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# Investigating the Variability of Voice Quality and Pain Levels as a Function of Multiple Clinical Parameters

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## Abstract

Pain is an internal construct with vocal manifestation that varies as a function of personal and clinical attributes. Understanding the vocal indicators of pain-levels is important in providing an objective analytic in clinical assessment and intervention. In this work, we focus on investigating the variability of voice quality as a function of multiple clinical parameters at different pain-levels, specifically for emergency room patients during triage. Their pain-induced pathological voice quality characteristics are naturally affected by an individual attributes such as age, gender and pain-sites. We conduct a detailed multivariate statistical analysis on a 181 unique patient's vocal quality using recordings of real triage sessions. Our analysis show several important insights, 1) voice quality only varies statistically with pain-levels when interacting effect from other clinical parameters is considered, 2) senior group shows a higher value of voicing probability and shimmer when experiencing severe pain, 3) patients with abdomen pain have a lower jitter and shimmer during severe pain that is different from patients experiencing musculoskeletal pathology, and 4) there could be a relationship between the variation in the voice quality and the neural pathway of pain as evident by interacting with the pain-site factor.
**Index Terms**: voice quality, pain site, age, gender, pain.

## 1. Introduction

Pain is a subjective internal sensation that provides a signaling to an individual to be self-aware of one's health conditions [1, 2], and it often influences our behaviors as it interacts with our cognitive appraisal process [3]. Being an important yet a complex internal construct, numerous clinical management strategies of pain have been established depending on a variety of patient's intrinsic characteristics, such as age and gender, and the identified underlying pathological cause [4]. For example, research shows that age plays an essential modifier for pain management during multiple drug treatments for sclerosis [5]; the outcomes of chronic pain treatment are often gender-dependent due to the differences in pain tolerant level [6]; research also shows that differential therapeutic strategies should be initiated based on the pain pathway and syndromes [7]. Aside from understanding pain with different clinical outcomes, research has also started to focus on measuring pain by modeling its associated expressive behaviors objectively.

In the current clinical practices, the assessment of pain relies heavily on patient self-disclosing his/her levels of pain verbally. While many research has already indicated that the facial muscle movements, i.e., action units, provide an indication of different pain levels [8, 9], several recent works have started to investigate the relationship between pain intensity and vocal cues. For example, Oshrat et al. analyzed the prosodic variation as a bio-signaling indicator of pain [10], Ren et al. recently proposed a database for evaluating pain from speech [11], Tsai et al. proposed several automated machine learning methods for recognizing self-reported pain-levels using speech and face multimodally in a real triage database [12, 13]. These studies tend to focus more on the prosodic and spectral properties of speech. Furthermore, except for a recent work done by Li et al. that integrated gender and age attributes as auxiliary information to improve the vocal-based pain-level recognition [14], little if any work has studied *exactly* how various clinical attributes interact with acoustic manifestation across different pain-levels.

In this study, we conduct a detailed statistical investigation with a goal to understand how different relevant clinical parameters interact with the voice quality variations at various pain-levels. Variation in an individual voice quality results from the physical muscular adjustments of the larynx and phonemic features indication, and perceptually, vocal quality has been used to quantify breathiness, hoarseness, roughness, whispery voice and modal voice. Studies have shown that voice quality reveals personal traits such as gender, age and attitude [15, 16, 17]. Further, voice quality has been extensively studied as measures to characterize pathological speech [18] for disorders such as Autism [19], Parkinsons disease [20], and other speech impairment [21]. It has recently also been shown to be indicative of pain in dementia patients [22].

Specifically, we conduct a multivariate statistical analysis on a 181 unique patient cohort within the Triage Pain-Level Multimodal Database [13]. We analyze the variations of different voice quality measures with the self-reported pain-levels as a function of the following list of clinical parameters:

- Age: Young Adult, Adult, Senior
- Gender: Male and Female
- Pain-Sites: Head, Chest, Abdomen, Limb, Back, Others

Our analysis reveal that: 1) voice quality varies statistically with pain-levels only when considering other clinical contributing factors, 2) senior aged group displays a more intense (higher) value of voicing probability and shimmer when experiencing severe pain, 3) patients with abdomen pain shows a lower jitter and shimmer when experiencing more severe pain, which is counter-intuitive and different from patients experiencing pains from neck and shoulder, and 4) there seems to be a complex relationship between the expressed voice quality and the nociceptive pain resulting from our analysis on the interacting factor of pain-sites with pain-levels.

