the characteristics and speed of finger movement as these relate to the EMG activity of the muscles that control them, providing information for potential biofeedback studies on problems related to instrument practice. Although Fjellman-Wiklund, Grip, Karlsson and Sundelin (2004) used EMG as a measuring instrument to study disorders related to playing stringed instruments, their study showed that EMG can be used to analyse individual differences in the performance of a musical piece and to evaluate different methods of action. And lastly, the aim of the study conducted by Granda, Barbero and Rodriguez (2010) was to analyse and describe the kinematic patterns of the right arm and muscle voltage levels of the anterior deltoid muscles, finger flexors and extensor pollicis of a professional and highly proficient cellist during the interpretation of different sections of a piece of music. Their study demonstrated a stable movement pattern during the performance of a musical piece, and also showed variation in the kinematic values and muscle activity of the arm segments studied, which were offset by adjustments in other segments of the arm. Another important finding of the study was the fact that the driving force for the right arm in a cellist's technique was the shoulder. The hand and fingers act to correct and absorb shock from the general movements stemming from the shoulder.

Using the abovementioned research as a foundation, the current research aims to determine muscle voltage levels through surface EMG recording during the performance of a musical piece by two highly proficient professional guitarists for two different stroke

techniques in order to describe and analyse motor control patterns used in guitar performance which are the result of attaining expertise in the execution of motor skills for both plucking methods.

METHOD

This study took the form of a case study experimental design with a single post-test. Each participant was considered a unique case, since the aim was to gain insight into the participants' performance behaviours (the patterns of activity of each participant) and to investigate possible intra-subject differences.

In the first phase of the experiment, an expert with over 40 years of experience as a teacher and more than 25 years dedicated to musical interpretation was asked what classical guitar piece would be most suitable for the study.

By this process, Estudio No. 5 by Francisco Tárrega (1993) was selected for the test protocol. The participants were then asked if they agreed that the piece would be useful for studying both right hand plucking techniques (rest stroke and free stroke) using the index and middle fingers.

This was necessary because, for many compositions, there can be a variety left and right hand fingering and plucking patterns. The participants agreed as to the appropriateness of the selected composition.

During this phase, two guitar virtuosos (experienced professionals) were asked to practice the aforementioned Estudio using both stroke techniques (rest stroke and free stroke) for 16 minutes a day (8 minutes of rest stroke practice, and 8 minutes of free-stroke practice) over the period of one month. They were also asked to take extreme care to keep their fingernails in optimum condition during their practice so that they would be in excellent condition on the day when the data was to be recorded.

In the second phase, data were collected on the levels of muscle activity and finger actions. Prior to starting the experiment, all participants performed warm-up exercises, basically consisting of scales and passages from the Estudio. They were told to take as much time as they needed to warm up, to ensure they were fully prepared to perform the test piece. In the data recording session, each guitarist played the Estudio 4 times: 2 times with the rest stroke technique and 2 times with the free stroke technique, starting with the technique each preferred (see Figure 1).

	Repetition 1	Repetition 2	Repetition 3	Repetition 4
Interpreter 1	Free stroke	Rest stroke	Free stroke	Rest stroke
Interpreter 2	Rest stroke	Free stroke	Rest stroke	Free stroke

Figure 1. Order in which each of the guitarists interpreted the piece.

The guitarists interpreted the piece from memory in each of the four repetitions, and in each repetition the guitarists employed the same fingerings for the left and right hands. All of

the soloists' performances were recorded using EMG equipment and two digital cameras. Surface EMG measurements were taken using the I-330 12-channel recording system (4 EMG), (J & J Engineering). Bipolar EMG recordings of extrinsic finger flexors were obtained using pairs of Ag-AgCl surface electrodes. EMG signals from the flexors of each finger were recorded on an ASUS F3J model laptop. Two Casio EXF1 digital cameras recording at 100 frames per second were used to record video and audio of the interpretation. These were positioned to facilitate subsequent analysis of the fingers involved in the study, the index and middle fingers, and for synchronisation of EMG data with each one of the moments (actions) of the fingers during the performance.

