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Sublime. Ilya Kaler plays the Vieuxtemps, crafted by Guarneri del Gesù in 1741.

CREDIT: EUGENE SCHENKMAN, *THE STRAD DIMENSION*

Probing the Secrets Of The Finest Fiddles

Violinmakers take up the tools of science in a study of Guarneri del Gesù's Vieuxtemps and other great violins

CHICAGO, ILLINOIS—Ilya Kaler, a renowned soloist, gazes admiringly at the 269-year-old violin. He has just played four other great old Italian instruments in an invitation-only recital in the cramped quarters of Bein and Fushi Inc., violin dealers whose shop looks out over Chicago's famous Michigan Avenue. Now Kaler holds the star of the 7 April event, a fiddle named the Vieuxtemps after a previous owner and crafted by Bartolomeo Giuseppe Antonio Guarneri, also known as Guarneri del Gesù, who, along with Antonio Stradivari, is widely considered the best violinmaker ever to have lived.

"This is one of the greatest instruments in existence, no doubt, one of two, maybe three," says Kaler, who, with his easy smile and a crimson handkerchief tucked into the breast pocket of his tuxedo, exudes the unassailable confidence of a virtuoso. Then he reconsiders that count. "Three is too many," he says.

For sale for $18 million, the Vieuxtemps is a superior instrument, a piece of 18th century art, a potential investment, a legend. It's also the subject of scientific study. With the permission of its owner and dealer Geoffrey Fushi, a team of violinmakers and scientists has put the Vieuxtemps and three of the other violins in the recital through tests including computed tomography (CT) scans and acoustic measurements. They hope to pinpoint traits that distinguish a great violin from a good one or a Stradivarius from a Guarneri.

The project also highlights an emerging trend within violinmaking. For decades, the instrument has fascinated a small community of scientists and engineers. Now, even as the scientific experts age and retire, some leading violinmakers are adopting their conceptual tools and experimental methods and taking a decidedly more scientific approach to their centuries-old craft.

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Podcast interview with author Adrian Cho.

"Violinmaking involves a lot of sitting around and scraping pieces of wood, and if you want to have a life of the mind, you want to be thinking about these [technical] things," says Joseph Curtin, a violinmaker from Ann Arbor, Michigan, who proposed the study to Fushi. But so far, science cannot tell the best fiddles from the merely good ones, cautions James Woodhouse, an acoustics engineer at the University of Cambridge in the United Kingdom who has studied the violin for 35 years. "We know pretty well how to distinguish a really bad instrument from a really good one. What distinguishes a pretty good instrument from a stratospheric instrument, I think we still don't know."

As Kaler plays, however, it's hard to believe that distinction will forever defy scientific analysis. The brilliance of another Guarneri del Gesù, the Sennhauser, slices through as he moves from the introspective andante to the skipping allegro of a sonata by Handel. The darker sound of a violin made by Giovanni Battista Guadagnini in 1752 conjures an image of molasses as the soloist wrings emotion from Schumann's melancholy *Romance in A*, and the Cathedral Stradivarius sings sweetly as he bows Gluck's soaring *Mélodie*.

Finally, the Vieuxtemps rings out almost painfully bright in three pieces including the playful *Rondino* by 19th century Belgian violinist Henri François Joseph Vieuxtemps, who once owned the fiddle. The violins speak with voices as distinct as people's, and it seems impossible that science cannot quantify the differences.

Scientists seduced

The violin has captivated scientists for more than a century. In 1862, German physicist Hermann von Helmholtz cobbled a stroboscope from a tuning fork to decipher the motion of a bowed string. A single kink zips back and forth between the "bridge," the stanchion on the violin's belly over which the strings run, and the spot where the player pins the string to the fingerboard. The vibrations pass through the bridge and into the violin's body, whose arched top is carved from a slab of spruce and whose back and sides are made of maple. Since the 1930s, researchers have learned much about how the violin converts those vibrations to sound.