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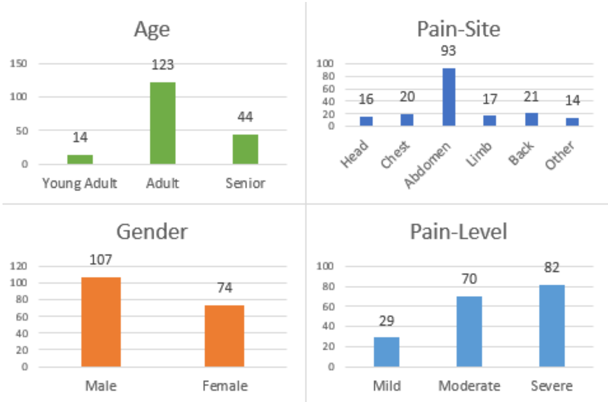


Figure 1: *A distributions of age, gender, pain-sites, and pain-levels used in this work*

# 2. Research Methodology

## 2.1. The Triage Pain Level Multimodal Database

In this study, we utilize the Triage Pain Level Database that was collected at the Department of Emergency of the ChangGung Memorial Hospital [13], which included audio-video recordings of on-boarding patients during triage sessions. A10-point self-reported (NRS) pain-levels [23] and a variety of clinical parameters including age, gender, vital sign, and pain-sites were also recorded as a part of the standard procedure during triage.

In this work, we only analyze a subset of the database that includes samples prior to the treatment. Specifically, we utilize a set of 181 unique patients. The age is grouped in three classes, i.e., Young Adult: 0-28 yrs, Adult: 28-65 yrs, and Senior: over 65 yrs. The pain-site is grouped into six categories: Head, Chest, Abdomen, Limb, Back and Others. Male and Female are the two gender groups. The pain-level is categorized into three commonly-used levels, which are mild: 0-3, moderate: 4-6 and severe: 7-10. Figure 1 shows a distribution of these parameters from the set of 181 patients used in this study.

## 2.2. Voice Quality Measures

We extract five low-level descriptors of voice quality measures [24], i.e., voicingFinalUnclipped, logHNR, Local jitter, jitterDDP and Local shimmer per utterance. Jitter and shimmer are two different variations, where the former measures the cycle-to-cycle variation of the fundamental frequency and the latter on the variation of the peak-to-peak amplitude. Local jitter/shimmer captures more specifically the average absolute difference between two consecutive periods, and jitterDDP computes the average absolute difference of difference between jitter cycles. VoicingFinalUnclipped represents the voicing probability of the final fundamental frequency candidate with no zero-clipping when falls below a voicing threshold, and HNR is the harmonic-to-noise ratio corresponding to the aperiodic noisy characteristics in the speech.

We further compute four different statistical properties on each of the five LLD measures over the speaking segments of a patient's voice. Since our methodology is based on multivariate analysis of variance (MANOVA), out of the 20 possible voice quality measures, only 7 of them are included in our study as they pass the normality test (Table 1).

Table 1: *Voice quality measures: seven parameters are used as the dependent variables in this study.*

| Voice Quality LLD | Functional |
|---|---|
| voicingFinalUnclipped | Mean, Max |
| logHNR | Max |
| jitterLocal | Standard Deviation |
| jitterDDP | Standard Deviation |
| shimmerLocal | Mean, Standard Deviation |

Table 2: *The multivariate tests results shown using Wilk's Lambda: significance level is denoted as:* $^{***}p < 0.001, ^{**}p < 0.01, ^{*}p < 0.05$.

