FORENSIC MUSICOLOGY- AN OVERVIEW

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The current evolution of the music industry into digital means of recording and dissemination has increased the necessary skill set required of experts by legal professionals. Expert testimony for forensic musicology supports a broad spectrum of legal issues, including the authentication and differentiation of published compositions and musical recordings, performance rights, and legal determinations regarding copyright infringement. While legal cases involving music and performance infringement date back as far as the 19th century, the field of forensic musicology has no stated methodology by which an objective forensic determination can be made. Expert opinions based merely on subjective impression or from "golden ear" analysis are pseudo-scientific and not objectively based. This paper proposes scientific methods and recommendations for analysis based on stated criteria, with the goal of controlling examiner bias. Considerations include analyses of composition, performance, and acoustical features, and factors such as melody, harmony, rhythm, and orchestration; pitch, tone, vibrato, and embellishment; metadata analysis; recording technologies; and digital signal processing, including "effects." By engaging in a series of structured categorizations, the forensic expert can establish a consistent, replicable, and objectively verifiable means of determining whether or not a recorded piece of music has been misappropriated.

INTRODUCTION

Forensic musicology refers to the application of musicological analysis and scholarship to a legal matter. A wide range of cases in the United States have appeared involving questions of copyright, plagiarism, misappropriation, and other forms of infringement since at least the 19th century; an excellent resource available on the worldwide web is provided by the University of Southern California's Gould School of Law "Music Copyright Infringement Resource" [1]. Two essential questions of interest to the legal community are (1) the degree to which expert testimony in forensic musicology can actually be deemed scientific, in the spirit of recent attention to the National Research Council (NRC) publication *Strengthening the Forensic Sciences* [2], and (2) what means of evaluation are there for the work of an expert by a legal professional who is not an expert in music. Attorneys must inherently trust the intellectual framework and specialized knowledge of the expert brought to bear on the matter. Yet, even amongst experts in forensic musicology, there are few standards, papers or methodologies available in comparison to other forensic science disciplines.

Complicating matters, the range of expertise demanded of the forensic musicological expert has expanded due to the complexities of recorded music and its distribution as digital media. An expert may be called upon to opine regarding not only traditional musicological areas such as melody, harmony, and rhythm, but also recording techniques, signal processing, digital musical instruments, and computer forensics, to expose an act of piracy or infringement. For this reason, the expertise required for a particular musicological forensic examination may be multi-faceted and complex.

The purpose of the present paper is to offer an overview of the field of forensic musicology and to propose analysis criteria, based on a series of structured categorizations. Application of these criteria may enable both experts and the interested legal community to determine if a particular forensic musicology expert has used a consistent, replicable, and objectively verifiable approach.

1 CAN FORENSIC MUSICOLOGY BE CONSIDERED SCIENTIFIC?

The word science appears in definitions of both forensics and musicology, but there are distinctions from other so-called hard sciences. The term forensic is often defined as the application of scientific methods and techniques to evidence used in a legal matter, and musicology is often similarly defined as the application of scientific methods and techniques to the investigation of music. The scientific method includes the formation

and testing of hypotheses via experiments that usually include a replicable methodology for measurement. For instance, psychoacoustic measurements of loudness that are reported in peer-reviewed literature usually involve replicable stimuli, apparatus, instrumentation, control of bias, and statistical treatment. However, unlike so-called hard sciences, musicological analysis can pursue levels of detail that are sometimes difficult to objectively analyze regarding a ground truth.

For example, two musicologists may agree regarding the notation or harmonic analysis of a specific musical work; but may arrive at different conclusions in analyzing its nascent, underlying structure, the historical influences for that music, or even the degree of similarity between two melodic phrases. Their work then becomes an argumentative discourse regarding the optimal means of analysis and interpretation.