To move a lot of air and sing loudly, a violin must vibrate readily, or "resonate," like a tuning fork. But whereas a tuning fork has a single soundmaking resonance at a sharply defined frequency, a violin has hundreds of resonances that overlap, enabling it to respond at pitches ranging from 196 hertz (open G) to above 20,000 hertz. Yet it should not ring equally at all pitches, as it would then sound lifeless. "It's not a loudspeaker with a flat-spectrum response," says George Stoppani, a violinmaker in Manchester, U.K. Instead, the spectrum with which a violin radiates

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sound resembles a mountain range, with each peak corresponding to a pattern of motion, or “mode,” of the body (see figure, below).

One way to study the spectrum and the modes is by thwacking the bridge with a small hammer and measuring the violin’s output and motion. Around 280 hertz lies the A0 mode, in which air flows in and out of the “f holes” on the violin’s belly. The B1– and B1+ modes, identified in the 1980s, lie around 480 hertz and 550 hertz. Around 2500 hertz lies a thicket of modes called the “bridge hill,” long thought to be due to motion of the bridge. Each mode can be complex, as the violin’s symmetrical exterior hides its asymmetrical interior. Under one foot of the bridge, a beam called the bass bar reinforces the top; beneath the other foot, a pillar called the sound post connects top and back.

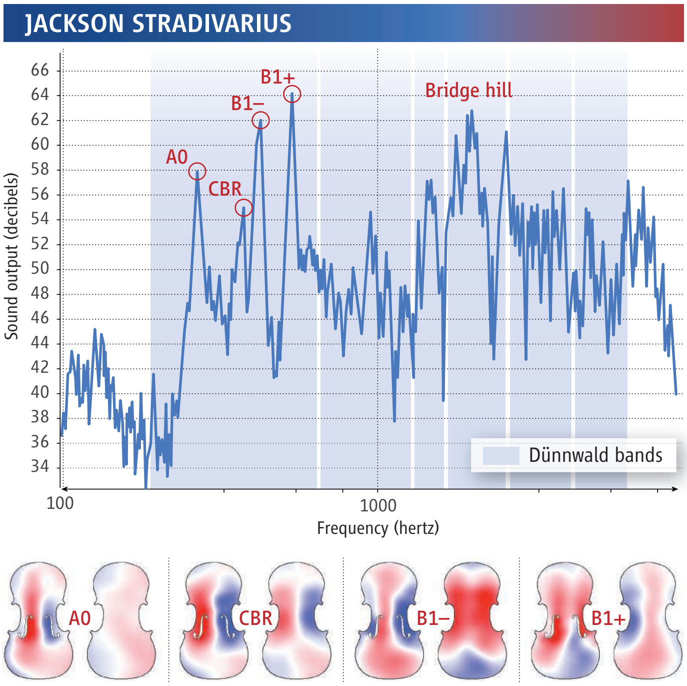
Much work has focused on the radiation spectrum, which varies among violins a bit like the way fingerprints vary among people. In 1991, German physicist Heinrich Dünnwald reported on the spectra of 700 violins including 53 old Italians, dividing them into six bands that he claimed are associated with qualities of sound. For example, Dünnwald said, a violin that radiates more strongly between 650 hertz and 1300 hertz than in the neighboring bands sounds “nasal,” whereas one that pumps out more energy from 4200 hertz to 6400 hertz than at lower frequencies sounds “harsh.”

Dünnwald defined a quality index according to which 92.5% of the old Italians ranked as superior, compared with 19% of quality instruments made after 1800. But some researchers question the simple association of frequency bands with sound qualities and the conceptual value of such correlations. “Of course, the old Italians were on top of the list, and that’s not that interesting to me because it doesn’t tell you how a violin works,” says Gabriel Weinreich, a physicist retired from the University of Michigan, Ann Arbor, who has studied the violin since 1978.

Scientists continue to probe the violin in ever greater detail, teasing out the interplay of modes and showing, for example, that the bridge hill does *not* stem from a simple rocking of the bridge. Until recently, however, their work attracted little interest from violinmakers. That’s changing, says Woodhouse. “There’s a lot of research going on, but it’s driven by makers,” he says. “And they’re top makers, not marginal makers who everybody laughs at.”

