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**Increased levels of bass over time in popular music recordings and their
relation to loudness**

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Abstract

The sound of recorded music changes over time, and can be captured by changes in audio features. Over the past decades, popular songs have shown clear increases in loudness (RMS energy), but far less attention has addressed whether this upward trend is more prevalent in specific frequency bands, such as the bass. Bass frequencies are especially important for movement induction and might offer competitive advantages of capturing attention and increasing engagement. Here, we examined the evolution of audio features, such as RMS energy and spectral fluctuations (changes in the audio signal's frequency content) in 10 frequency bands from songs on the Billboard Hot 100 charts from 1955-2016. Over time, RMS energy increased and dynamic range decreased. The largest increases were found in the bass range: Spectral flux increased most strongly in the lowest frequency bands (0-100 Hz), and when controlling for overall RMS, only the lowest frequency bands showed an increase over time. The upward trend of bass could reflect changes in technology and style; but based on links between bass and movement, it is likely a widespread technique to increase engagement and contribute to chart success.

Music changes over time. When listening to music on the radio, the era of even unfamiliar songs is usually easy to discern. Each era has characteristic styles, but also a characteristic “sound.” How this “sound” changes over time might be captured by changes in certain audio features. These audio features might be especially relevant for attracting attention, inducing movement, or making a song stand out in another way that increases the chances for chart success. Here we examine the evolution of audio features, including energy and fluctuations in different frequency bands, in popular songs from 1955 to 2016.

Previous research has uncovered trends of how popular music changes over time. An analysis of the evolution of harmonic and timbral features of popular recordings from 1960 to 2010 revealed that some features decreased over time (e.g., dominant 7th chords), whereas others increased (e.g., “no chords”, potentially related to the rise of Hip Hop/Rap music in the late 1980s), or peaked at a certain time (e.g., “drums, aggressive, percussive” in 1990, potentially related to the increasing and decreasing popularity of drum machines) (Mauch, MacCallcum, Levy & Leroi, 2015). In a similar timeframe (1955-2010), chord progressions and timbral palettes of popular songs became simpler and more homogenous (Serrà, Corral, Boguñá, Haro, & Arcos, 2012). An analysis of popular songs from 1985 to 2015 revealed downward trends of features such as of “happiness” and “brightness” and upward trends of “electronic sound type” and “danceability” (Interiano et al., 2018).

Most previous studies on the evolution of audio features in music are exploratory and analyze complex high-level features. One of the most discussed changes in music, however, is based on a simple low-level feature: loudness¹. An increase in loudness of popular songs over time (1955-2010) has been shown by Serrà and colleagues (2012). They also found that in spite of increased loudness, the dynamic variability of loudness remained constant over time. This seems to counter the common assumption that increased loudness is associated with decreased dynamic range (e.g., Croghan, Arehart, & Kates, 2012; Oehler, Reuter & Czedik-Eysenberg, 2015; Vickers, 2010), although this discrepancy might stem from differences in how “dynamic range” is quantified (see e.g., footnote 2).

¹ Loudness relates to the perception of sound amplitude. In accordance with Serrà et al. (2012), we refer to the inherent loudness of a recording, which should not be confused with the loudness that can be manipulated by the listener (e.g., by turning up the volume on a stereo).

While an increase in overall loudness over the past decades is well known (Devine 2013; Oehler et al., 2015; Serrà et al., 2012; Vickers, 2010), far less attention has addressed whether this upward trend is more prevalent in and especially affected by specific frequency bands. A recent analysis of songs on German charts (1965-2013) showed that the ratio of low-to-high frequencies has increased over time (where the cutoff frequency separating “low” from “high” frequencies was 182 Hz) (Oehler et. al., 2015). This suggests an increase in bass, which could relate to increased loudness.

Bass frequencies seem to be especially important for inducing and stabilizing movement to music (e.g., Burger, Thompson, Luck, Saarikallio, & Toiviainen, 2013; Hove, Keller & Krumhansl, 2007; Stupacher, Hove, Novembre, Schütz-Bosbach, & Keller, 2013; Stupacher, Hove, & Janata, 2016; van Dyck, Moelants, Demey, Deweppe, Coussement, & Leman, 2013). In a recent study on the mechanism underlying movement-bass links, when music was presented over a subwoofer and stimulated the body (compared to earphones only), subjects moved more and rated songs as more enjoyable and “groovy.” Interestingly, these subwoofer effects were stronger for the newer songs (from 2004-2015) than older songs (from 1972-1986). The newer songs had significantly more *spectral flux* (i.e., fluctuations in the frequency content of an audio signal) in the bass range (0-100 Hz), and thereby created more tactile sensation (Hove, Martinez, & Stupacher, under review). To investigate if the increased bass in newer songs was limited to the 10 selected songs or if it captured a larger musical trend, we analyzed energy and fluctuations in 10 frequency bands in the most popular songs from the last 6 decades. We expected that the bass frequencies in the audio signal would show the largest changes over time and play a major role in the loudness increase.