In fact, the problem for forensic musicology is common to many types of the "identification" forensic sciences, where an opinion is given by an expert on an interpretation of the magnitude of similarity (match) between two evidence exemplars. Unlike a normal scientific study, where experimental replication can be applied, the materials and context for each forensic case analyzed by an expert are typically unique, and the analytical methods used by two experts to approach the same material can differ. With regards to uncertainties and bias, the NRC publication states:

> Few forensic science methods have developed adequate measures of the accuracy of inferences made by forensic scientists. All results for every forensic science method should indicate the uncertainty of the measurements made…with that information, one could … begin to develop an understanding of how much similarity is needed to attain a given level of confidence that a match exists [2].

Notwithstanding the NRC's recommendation for additional peer-reviewed research, many issues addressed by the forensic musicologist lack a ground truth for which particular results can be compared statistically. Experts can be said to act scientifically, using scientific methods, equipment, and procedures, but an absence of experimental replication, confidence intervals, and consequent peer review of studies in published journals stand in contrast to some disciplines. Each real-world forensic case presents unique factors that hamper replication.

Addressing limitations of voice "identification" the eminent phonetician Peter Ladefoged commented, "every court case is like an experiment in which there are only one or two observations, made under unique circumstances … forensic phoneticians are like medical doctors giving prognoses. They make many tests that provide useful clues, but their opinions are inevitably based on their own experience…they have evidential value, but they are not established scientific truth" [3].

2 SUGGESTED STRUCTURAL ANALYSES

To strengthen the opinion of the forensic musicologist from a scientific standpoint, we recommend an approach where the analysis criteria for determining the similarities and differences between disputed musical works be documented in advance of the actual forensic analysis, and then used to guide the report and testimony to the trier of fact. In essence, the approach includes the following maxims:

• *Establish and Document the Experimental Procedure at the Outset.* A forensic musicologist can provide expertise in their ability to inventory both musical and technological similarities and differences as a series of points of comparison. The selection of comparisons should be musically and technically inclusive as possible; done in a manner that is appropriate to the type of case; and fully replicable by another expert, with the expectation of yielding a similar or identical result. The comparisons typically would involve structured categorizations for objective melodic, harmonic and rhythmic analyses, applied to both foreground and accompaniment elements.

In certain cases, the comparison may involve technological analyses of the recording process, or digital analyses of signatures, watermarks, or other non-audio components. While there are practical limits to the number of comparisons that can be made, inclusion of multiple categories of comparison is a control for selective bias, and reliability can be improved by testing multiple exemplars from the works compared. In addition to identifying the types of comparisons to be made in advance, it is also recommended that the expert explicitly establish decision criteria for a "match" or "no match" for each individual point of comparison. The results of two experts who adopt this methodology can be evaluated in terms of the selective bias and decision criteria adopted.

• *Avoid Disparaged Methods.* In particular, experts should avoid offering their personal subjective impressions of similarity or dissimilarity in place of lay opinion (the golden ear analysis); the use of recording mash-ups as demonstrative examples of similarity (except in rebuttal); the opinions of non-experts; analytic exaggeration; and the intent or psychology of the potential infringer. Further discussion of why these methods are disparaged is given below. While it is fair to offer opinions regarding the distribution or airplay of a particular work, the expert cannot state, e.g., that a particular musician or composer would have subconsciously absorbed the work of another composer as an influence.

• *Report Complete Results—along with Limitations—to the Analytical Approach.* The NRC publication indicates several recommendations for methodology and the reporting of results pertinent to forensic musicology. Reports should indicate "methods and materials,

procedures, results and conclusions," and should identify "sources of uncertainty." The reported methods should include the details of the structured analysis and the decision criteria employed. Reports and testimony "must include clear characterizations of the limitations of the analyses…testimony should be given in lay terms so that all trial participants can understand how to weight and interpret the testimony." Finally, the reasons for why a particular match or mismatch occurred for a particular point of comparison should be given.

