PRODUCING SUBHARMONICS ON VIOLIN BY MEANS OF THREE ELEMENTS:
TWISTED STRINGS, BOW LOCATION AND ROSIN AMOUNT

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ABSTRAK

Dunia muzik klasik telah mengalami suatu perubahan *timbral* yang bersifat revolusi sejak lima puluh tahun kebelakangan ini, begitu juga pada alat muzik violin dan teknik permainannya. Banyak bunyi dan *timbre* baru yang telah ditemui dengan penggunaan teknik lanjutan baharu. Penghasilan nota yang lebih rendah daripada frekuensi asas pada alat muzik bertali dianggap mustahil, sehinggalah seorang pemain violin Jepun, Mari Kimura, berjaya menghasilkan teknik yang mampu berbuat sedemikian. “Violin mampu mencapai julat bunyi serendah cello”, kata Kimura. Beliau telah memperkenalkan teknik ini sebagai suatu elemen muzik untuk memperluas teknik permainan violin pada tahun 1994 dan memanggilnya sebagai “Subharmonic”.

Sedikit awal daripada Kimura, pada tahun 1989, seorang professor muzik, Fredrick Halgedahl, dan seorang saintis, Roger Hanson, telah membuat analisis terhadap not-not ini dan kemudian menggelarnya sebagai “Anomalous Low Frequency” atau ALF. Kemudian, Kimura telah mengadaptasi istilah ini ke dalam istilah muzik melalui artikel dan komposisi beliau. Parameter bow seperti tekanan bow, ketepatan posisi bow, dan kelajuan bow dikatakan sebagai elemen terpenting untuk menghasilkan subharmonic,

Tujuan utama kajian ini adalah menilai elemen dan parameter yang digunakan untuk menghasilkan subharmonic pada violin seperti tekanan bow, ketepatan posisi bow, memutarkan tali pada arah berlawanan jam, dan jumlah rosin yang diletakkan pada bow. Faktor lain yang boleh dimanipulasi untuk mendapatkan subharmonic seperti kelajuan bow, ketebalan serta usia tali, tidak dikupas dalam kajian ini. Kajian ini juga memberi fokus kepada penghasilan subharmonic hanya pada tali G dan D pada violin.

Dalam kajian empirical ini, tiga orang pemain violin telah dipanggil bermain untuk menghasilkan subharmonic dengan memanipulasi elemen yang dikaji (tekanan bow, ketepatan posisi bow, memutarkan tali pada arah berlawanan jam, jumlah rosin yang digunakan) dan pemerhatian bagi sesi ini telah dibuat. Pemerhatian ini telah dirakam menggunakan 4K kamera perakam digital. Rakaman ini akan digunakan bagi tujuan perbandingan analisis data.

ABSTRACT

During the previous fifty years the world of classical music has been experiencing a timbral revolution, as well as violin and its techniques. A huge number of new and stimulating sounds and timbres have been discovered with the help of new extended techniques. To produce undertones lower than the fundamental frequency on a string instrument seems unexpected until a Japanese violinist Mari Kimura has reached the technique of playing low-pitched tones below the fundamental frequency. "A violin can reach the range of a cello" says Kimura. She has introduced this technique to the world as a musical element to extend the violin techniques in 1994 and called this phenomenon "Subharmonic".

Prior to Kimura in 1989 a music professor Fredrick Halgedahl and a scientist Roger Hanson had analyzed these tones then later Roger Hanson and Oliver Rodgers considered and introduced them as "Anomalous Low Frequency" or "ALF", however Kimura has improved these anomalous low frequencies as musical terms in her articles and compositions. To produce subharmonic, the bow parameters like bow pressure, accurate bow placement and bow speed are mentioned as the most important and impressive elements.

The main purpose of this research is to examine the elements and parameters which are used to produce subharmonics on the violin such as bow pressure, bow placement, twisting the string counterclockwise and the amount of rosin on the bow hair, although there are other affective factors to obtain subharmincs like bow speed, the age and thickness of the string. In this study in addition to other studies which has been done only on "G" string, the "D" string will be examined, too.

In this empirical study, three violinists have tried to produce subharmonics on violin using three elements (bow placement, twisting the string and amount of rosin), and their performing have been recorded by a 4K digital camera recorder. The recordings will be used for comparative data analysis.

In this study the results show that different bow placements, various dosages of rosin amount used on the bow hair and different numbers of twisted string cause different subharmonics on both G and D strings. The produced subharmonic intervals on G and D strings included diminished and perfect fifth, minor and major sixth, minor and major seventh, octave and minor and major ninth.

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1 CHAPTER I: INTRODUCTION

1.1 Introduction

1.1.1 Violin

As a string-bowed instrument, violin has the potentials of creating extremely broad diversities of sound, which range from the dreadful to the excellent with the great variety of fundamental frequencies[1]. Violin's pitch range goes from G3 at 196Hz to approximately A7 at 3520Hz. The violin makes sound through vibrations, which are transmitted by the bridge from strings onto the top plate of the body. Then as the vibrations are transferred to the rest of the body via the ribs and soundpost, the body works as an acoustic amplifier and the sound will be amplified. The violin tone is thus produced.

1.1.2 Violin new techniques

During the past fifty years, the world of classical music has been experiencing a timbral revolution, where a vast number of new and stimulating sounds and timbres have been discovered with the help of new extended techniques. These developments have included bowing techniques, left-hand techniques, right-hand and let-hand percussive technique improvements, and new harmonic advances.

Right-hand techniques, which include bowing parameters, also have been undergoing an enormous progress during the second half of twentieth century. Many new extended bowing techniques, as an important part of right-hand techniques, have been discovered and introduced to the world during these years such as Sul ponticello, Sul tasto,

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[1] Fundamental frequency is the lowest frequency produced by an instrument.

Col legno tratto, Col legno battuto, Circular bowing, Son filé, Overpressure, Subharmonics and Anomalous Low Frequency (ALF).

Left-hand techniques as mentioned above have been improved in the past fifty years. Natural harmonic glissando, False harmonic glissando, Pizzicato harmonics, Fawcetts, Harmonic trills and Multiphonics are some of the contemporary left-hand techniques which will be discussed later.

Percussive techniques, which are produced by both left and right hand, include fingertips, fingernails, knuckle, palm, nail pizzicato and bartok pizzicato.

1.1.3 Subharmonic background

Around 140 years ago a physicist named Helmholtz discovered a fact about the string instruments. Helmholtz observed the motion of a bowed string during a normal tone. This motion was described as a sharp corner moving back and forward as “V”-shape while the string vibrates. This motion which produces an acceptable pitched tone is the target for most normal bowing techniques (Jim Woodhouse & PM Galluzzo, 2004). Later some physicists and scientists such as Knut Guettler, Erwin Schoonderwaldt and Anders Askenfelt discovered since all periodic waveforms with any slight change in bowing conditions, are unstable, with a bow force above the maximum value and a careful control on the bow, it is possible to break down the Helmholtz motion and produce frequencies lower than fundamental frequencies of a string instrument (Hanson, Halgedahl, & Guettler, 1995). They have studied and discussed about this phenomenon from a scientific point of view and named it as Anomalous Low Frequency (ALF).

Around 20 years ago, a Japanese violinist Mari Kimura of New York University confronted this technique during her practicing. She found that with a greater force than normal value on the bow, without changing the tuning it is possible to play a G note a whole octave below the open G, which is the lowest pitch in violin. She introduced this phenomenon as musical terms to the world and named it as “subharmonic” (Kimura, 1999).

“Subharmonic” technique is to produce pitches with a frequency below the fundamental frequency on a string instrument. Producing subharmincs is affected by some elements such as bow parameters (pressure, placement and speed), the amount of used rosin on the bow hair, the age and material of the strings and twisting the string. By a careful combination of these elements, it is possible to reach the undertones down to an octave lower than fundamental frequency on the violin.

Kimura used this technique for the first time in the third movement of one of her solo work named ALT in 1992. Since then she continued to develop this technique and used subharmonics in many compositions for solo violin like Gemini (1993), the 6 Caprices for Subharmonics (1997) and Subharmonic Partita (2004) (Reel, 2009).

1.2 Aim of study

Since the Anomalous Low Frequencies and producing Subharmonics is a new technique in playing string instruments, there is lack of enough documented evidence coupled with the absence of accurate written methods to perform this technique. In this study I am going to examine one of the mentioned techniques named “subharmonic” and the ways of producing it on violin. The focus of the study is on investigating the three elements which have important roles in producing subharmonics such as bow placement, twisting string and amount of rosin among the mentioned.

All the publications and records investigating this technique have observed the G string on the violin and have discussed about producing these tones on G string, while in this research the other string of the violin “D” has been investigated.

In all the documented evidence the amount of rosin on the bow hair has been considered as a significant element to produce subharmonics however there are no supporting articles that have investigated and measured the amount of rosin and its effects on playing these undertones or subharmonics.

The aim of this study is to explain the empirical data and elements by evaluating audios and videos recorded by three violinists who have performed and produced subharmonic on both “G” and “D” strings by using the above elements.

1.2.1 Research objectives

- To use systematic experimental investigation of producing subharmonics on violin focused on three elements (bow location, the amount of rosin, twisted string) on G string, while keeping track of bow pressure (moderate, heavy, extra-heavy).
- To use systematic experimental investigation of producing subharmonics on violin focused on three elements (bow location, the amount of rosin, twisted string) on D string, while keeping track of bow pressure (moderate, heavy, extra-heavy).
- To investigate the effects of the rosin and to measure the amount of using rosin on the bow hair as an important element in producing subharmonics.
- To compare the resultants of the participants in performing subharmonics on “G” and “D” strings on violin.