For surface EMG recording, electrodes were placed in accordance with the recommendations of Basmajian and Blumenstein (1989). Two pairs of electrodes were placed parallelly and longitudinally from the proximal to the distal insertion, so that each pair recorded tension generated by the actions of each of the fingers studied, with each compartment separated by 13 mm, the distance recommended by Shan and Visentin (2005) to avoid the cross-talk effect between the segments of muscle studied. This placement of surface electrodes did not allow the activity of the FDS finger superficial flexor to be separated from the FDP finger deep flexor. However, as force was applied in the distal phalanges of the finger position studied the deep flexor FDP was the main contributor to finger forces (Li, Zatsiorsky and Latash, 2000). The reference ground electrode was placed on the dorsal side of the forearm. All the EMG signals were sampled at 100 hertz, amplified, and then filtered using a high-pass filter at 10 hertz and a low-pass filter at 500 hertz, effectively resulting in band pass data of 10-500 hertz.

Each pair of electrodes recorded voltage generated by the muscles needed to produce the actions of each of the fingers studied. This allowed the researchers to verify the relationship between finger placement and muscle activity in order to analyse the motor control patterns of the finger segments. To ensure the validity and reliability of data recording, the activity of each finger was sampled separately with EMG recording software. The level of activation of performing fingers was verified, while the fingers which remained inactive showed minimum and unchanged tension.

For data analysis, a section of the Estudio was selected (Figure 2). In this passage, performers only use the index and middle fingers of the right hand. This section presented a series of relevant guitar technique challenges to be used in subsequent study of the action of the fingers which are the primary object of this study. The results for the technically challenging section selected correspond to transverse displacement of the fingers of the right hand, i.e., string crossing.

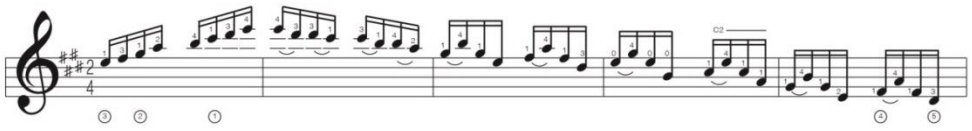

Figure 2. Selected passage (measures 3 to 7) of Estudio No. 5 by Francisco Tárrega (1993).

For the analysis of surface EMG measurements, the data collected was first synchronised with the videos recorded of the participants' performance using EMG recording software. Post-synchronisation, the videos were viewed to identify precisely which situations

corresponded to the musical passages that were the focus of the study. Using this process, sections of EMG data that matched these video segments were then identified.

After extracting the audio-video recordings and the EMG for the identified musical passages, each section was viewed frame by frame in order to precisely and rigorously determine the EMG value for each moment of finger control during the execution of the stroke, providing the information that would later be used for analysis and interpretation of emergent behaviours in each situation analysed.

RESULTS AND DISCUSSION

Surface EMG patterns for the index and middle fingers and the technique employed (rest stroke or free stroke) in each case are indicated below for some of the musical segments analysed. In each instance, the guitarists were performing a transverse hand movement, i.e., moving the fingers from one string to another laterally across the fret board. Transverse right hand movement requires correct left hand finger posture and therefore presents a technical challenge which is practiced from the initial stages of studying the instrument (Carlevaro, 1979).