It is useful to discern between the forensic musicologists' report and legal claims of infringement or plagiarism. A similar distinction exists for audio recording authenticity analysis: authentication relates to a judicial definition of authenticity, e.g., U.S. Federal Rule of Evidence 901: "evidence that the item is what the proponent claims it is," whereas a forensic audio expert can only offer opinions regarding "technical authentication" [4]. Statements regarding infringement or plagiarism are legal opinions that can be supported not only by an expert, but also by lay opinion of the jury (referred to as the *extrinsic* and *intrinsic* tests for the legal definition of *substantial similarity*). The extrinsic test requires a trial judge to dissect and perform detailed analysis of the features of the two works in question with the help of the expert. Under the intrinsic test, "the trier of fact should not consider expert testimony when deciding whether a lay observer would perceive that the copying was of protectable elements of the plaintiff's work" [5].

3 DISPARAGED METHODS

The following gives examples of expert testimony and reports that characterize the disparaged methods asserted above. Their uses clearly fall short of a scientific approach, and are easily avoided.

A person with a "golden ear" is purported to have special talents for listening not available to lay persons. Although training can be used to increase the sensitivity of listeners to small changes in such things as loudspeaker frequency response (and their ability to discriminate and report their sensitivity), there is no scientific evidence that "expert listeners" are any better than lay listeners for forensic challenges such as speech intelligibility from noisy recordings [6], or presumably, for determining whether or not there is a substantial similarity between two recordings.

In the 2003 case *Cottrill v. Spears*, the plaintiff's expert stated that the two works "are strikingly similar, although not identical, from a musical (as distinct from a textual) standpoint, resulting in their *sounding very much the same to the average lay listener who perceives them aurally* rather than reading them from notation" (italics added) [5]. The expert also cited an idiosyncratic method of melodic analysis. In this case, the judge ruled against the plaintiff, largely on the basis that the expert's report was not extrinsic, i.e., based on factual comparisons, and that it instead attempted to use expert (extrinsic) analysis to characterize the subjective impressions of lay listeners regarding copying.

The mash-up technique uses the simultaneous mixing of two recordings (one song overlaid by another), usually after one song is processed in pitch or tempo to match the other. It is often used as a means to demonstrate similarity. Novelty mash-ups of controversial who-copied-whom songs proliferate on websites. The mash-up technique was used in *Cottrill v. Spears* by plaintiffs to demonstrate similarity; the respondents used the same technique but with other musical material to show that perceived similarity results as a result of the *technique*, and not the *inherent similarity* between the two music examples in question. The judge wrote:

> After listening to both Plaintiffs' and Defendants' CDs, it is clear to the Court that the comparison offered by Plaintiffs' CD is unhelpful under the extrinsic test and only further demonstrates the necessity to dissect the works in question in order to discern the protectable similarities from the similarities common to songs of this particular genre [5].

Established psychoacoustic investigations of auditory scene analysis demonstrate that the cognitive process of listening includes forming meaningful patterns from disparate signals; the similarity of many elements of popular music particularly enables forming a common gestalt pattern from two different musical sources [7]. In other words, listeners are wired to form a single coherent pattern from different sound sources that share common attributes. What usually goes unstated is that the mash-up creator must use music editing software to shift the time—or pitch—of one of the exemplars. The aesthetic choices required to make the songs match are far from objective. A mash-up is, inherently, a subjectively created new form. Rather than breaking the song down into recognizable and identifiable elements as demanded by extrinsic analysis, a mash-up compounds the material.

An intrinsic test follows an expert's extrinsic analysis; but lay opinion in itself is an insufficient source for proving infringement on the basis of substantial similarity, and can be prone to bias. Lay listeners on a jury given the task of determining infringement under the intrinsic test have been shown in one study to be easily biased by the style of playing and instrumentation of a performance in determining "substantial similarity." The tendency is for a lay listener is to focus on the similarity of the recorded exemplars introduced as evidence, as opposed to the underlying musical material (melody, harmony and rhythm). Lund [8] compared two sets of participants who evaluated the similarity and differences between paired exemplars from actual cases. Participants who heard the comparison material performed in the same style

(orchestration, timbre, key and style) would rate the similarity between the exemplars higher than the same exemplars played in a different style. Lund concluded that an improved version of the intrinsic test would mitigate prejudice "through the use of expert testimony, special verdict forms, or through the use of multiple recorded versions of the same songs."