Method and Results

We analyzed audio features of the top two songs from every year-end *Billboard* Hot 100 Chart from 1955-2016 (cf. Krumhansl & Zupnick, 2013; see appendix). We used the iTunes preview of each song, and each clip’s .wav file was peak-amplitude normalized to control for overall levels (Stupacher et al., 2013; 2016). Of the 124 song clips, 110 were 90 seconds long, and 14 were 30 seconds long. Using the MIR Toolbox for MATLAB (Lartillot & Toiviainen, 2007), we extracted audio features including root mean square energy (*RMS energy*) and *spectral flux*

from the full frequency spectrum and within 10 frequency bands (0-50 Hz, 50-100 Hz, 100-200 Hz, 200-400 Hz, 400-800 Hz, 800-1600 Hz, 1600-3200 Hz, 3200-6400 Hz, 6400-12800 Hz, and 12800-22050 Hz). *RMS energy* describes the total energy in an audio signal's waveform. *Spectral flux* indicates the fluctuation of frequency content in the audio signal's spectrogram (see Figure 1). Additionally, in order to get a measure of *dynamic range*, we used the TT dynamic range meter (Tischmeyer, 2009), which measures a variant of the crest factor² and is often used to estimate loudness dynamics in popular recordings (e.g., Vickers 2010; Oehler et al., 2015). The audio features' values were averaged for the two tracks in each year, and these year averages were correlated with and regressed onto release year.

Figure 1. Examples for recordings with low (A) and high (B) fluctuations of frequency content (*spectral flux*) in frequency bands 1 (0-50 Hz) and 2 (50-100 Hz). Bright/yellow areas represents high energy at the corresponding time and frequency, blue/dark areas represent low energy.

Results showed that over the years, popular song recordings had clear increases in *RMS energy* and *spectral flux* in the full spectrum and in all frequency sub-bands. Similar to earlier reports on increased energy and loudness over time, we observed increases in full spectrum *RMS*

² The TT dynamic range meter does not measure the complete dynamic range of an audio signal; it focuses on the highest 20% of RMS values and is therefore especially sensitive to compression and limiting (Skovenborg, 2012).

energy, $r(60) = .842$, $p < .001$, and *spectral flux*, $r(60) = .693$, $p < .001$. *Dynamic range* decreased over time, $r(60) = -.65$, $p < .001$, and was negatively correlated with *RMS energy*, $r(60) = -.88$, $p < .001$.

Looking at individual frequency bands, the largest increases were in the bass range. Figure 2a depicts the striking increases over time of *spectral flux* in frequency band 1 (0-50 Hz), $r(60) = .78$, $p < .001$, and frequency band 2 (50-100 Hz), $r(60) = .72$, $p < .001$. Figure 2b shows that the lowest two frequency bands (0-50 Hz and 50-100 Hz) had the highest correlations ($rs > .7$) and regression slopes ($bs > .4$). The next strongest correlations occurred for the two highest frequency bands (6400-12800 Hz and 12800-22050 Hz) with rs of .67 and .64, respectively. Sub-band *RMS energy* showed the same pattern over time: The two strongest correlations occurred for the two lowest bands (rs of .77 and .79), followed by the two highest bands (rs of .68 and .66).

Figure 2. Analyses of the *spectral flux* across frequency bands for the top two songs from every year-end *Billboard* Hot 100 Chart from 1955-2016. Figure 2a depicts the striking increase of *bass flux* (bands 1 and 2) over time. Figure 2b depicts the correlation coefficients (●) and regression slopes (□) between year and *spectral flux* in bands 1-10, and that the most prominent increases are in the low-frequency bands.