Participant 1

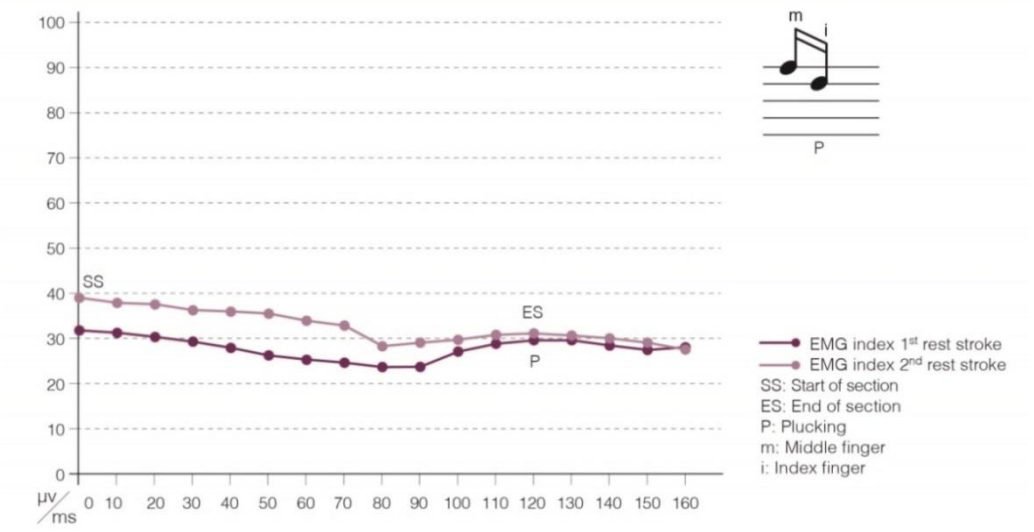

Figure 3. Surface EMG pattern for the index finger of the right hand, rest stroke, measure 5, second part.

As illustrated in Figure 3, during the execution of identified technical passage using the rest stroke technique, the guitarist (participant 1) changed from the first string plucked with the middle finger to the second which was plucked with the index finger. When the second string is plucked, a minimal rise in voltage is observed which decreases as the index finger action ends and comes to rest on the neighbouring string. The higher voltage levels attained in

the action of the plucking finger is the result of the intensity with which the guitarist executes this moment of the interpretation, in accordance with the requirements of the piece. In this same vein, in a study of pianists, Montes et al. (1993) noted that variation in EMG activity was related to stroke intensity.

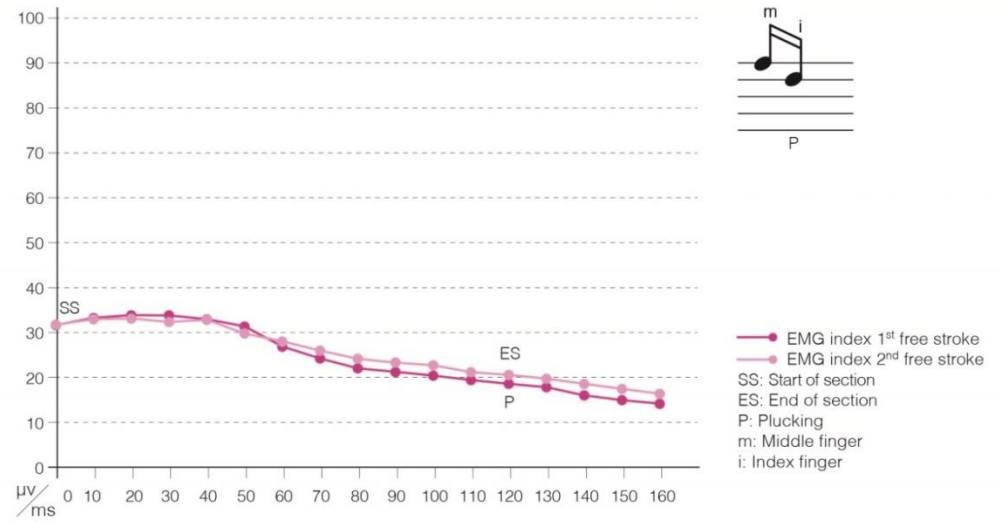

Figure 4. Surface EMG pattern for the index finger of the right hand, free stroke, measure 5, second part.

In Figure 4, while crossing strings using the free stroke technique, the explanation for the surge in muscular voltage levels at the beginning of the action when approaching the string, and the reduction of these in the final moments of the action, may lie in the fact that when the free stroke is executed the guitarist does not have a point of support or reference to complete the action, and must apply greater control over the movement and speed of execution prior to plucking the string. To do otherwise an uncontrolled movement may occur in the impulse of the final action, and, as a consequence, an unintended musical effect may result.