In the case of *Samuel Steele v. Jon Bongiovi [Bon Jovi]*, the plaintiff submitted affidavits from "ordinary listeners" who claimed detection of similarity between the songs at issue. The judge, in dismissing the case in summary judgment, wrote that "a court must engage in dissection of the copyrighted work by separating its original, protected expressive elements from those aspects that are not copyrightable…and overall impression of similarity may not be enough if such and impression flows from similarities that are not themselves copyrightable." The ordinary listeners were pointed out by the judge to be "friends or acquaintances" of the plaintiff, that there was no evidence that those ordinary listeners were "correctly applying the pertinent legal standards" and were in any event inadmissible lay opinion and not appropriate for consideration. Other expert reports pointed to "purported similarities between the structure and rhyme scheme of the Steele song and the Bon Jovi song" but did not prove that these were in fact not common rhyme schemes, or a "stereotypical building block [which lacks originality]" [9].

Analytic exaggeration refers to a type of extrinsic analysis where the expert over reaches to a level of complexity that clearly contradicts a more direct, simple analysis, by attempting to use techniques that go beyond normal or due proportions. Consider the case of *Johnson v. Gordon*, where the plaintiff's expert asserted the similarity of two melodies only after transforming one of them using the compositional technique of retrograde inversion (essentially, rewriting the melody upside down and backwards). Rhythmic alteration was also performed. The judge referred to the "Herculean effort" of the expert and commented:

> In comparing the retrograde variation of the plaintiff's bars 16 and 17 to defendants' bars 1 and 2, [the expert] again altered the rhythm to match the defendants' song and added an A flat note. Yet, even with the benefit of these emendations, differences persisted between the retrograde version of the defendant's two-bar melody and its proposed counterpart. For example, the third notes of the sequences do not coincide [10].

The expert was also not familiar with many areas of forensic expertise necessary for modern musicological investigations.

> [regarding sampling]…the witness admitted that he lacked a proper foundation on which to make the assessment. For example, he had not performed a technical analysis of the type used by musicologists to detect samples in sound recordings; he had not noted the existence of sampling in his report; and he could not point to the sheet music corresponding to the relevant sound recordings to indicate where sampling might have occurred [10].

4 TYPES OF MUSICOLOGICAL FORENSIC INVESTIGATIONS

Forensic musicological investigations can be categorized in three ways: (1) the composition, or, the underlying musical work (*composition analysis*); (2) the sound recording, including the provenance and performers on a particular work, and the underlying technologies involved (*recording analysis*); and/or (3) the means of production or distribution of the physical product (*production analysis*). Definitions and examples of each type of investigation follow.

4.1 Composition Analysis

Composition analysis is necessary when copyright issues involve a claim of plagiarism independent of the recording media. Analysis of the underlying musical structure is the concern of licensing organizations such as the American Society of Composers, Authors and Publishers [11]. Legally, a plaintiff must prove that: (1) the defendant had previous access to a song and (2) the song in controversy has "substantial" or "striking" similarity in melody, rhythm and structure to an existing work [12]. Finding out whether or not a song was accessible might necessitate research along the lines of tracing the history of radio playback, sales figures, or presence of the song in mainstream media. "Substantial similarity" leads to determination of whether or not particular musical material is truly copyrightable as unique, or something pervasive and obvious in music generally.

Usually, substantial similarity between two compositions is defined in terms of rhythm, melody and harmony, i.e. those elements of music that can be notated and reproduced in performance via sheet music. Musical compositions first achieved copyright protection in the United States in 1831, when sheet music was the only means of establishing a musical composition in fixed form; attempts to expand the definition to include other factors such as orchestration, phrasing and structure have not been successful, despite the fact that music is often composed "directly" to the recording with a complete absence of notation [8].