2 CHAPTER II: LITERATURE REVIEW

2.1 Introduction

This thesis is an analysis of an advanced bowing technique on the violin, termed subharmonics, in which a performer may produce tones lower than the fundamental period on any chosen string. This study will examine the influence of three elements, bow location, twisted string and rosin amount, which help to produce subharmonics on the violin.

2.2 History

During the centuries violin and its bow have been under an evolution and development. The playing of stringed instruments perhaps derived during the 9th century AD in Central Asia, and then it has developed in other countries. As Bachmann cited the plucking of the strings is an older technique than bowing (Bachmann, 1969).

One of these early instruments is the Rebek, which is originated in Spain with one, two or three strings. The Rebek was connected to the Lyre which is a famous instrument derived from Byzantium. The Rebek was played in the standing position, supported either by the chest or the shoulder (Naumann, 2013).

The second primary form of stringed instrument is the Fiddle that was popular and beloved all over the Europe and had a vast diversity of forms and types. The Fiddle had between one and six strings and remained popular until the 16th century (Bakan, 2007).

By the combination of the medieval stringed instrument's specifications before the end of the 15th century, two different instrument families with distinct construction and playing technique and different sound have been emerged: the Viola da Gamba and the Viola da Braccio. The Viola da Gamba was held between the knees to play and the Viola da Braccio was held on the shoulder by the left hand to play (Rossing, 2010). The

Violin was developed from the Viola da Braccio family during the 16th century in the upper Italian towns like Milan, Brescia, Cremona and Venice. The word "Violin" (from the Italian word Violino) is descended from the word Viola that means "small stringed instrument". The earliest existed violins are those made by the famous violin maker Andrea Amati in the year 1542 which have only three strings: G, D and A. Around 1550 Amati made the first violins with four strings.

Like the violin, the bow has passed across the periods of development while this development achieved its highest point a century after the violin was perfected. Werner Bachmann cited that for the purpose of making music in string instruments, the strings were possibly plucked before they were bowed. The development of the bow began in the 10th century (Bachmann, 1969). The original form of the bow's stick, which the Rebek was played with, was very much bent, and a piece of gut was tied to each end. During the 13th century, the stick of the bow became less curve than previous and was made with hair stretched from end to end and also a nut and a head was added to the bow. Later during the 17th and 18th centuries, the bow, which was used by Corelli and by Vivaldi, became still less curved and its head became well improved. In the next stage of development, the tension of the bow-hair could be adjusted by a screw fixed to the nut. This kind of bow that was made of light wood with the straight stick was used by Tartini (Abele, 1905).

The French man who designed a new version of the violin bow, which was the highest point of development, was Francois Tourte. He made his first bows with valueless wood obtained from sugar-barrels then later among every kind of wood that he tried to make bow, he found Brazil wood the most proper because of its qualities of lightness, firmness and elasticity (Abele, 1905). Tourte was influenced by conferring with famous virtuosi such as Giovanni Battista Viotti (1755-1824), Rodolphe Kreuzer (1766-1831), and Pierre Rode (1774-1830) achieved the improvement of the bow to its modern form. Around

1820 he changed the length of the violin bow and fixed it at 74 or 75 cm which still used today (Rossing, 2010). The superiority of Tourte's bows lies in three points: their lightness, their elegantly equal curve, and their fantastic precise and neat workmanship. Also the number of hairs in the bow has been changed from 80 to 100 to 175 to 250 single hairs (Abele, 1905).

The other significant issue in developing of the violin was string technology, which occurred specifically during mid-twentieth century, while gut was replaced with synthetic core materials. Besides a better contributing to power and brilliance, this replacement also improved constancy and playability of the string (Rossing, 2010). The musical instruments and their techniques have grown and improved during the last fifty years while a vast number of new and stimulating sounds and timbres have been discovered (Vincent, 2003).

2.3 Techniques

Performance practice with bowed string instruments may be separated into two related technical issues: those associated with left-hand technique and those associated with right-hand techniques. “Technique is the ability to direct mentally and to execute physically all of the necessary playing movements of left and right hands, arms, and fingers” (Galamian, 1982).

Some of the right-hand techniques include:

- Detaché: A separate bow with no variation of pressure taken for each note (Galamian, 1982).
- Martelé: A separate bow stroke with a sharp accent at the start of each note and a rest between strokes (Galamian, 1982).
- Portato: A series of detache porte strokes performed in the same bow (Galamian, 1982).

- Staccato: A short, evidently separated stroke on one bow, with permanent contact of the bow hair with the string (Galamian, 1982).
- Spiccato: A bow, which is dropped from the air and leaves the string again after each note (Galamian, 1982).
- Tenuto: A sustained bow for the whole value of the note (Galamian, 1982).
- Sautillé: A kind of jumping bow, which is left mainly to the resiliency of the stick (Galamian, 1982).
- Bow Tremolo: Very short, fast and unaccented up and down bow strokes, for the duration of the note value (Galamian, 1982).
- Pizzicato: To pluck the note with the finger instead of the bow (Galamian, 1982).

Some of the left-hand techniques consist of:

- Trills: A rapid alternation between two pitches that ornaments a note (Galamian, 1982).
- Finger Tremolo: A rapid alternation between two notes of the interval in a sustained bow stroke (Galamian, 1982).
- Vibrato: A slight fluctuation of a pitch produced by the motion of left fingers and hand on the string (Galamian, 1982).
- Glissando: To glide from one pitch to another pitch by left hand fingers (Galamian, 1982).
- Finger Pizzicato: To pinch the string with one of the left hand fingers and pluck the string with the fingertip downward (Galamian, 1982).
- Natural Harmonic: To touch the open string at one of the located nodes at 1/2, 1/3, 1/4, etc. the length of the string with left hand finger (Zukofsky, 1968).

- Artificial Harmonic: To stop the string by pressing the lower finger and touching lightly with a higher finger (Zukofsky, 1968).

After 1945, the attachment to nineteenth-century sonic models and techniques began to be replaced by explorations of sound production, in which a considerable number of new techniques were created and expanded by a new collaboration between composers and performers. According to Vincent, within the previous fifty years some new techniques considered as extended techniques have been appeared that include harmonics, percussive and bowing techniques (Vincent, 2003).

2.4 Harmonics

By touching the string lightly with a finger at one of its nodes, while bowing lightly, the amplitude of the string's fundamental frequency can be reduced in order that the amplitude of one or more harmonic is increased. In some cases, one of the partials may serve as the new fundamental in order to produce the perception of other more distantly related harmonics. There are two types of string harmonics: natural harmonic (open harmonic) and artificial harmonic (stopped harmonic) (Fletcher & Rossing, 1998).

Natural harmonic: A natural harmonic or open harmonic is the pitch produced by touching an open, vibrating string at one of the located nodes at 1/2, 1/3, 1/4, etc. the length of the string. For example by touching the string at the node ½ it is possible to produce the octave harmonic(Fletcher & Rossing, 1998; Strange & Strange, 2003).The range of the applied natural harmonic on the violin without changing the tuning goes from G4 at 392Hz which is produced on G string up to E7 at 2637Hz that is produced on E string (figure 2.1) (Abele, 1905).

Figure 2.1. Natural harmonic

Artificial harmonic: An artificial harmonic or stopped harmonic is a harmonic with an artificial fundamental created by stopping the string to the wanted fundamental by left hand finger. This is made by pressing powerfully with a lower finger (usually the first), and then obtaining the resultant by touching lightly with a higher finger (usually the fourth) one of the nodes at 1/2, etc. the length of the shortened string. By using this kind of harmonic, every note from a specific pitch higher can therefore be produced as an artificial harmonic. The range of the applied artificial harmonic on the violin without changing the tuning goes from C5 at 524Hz which is produced on G string up to D8 at 4698Hz that is produced on E string (figure 2.2) (Rossing, 2010; Strange & Strange, 2003).

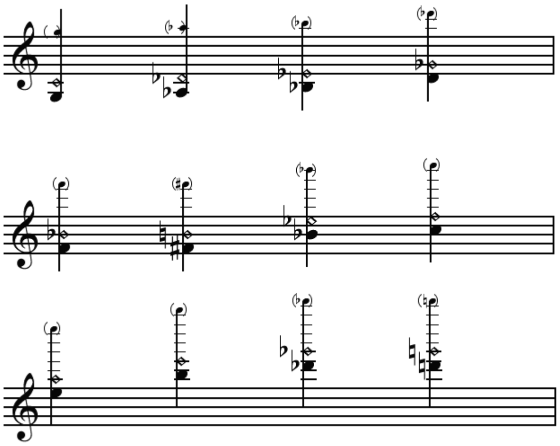

Figure 2.2. Artificial harmonics

A harmonic can have different timbres when it is played with different bow placements, fingerings or on different strings because of the different material and size of the strings. As an example, it is possible to produce an E5 harmonic in eight various ways (Strange & Strange, 2003). Also because of the substance and size of the strings, a harmonic that is played on the E string sounds more brilliant and louder than a harmonic in the same point on the G string.

Harmonics like other violin techniques have been developed over the last decades. The followings are some of the harmonic variants: pizzicato harmonics, harmonic glissandi, false harmonic glissando, fawcetts, multiphonics and harmonic trills (Strange & Strange, 2003).