Full spectrum *RMS energy* correlated with *sub-band flux* in all frequency bands, and the strongest correlations were in the lowest frequency bands (Table 1). Finally, when looking at changes in sub-band *spectral flux* over time in partial correlations that control for full spectrum

RMS energy, the only significant positive correlation between sub-band *spectral flux* and year was found in frequency band 1, $r_{\text{RMS}}(59) = .30, p = .021$. Partial correlations between year and *spectral flux* in the other sub-bands were either negative (bands 4-6) or nonsignificant (Table 1).

Table 1

Mean *spectral flux* for sub-bands 1-10, correlations between sub-band *spectral flux* and full-band *RMS energy* (r), and partial correlations between year and sub-band *spectral flux* controlling for the effect of full spectrum *RMS energy* (r_{RMS}). Bands 1-10: 0-50 Hz, 50-100 Hz, 100-200 Hz, 200-400 Hz, 400-800 Hz, 800-1600 Hz, 1600-3200 Hz, 3200-6400 Hz, 6400-12800 Hz, and 12800-22050 Hz.

Frequency band	1	2	3	4	5	6	7	8	9	10
Mean flux	14.8	25.8	29.7	30.8	34.2	31.8	27.7	20.3	14.0	6.3
r (full-band RMS * sub-band flux)	.82***	.77***	.60***	.67***	.67***	.66***	.56***	.59***	.72***	.64***
r_{RMS} (year * sub-band flux)	.30*	.21	-.05	-.36**	-.32*	-.30*	-.18	-.11	.16	.24

* $p < .05$, ** $p < .01$, *** $p < .001$

Discussion

The current results show that popular music has been getting louder, more compressed, and more bass-heavy. While increases in loudness and compression in music recordings are well known (e.g., Devine, 2013; Oehler et al., 2015; Serrà et al., 2012; Vickers, 2010), far less attention has been devoted to differences across the frequency spectrum. We observed that during the last decades the strongest increases in fluctuations of frequency content occurred in the lowest frequency bands (0-100 Hz). The lowest frequency bands were most closely associated with full-band *RMS energy*. When controlling for full-band *RMS energy*, only the lowest frequency band (0-50 Hz) still showed a significant increase over time, whereas midrange frequencies (200-1600 Hz) showed significant *decreases* over time. The upward trend of bass could reflect changes in preference, musical style, instrumentation, mixing, and/or recording equipment; but the bass boost in popular music over the last decades is clear and striking.

The evolution of recorded music partly mirrors evolution of technology. The 20th century brought electronic instruments and digital audio workstations for music recording and production. These workstations enabled sound engineers and music producers to apply more and more dynamic compression to make the recordings louder and louder. This “loudness war” has been widely reported (Devine 2013; Oehler et al., 2015; Serrà et al., 2012; Vickers, 2010), and is also apparent in our data: *RMS energy* increased and *dynamic range* decreased over the last decades. While increases in loudness and compression are common in the recording industry, recent work counters the view that louder and more compressed music sounds better – Croghan and colleagues (2012) showed that moderately compressed music might be preferred compared to uncompressed and heavily compressed music. These findings may explain why some studies report that *RMS energy* and compression have stabilized (Deruty & Tardieu, 2014) or even decreased (Deruty & Pachet, 2015) during the last few years.

The increase of bass frequencies over time may also be linked to technological evolution. For example, the upright acoustic bass in 1950s rock and roll eventually gave way to the more prominent electric bass of Paul McCartney and the British invasion in the 1960s. In the 1980s, the advent of drum machines allowed bass to grow louder and lower. Low-end bass levels continued to increase as portable boomboxes in the 1980s were supplanted by subwoofers in the 1990s and 2000s as the fashionable playback device. In music production, loud and clear low-end bass was difficult for producers to achieve before digital audio workstations; whereas now it can be achieved with the turn of a knob or the push of a button.

The technological evolution of recording and editing equipment might go hand in hand with the evolution of musical styles, genres, and listening preferences. Hip-hop/rap and electronic genres (e.g., electronica, breakbeat, house, techno) are characterized by prominent low-end bass frequencies (Pestana, Ma, Reiss, Barbosa, & Black, 2013) and became increasingly popular during the 1980s and 1990s (Mauch et al., 2015). Prominent low-end bass is featured in currently popular genres including dubstep and trap. In our sample, the recordings with the highest bass fluctuations are from similar genres: electronic/dance, hip-hop/rap, and R&B.