The 1976 case of George Harrison's "My Sweet Lord" vs. The Chiffons' "He's So Fine" (Bright Tunes Music v. Harrisongs Music) is an example of compositional infringement, where focused analysis of the compositional structure of the melody proved crucial to the court's decision [13]. Regardless of differences in

performance style, Harrison was found guilty of "subconsciously plagiarizing" "He's So Fine" due to his use of two melodic motifs that were structured in a particular way (the formal structure as "A A A A, B B B"). Figure 1 (shows the "kernels" of Harrison's composition, motifs A and B[1]. Figure 2 shows motifs A and B of "He's So Fine," composed by Ronnie Mack and copyrighted by Bright Tunes Music. These motifs are not particularly original in and of themselves; what was deemed original was the number of repetitions of Motif A followed by the number of repetitions of Motif B. Harrison's structure imitates the number of repetitions in "He's So Fine."

Also, of particular interest in this case was the so-called grace note sung by The Chiffons, which was performed by Billy Preston in the earliest recording of the song. The note in question, perhaps more correctly termed an appoggiatura, is circled in Figure 3. The imitation of that particular melodic variation convinced the Court that Harrison, who would have had "access" to the musical material ("He's So Fine" topped the Billboard charts in 1963) plagiarized the tune, whether consciously or not. (Harrison later removed this note from his performance; the sheet music for "My Sweet Lord" does not contain the particular pitch in question, either.)

Compositional analysis of popular music usually requires a reductive approach to notation for forensic analysis, since a literal transcription of a recording conflates the underlying composition and its performance. However, such notation is not completely objective; Bennet has cautioned that reductive transcription can be used to bias melodic or harmonic content so as to suggest more or less similarity than objectively evident [14]. The structural analysis of "My Sweet Lord" and "He's So Fine" presented here is reductive in nature. By reducing the melody and repetitive structure in the two pop songs to more basic forms, the forensic analysis demonstrated a level of similarity that was deemed significant by the court. Although some degree of musical intuition made the final judicial decision subjective, it was made independently of aspects of performance style, cultural context, or the composer's tales of how they were inspired to write the song. Rather, the plaintiff's expert stripped away stylistic concerns and focused on the melodic notes and formal structure of each song. Although the initial notes of the B motif differed literally, the number of similarities between the melody and the structure were found to be substantial enough to support the plaintiff's claim.

[1] Figures appear at the end of this paper to accommodate music notation.

4.2 Recording Analysis

In cases where the claim of infringement involves the use of a specific recording in a given context, the forensic musicologist employs the techniques of recording analysis. Recording analysis represents an increasingly predominant analysis focus for forensic musicology. Unlike compositional analysis, which necessarily establishes similarity by a reductive approach, recording analysis typically involves *identification* and *differentiation* between two exemplars in terms of melody, harmony, and/or digital signal analysis, in the exact form in which they were recorded. Hence, the tools used for recording analysis tend to include those from the domain of audio engineering as much as from the domain of music theory.

Intuitively, differences in melodic expression are an obvious first place to test the similarity of two recordings. The principles apply not only to vocalizations of the principal melody, but also to accompaniment, whether vocal or instrumental. A melody is commonly defined as a time-ordered sequence of pitches that the listener perceives as a single entity. Different recordings of the same composition by the same artist often include unique forms of melismatic expression, that is, improvisatory singing of a phoneme or a syllable across multiple notes, beyond what is notated as the essential aspect of the melody. Classical music composers, for example, frequently employ melisma on the first syllable "a" of "amen," creating expressive, often virtuosic phrases out of what is essentially a simple cadence. In classical music, such prolongations of the text via melody are typically fully notated (Figure 4).