- Pizzicato Harmonics: This is produced by touching or stopping the string with finger at a pitch one octave below the wanted pitch and plucking the string against the fingerboard. The string would be struck by the nail or flesh of the finger. To produce a more resonant sound, the player must immediately release the left-hand finger from the string after the string is plucked. To play stopped harmonic pizzicato, it is better to pluck the string closer to the bridge.
- Harmonic Glissando: This technique is obtained by rapidly gliding the finger up and down the length of the string, producing the overtone series on the string. It can be done both as an open and stopped harmonics with different effect. Any part of the string can be used for the open harmonic and for the stopped harmonic the fundamental pitch is held by the first finger as the fourth finger glides between nodes a fifth above and close to the first finger.

- False Harmonic Glissando: This technique is produced by stopping the string with the first finger and lightly touching the string by the fourth finger and gliding up and down the length of the string, while the fourth is closer than normal interval to the first finger.
- Fawcetts: It is a type of double or compound harmonic which is produced on G string by gently stopping the string with the third finger on note C. By bowing very slightly a pitched noise band or possibly the third harmonic of the open G (G4) would be produced.
- Multiphonics: This technique is mostly used for double bass, cello, viola and wind instruments. Multiphonics can be played by touching the string lightly at the highest node of the harmonic desired, while bowing the string at the fingerboard side of the touching finger. The wind instruments can produce multiphonics by altering the way of blowing to play two or more tones at the same time.
- Harmonic trills: This technique is the use of a trill between two or more harmonics, which should not be mistaken with multiphonics. This technique can be produced both as open and stopped harmonic.

2.5 Percussive Techniques

Except pizzicato, which has been used since previous centuries, there is not any historical consideration of using other percussive techniques for the violin earlier than 20th century. To produce percussive sounds on a violin, the hand’s four general areas such as fingertips, fingernails, knuckles, and palm are used. Another common method for the percussive techniques is using the hand as a mallet. Each of them can produce a special timbral effect (Strange & Strange, 2003; Vincent, 2003). The followings are some of the surfaces that can produce a percussive technique: fingertips, fingernails, knuckle, palm, nail pizzicato and bartok pizzicato.

- Fingertips: The use of the right hand fingers to strike the fingerboard in order to produce a pitched or non-pitched sound. The other possibility is to use the fingertips for rubbing across the instrument body, which can be obtained better by putting some rosin powder on the finger to increase the friction.
- Fingernails: The use of fingernails to strike the fingerboard, which provides a sharper, sound because of the acoustic augmentation of the high partials. It can be played by simple tapping or tremolo.
- Knuckles: The use of the right hand to knock on a violin body with the knuckles.
- Palm: The use of the right hand palm to slap the instrument surface as mallet to produce a loud percussive sound.
- Nail Pizzicato: By using the nail to pluck the string it is possible to sharper sound rather than using the fingertip. This is also possible to use a finger pick instead of nail and also a thimble for left hand to produce the more constant sound.
- Bartok Pizzicato: To produce this pizzicato, a player should pluck the string vertically with the right hand and release so that to create a snap against the fingerboard to get sharp attack sound.

2.6 Bow Techniques

By bowing on the violin strings, the basic vibration system would be established. To produce the vibration with the bow, two general issues are considered: how the bow is moved across the string and at what point on the string the bow is drawn (Strange & Strange, 2003). The followings are some of the bowing techniques created during the 18th and 19th centuries: sul ponticello, sub ponticello, sul tasto, col legno*,* son file. Also there are some techniques that have been created during the 20th century such as overpressure, circular bowing, subharmonics and alf's.

- Sul ponticello: One of the remarkable inventions in bowing techniques is Sul ponticello, which is a development of an old technique. It is produced by playing near or on the bridge in order to create either a timberal effect or a pitched effect and a glassy smooth sound. "The nebulous environment suggested by sul ponticello is created by the narrow boundary between a slight pitch and the production of a non-pitched timbre" (Strange & Strange, 2003).
- Sub ponticello: Playing behind the bridge, which is between the bridge and the tailpiece. It gives a non-determinant high-pitched sound. By different amount of bow pressure, different colors can be produced while with a light bow pressure high pitches are produced and with heavy bow pressure lower pitches can be produced on the same string (Strange & Strange, 2003).
- Sul tasto (also Flautando): This technique has also been developed. Playing over the fingerboard to create an obscure fluty sound is called sul tasto. There are a diversity of sounds that can be produced with sul tasto, considering the precise placement of the bow on the string and how the bow is drawn across the string(Strange & Strange, 2003).
- Col legno (col legno trattto): Drawing the bow on the string using the wooden stick that produces an unclear, transient, interrupted sound because the surface of the stick is smoother than the bow hair. It is possible to extend the col legno technique by using it in combination with other techniques (Strange & Strange, 2003).

- Col legno (col legno battuto): Bouncing the stick of the bow which means to strike on the instrument's string with the wooden part of the bow which produces a sharp, percussive sound (Strange & Strange, 2003).
- Son filé: Issuance of a sustained note from a very low noise level to a strong level with a gradual return to the silence(Strange & Strange, 2003).
- Overpressure: Another extended technique that means bowing with heavy pressure to the bow to produce both pitched and non-pitched sound. To produce a pitched sound, besides the heavy pressure, the performer must bow faster and if no pitch is desired, a slow bow with heavy pressure would produce the non-pitched sound (Strange & Strange, 2003).
- Circular bowing: To bow in a circular motion across the string, an intermittent tone with a variable frequency (depending on the size and speed of the circle) is produced (Strange & Strange, 2003).
- Subharmonics and ALF's: One of the new extended techniques, which is produced by applying a very hard pressure and accurate bow placement in order to reach pitches below the fundamental (Strange & Strange, 2003).

2.7 Subharmonic

"A violin can reach the range of a cello" says Mari Kimura (Peterson, 1995). According to Mari Kimura, a Japanese violinist it is possible to produce pitches below the fundamental frequencies on any of the strings on a violin. Within the last five centuries, the range of a violin bottomed out on the G below middle C, the fundamental pitch of the fundamental pitch of the violin with a normal tuning. The normal range of violin goes from the G3 at 196Hz to approximately A7 in 3520Hz while with using the subharmonic technique this range comes down to G2 at 98Hz (Fletcher & Rossing, 1998). Around 20 years ago on April 1994 Kimura introduced the term “subharmonic” as a musical element to extend the violin techniques in public in Merkin Hall, NYC (Kimura, 1999).

Subharmonics (or undertones) are the pitches below the fundamental frequency of an open string, which need overpressure in bowing on a node over the fingerboard to be produced. The different between harmonics (overtones) and subharmonics (undertones) is that to play harmonics the left hand fingers touch the string lightly but for playing subharmonics contrasting the harmonics the fingers must be pressed down to the fingerboard as usual (figure 2.3).

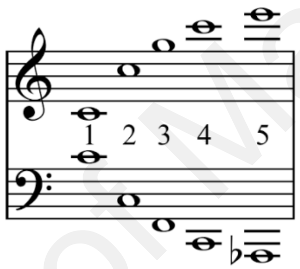

Figure 2.3. Overtone and undertone series

Kimura found that by drawing the bow in unusual ways on the violin it is possible to produce pitches below the fundamentals while she was practicing a Son filé[2]exercise on G string (Reel, 2009). While she was drawing the bow slowly with more pressure than usual, among the a crunch and scrape sound she suddenly heard a G note an octave below which the violin is not supposed to be able to produce without changing the tuning.

According to Erwin Schoonderwaldt a pitch can be influenced significantly by combination of the bowing parameters. Bow pressure, bow-bridge distance (bow placement) and bow velocity are the three main parameters to obtain a low-pitched tone(Schoonderwaldt, 2009b). So by a careful control of the bow and altering the bow pressure and speed considering the accurate bow-bridge distance (bow placement) on the

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[2] Son filé involves the gradual issuance of a note from a very low noise level to a Nuance strong then a gradual return to the silence (crescendo and decrescendo).

string a subharmonic can be obtained moreover there are some other floating parameters to produce subharmonics such as the amount of rosin, the age, material and width of the string and also twisting the string counterclockwise (Kimura, 1999).

In Kimura's case, she was able to remove the transient noises and produce clear and steady "subharmonic" pitches down to an octave G at 98Hz and approximately all the chromatic intervals between by using different levels of bow pressure (Kimura, 1999). Afterward Kimura decided to master the technique and fix the sound in order to use it in her compositions[3].

Kimura is one of the first musicians to have explicitly articulated subharmonics as the desired sonic target of sound production in an article in String magazine 2001; however according to Allen Strange, subharmonics have been used before in the piece "Black Angels" written by George Crumb in 1971. Crumb has considered these pitches as pedal tones in his composition (Strange & Strange, 2003). James Reel also cited Paganini as a musician who has reached these pitches during his private practices but not in performance, although there is no use of this technique in his compositions (Reel, 2009).

Also there were other expert players and composers who developed the extended technique in other instrument like the double bass player, Stefano Scodanibbio, who was a student of Fernando Grillo for a short time. He had rapidly achieved a reputation as the "Buddha of the double bass". "The last major development of new, idiomatic flageolet techniques took place with Stefano Scodanibbio during the 1980s" (Thelin).The uniqueness of Scodanibbio's music lies in his use of harmonics from the nut to the bridge on the string.

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[3] Mari Kimura's compositions: ALT (three movements), 1992, Gemini, 1993, Six Caprices for Subharmonics, 1997, Subharmonic Partita, 2004.

2.8 Bow parameters

On of the important elementconsidered by Kimura is bow location or bow placement (bow distance from the bridge) which can affect the pitches. She found that it is possible to produce different subharmonic intervals with different bow location maintaining the same pressure and finger position. For a better outcome to produce subharmonic, the bow pressure must be constant throughout the bowing and the bow hair is better to be kept flat to apply the maximum pressure. As shown in the figure 2.4, the fundamental pitch (open G), is constant and the changing element is the bow location.