This data corroborates the findings of Carlevaro (1979) on the mechanics of attack, which indicates that work is not completed with the attack itself, but must be complemented by counterforce as strong as or stronger than the original action to avoid abandoning the finger once plucking is completed. This is due to the fact that, in this musical situation, results indicate that the force applied is greater in the phase of impulse towards the string and, at the time of completion of the impulse, this may require compensatory action of the extensor muscles of the fingers to balance the action. This counteraction demonstrates the system may dictate different activation thresholds for each of the muscle groups in order to achieve greater control over the action (Feldman, 1998).

In Figure 5, during the execution of the technically challenging section using the rest stroke technique, the second string was plucked with the index finger, then the first string was plucked with the middle finger. At the moment of plucking, the lowest muscle voltage value was recorded in both repetitions.

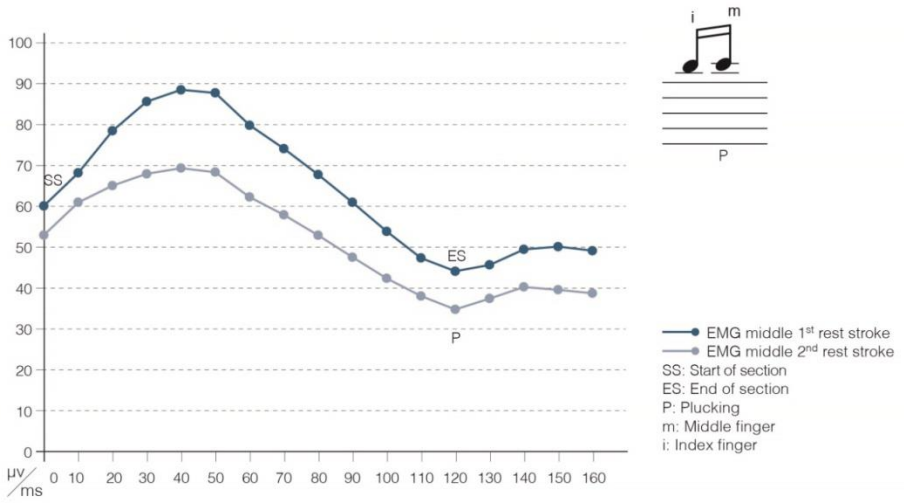

Figure 5. Surface EMG pattern for the middle finger of the right hand, rest stroke, measure 3, second part.

The explanation for why voltage levels increase at the beginning of the action of the middle finger may be that at this moment an impulse must be generated to ensure that the finger reaches the corresponding string and presses it with the required force while counteracting the action of the finger extensors in the opposite direction.

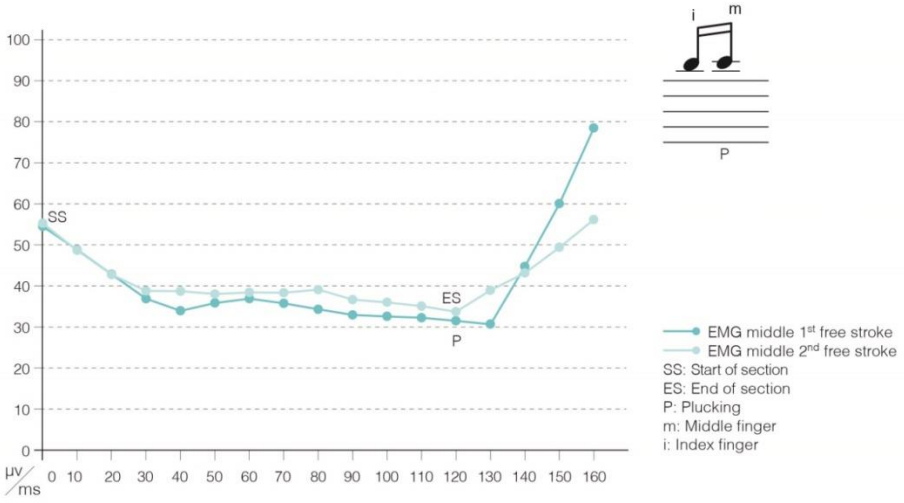

Figure 6. Surface EMG pattern for the middle finger of the right hand, free stroke, measure 3, second part.