In popular music, the melismatic style of singing is an improvisatory technique; e.g., popular music lead sheets might not always convey what a singer performs in the moment. Figure 5 shows an approximation of the basic melody of a popular song as it might be notated, while Figures 6 and 7 show the literal notations for how a performer might stylize (embellish) the melody during two different recordings.

In forensic analysis, the compared examples under controversy are usually much more subtle, but the basic analysis of differences in melodic embellishment can support a conclusion of differentiation. By contrast, in compositional analysis, performed embellishments are reduced to the underlying melody (e.g., comparing Figure 5 to Figure 6), while two different performance recordings rarely have the same exact form of embellishment (e.g., comparing Figure 6 to Figure 7).

While differentiation can be established via melodic analysis, other means can be more efficient for showing that two recordings are based on the same original source. Timing analysis can be very precise and allow detailed comparison of exemplars at various points

throughout the recordings, assuming that the sources were both digitally recorded and no means of disguising or altering timing were used. Noting subtle differences in timing between performers such as accents can be useful in comparing popular music recordings [15].

For comparison of live classical music recordings that were otherwise differentiated in terms of spatial, dynamic and timbral characteristics, DeFrancisco found analysis of timing and incidental differences ("unexpected accidents") in the recordings to be most salient [16]. The unexpected accidents in live performance can include coughs, unexpected noises, wrong notes, and similar extraneous sounds. DeFrancisco also notes that "details of intonation fluctuations, ensemble precision at particular instants, balances of voices and especially changes in the dynamics of time of the musical performance, like stretches and compressions of the musical tempo" as useful means for comparing exemplars.

In recording analysis, some forms of plagiarism are overt such as a literal sampling of a section of a recording, and can be established using the matching of waveforms, spectral analysis, or other techniques, allowing for a more precise and objective comparison compared to using musical notation by the expert. To avoid detection, specialized editing or signal processing can be used to obscure or hide the original source of material used in a questioned work. Digital editing can allow for the seamless re-ordering, repetition, or deletion of material from an original source into a new variant that requires the expert to identify the means by which the original version maps to its altered equivalent. Such editing might be done to match music to the narrative of a film or television commercial, or to extract very small yet identifiable fragments to use as the sampling resources of a subsequent work. Digital editing allows specific sections to be faded or their timbre adjusted; if access to the original multi-track recording is possible, then entire vocal instrumental stems can be removed and replaced by newly recorded material.

Two increasingly popular types of signal processing for disguising or purposely differentiating original material from a copy are time compression/expansion and pitch shifting. These algorithms are usually based on an underlying signal processing technique originally known as "phase vocoding" [17], and easy-to-use implementations have been ubiquitous in desktop computer editing software for some time. Essentially, this allows a sound editor to take an original recording and alter the pitch of the music upwards or downwards without changing timing (rhythm or metronomic tempo), or conversely, alter the timing without changing the pitch. The technique is also sometimes employed in making mash-up recordings. While with analog tape recordings, the two processes are inextricably linked, signal processing of digital recordings allows independent manipulation of both factors. This allows a recording engineer to take original material and make a version that sounds familiar or identifiable as the original composition, but that would not result in a match if one were to do a comparison of the waveforms, vocal quality, melody or timing. The expert must attempt to undo the disguise before proceeding with an analysis of similarities and differences.

Other signal processing techniques include the use of vocal eliminators, popular in Karaoke performance. These devices work by reducing the level of the signal common to both channels, typically the lead vocal, and leaving the signals unique to both channels, typically the accompaniment, somewhat intact. This allows a recording engineer to add a new vocal track or other material to the extracted material. Other means of obscuring an original recording include the addition of reverberation, stereo synthesis, and a plethora of techniques available on even the most inexpensive desktop waveform editors.

Recording analysis is also used to compare the sources or performers in a recording. Due to the density of sound sources produced by modern music mixing techniques, it is often impossible to extract a particular background performer in a reliable manner. However, filtering techniques can be used successfully to isolate frequency information not predominant in other instruments, e.g. bass and percussion. It can also be useful to analyze timing in a popular music track to determine if a 'click track,' electronic drums or other precise means of timing were used, or if the timing contained the randomness associated with purely human performance.