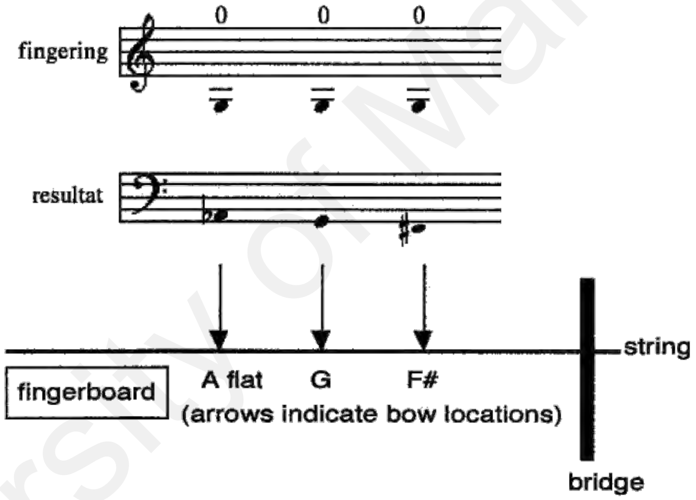

Figure 2.4. Subharmonic octave with a different bow location creating pitch shifting (major 7th, octave, minor9th)(Kimura, 1999).

Kimura also found it is possible to make different subharmonics with the same bow location and fingering position, while the bow pressure is different. The result in the figure 2.5 shows that with the same finger position (the note C on G string) and the same bow location, but different bow pressure, different subharmonic intervals such as octave, third, and fifth can be produced.

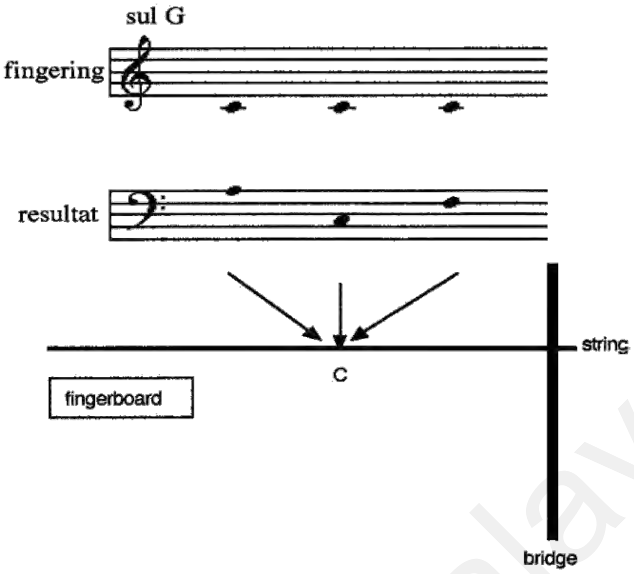

Figure 2.5. The bow location playing different subharmonics on the same note using different bow pressures (Kimura, 1999)

2.9 String

Kimura found that using older strings improves the ability to produce subharmonics. Additionally, she found that twisting a new string can simulate the effect of an old string. This occured when she discovered that twisting the string counterclockwise helps to produce suharmonics, since violinists, in general are loath to perform on old strings.(Kimura, 1999). Through this study I will show that string twisting is important by helping to find and play different subharmonic intervals on violin.

Kimura could produce subharmonics like third and fifth easier on new string by using this method since by twisting the string counterclockwise, the distance of the correct bow location from the bridge, and also the distances between the intervals are increased(Kimura, 1999). The comparison of the bow locations in producing subharmonics between new string and old string has been shown in the figure 2.6.

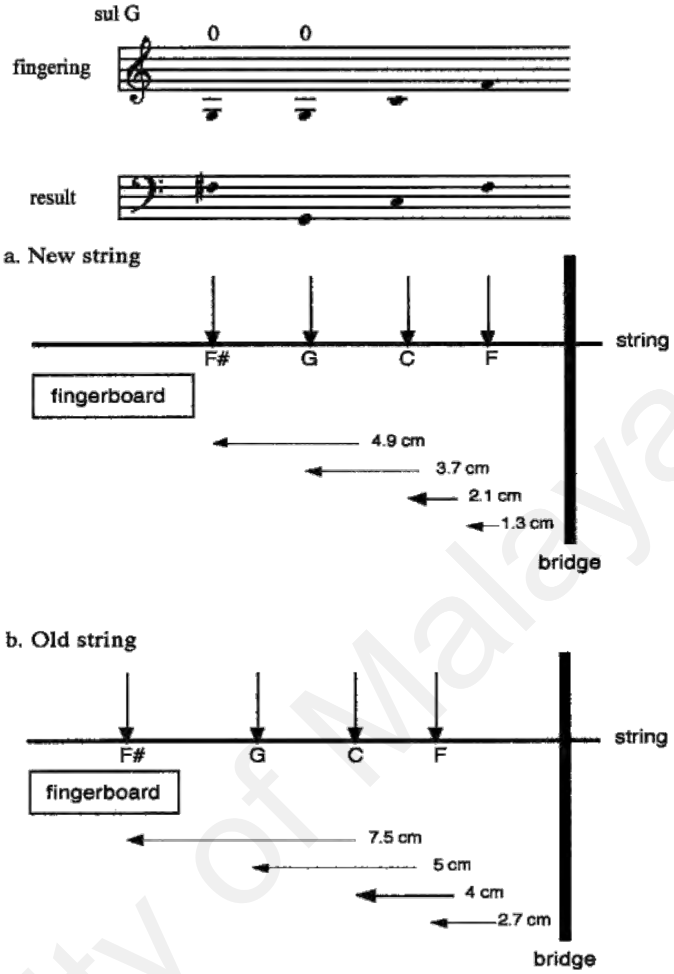

Figure 2.6. The bow locations of subharmonicoctave on new and old string (Kimura, 1999).

The result of the subharmonics produced by means of twisting string is shown in the figure 2.7. In comparison with the figure 2.6, it is observable that for producing the same subharmonics with one twist of string counterclockwise, the location of the bow and its distance from the bridge is changed and became closer to the bridge. Thickness and material of the string are also mentioned as important factors by Allen and Patricia Strange(Strange & Strange, 2003).

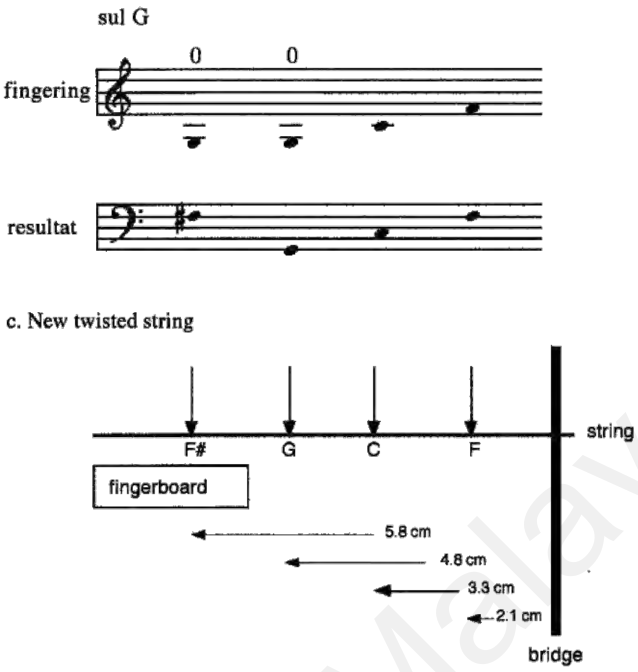

Figure 2.7. The bow location ofsubharmonic octave
using new twisted string.(Kimura, 1999).

2.10 Anomalous Low Frequency (ALF)

Prior to Kimura, a related phenomenon had been discovered. In 1989, Fredrick Halgedahl, a music professor considered some undertones on violin and then Roger Hanson a physicist tried to analyze them. They found that by forcing the bow more than normal value on the open G string it is possible to produce low-pitched tones below the fundamental frequency of the string (Benka, 2008). Later in 1991 Roger Hansson and Oliver Rodgers introduced this phenomenon as Anomalous Low Frequency (ALF) performed on a viola (Knut Guettler, 1997). They did not mention these frequencies as true subharmonics because the pitches are not always in the correct octave, however they appear to be related to the fundamentalvery closely by whole-number ratios (Strange & Strange, 2003).

2.11 Physics of string production

To know what happens when a subharmonic is produced on a bowed string instrument, it is needed to explain about the string vibration. Around 140 years ago a physicist Hermann von Helmholtz discovered that what we can see of a string vibration with the naked eye in the string instruments, is just an envelope, or outline, of the motion and in fact the string moves in a *"V"*-shape (not rounded) during the normal bowing and producing a normal acceptable sound.

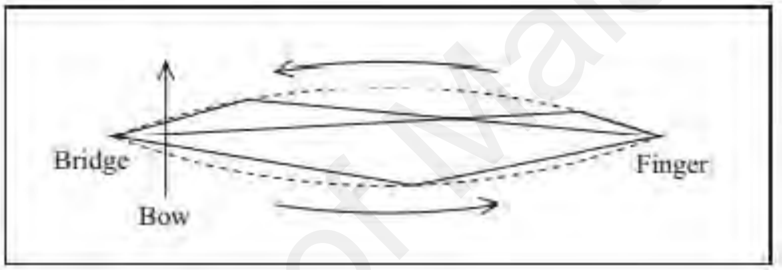

Figure 2.8. The Helmholtz motion.
The Helmholtz motion of a bowed string. The dashed line shows the envelope of the motion, and the solid lines show three different snapshots of the string position at different stages in the cycle. The "Helmholtz corner" circulates as indicated by the arrows (JAMES Woodhouse & PM Galluzzo, 2004).