As illustrated in Figure 6, when the free stroke was, the level of activation (voltage) dropped at the moment of plucking and increased at the end of the action, i.e., when the middle finger had finished plucking.

The reason why the maximum level activation (voltage) is reached when the string has been plucked (graph value 17), is due to adjustments that may be related to a choice of musical interpretation - something the interpreter decided to apply when performing an ascending scale.

Lastly, the temporal stability presented by Participant 1 in all of the musical passages analysed using both fingers and techniques should be noted.

This provides a clear example of the degree of precision and control that expert performers employ when interpreting a piece.

Participant 2

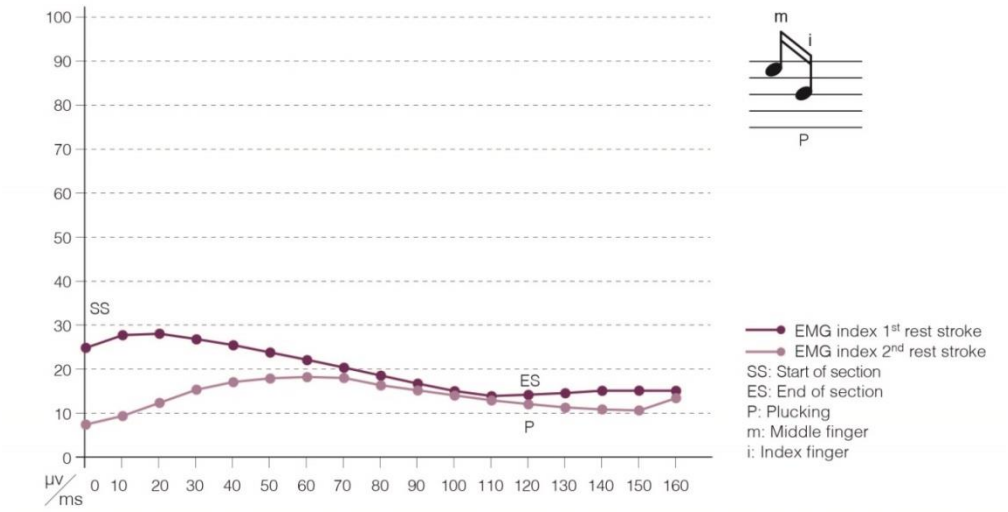

Figure 7. Surface EMG pattern for the index finger of the right hand, rest stroke, measure 6, first part.

In Figure 7, during the execution of the technical section using the rest stroke technique, the participant (guitarist 2) changes from the first string plucked with the middle finger to the second which is plucked with the index finger.

This activation pattern, which lasts from the start of the action until the time of the stroke, can be explained by the need to adjust finger action to control intensity in the execution of these notes.

In Figure 8, when the guitarist plays the passage using the rest stroke technique, the decrease in muscle voltage as the finger approaches the strings to be plucked and during plucking may be motivated by the desire to ensure greater motor control over the execution of the plucking, and to properly adjust this to the intensity with which the corresponding note is to be executed.

As shown in Figure 9, when the guitarist changed from plucking the second string with the index finger to plucking the third string with the middle finger, an increase in the level of muscular voltage was registered during the stroke. This may be due to an attempt to produce a specifically desired tone.