In one example, a group of vocalists singing *a cappella* (unaccompanied) performed music that was recorded by a client and then purportedly used in a later broadcast without their permission. The respondent claimed that a new vocal group was recorded for use in the broadcast, and that the original vocal group recording was not used at all. It was possible to eliminate the original recording by analyzing the variation of pitch of the two vocal groups against a reference. The original group's pitch drifted downwards (i.e., "flat") over the course of the performance, while the later recording's group maintained pitch, likely due to instrumental accompaniment. The possibility that the original group's pitch was corrected by a pitch correction algorithm (similar to phase vocoding techniques discussed above) required the expert to attempt this modification, but was found to be unlikely due to moment-to-moment pitch fluctuations (i.e., individuals in the group being out of tune with one another). Timing and melodic analysis also revealed differences.

Sometimes recording analysis requires examination or analysis of recording hardware and software and available "effects." For example, familiarity with the nuances of electronic reverberation development can

effectively restrict a source recording to a particular era. For instance, in one case, an individual respondent claimed to have made a demo tape using only their personal 4-track analog cassette tape recorder dating from the 1980s. The plaintiff claimed that the demo tape was made in their far more sophisticated recording studio. Devices such as the 4-track analog cassette machine allowed impressive imitations of more complex recordings by the use of track bouncing (successive mixing two tracks down to one, so as to empty a track for additional material). However, each successive track bounce adds noise to the overall mix, and analysis of the signal-to-noise ratio of the recording was among the methods used to eliminate the device as the source of the demo tape. Additionally the use of a particular delay effect in the demo recording was not a feature of the native recording device, and no outboard signal-processing device was claimed to have been available or used.

4.3 Production Analysis

Production analysis focuses on the means of production or distribution of the recording product once it has left the studio. This area can be considered a specialized aspect of recording analysis that focuses on bootlegged and pirated versions of recordings, primarily by means of computer forensic techniques [18]. Physical examination of the media (e.g., compact discs and their labeling) can also be involved. Examination of digital metadata can reveal the source and the means of audio compression used in a recording. A simple example of determining whether or not a recording is a "genuine" version is to not only examine recording analysis features such as frequency response or overall duration, but to also examine data features such as audio compression, file size, and metadata tags. The expert should note any differences in comparison to the originally distributed version of the product.

With the introduction of digital media, rights management has become more complex. Many digital audio formats (e.g., AAC and WMA) utilize a Digital Rights Management system to limit the number of devices that a file is able to be played on, thus attempting to limit the illegal distribution of the music. Another technique is audio watermarking. Using audio watermarking to protect copyright of a recording is a complex topic that goes far beyond the current discussion [19]. This involves the use of inaudible signals that can be embedded within a digital audio stream, designed either to not withstand a copying process, or to identify an original source of a recording despite copying. Testimony based on this type of evidence may require either specialized expert testimony to explain, e.g., watermark robustness, or alternatively, a fact witnesses who would simply testify that recognized computer software for watermark detection indicated the absence or presence of a watermark, and the contents of the watermark reported by the software.

5 CONCLUSION

The field of musicological forensics continues to evolve with the development of digital means of audio production, transformation, distribution, and copyright protection, and yet in most cases, it remains dependent on basic elements of musicological investigation and music theory. Although quantifiable error rates for musicological interpretation may not be forthcoming for some time, due in part to the wide variations in the context of real-world cases, it is still possible for experts to adopt scientifically-based procedures for establishing an experimental procedure and reporting results while avoiding those methods that can be proven to be disparaged or pseudo-scientific. Dissemination of the techniques used and reports given by experts in forensic musicology can help establish standards that have a factual basis; the authors encourage experts in the field to publish their findings and case studies, and commend efforts such as USC's Music Copyright Infringement Resource for providing a useful repository of legal opinions. Several recent techniques that include computational analysis (e.g. [20]) and thematic database searching (e.g., Stanford University's Center for Computer Assisted Research in the Humanities "Themefinder" software) have not been considered here.