The production of sound between string and bow involves this sticking and a slipping phase. For a desired normal bowing, this sequence results in one slip and one stick per cycle. The length of the slipping time is approximately equal to the placement of the bowing point, or the distance of the bow to bridge (M. E. Edgerton, Hashim, & Auhagen, 2014; Guettler[1], Schoonderwaldt, & Askenfelt, 2003; Jim Woodhouse & PM Galluzzo, 2004). This motion, which is the target for the huge majority of musical bow-strokes, is known as Helmholtz motion. The fundamental period of vibration is determined by the time it takes a corner to make a single round trip.

The vertex of the *"V"* which is named Helmholtz corner and is visible in figure 2.8, goes back and forth along the string and triggers a transition as it passes the bow.

"A transition between sticking and slipping friction is triggered as this corner passes the bow: the string sticks to the bow while the corner travels from bow to finger and back, and it slips along the bow hairs while the corner travels to the bridge and back" (JAMES Woodhouse & PM Galluzzo, 2004).

Schelleng found a strong relationship between bowing parameters during playing a normal pitched tone. Importantly, he found that as the bow-bridge distance increases, the minimum and maximum bow force decreased. On the other hand, he reported that the minimum and maximum bow force increases by increasing the bow velocity(Schelleng, 1973). Figure 2.8 shows the shape of Helmholtz corner, which determines the spectral outcome of the string and instrument. As Schelleng has explained, with light bow pressures the Helmholtz corner is considerably rounded so the outcome is like flautando playing, while with higher pressure it would be sharper so the outcome is the greater the brilliance sound.

To get the Helmholtz motion and produce an acceptable pitched tone, a player must control the bow force and press the bow hard enough within minimal and maximal values since the bow force lower than minimum causes multiple slipping (surface noises) and the force higher than a maximum produces a raucous, non-pitched tone as Schelleng considered (Schelleng, 1973; JAMES Woodhouse & PM Galluzzo, 2004).

To maintain the Helmholtz motion of one stick/slip per cycle, the proper bow placement for pressure and distance at a fixed bow velocity is shown in the following Schelleng diagram (figure 2.9) as shaded wedge area. As shown in figure 2.9, within normal bowing, when the distance of the bow placement from the bridge increases, the pressure must lessen and as the bow placement moves close to the bridge the pressure must increase.

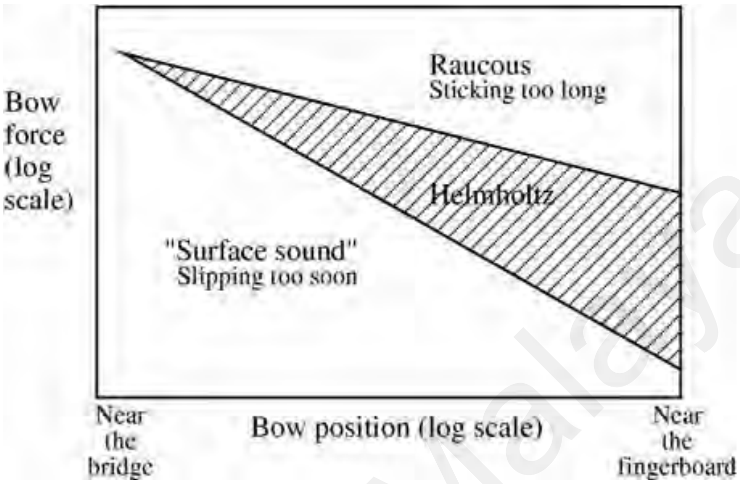

Figure 2.9. The Schelleng diagram

Due to the Schelleng diagram, by altering bow force higher or less than maximum and minimum value, the Helmholtz motion would degenerate. If the bow force is not high enough and is below minimum value, the friction would be too weak to hold the string during the sticking portion of the cycle, so that an inappropriate slip (usually including more than one slip per cycle) happens, and Helmholtz motion degenerates into a sound which string players sometimes describe it as surface sound. Also if the bow force exceeds the Schelleng maximum, the bow hair's stick on the string is too strong to be shaken loose by the corner so that the produced sound degenerates again and a raucous or crunchy non-periodic sound is heard (Rossing, 2010).

Friedlander and Keller discovered that with any slight change in bowing conditions, all periodic waveforms would be unstable so that the bow pressure above the Schelleng maximum value causes an aperiodic string motion and with a careful control on the bow, the Helmholtz motion would be broken down, thus these anomalous low frequencies (ALF) or subharmonics can be performed on a violin of clear pitch ranging almost a musical third to twelfth or even more below the normal pitch(Hanson et al., 1995). As the bow force is high enough to prevent the Helmholtz kink from triggering the normal release of the string from the bow hair, the anomalous low frequencies (ALF) happen(Hanson et al., 1995). “Subharmonics are caused by the delay of the slip at the first arrival of the Helmholtz corner, which is then reflected back towards the nut, and only finally released at the second or third return of the kink to the bow. The role of the increased force is to produce a friction force that is strong enough to maintain the sticking phase until the corner returns again” (M. E. Edgerton et al., 2014).

2.12 Rosin

Besides the bowing parameters, there are other elements, which play important roles for producing subharmonics such as amount of rosin that has been mentioned as a considerable issue in producing subharmonics. Rosin, also called colophony, is a solid form of resin obtained from pines and some other trees, mostly conifers, produced by heating fresh liquid resin to vaporize the unstable liquid terpene components (Keira et al., 1997). he effects of rosin attributes on the bowed-string sound are frequently considered. Rosin is used on the bow hair in order to make good sound while a bow without rosin makes little or even no sound. Increasing the amount of rosin help to produce louder sound however there is a limit of using rosin to make a good sound.

The Helmholtz corner would never be perfectly sharp and is always nearly rounded. However, each time the rounded corner travels toward the bridge under the bow, friction would sharpen it while the string makes a transient from the sticking phase to the slipping phase. The properties of the rosin have an important affect and determine how quickly this transition occurs (Knut Guettler, 2011). While bowing, the friction between bow hair and string causes high temperature. As the temperature goes high the rosin on the bow hair would be softened and melt so that the sticking between the bow hair and the string would happen.

The frictional properties of rosin cause stick-slip vibration easier to obtain, which bowed string players use on their bow hair to achieve a clean attack. As Guettler has mentioned the most important feature of rosin is its ability to produce clean attacks. “Clean attack means the shortest possible time interval before a regular periodic stick-slip pattern between the string and bow hair is established” (Knut Guettler, 2011). This is a kind of attack with the least strident noises at the beginning of the stroke, which though is not always essentially for the timbre of a sustained tone.

According to Woodhouse there are some factors that affect the rosin’s behavior such as temperature since its mechanical characters would change with even small raises of temperature (JAMES Woodhouse & PM Galluzzo, 2004). Kimura has considered the rosin amount effects as an important role in playing subharmonics but the measurements and accurate sum of using it have not been studied in current studies.

3 CHAPTER III: METHODOLOGY

3.1 Method

To have relevant data, secondary research from both scientific resources and musical research consisting library and online data is necessary, however experimental results are needed to make my results legitimate therefore empirical study and experimental replication are the main parts of this study. In this research quantitative methodology would have been used and the processes of the study have been recorded audio and video by means of a video-based analysis method and comparative data analysis. The existing analyses in this study are based on 400 recorded samples of three violin players. On average, the participants had 20 years of musical training and two of them are currently university violin lecturers.

3.2 Equipment

The violins used in this study included Italian maker JoannesVettori's work, made in 1984, a German Copy of Antonio Stradivari made in 1910 and a D'Clair brand (Australian manufacturer) model (M-300731), and the bows included one from Jean-Jaques Millant's workshop, Paris, and two Schroetter Violin Bows (AS-22-V), Germany.

The violin "D" and "G" strings were Pirastro – Evah Pirazzi brand, which have a core made of modern synthetic multifilament fibre and a silver winding. The violins were tuned to [a=440 Hz] using a chromatic Wittner AT700 tuner. The rosins used in this study were two W.E. Hill & Sons light rosin. The recording technology included a Sony FDR-AX1 digital 4K video camera recorder.

3.3 Procedure

Each of the three participants was asked to produce subharmonics on the "G" and "D" strings focused on systematic variations of three elements: bow location, the amount of used rosin on the bow hair and twisting the string. The results were recorded by the previously mentioned camera. The recordings were taken by Sony FDR-AX1 digital 4K video camera recorder at a distance of 2 meters in an acoustic room at University of Malaya in three different days. The camera has a Zoom Microphone (stereo) Sony 2ch 48kHz/16 bit.

For each parameter alteration, only one element was changed for any sound production event; all other parameters remained constant. In all sessions different fingerings have been used. For each part of this research four different fingerings on left hand have been considered.

3.4 Bow location

Bow location was identified as a function of bow-bridge distance based on a study by Kimura (Kimura, 1999). The bow location was measured by a ruler and marked with a white pencil every centimeter as a point from 2cm to 6cm, considering the distance from the bridge (figure 3.1). The posture of measuring has been shown in the following figure 3.1. In addition to bow placement, each of the four bow pressure levels was used, while all other elements were constant.