The rise of these movement-inducing genres might also explain the increase of “danceability” of music during the last decades (Interiano et al., 2018). Musical pieces with high “danceability” are more likely to end up at a high chart position (Askin & Mauskapf, 2017). The

ease of moving with music is tightly linked to bass frequencies on various levels. High energy in bass frequencies is positively associated with groove ratings (Stupacher et al., 2016; Hove et al., under review) and the induction of beat-related body movements (Burger et al., 2013; van Dyck et al., 2013; Varlet, Williams & Keller, 2018). Additionally, bass frequencies increase the behavioral and neural sensitivity to timing variations (Hove, Marie, Bruce, & Trainor, 2014), and enhance neural entrainment to meter-related frequencies (Lenc, Keller, Varlet, & Nozaradan, 2018). DJs commonly induce movement in listeners on the dancefloor with a “bass drop”: The removal of bass and bass drum from the audio mix to build tension, which is later released by reintroducing the bass instruments (Solberg, 2014). The “bass drop” might increase the amount of movement and improve synchronization of body movements and beat (Solberg & Jensenius, 2016). Musicians and producers cultivate many techniques to make their music more engaging; turning up the bass is one simple technique to increase engagement and contribute to chart success.

Conclusions

In sum, the observed increase in *RMS energy* and bass fluctuation over time is likely associated with a variety of technological and stylistic adaptations. We show that lower and louder bass frequencies contribute most strongly to the increase of *RMS energy* during the last decades. The increase in *RMS energy* likely stemmed from a view that it offered some competitive advantage of capturing attention, but it soon brought countervailing technology, such as heavy dynamic compression and limiting (e.g., as commonly used by radio stations to equalize loudness between songs). Limiting dynamic range may be undesirable (Croghan et al., 2012) and could contribute to the recent stabilization or decrease of *RMS energy* (Deruty & Pachet, 2015; Deruty & Tardieu, 2014). Similar to the evolution of *RMS energy*, increased loudness and fluctuation in bass frequencies might reflect the goal to make music more engaging and danceable by capturing a listener’s attention and inducing movement. However, increases in bass clearly have limits. While loud and clear low-end bass is engaging, on many playback devices, high bass levels sound distorted and unclear, and the lowest frequencies often fall below the device’s frequency-response range. Such issues commonly occur in Bluetooth speakers, which are popular today and projected to increase in popularity (“Bluetooth Speaker Market,” 2018). Future research will uncover

whether levels of bass frequencies – not unlike the evolution of overall loudness – might have already peaked.

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Appendix

Year	Song title	Artist
1955	Cherry Pink and Apple Blossom White	Perez Prado
1955	Rock Around the Clock	Bill Haley & His Comets
1956	Heartbreak Hotel	Elvis Presley
1956	Don't Be Cruel	Elvis Presley
1957	All Shook Up	Elvis Presley
1957	Love Letters in The Sand	Pat Boone
1958	Volare (Nel Blue Dipinto Di Blu)	Domenico Modugno
1958	All I Have to Do Is Dream	Everly Brothers
1959	The Battle of New Orleans	Johnny Horton
1959	Mack the Knife	Bobby Darin
1960	Theme From "A Summer Place"	Percy Faith
1960	He'll Have to Go	Jim Reeves
1961	Tossin' and Turnin'	Bobby Lewis
1961	I Fall to Pieces	Patsy Cline
1962	Stranger on The Shore	Mr. Acker Bilk
1962	I Can't Stop Loving You	Ray Charles
1963	Sugar Shack	Jimmy Gilmer & the Fireballs
1963	Surfin' USA	Beach Boys
1964	I Want to Hold Your Hand	The Beatles
1964	She Loves You	The Beatles
1965	Wooly Bully	Sam the Sham & the Pharaohs
1965	I Can't Help Myself (Sugar Pie Honey Bunch)	Four Tops
1966	The Ballad of the Green Berets	Sgt. Barry Sadler
1966	Cherish	Association
1967	To Sir With Love	Lulu
1967	The Letter	Box Tops
1968	Hey Jude	The Beatles
1968	Love Is Blue	Paul Mauriat
1969	Sugar, Sugar	Archies
1969	Aquarius/Let the Sunshine In	Fifth Dimension
1970	Bridge Over Troubled Water	Simon & Garfunkel
1970	(They Long to Be) Close to You	Carpenters
1971	Joy To The World	Three Dog Night
1971	Maggie May	Rod Stewart
1972	The First Time Ever I Saw Your Face	Roberta Flack
1972	Alone Again (Naturally)	Gilbert O'Sullivan
1973	Tie a Yellow Ribbon 'Round the Ole Oak Tree	Tony Orlando
1973	Bad Bad Leroy Brown	Jim Croce
1974	The Way We Were	Barbara Streisand
1974	Seasons in the Sun	Terry Jacks
1975	Love Will Keep Us Together	Captain & Tennille
1975	Rhinestone Cowboy	Glen Campbell
1976	Silly Love Songs	Wings
1976	Don't Go Breaking My Heart	Elton John & Kiki Dee
1977	Tonight's the Night (Gonna Be Alright)	Rod Stewart
1977	I Just Want To Be Your Everything	Andy Gibb
1978	Shadow Dancing	Andy Gibb
1978	Night Fever	Bee Gees
1979	My Sharona	Knack
1979	Bad Girls	Donna Summer
1980	Call Me	Blondie