| *Wilk's Lambda* ($\lambda$) | | | | |
|---|---|---|---|---|
| *Effect* | *Value* | *F* | *Sig.* | $\eta_p^2$ |
| Age | .762 | 2.309 | **.006**$^{**}$ | .127 |
| Gender | .688 | 7.202 | **.000**$^{***}$ | .312 |
| Pain-Site | .781 | .810 | .774 | .048 |
| Pain-Level | .935 | .544 | .905 | .033 |
| Age x Gender | .867 | 1.168 | .301 | .069 |
| Age x Pain-Site | .429 | 1.627 | **.002**$^{**}$ | .114 |
| Age x Pain-Level | .661 | 1.747 | **.012**$^{*}$ | .098 |
| Gender x Pain-Site | .643 | 1.483 | **.040**$^{*}$ | .084 |
| Gender x Pain-Level | .875 | 1.092 | .366 | .064 |
| Pain-Site x Pain-Level | .443 | 1.401 | **.021**$^{*}$ | .110 |
| Age x Gender x Pain-Site | .757 | 1.546 | .061 | .089 |
| Age x Gender x Pain-Level | .932 | .565 | .890 | .034 |
| Age x Pain-Site x Pain-Level | .825 | 1.057 | .395 | .062 |
| Gender x Pain-Site x Pain-Level | .649 | 1.030 | .421 | .060 |
| Age x Gender x Pain-Site x Pain-Level | .916 | .709 | .764 | .043 |

# 3. Analysis Results and Discussions

We first perform MANOVA using gender, age, pain-levels, and pain-sites as factors (clinical parameters) with multivariate dependent variables including all seven voice quality features (section 2.2) to analyze different independent variable's interaction effect on voice quality. Further, we perform a main effect analysis to examine the detailed relationship between each of the parameters to different measurements of voice quality. This main effect is analyzed using univariate test (assessing an overall effect) and and pair-wise comparison test (assessing vocal quality values changes as a function of each parameter). The analysis results are presented in this section.

## 3.1. Analysis of Main and Interaction Effect of Clinical Parameters on Voice Quality

The result of a general linear model with multivariate analysis using Wilk's Lambda test is shown in Table 2. The main effect occurs for age (*F(14,222)=2.309, p*=.006<.05, $\eta_p^2$=*.127*) and gender (*F(7,111)=7.202, p*=.000<.05, $\eta_p^2$=*.312*). While there is no main effect of pain-levels and pain-sites on voice quality directly, the interaction of age with pain-sites (*F(63,631.266)=1.627, p*=.002<.05), age with pain-levels (*F(28,401.638)=1.747, p*=.012<.05), gender with pain-sites (*F(35,469.365)=1.483, p*=.04<.05), and pain-sites with pain-levels (*F(70,654.052)=1.401, p*=.021<.05) all show statistically significant effect in explaining the total variances of the seven voice quality measures.

The partial $\eta_p^2$ shown on the right most column indicates the proportion of multivariate variance in the dependent variables that is explained by the parameter factors. The age factor alone

Table 3: *Statistical testing results between subjects effect*

| **Dep. Var.** | *voicingFU*[1] | *shimmerLo*[1] | *voicingFU*[2] | *logHNR*[2] | *jitterLo*[3] | *jitterDDP*[3] | *shimmerLo*[3] |
|---|---|---|---|---|---|---|---|
| **Effect** | p / $\eta_p^2$ | | | | | | |
| *Age* | .059 / .047 | **.031**$^{*}$ / .057 | **.005**$^{**}$ / .088 | **.000**$^{***}$ / .168 | .168 / .03 | .072 / .044 | **.003**$^{**}$ / .096 |
| *Gender* | **.016**$^{*}$ / .048 | .834 / 0 | **.000**$^{***}$ / .116 | .979 / 0 | **.004**$^{**}$ / .069 | **.000**$^{***}$ / .108 | **.024**$^{*}$ / .043 |
| *Pain-Site* | .906 / .013 | .885 / .014 | .996 / .003 | .771 / .021 | .673 / .026 | .649 / .028 | .256 / .054 |
| *Pain-Level* | .802 / .004 | .943 / .001 | .793 / .004 | .388 / .016 | .447 / .014 | .578 / .009 | .618 / .008 |
| *Age x Pain-Site* | .071 / .123 | **.019**$^{*}$ / .152 | .789 / .045 | .436 / .072 | .267 / .088 | .161 / .103 | **.011**$^{*}$ / .164 |
| *Age x Pain-Level* | **.016**$^{*}$ / .098 | **.019**$^{*}$ / .095 | .777 / .015 | .297 / .041 | .062 / .073 | .052 / .077 | .072 / .07 |
| *Gender x Pain-Site* | .566 / .032 | .257 / .054 | .528 / .034 | .179 / .062 | .105 / .074 | .055 / .087 | **.047**$^{*}$ / .09 |
| *Pain-Level x Pain-Site* | **.008**$^{**}$ / .178 | **.001**$^{**}$ / .226 | .212 / .104 | **.017**$^{*}$ / .164 | **.013**$^{*}$ / .169 | **.003**$^{**}$ / .195 | **.013**$^{*}$ / .17 |