A revolution in the making

The meeting of minds hasn’t come easy, says Samuel Zygmuntowicz, a violinmaker from New York City who made a violin that sold at auction for $130,000, a record for a living maker. Scientists responded tepidly a few years ago when he presented work at an acoustics meeting at Cambridge, he says. “They were trying to explain to me how to do better measurements, and I was trying to explain the phenomena I thought I was discovering,” he says. “We couldn’t get past it.” But Zygmuntowicz boned up on physics and says a meeting in Cambridge last September went much better.



Sonic fingerprint. Each peak in a violin’s spectrum corresponds to a mode of vibration. Red and blue denote motion in opposite directions.

Working with scientists has given violinmakers access to tools far more sophisticated than the chisels and calipers they traditionally use. As early as the 1980s, researchers put violins through CT x-ray scanners, to trace an instrument’s internal structure and look for defects and repairs. High-resolution scans may also provide insight into a long-debated issue of whether the wood in the old instruments differs from that in newer ones, perhaps because it was treated in some way.

Terry Borman, a violinmaker from Fayetteville, Arkansas, and Berend Stoel, a computer scientist working on image processing at Leiden University Medical Center in the Netherlands, took high-resolution scans of three Guarneri del Gesùs, two Stradivariuses, and eight modern violins. They found no difference between the average densities of the wood in the tops of old and new violins. Within the old tops, however, the density varied less between the light grains produced as trees grow during the warmer months and the dark grains produced during colder months, they reported 2 July 2008 in *PLoS ONE*. “So the old violins were a lot more homogeneous,” Borman says.

Conversely, teaming with leading makers gives scientists access to rare old instruments. George Bissinger, a physicist at East Carolina University in Greenville, North Carolina, has studied the violin since 1969. But it wasn’t until he teamed with Zygmuntowicz in 2006 that he was able to put a Guarneri del Gesù and two Stradivariuses through testing in a project called Strad3D. He and eight violinmakers, a radiologist, and an engineer used a three-dimensional laser vibrometer to map the fiddles’ mode, an anechoic chamber to analyze their spectra, and CT scans to probe their guts.

The study has provided no simple way to separate the good violins from the bad ones, however. For example, the spectra of fine old violins differ from those of poorer new ones only in a few subtle ways, Bissinger says. The old Italians have slightly more uniform spectra and slightly greater damping than 14 lesser violins, Bissinger reported in the *Journal of the Acoustical Society of America* in September 2008. They also have stronger A0 modes. “That’s the one robust difference between a good and a bad violin,” he says.

The current study suggests that the Vieuxtemps sings in a way that other fiddles do not. In fact, that observation was the impetus for the project. Curtin had heard that Fushi had the fiddle and talked his way into making some measurements. As other analysts do, he uses a tiny automated impact hammer to strike the bridge from the side. But Curtin also tapped it from the top. “I found an acoustical feature that showed up spectacularly well in the Vieuxtemps, in fact more so than with any other violin I’ve seen,” he says.

Curtin had pinged other instruments that way and saw signs of a second bridge hill above 3500 hertz. But when its bridge is struck

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Like new. Typical patches and repairs show up as light spots in the CT scan of a 1730s violin (*right*). The Vieuxtemps (*center*) is spotless.

vertically, the Vieuxtemps resonates sharply at 4125 hertz, Curtin explains a few days after the recital. In his quiet studio off a dirt road outside Ann Arbor, he shows several plots—made with software written by Stoppani. The Vieuxtemps's spectrum shows a peak about 5 decibels high that is absent in the spectrum of the Cathedral Strad. The Jarnowich Guarneri del Gesù shows a smaller feature, so the resonance may be common to Guarneri del Gesùs, says Curtin, who wants to trace its origin.