1980	Another Brick in The Wall	Pink Floyd
1981	Bette Davis Eyes	Kim Carnes
1981	Endless Love	Diana Ross & Lionel Richie
1982	Physical	Olivia Newton-John
1982	Eye of the Tiger	Survivor
1983	Every Breath You Take	The Police
1983	Billie Jean	Michael Jackson
1984	When Doves Cry	Prince
1984	What's Love Got to Do With It	Tina Turner
1985	Careless Whisper	Wham!
1985	Like a Virgin	Madonna
1986	That's What Friends Are For	Dionne & Friends
1986	Say You, Say Me	Lionel Richie
1987	Walk Like an Egyptian	Bangles
1987	Alone	Heart
1988	Faith	George Michael
1988	Need You Tonight	INXS
1989	Look Away	Chicago
1989	My Prerogative	Bobby Brown
1990	Hold On	Wilson Phillips
1990	It Must Have Been Love	Roxette
1991	(Everything I Do) I Do It for You	Bryan Adams
1991	I Wanna Sex You Up	Color Me Badd
1992	End of the Road	Boyz II Men
1992	Baby Got Back	Sir Mix-a-Lot
1993	I Will Always Love You	Whitney Houston
1993	Whoomp! (There It Is)	Tag Team
1994	The Sign	Ace of Base
1994	I Swear	All-4-One
1995	Gangsta's Paradise	Coolio
1995	Waterfalls	TLC
1996	Macarena (Bayside Boys Mix)	Los Del Rio
1996	One Sweet Day	Mariah Carey & Boyz II Men
1997	Candle in The Wind	Elton John
1997	Foolish Games/You Were Meant for Me	Jewel
1998	Too Close	Next
1998	The Boy Is Mine	Brandy & Monica
1999	Believe	Cher
1999	No Scrubs	TLC
2000	Breathe	Faith Hill
2000	Smooth	Santana featuring Rob Thomas
2001	Hanging by A Moment	Lifhouse
2001	Fallin'	Alicia Keys
2002	How You Remind Me	Nickelback
2002	Foolish	Ashanti
2003	In Da Club	50 Cent
2003	Ignition	R. Kelly
2004	Yeah!	Usher featuring Lil' Jon & Ludacris
2004	Burn	Usher
2005	We Belong Together	Mariah Carey
2005	Hollaback Girl	Gwen Stefani
2006	Bad Day	Daniel Powter
2006	Temperature	Sean Paul
2007	Irreplaceable	Beyonce
2007	Umbrella	Rihanna featuring Jay-Z

2008	Low	Flo Rida featuring T-Pain
2008	Bleeding Love	Leona Lewis
2009	Boom Boom Pow	The Black Eyed Peas
2009	Poker Face	Lady Gaga
2010	Need You Now	Lady Antebellum
2010	Tik Tok	Kesha
2011	Party Rock Anthem	LMFAO featuring Lauren Bennett & GoonRock
2011	Rolling in the Deep	Adele
2012	Call Me Maybe	Carly Rae Jepsen
2012	Somebody That I Used to Know	Gotye featuring Kimbra
2013	Can't Hold Us	Macklemore & Ryan Lewis
2013	Harlem Shake	Baauer
2014	Dark Horse	Katy Perry featuring Juicy J.
2014	Happy	Pharrell Williams
2015	Thinking Out Loud	Ed Sheeran
2015	Uptown Funk	Mark Ronson featuring Bruno Mars
2016	Love Yourself	Justin Bieber
2016	Sorry	Justin Bieber