6 ACKNOWLEDGEMENTS

The authors acknowledge the forensic musicology and audio forensic experts who read and commented on earlier versions of this paper. The realization of this work was supported by Charles M. Salter Associates, San Francisco, CA. An earlier version of this paper titled "Analysis Criteria for Forensic Musicology" was presented at the ICA 2013 21st International Congress on Acoustics/ 165th Meeting of the Acoustical Society of America/ 52nd Meeting of the Canadian Acoustical Association, Montréal, Québec, Canada, 2 – 7 June 2013. The current version has been revised and expanded. Prior material has been used with permission.

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FIGURES

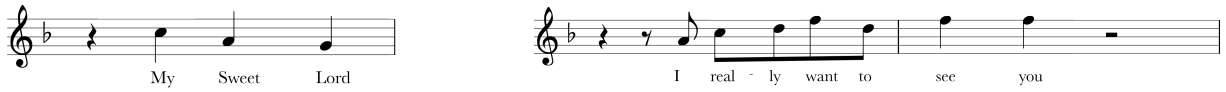

Figure 1: (left) George Harrison, “My Sweet Lord” motif A and (right) motif B.

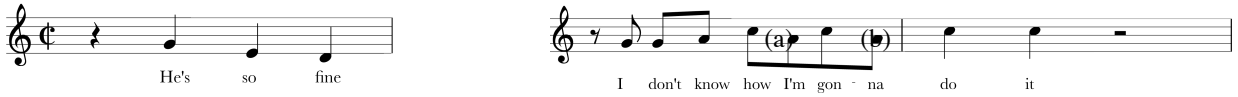

Figure 2: (left) Bright Tunes Music, “He’s So Fine” motif A and (right) motif B.

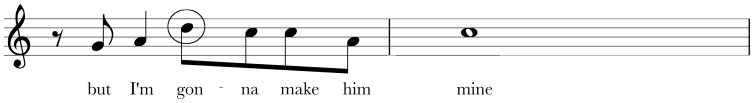

Figure 3: Bright Tunes Music, “He’s So Fine” so-called grace note (circled).

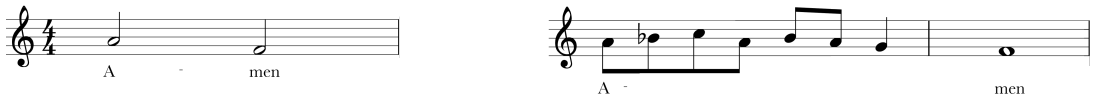

Figure 4: (left) Syllabic setting of “amen” and (right) melismatic setting of “amen”.

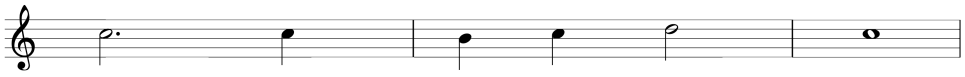

Figure 5: Simple notated melody of a popular song.

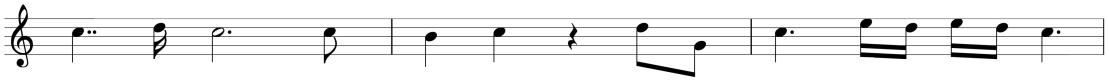

Figure 6: Transcription of a hypothetical performance of the melody of Figure 5.

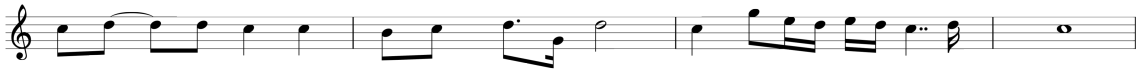

Figure 7: Transcription of an alternate hypothetical performance of the melody of Figure 5.