Spurred by that observation, Curtin talked Fushi into letting him conduct more tests and assembled a team including Borman, Stoel, Stoppani, Weinreich, and Woodhouse. The researchers are still analyzing their data, but one fact is already clear. Most old instruments have been repaired multiple times and patched near the bridge and sound post. A CT scan shows that the Vieuxtemps is pristine (see figures, above), Borman says. So compared with other old Italians, it may sound more like its maker intended.

What difference?

But can subtle density variations or spectral features explain the supposedly superior qualities of Strads and Guarneris or distinguish between them? Cambridge's Woodhouse has doubts. Acoustically speaking, researchers can now say why a violin sounds like a violin and not a guitar, he says, but they struggle to make finer distinctions. "If you chose any particular feature, you can probably find two million-dollar violins that differ from each other in that one feature as much as the million-dollar ones differ from a good $10,000 modern one," Woodhouse says.

In fact, Woodhouse and Claudia Fritz, a psychoacoustician at Pierre and Marie Curie University in Paris, have studied how big the changes in a violin's spectrum must be before listeners can tell the difference. To do that, Fritz digitized the spectrum of a violin to create a "virtual violin." When a violinist plays, say, an A, the string vibrates at 440 hertz and multiples of that frequency, or "harmonics." The violin's spectrum then determines how strongly it radiates at each of those frequencies. With the virtual violin, Fritz can change that spectrum, raising and lowering peaks or shifting their frequencies.

Not surprisingly, musicians have proved much more sensitive than nonmusicians to small changes in the spectrum, as Fritz and colleagues reported in December 2007 in the *Journal of the Acoustical Society of America*. When comparing single notes, musicians could tell if the strength of a resonance like the A0 or B1+ changed by about 4 decibels—slightly more than a doubling in intensity. They could tell if the frequency of the resonance was shifted by about 5%, roughly the difference between, say, C and C-sharp. Curtin says the Vieuxtemps's B1+ resonance is about 10% higher in frequency than those of the Strads. Listeners could detect smaller changes in a Dünnwald band.

The researchers also tested the correlations between subjects' perceptions and the relative strengths of the Dünnwald bands, which are used as guides by makers, and came up with some surprises. For example, some people thought notes with stronger low-frequency components sounded nasal, whereas others thought just the opposite. "When violinmakers are talking about the nasal band, they should be careful," Fritz says, "because there is no nasal band at all."

Such results further complicate an already confusing situation. Yet, collaborations between scientists and violinmakers seem likely to continue, as they offer makers greater insight into their creations, which for centuries they have crafted by copying excellent old instruments. "I think the best way to make a great violin is to understand what makes an instrument great and what's peripheral," Curtin says. "When we copy, we tend to copy everything."

Moreover, the fact that so far tests have identified no obvious difference between great and good violins may actually be telling researchers something. Most studies have been made on violins in pristine isolation, typically suspended by rubber bands from a mount. Of course, when played, a fiddle lies clamped beneath a violinist's jaw, its neck cradled in the musician's hand, its strings worked by the bow. The instrument's defining qualities may show through only in that interaction.

"I can tell you that the violinist is the big deal," Bissinger says. "A great violinist can make even a bad violin sound good." Zygmuntowicz agrees but warns that researchers may struggle to get reliable data on the working violin. "The situations that a violin operates in are really contaminated circumstances for testing," he says. "Science has shied away from that interaction because it doesn't make good papers yet."

To hear Kaler tell it, the violin-violinist interaction is subtle. Asked what distinguishes the Vieuxtemps, he cites its resonance and ease of response. Then he adds, "If a violin responds too easily, it limits the possibility of a performer to produce many colors or to put his or her own imprint on the instrument because the instrument anticipates your desires too much." So a violin must resist just enough to make the violinist work for what he wants, he says.

If the Vieuxtemps resists Kaler, it doesn't show. He closes the recital on the Vieuxtemps with Alexander Glazunov's dreamy *Meditation*, its luminous last note, a seemingly impossibly high D, hanging in the air like twilight. To the scientifically minded, it whispers, "Explain my beauty!" But doing so may be as difficult as grasping the fading reverberations of the music itself. **–ADRIAN CHO**

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