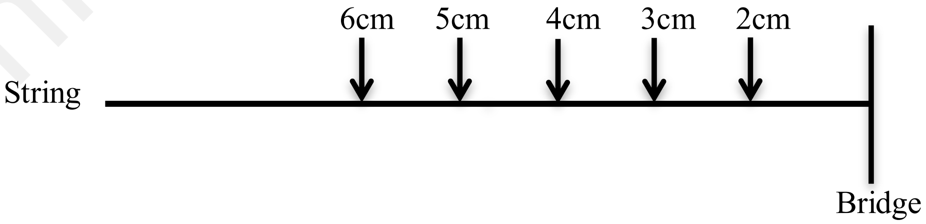

Figure 3.1. Bow placements from the bridge

During the first part, the participant were asked to try to produce subharmonics on both “G” and “D” string in terms of different bow placements considering different levels of pressure. Four different finger positions included open string, the first finger, the second and the third finger have been investigated in this part and also different bow speed has been observed.

3.5 Amount of rosin

The amount of bow rosin used was controlled at four different quantities: 0.25 gram, 0.5 gram, 0.75 gram and 1 gram. The two previously mentioned rosins were blended by a blender to become very soft powder. The amounts of powdered rosin have been measured by a laboratory digital balance.

The amount of rosin to be applied was spread on the middle third part of the bow hair equally by a brush. To obtain reliable and effective results, prior to testing and spreading the amounts on bow hair in each section, the participants were asked to wash the bow hair thoroughly with soapy water. In this phase all other elements remained constant. To get a better outcome and to compare the results of the different rosin quantities, in this session the bow location was considered at the distance of 5cm from the bridge and was not changed.

3.6 Twisting of the string

Twisting of the strings was examined by twisting each string in a counterclockwise motion. Each time, the participants were asked to take out the tail-pin end of the “G” and “D" strings and twist them counterclockwise at 1, 2, 3 and 4 twists. In this part the previous element (amount of rosin) is constant while the other two elements, bow location and, bow pressure are variable. The bow locations were in different distances (every centimeter as a point from 2cm to 6cm, considering the distance from the bridge) and the pressure was considered in 4 levels as mentioned above. Each number of the twist has been observed in different finger positions (open string, the first, second and third finger).

3.7 Bow pressure

Bow pressure was not identified in this study as a separate element, as it is difficult to measure and evaluate this element for accurate and exact measurement without an external monitoring and/or control system, such as a bowing machine which was not possible to find nor to build. However, this parameter was loosely controlled through the application of 4 pressure levels identified subjectively by each violinist: low pressure, medium, high, extremely high.

3.8 Data analysis

To analyze the recorded audio samples two music software were used. To recognize and measure the exact pitched harmonics and subharmonics, all the recorded audio samples of produced harmonic and subharmonic pitches were analyzed and distinguished in both Praat and TF 32 software.

4 CHAPTER IV: RESULTS

4.1 Results

The following results are the outcomes of producing subharmonics on the G and D strings by means of three elements: bow placement, twisting the string counterclockwise and amount of rosin.

4.1.1 Bow placement on G string

Table 4.1 shows the result of producing subharmonics on the "G" string in terms of different bow placements (every centimeter as a point from 2 cm to 6 cm, considering the distance from the bridge) and different finger positions (open string (G), the first (A), the second (B) and the third finger (C)). The fundamental frequency in this step is G 3 at 196 Hz and the subharmonic pitch range is between F# 2 at 93 Hz (minor ninth) to C# 3 at 139 Hz (diminished fifth).

Table 4.1. Subharmonic intervals on "G" (196Hz) string
in terms of different bow placements

Pitch / Bow Placement	**G 3** **(196Hz)**	**A 3** **(220Hz)**	**B♭3** **(233Hz)**	**B 3** **(247Hz)**	**C 4** **(261Hz)**
2 cm	**G 2** **(98Hz)**	**B♭2** **(116.5Hz)**	**B♭2** **(116.5Hz)**	**C 3** **(130Hz)**	**C# 3** **(139Hz)**
3 cm	**G 2** **(98Hz)**	**B♭2** **(116.5Hz)**	**B♭2** **(116.5Hz)**	**B 2** **(123.5Hz)**	**C 3** **(130Hz)**
4 cm	**A♭2** **(103Hz)**	**A 2** **(110Hz)**	**B♭2** **(116.5Hz)**	**C 3** **(130Hz)**	**C# 3** **(139Hz)**
5 cm	**F# 2** **(92.5Hz)**	**B♭2** **(116.5Hz)**	**B 2** **(123.5Hz)**	**C 3** **(130Hz)**	**C# 3** **(139Hz)**
6 cm	**G 2** **(98Hz)**	**A 2** **(110Hz)**	**B 2** **(123.5Hz)**	**B 2** **(123.5Hz)**	**-**

As shown in the table 4.1 by different bow placement and different finger positions, it is possible to produce different subharmonic intervals lower than fundamental frequency (G 3). On the open string G, these subharmonic intervals include the diminished fifth, perfect fifth, minor sixth, major sixth, minor seventh, major seventh, octave and minor ninth. The followings are the results of bowing on the open G string on the points of 2cm, 3cm, 4cm, 5cm and 6cm distance from the bridge. Bowing at the distance of 2cm and 3cm produces an octave (G 2); the distance of 4cm can produce major seventh (A♭2); the distance of 5cm produces minor ninth (F# 2) and the distance of 6cm produces again one octave lower (G 2).

When the fundamental pitch is changed to A3, which is the first finger on G string, bowing at the distances of 2cm, 3cm and 5cm from the bridge produces the subharmonic interval of a major sixth (B♭2), while at the distances of 4cm and 6cm, produces the lower interval of minor seventh (A 2).

When the fundamental is B♭3, bowing at the distances of 2cm, 3cm and 4cm produces the interval of a major sixth (B♭2), while bowing at the distances of 5cm and 6cm produces minor sixth (B 2). Bowing at the distances of 2cm, 4cm and 5cm while putting the third finger (B) on G string can produce C3 which is the perfect fifth lower than G3 and at the distances of 3cm and 6cm produces minor sixth (B 2).

4.1.2 Twisted string on G string

One of the other elements mentioned in this study to produce subharmonics is twisting the string counterclockwise. Table 4.2 shows the results of producing subharmonics on the “G” string utilizing different torsional values (twisting the string) accompanied by different finger position (open string, the first and second finger), while the bow distance from the bridge is kept constant at 5 cm.

Table 4.2. Subharmonic intervals on “G” string
in terms of number of twisted string

Fundamental Pitch Num. of Twist	**G 3** **(196Hz)**	**A 3** **(220Hz)**	**B 3** **(247Hz)**	**B♭3** **(233Hz)**
1	**F 2** **(87.5Hz)**	**B♭2** **(116.5Hz)**	**B 2** **(123.5Hz)**	**C 3** **(130Hz)**
2	**G 2** **(98Hz)**	**B♭2** **(116.5Hz)**	**B 2** **(123.5Hz)**	**C# 3** **(139Hz)**
3	**A♭2** **(103Hz)**	**B♭2** **(116.5Hz)**	**C 3** **(130Hz)**	**C# 3** **(139Hz)**
4	**A♭2** **(103Hz)**	**B♭2** **(116.5Hz)**	**B 2** **(123.5Hz)**	**C# 3** **(139Hz)**

The table 4.2 shows that by different number of twist, different subharmonic intervals are produced. As the “G” string is twisted one turn, the produced subharmonic intervals include the perfect fifth (C 3), minor sixth (B 2), major sixth (B♭) and major ninth (F 2). By twisting the string two times the diminished fifth (C# 3) and octave (G 2) could be produced. It is also possible to produce the major seventh (A♭2) when the string is twisted 3 times.

4.1.3 Bow placement on “D” string

The other string, which was studied, is the “D” string. Table 4.3 shows the result of producing subharmonic on the “D” string when changing the parameters bow placement (every centimeter as a point from 2 cm to 6 cm, considering the distance from the bridge) and finger position (open string (D), the first (E), second (F, F#) and third finger (G)). The fundamental frequency in this step is D 4 at 294 Hz and the available subharmonics range is between C# 3 at 139 Hz (minor ninth) to G# 3 at 139 Hz (diminished fifth).

Table 4.3. Subharmonic intervals on “D” (294 Hz) string
in terms of bow placement and finger position

Pitch Bow Placement	**D4** **(293Hz)**	**E4** **(329Hz)**	**F4** **(349Hz)**	**F#4** **(370Hz)**	**G4** **(392Hz)**
2 cm	**-**	**-**	**F# 3** **(185Hz)**	**F# 3** **(185Hz)**	**F 3** **(174.5Hz)**
3 cm	**D 3** **(147Hz)**	**F 3** **(174.5Hz)**	**E 3** **(164.5Hz)**	**F 3** **(174.5Hz)**	**G 3** **(196Hz)**
4 cm	**C# 3** **(139Hz)**	**F 3** **(174.5Hz)**	**F 3** **(174.5Hz)**	**F# 3** **(185Hz)**	**G 3** **(196Hz)**
5 cm	**D 3** **(147Hz)**	**F 3** **(174.5Hz)**	**F# 3** **(185Hz)**	**G 3** **(196Hz)**	**G# 3** **(207.5Hz)**
6 cm	**E♭3** **(155.5Hz)**	**F# 3** **(185Hz)**	**G 3** **(196Hz)**	**F# 3** **(185Hz)**	**E♭3** **(155.5Hz)**

As shown in the table 4.3 like “G” string, by different bow placement and different finger positions on “D” string, it is possible to produce different subharmonic intervals lower than fundamental frequency which is (D 4) such as diminished fifth (G# 3), perfect fifth (G 3), minor sixth (F# 3), major sixth (F 3), minor seventh (E 3), major seventh (E♭3), octave (D 3) and minor ninth (C# 3).