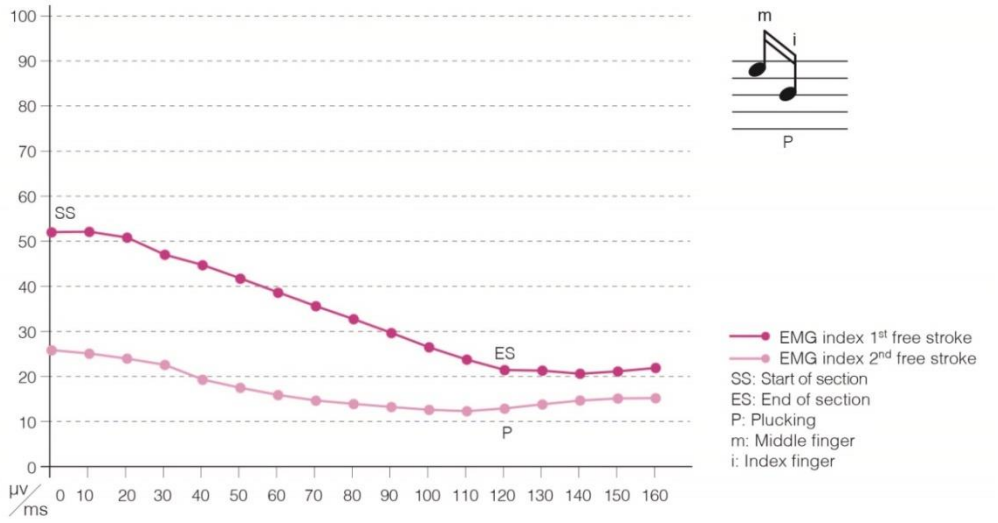

Figure 8. Surface EMG pattern for the index finger of the right hand, free stroke, measure 6, first part.

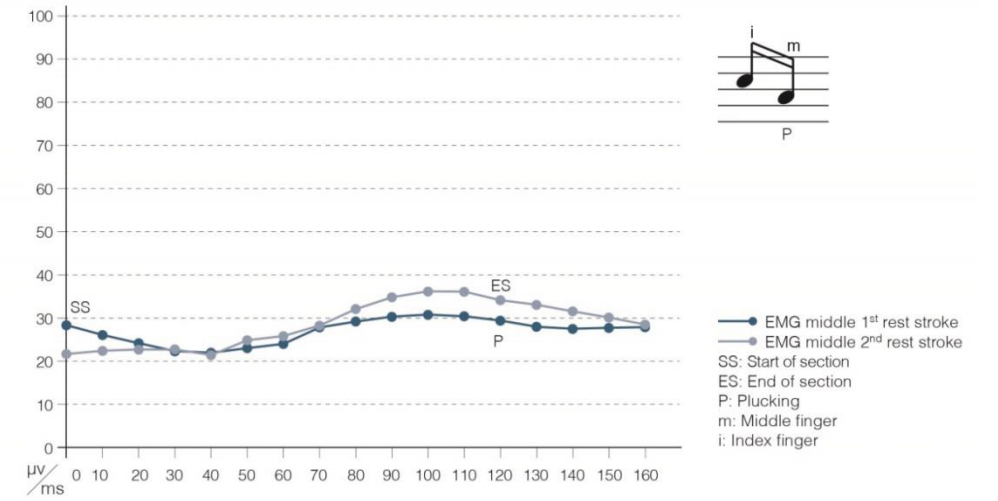

Figure 9. Surface EMG pattern for the middle finger of the right hand, rest stroke, measure 6, second part.

Also, when changing the fingering of the right hand required for the interpretation of the score (index and middle fingers), a situation arises in which the fingering is reversed (with the index finger on the second string and the middle finger on the first string). It is important to note that when playing guitar scales, the index and middle fingers are used primarily, but the ring finger and/or thumb are also used to avoid awkward string crossings Wen-Tzu (1999). The graph shows that this issue does not affect the EMG voltage pattern. The levels remain constant in the two repetitions in the most important moments, which correspond to contact with the string, plucking, and the end of the action (graph values 9-17).