voicingFU indicates voicingFinalUnclipped; shimmerLo/jitterLo indicates shimmerLocal/jitterLocal
[1]Mean of segments. [2]Maximum of segments. [3]Standard deviation of segments. $^{***}p < 0.001, ^{**}p < 0.01, ^{*}p < 0.05$

Table 4: *The univariate test and pairwise comparison test for analyzing the effect of age interacts with pain-levels have on two different voice quality measures (voicingFU[1],shimmerLo[1]).*

| | **Dep. Var.** | ***voicingFU*[1]** | | |
|---|---|---|---|---|
| | **PainLevel** | Mild | Moderate | Severe |
| Uni-Test | ***F*** | 2.241 | 2.725 | 6.335 |
| | ***Sig.*** | 0.111 | 0.07 | **0.002**** |
| | $\eta_p^2$ | 0.037 | 0.045 | 0.098 |
| Pair-C. | ***MeanDiff.*** | – | – | S >YA : .07<br>S >A : .053 |
| | ***Sig.*** | – | – | S >YA : .005<br>S >A : .002 |
| | **Dep. Var.** | ***shimmerLo*[1]** | | |
| Uni-Test | ***F*** | 2.572 | 3.759 | 3.092 |
| | ***Sig.*** | 0.081 | **0.026*** | **0.049*** |
| | $\eta_p^2$ | 0.042 | 0.06 | 0.05 |
| Pair-C. | ***MeanDiff.*** | – | S >YA : .077 | S >A : .038 |
| | ***Sig.*** | – | S >YA : .007 | S >A : .02 |

**Uni-Test** stands for Univariate Tests; **Pair-C.** stands for Pairwise Comparison;
**S** stands for Senior (>65yrs); **A** stands for Adult (28-65 yrs);
**YA** stands for Young-Adult (<28 yrs);

($\eta_p^2$=*.127*) shows a stronger effect on the seven voice quality features than when interacting with pain-sites ($\eta_p^2$=*.114*<.127) or with pain-levels ($\eta_p^2$=*.098*<.127). The same phenomenon occurs for gender factor as well. In other words, gender and age has the most direct effect on the variation of the voice quality as a whole. While pain-levels and pain-sites do not have the univariate main effect on the variation of the voice quality, when interacting with gender and age, we show that they indeed contribute significantly to the variances observed in the voice quality measures.

Since the MANOVA result is statistically significant, we then further examine the univariate ANOVA to examine which specific voice quality measure is being affected by each of the parameter group. The results are summarized in Table 3. While age has significant impact on the *shimmerLocal*[1,3], and gender affects significantly *shimmerLocal*[3]. These two results can not be directly interpreted due to their statistically significant interactions observed for age with pain-sites (*p=.019<.05)* and age with pain-levels (*p=.019<.05)*. The same applies in cases where we find significant interaction effect of gender with pain-sites for *shimmerLocal*[3] (*p=.047<.05)*.

Hence, from Table 3, we conclude that main effect for age is significant in response to *voicingFinalUnclipped*[2] and *logHNR*[2]. Specifically, we observe that senior ($>65yrs$) age group has a higher value than adult ($28-65yrs$), and adult group also displays a significantly higher value than young adult ($<28yrs$) (*voicingFinalUnclipped*[2]*: Young Adult(mean = .050) <Adult(mean = .057) <Senior(mean = .061); logHNR*[2]*:Young Adult(mean = .053) <Adult(mean = .056) <Senior(mean = .059)*). In short, we observe an intuitive finding that senior group has a nosier voice with breathiness when experiencing higher level of pain.