4.1.4 Twisted string on “D” string

Table 4.4 shows the available subharmonics on the “D” string when changing the amount of counterclockwise string twist and different finger position (open string, the first and second finger), while the bow distance from the bridge is kept constant at 5 cm during the step.

Table 4.4. Subharmonic intervals on “D” string
in terms of number of twisted string

Fundamental Pitch / Num. of Twist	**D 4** **(293Hz)**	**E 4** **(329Hz)**	**F 4** **(349Hz)**	**F# 4** **(370Hz)**
1	**D 3** **(147Hz)**	**E 3** **(164.5Hz)**	**E 3** **(164.5Hz)**	**G 3** **(196Hz)**
2	**E 3** **(164.5Hz)**	**E 3** **(164.5Hz)**	**E 3** **(164.5Hz)**	**G# 3** **(207.5Hz)**
3	**E♭ 3** **(155.5Hz)**	**D 3** **(147Hz)**	**F 3** **(174.5Hz)**	**G 3** **(196Hz)**
4	**E♭ 3** **(155.5Hz)**	**D 3** **(147Hz)**	**E 3** **(164.5Hz)**	**G 3** **(196Hz)**

As shown in the table and mentioned before, by different number of twist, different subharmonic intervals are produced. As the “D” string is twisted one turn and then, by bowing at the point of 5cm from the bridge on open D, the produced subharmonic interval is an octave lower (D3). As was shown earlier, bowing on a stopped string produces different subharmonics than when bowing on an open string. When bowing at a point 5cm from the bridge on the twisted D string, bowing the fundamental pitches E4 and F4 produced subharmonic intervals of a minor seventh (E 3) lower and as the fundamental pitch is F#, the produced subharmonic is a perfect fifth (G 3) lower. By twisting the string two times and bowing at the point of 5cm from the bridge, the diminished fifth (G# 3) is also possible to produce while the fundamental pitch is F#. It is possible to produce a major seventh (E♭ 3) lower as twisting the string three and four times and the fundamental pitch is open D. Bowing on the three times twisted string while the fundamental pitch is F, produces a major sixth (F 3) lower.

The following table 4.5 shows the result of producing subharmonics on “D” string using different bow placements (every centimeter as a point from 2 cm to 6 cm, considering the distance from the bridge) and different finger position (open string, the first, second and third finger) while the string is twisted counterclockwise. This table shows the difference between the subharmonics produced with no twisted “D” string and a twisted “D” string. The differences between the results show the influence of twisting the string counterclockwise in order to produce subharmonic. With different number of twists, different resultants are obtained.

Table 4.5. Subharmonic intervals on one turn twisted “D” string in terms of bow placement and finger position (one twist)

Pitch Bow Placement	**D4** **(293Hz)**	**E4** **(329Hz)**	**F4** **(349Hz)**	**F#4** **(370Hz)**	**G4** **(392Hz)**
2 cm	**-**	**D 3** **(147Hz)**	**F 3** **(174.5Hz)**	**F# 3** **(185Hz)**	**F 3** **(174.5Hz)**
3 cm	**C 3** **(130Hz)**	**F 3** **(174.5Hz)**	**E 3** **(164.5Hz)**	**E 3** **(164.5Hz)**	**F# 3** **(185Hz)**
4 cm	**E♭3** **(155.5Hz)**	**D 3** **(147Hz)**	**E 3** **(164.5Hz)**	**F 3** **(174.5Hz)**	**F# 3** **(185Hz)**
5 cm	**C 3** **(130Hz)**	**D 3** **(147Hz)**	**E 3** **(164.5Hz)**	**F# 3** **(185Hz)**	**G 3** **(196Hz)**
6 cm	**C 3** **(130Hz)**	**E 3** **(164.5Hz)**	**F 3** **(174.5Hz)**	**G 3** **(196Hz)**	**-**

As shown in table 4.5, different subharmonic intervals such as fifth, minor sixth, major sixth, minor seventh, major seventh and octave have been produced in this session.

4.1.5 Amount of rosin

The third element, which has been observed in this study, is the amount of rosin on the bow hair and its presumed effect on producing subharmonics. The amount of bow rosin used in this study was controlled at four different quantities: 0.25 gram, 0.5 gram, 0.75 gram and 1 gram. These different dosages were spread on the third middle part of the bow hair and caused three different kinds of sound such as surface noises, subharmonics and raucous noises. Table 4.6 shows the result of using different amount of rosin on the bow hair in order to produced subharmonics.

Table 4.6. The result of using different amount of rosin

Amount of Rosin **Produced Sound**	**0.25 gram**	**0.50 gram**	**0.75 gram**	**1 gram**
Surface noise	✓	-	-	-
Subharmonic pitch	-	✓	✓	-
Raucous noise	-	-	✓	✓

The amount of 0.25 gram did not work at all and just caused surface noises since with this amount of rosin the friction level between the bow hair and the string was very low. As the amount of rosin raised to 0.5 gram, producing subharmonics became easier and the friction level was proper. By using the amount of 0.75, besides producing subharmonic tones, some extra noisy raucous sound has been produced that was heard stronger that the subharmonic pitch. These raucous sounds reached at the highest level while using the amount of 1 gram because of the high level of friction between the bow hair and the string. When using the amount of 1-gram rosin, it was difficult to produce and hear clear subharmonics.

4.1.6 Bow pressure

An informal experiment to measure bow pressure was conducted. We found that bow pressure could be considered to use 4 relative levels including: low pressure (~190 gram), medium pressure (~380 gram), high pressure (~560), and extremely high pressure (~ 980 gram).

As mentioned above an informal experiment was used to measure the bow pressure. The pressure was measured with a plastic rod and a laboratory scale, however, since we were not able to acquire nor build a bowing machine, we consider our results to be approximate, since human variability could not be avoided. The laboratory balance was held by the left hand as a pressure pad and the plastic rod was held by the right hand as the bow. By pressing the top of the rod on the scale, different levels of the pressure were measured.

5 CHAPTER V: DISCUSSION

5.1 Discussion

To produce subharmonics on the violin there are different elements such as bow placement, bow pressure, bow velocity, age of the strings, twisting the string and amount of rosin. As explained before, the main elements in this study are bow placement, twisting the string and amount of rosin. Different bow placements, different number of string twists and different dosages of rosin on G and D string have been examined in this study.

Bow placement has been mentioned in all studies as an important factor to produce subharmonic, while different bow placement causes different subharmonic. The comparison between the result of Mari Kimura's study and this study show the value and effect of other bow parameters such as bow pressure and bow speed.

5.2 Bow placement

Figure 5.1 shows the result of producing subharmonics on open "G" string considering different bow placements by Mari Kimura and figure 5.2 shows the results of producing subharmonics considering different bow placements on open "G" string by the participants of this study.

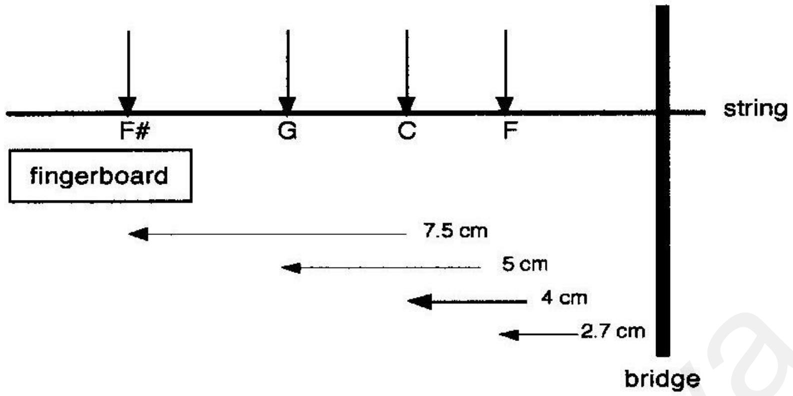

Figure 5.1. Subharmonics on open G in terms of bow placement (Kimura)

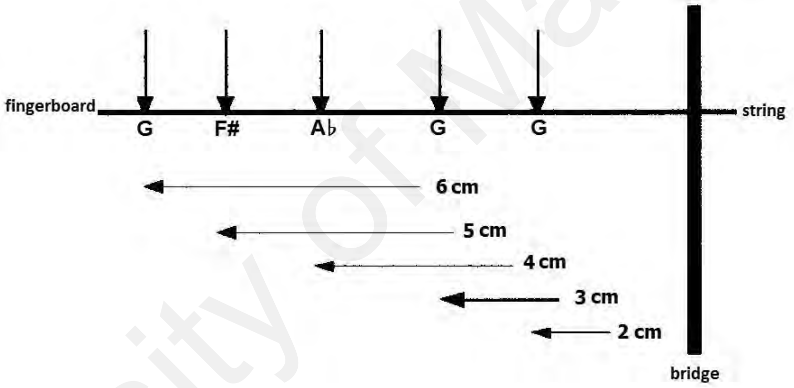

Figure 5.2. Subharmonics on open G in terms of bow placement (Kiumarsi)

As shown in figure 5.2 when bowing at the point of 2cm and 3cm from the bridge, an octave lower (G2) can be produced. While the bow placement from the bridge is 4cm the produced subharmonic is a major seventh lower (A♭2). Bowing at the distance of 5cm from the bridge can produce a minor ninth lower (F#2). When the bow location is 6cm from the bridge also an octave lower (G2) can be heard. This figure shows that besides the bow placement there are other effective elements to produce subharmonics since, for example, a subharmonic an octave lower can be produced with different placement.