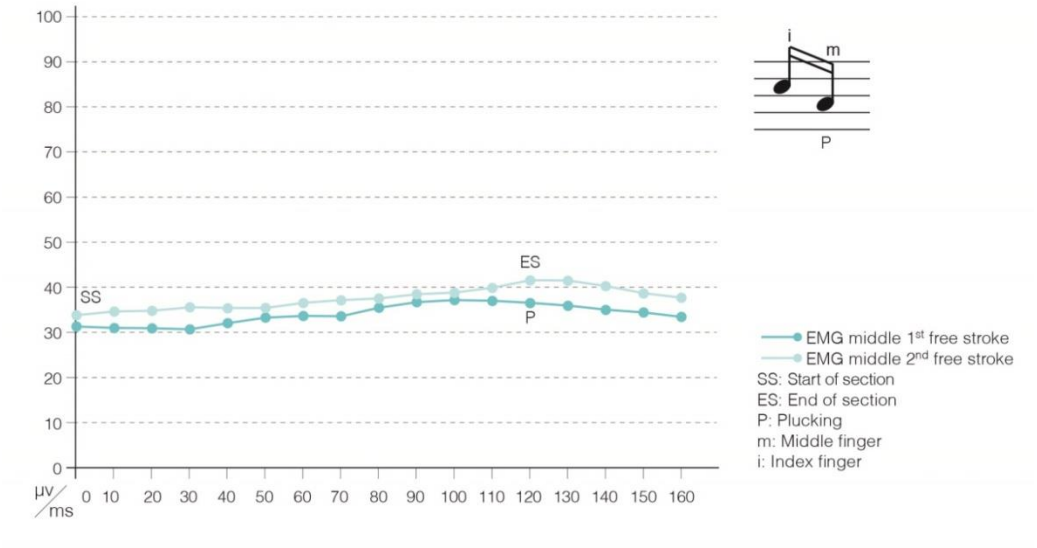

Figure 10. Surface EMG pattern for the middle finger of the right hand, free stroke, measure 6, second part.

In Figure 10 (as in Figure 9 with the rest stroke technique), when the guitarist performed the musical passage using the rest stroke technique, the highest values were recorded at the moment of the stroke. This is comparable to other situations using the index finger in both techniques mentioned above. This may be due to anatomical-functional limitations which intervene in the action of the middle finger, i.e., the middle finger is not completely independent like the index finger because when it is free next to the index finger the intertendinous connection joins it with the ring finger (Latarjet and Ruiz Liard, 1990). These higher values may also be the result of adjustments made by the performer meant to facilitate the action of the finger. In this situation, the same reverse fingering mentioned above takes place. This added challenge did not affect the surface EMG pattern.

Lastly, Interpreter 2 presented similar temporal parameters in all of the repetitions and situations analysed, demonstrating a clear mastery of musical execution.

CONCLUSION

The results of this study indicated a high degree of stability and consistency in terms of muscle requirements for both participants, which is evidence of the excellent motor control required to become an expert guitarist. It is important to note that each of the performers presents different surface EMG patterns in the fingers (index and middle) and for the stroke systems studied (rest stroke and free stroke), but inter-subject trials were similar for all of the musical passages.

The data showed that Participant 1 presented the same index finger pattern at the moment of the stroke and afterwards in both techniques. It also showed an identical pattern for the middle finger when approaching the strings, during the attack, and in the final stages of the actions.

Participant 2 presented a single pattern for the index finger and a different pattern for the middle finger on the approach to the strings, during the stroke, and at the end of the action.

Of particular importance is the fact that sometimes the participants presented variable muscle activation values in the initial and end phases of their actions for each of the repetitions studied in all musical situations, but there was clear pattern of similar values – which at times were even identical – in key moments of technical difficulty such as contacting and plucking the strings. This means that muscle activation during plucking is directly related to the intensity of execution that the guitarists chose to employ for the interpretation of each note.

Lastly, it should be noted that both performers maintained a high degree of temporal stability in the different musical passages, which demonstrates the extremely high degree of accuracy applied to the interpretation of the musical piece.

In summary, the current study provides an empirical basis to help understand underlying motor control processes in classical guitar performance technique. Further it establishes a process for exploring instrumental performance technique that may be understood as arising from performers` individualized musical motivations or approaches to performing on the guitar.

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