Furthermore, the gender's main effect (*F(7,111)=7.202, p=.000<.05,* $\eta_p^2$*=.312*) is significant for *voicingFinalUnclipped*[1,2], *jitterLocal*[3] and *jitterDDP*[3]. We observe that male has significantly higher values in these measures than female (*jitterLocal*[3]*:Male(mean=.057) >Female(mean=.048); jitterDDP*[3]*:Male(mean=.058) >Female(mean=.046)*), which is consistent with the previous study that demonstrates a higher jitter for male than for female [25].

Another interesting observation aside from showing gender and age that is both well-known in affecting an individual's voice quality. We observe out of the seven voice quality measures, except for the maximum of *voicingFinalUnclipped*, all show statistically significant effect when pain-level interacts with pain-sites ($p = .008, p = .001, p = .017, p = .013, p = .003, p = .013$). In fact, when comparing to age interacts with pain-levels, pain-site interacts with pain-levels demonstrates an even stronger effect size on *voicingFinalUnclipped*[1] ($\eta_p^2 = .178$ >.098) and *shimmerLocal*[1] ($\eta_p^2 = .226$ >.095). Locations of pain often correspond to the underlying disease; it is interesting to observe that an individual's voice quality can be more affected by these clinical conditions than the general demographics variables, which is yet another evidence in showing the usefulness of voice quality in measuring pathological state.

### 3.2. Analysis of Voice Quality Variation for Different Pain-levels under Age and Pain-sites Interaction

Since significant variance of voice quality is contributed from the interaction of age with pain-levels and also pain-sites with pain-levels, we further focus on these interaction factors for the subsequent analysis. There are two results being shown for each group of the interaction (pain-levels with age, pain-levels

[1]mean of segments

[2]maximum of segments

[3]standard deviation of segments

Table 5: *The univariate test and pairwise comparison test for analyzing the effect of pain-site interacts with pain-level have on six different voice quality measures (voicingFU[1],shimmerLo[1], logHNR[2],jitterLocal[3],jitterDDP[3],shimmerLo[3])*

| | | Univariate Tests | | | Pairwise Comparison | |
|---|---|---|---|---|---|---|
| Dep. Var. | ***PainSite*** | ***F*** | ***Sig.*** | $\eta_p^2$ | ***Mean Difference*** | ***Sig.*** |
| **voicingFu**[1] | Other | 3.993 | **0.021*** | 0.064 | .114 (L<M) | 0.039 |
| | | | | | .145 (L<H) | 0.006 |
| **shimmerLo**[1] | Other | 5.328 | **0.006**** | 0.083 | .119 (L<M) | 0.026 |
| | | | | | .160 (L<H) | 0.002 |
| **logHNR**[2] | Other | 6.046 | **0.003**** | 0.094 | .010 (L<M) | 0.004 |
| | | | | | .011 (L<H) | 0.001 |
| **jitterLocal**[3] | Other | 3.723 | **0.027*** | 0.06 | .038 (L<H) | 0.008 |
| **jitterDDP**[3] | Abdomen | 3.174 | **0.045*** | 0.051 | **.014 (L>M)** | 0.016 |
| | | | | | **.013 (L>H)** | 0.043 |
| **shimmerLo**[3] | Abdomen | 5.03 | **0.008**** | 0.079 | **.008 (L>H)** | 0.002 |
| | | | | | **.004 (M>H)** | 0.037 |
| | Other | 4.723 | **0.011*** | 0.075 | .021 (L<M) | 0.003 |
| | | | | | .018 (L<H) | 0.007 |

voicingFU indicates voicingFinalUnclipped; shimmerLo/jitterLo indicates shimmerLocal/jitterLocal
**L** stands for Mild Pain-Level; **M** stands for Moderate Pain-Level; **H** stands for Severe Pain-Level;
$^{***}p < 0.001, ^{**}p < 0.01, ^{*}p < 0.05$

with pain-sites). The first one is the **Univariate Analysis** table, which decomposes the interacting factors to demonstrate where the differences occurs, and the **Pairwise Comparison** table, which shows the direction of the differences.