By observing the figures 5.1 and 5.2, it can be obviously seen that the subharmonics produced at the distances of 4cm and 5cm from the bridge are different. In the figure 5.1 the subharmonic produced at the distance of 4cm is C 3 (a fifth lower than fundamental frequency) while in the figure 5.2 and with the same distance the produced subharmonic is A♭ (a major seventh below the fundamental frequency). Also the subharmonic produced at the distance of 5cm from the bridge in figure 5.1 is G 2 (an octave lower than fundamental frequency) since the produced subharmonic in the same distance in figure 5.2 is F# 2 (a minor ninth lower than fundamental frequency).

5.3 Twisting the String Counterclockwise

Twisting the string counterclockwise as mentioned before is a good and reliable way to produce subharmonics on a new string. As the string is twisted one turn counterclockwise, it is like that the location of the bow and its distance from the bridge is changed and gets closer to the bridge. By twisting the string counterclockwise it is easier to produce lower subharmonic intervals. The outcomes of this study for the twisting the string part also has been compared with the Kimura's study. There are some similarities and differences between the results of Kimura's study and this study, since as mentioned before the pressure can be essentially effective. As a similar result we can state the subharmonic interval on open "G" while the string is twisted one. In the Kimura's study and this study some of the results are very close. As an example, in one part, the Kimura's result is minor ninth (F# 2) and this study's result in the same situation is major ninth (F 2).

These differences between the resultants of two different string show that some string parameters like the material or the thickness of the strings can influence the creation of subharmonics on violin. Another considerable issue is that the brand and material of the string are important; for instance while the brand Alice for the strings was not proper and the brand Pirastro – Evah Pirazzi was suitable.

5.4 Amount of Rosin

The effects of the amount of rosin used on the bow hair were considerable in this study. As the rosin has frictional properties, it contributes to the sticking portion and reduces the slip in stick-slip vibration (Knut Guettler, 2011). The amount of used rosin powder for the third middle part of the bow hair in this study included four different dosages such as: 0.25 gram, 0.50 gram, 0.75 gram and 1 gram.

By using the amount of 0.25 was not proper and did not work. Since this amount caused very low level of friction between the string and bow hair, the level of multiple slipping increased so the result was the surface noises which has been mentioned in table 5.6. As shown in table 4.6, the amount of 0.50 gram helped to produce subharmonic easier since the friction level increased. As the amount of rosin has been increased to 0.75 gram, the friction level between the string and the bow hair became higher and the sticking phase became longer so besides the subharmonics, the extra raucous sounds were heard. These extra raucous sounds reached at the highest level as the amount of rosin has been raised to 1 gram that prevented the subharmonic pitches to be heard. To produce subharmonics the most eligible and suggested amount of rosin is 0.50 gram for one-third part of the bow hair.

5.5 Bow Pressure

Additionally, other bowing parameters, not directly studied in this thesis are important in the production of subharmonics on the violin. One of the other elements, which caused these differences, is bow pressure that as a relative parameter is not the same in different players. As mentioned before an informal experiment was used for this part of study since a bowing machine needed to measure the accurate pressure.

To compare the resultants of producing subharmonics on “G” string and “D” string in the collected data of this study, also some differences can be seen. This difference shows that by changing the bow pressure it is possible to produce various subharmonics, while even the same level of bow pressure in different player is not similar. This comparison between the results of the participants of this study shows that each level of the pressure in each player is a little bit different while for example each player produced the same subharmonic with different level of pressure.

As an example with refer to the tables 4.1 and 4.3, it can be observed that the produced subharmonic interval on open G string at the bridge distance of 2cm is an octave lower, while the in the same situation on open D string no subharmonic is obtained. Another remarkable example can be the difference between the results at the distance of 4cm on open “G” and “D”. The produced subharmonic interval on open G is a major seventh lower while in the same situation on open D the result is a minor ninth lower. However there are some similarity between the results like the produced subharmonic intervals at the distance of 3cm (an octave) on both open “G” and “D”.

5.6 Bow Speed

The other element studied in this report was speed, which is a relative parameter. It has been observed that while all the elements are constant, by altering the bow speed it is possible to change the subharmonics. But since it is not feasible to measure the bow speed without any bowing machine, this parameter also is not considered as a main part of this study.

5.7 Partials and Sub-partials

Normally, any complex musical tone can be represented as the total number of pure tones of various frequencies and amplitudes. When striking a metallic lightshade and listening carefully, at least a couple of the different frequencies can be heard which make the full complex tone. “These different components, which together make up the sound produced by the flute, violin, or cymbal, are called partials and their individual frequencies are called partial frequencies.”(Randel, 2003). These partial tones are heard in addition to the whole length or fundamental tone and the relative weight (amplitude) of the partial tones causes the individual timbre of the note (Nelson, 2003). For many musical sounds, especially the sounds produced by a single source like the bowed violin, oboe, or voice, there is a specific relationship between the partial frequencies: they are nearly equal to an integer times the fundamental frequency. The partial frequencies are typically listed as a series of numbers and the fundamental pitch or the first partial is considered as f0.

In general, sustained tones involve specific weightings of frequency information (both harmonic and inharmonic) within a recognized temporal envelope for any dynamic level. Thus a percussively produced musical tone like those from the bell, piano, cymbal, marimba, pizzicato violin, and drum, would have partial frequencies that are not exactly harmonic. In some cases, certain registers will be nearly harmonic, while the extreme registers will not be. Also there are other tones like the tones of the cymbal, gong, and many drums, which have a rich set of partials with no simple harmonic ratios, and thus no well-defined pitch. “The harmonically related partials establish a well-defined pitch, while additional partials, which are not harmonically related to the pitch, contribute importantly to the tone quality of the instrument” (Randel, 2003). So all the harmonics can be said to be included within the term, partials, but the inverse is not similar, as some partials may involve either harmonic or non-harmonic ratios.

Since some of the anomalous low frequencies are not simply related to f0 and are not always in the correct octave, cannot be considered as true subharmonics although they seem to be so nearly related to the fundamental by whole-number ratios (Hanson et al., 1995). If subharmonics are considered as the inverse of harmonics, so we can consider these low frequencies as sub-partials, which refer to the inverse of partials.

6 CHAPTER V: CONCLUSIONS

In a conclusion, to produce undertones or subharmonics on the violin, the most important elements are bow parameters, which include bow location (bow-bridge distance), bow pressure and bow speed, although there are some other elements that influence producing subharmonics like the amount of rosin, age and material of the string and twisting the string counterclockwise. The focused elements in this study were bow location, amount of rosin and twisting the string counterclockwise, while the other bow parameters such as bow pressure and bow speed have been considered as relative elements.

Bow location or bow-bridge distance is a very important element in producing subharmonic, since with any little change in the bow location the produced subharmonic would be changed. When the bow location is close to the bridge, it is difficult to produce subharmonic and as it gets close to the fingerboard it become easier to produce subharmonics especially lower subharmonic pitches.

Also by altering the bow pressure while keeping the bow location constant it is possible to make different subharmonics. As the bow location is close to the bridge the bow pressure level has to be high or extremely high to make subharmonics and as in gets close to the fingerboard it is possible to produce subharmonics with lower level of pressure like moderate or even low. Bow pressure also can be changed in each player; hence some results of producing subharmonic in some parts of this study were slightly different. Different players in the same situation can obtain different outcomes. As an example, a subharmonic pitch has been produced by a player with high bow pressure while the same subharmonic pitch has been obtained with medium pressure by another player. As a conclusion the bow pressure has a direct relation to the player, it would be considered as a relative element unless it would be measured by a bowing machine.

String parameters like age, material and thickness are other effective elements to produce subharmonics. As the string is old (6 to 9 months old) it is easier to get subharmonics although there is a way to obtain subharmonics on new string as well. The material of the string is also effective on subharmonics while it was difficult to produce subharmonics on the Alice brand strings but much easier to play subharmonics when using the Pirastro – Evah Pirazzi brand. The thickness of the string also has effects on subharmonic while it is more convenient to play subharmonics on "G" string than "D" string.

Twisting the strings counterclockwise helps to get subharmonics on new strings much more easily. As the string is twisted in different number, while the other elements are constant, different subharmonics are obtained. Also by twisting the string counterclockwise it was possible to play subharmonic on "D" string at the distance of 2cm and 3cm from the bridge whereas it was not possible to play as the string was not twisted. This is because the distance of the bow from the bridge would be changed and increased as the string is twisted. In conclude as the string is twisted more it is easier to produce lower pitched subharmonics.

The amount of rosin, which plays an important role in producing subharmonic, was a focused part of the study. Among the four different dosages of used powdered rosin in this study, the amount of 0.50 gram for the third middle part of the bow hair has been found the most functional. The lower amount (0.25 gram) caused surface noises because of the low level of the friction and the higher amounts (0.75 and 1 gram) caused extra raucous sounds since the level of friction reached the highest level. To conclude, the amount of 0.50 gram was the most eligible amount, since the proper level of friction was created and clear subharmonic pitches have been produced by using this dosage. Different types of rosin and rosin tribology and its effect on subharmonics are suggested for the further studies.

As mentioned in this study, the bow pressure has an important effect on producing subharmonics. Since to measure the bow pressure precisely needs a bowing machine, it would be considered for the future study.

The bow speed also has a significant impression on producing subharmonics. As the bow speed was changed while all other elements were kept constant during the training, different subharmonics were heard. Like the bow pressure, the bow speed is also a relative element and is variable in different player and also is hard to measure, therefore it was not a part of this study but it is strongly suggested to be studied and examined since its effect on producing subharmonics is undeniable.

The different bows in terms of weight and wood types and different types of violins also can be effective and suggested for the further studies. Also a comparison between the results of more participants is suggested while it can be possible to find a specified and accurate way of combination of the effective parameters to produced subhrmonics is suggested.

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