*3.2.1. Voice Quality Dependent on Pain-levels with Age*

Table 4 shows the analysis results of two voice quality measures variation as a function of three different pain-level interacts with three different age groups. Specifically, it reveals that patients under severe pain would show a reduction in the mean of *voicingFinalUnclipped* and the mean of *shimmerLocal* when compared between senior to adult (*voicingFinalUnclipped*[1] *in severe pain: mean difference = .07 (Senior>Young adult); .053 (Senior>Adult); shimmerLocal*[1] *in severe pain: mean difference = .038 (Senior>Adult)*). Under the severe pain, the elderly usually present more noise and breathing voice, which is also consistent with a previous study [16]. In summary, the voice quality especially in voicing probability and variation of period amplitude, lesser noisy sounding variation is observed significantly in younger age patients under the severe pain scenario only but not for mild nor moderate pain experiences.

*3.2.2. Voice Quality Dependent on Pain-levels with Pain-sites*

Table 5 shows the analysis results of six voice quality measurement variations as a function of three different pain-levels interacts with six different pain-sites. There are a total of six categories of pain-sites used in this work, i.e., head, chest, abdomen, limb, back, and other. Patients reporting on their right/left lower quadrant, neck and shoulder are grouped as the 'other' pain-site; this type of pain is often categorized clinically as somatic pain or regional pain that may be caused by the musculoskeletal pathology [26]. Abodomen pain, in contrast, is more likely be induced from the visceral organ [27].

Our analysis result reveals a significant effect for the four voice quality measures (*voicingFinalUnclipped*[1], *shimmerLocal*[1], *logHNR*[2], *jitterLocal*[3]) only under the other pain-site condition ($p = .021$, $p = .006$, $p = .003$, $p = .027$). *jitterDDP*[3] only shows significant difference under abdomen pain ($p = .045$). Under both abdomen pain and other pain-site, a significant mean differences of *shimmerLocal*[3] is also found between each level of pain (abdomen pain: $p = .0008$, other pain: $p = .011$), where the effect of abdomen pain is a little bit stronger than other pain-site ($\eta_p^2$=*.079* $>\eta_p^2$=*.075*). In addition, all listed pairwise comparison results are statistically significant. It shows that patients reporting higher level of pain will display significantly larger mean values on voice quality measurement especially under other pain-site condition (*mean-difference (mild pain <severe pain) = .145 (*$p = .006 < .05$*), .160 (*$p = .002 < .05$*), .011 (*$p = .001 < .05$*), .038 (*$p = .008 < .05$*)*) This results shows a general pattern that when patients suffer from the 'other' pain-site would result in having higher values of jitter and shimmer that are positively correlated with the severity of the pain experienced.

Surprisingly, we observe that there is a reduction of *jitterDDP*[3] and *shimmerLocal*[3] from mild to severe pain (*mean-difference (mild pain >severe pain) = .013 (*$p = .043 < .05$*), .008 (*$p = .002 < .05$*)*) for patients reporting abdomen pain. This results shows a reverse effect when comparing to patients reporting other as pain-site. In other words, when patients suffer from visceral organ pathology may have a variation on fundamental frequency and energy for phonation that are both negatively correlated to the pain intensity. This result is quite intriguing as it implies the types of pain that a patient experiences, which is caused by different pathology and likely transmitted via different neural pathways, may affect the expressive aspect of an individual patient's voice quality completely differently.

## 4. Conclusions and Future Works

In this work, we present a detailed investigation of voice quality and pain-levels as a function of clinical parameters, i.e., age, gender, and pain-sites. Main effect of age and gender are observed, where male shows a higher value of jitter. The age parameter highlights the difference in shimmer between senior and adult group only under severe level of pain, and pain-site parameter surprisingly demonstrates that patients suffering from more severe abdomen pain has a decreased value in voice quality measurements, which is a finding that is in reverse for patients suffering from musculoskeletal pathology or somatic pain. To the best of our knowledge, this is one of the first works that have systematically analyzing pain using a key voice-based indicator that jointly considers multiple clinical factors. We will continue to integrate other potential contributing factors to understand the mechanism of pain-induced changes in vocal cues and inspire new algorithmic approaches in better recognizing the pain-levels automatically.

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