

Characteristics of Top Songs Has Changed from Pandemic Brain*

An analysis of songs on Billboard's Year-End Hot 100 singles list (2014 to 2023)

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April 17, 2024

Music often reflects the current climate of society and there is a growing interest in how hit songs as seen on Billboard's Year-End Hot 100 singles has changed after the COVID-19 pandemic. This paper looks at music characteristics such as tempo, song duration, loudness, and modality of songs from Billboard's Year-End Hot 100 singles list from 2014 to 2023 to reveal patterns and relationships to explain the difference between top songs before 2020 and 2020 onwards. The results show that hit songs from 2020 onwards had become on average shorter, quieter, but slightly faster with the melody of songs being in a major key. These results can support the evaluation of the emotional state of different populations and improve treatments such as music therapy, however further investigation is needed on the influence of lyrics on different music characteristics.

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*Code and data are available at: <https://github.com/ moonsdust/top-songs>.

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1 Introduction

During the COVID-19 pandemic, viral songs on social media sites such as TikTok were met with thousands of listens on streaming platforms such as Spotify and at times go onto being on lists like the Billboard Year-End Hot 100. These songs often accompany thousands of short clips of people talking about their lives, challenges, etc. Ghaffari et al in their study, “The impact of COVID-19 on online music listening behaviors in light of listeners’ social interactions” noted that other studies have found that people used music as a way to cope and regulate their thoughts and emotions during the pandemic and the lockdowns that came with it (Ghaffari et al. 2023). We can see this translated through the short-form videos where users don’t talk and instead have the song play out to convey how they are feeling or thinking. Ghaffari et al’s findings are similar to how music therapy works. As defined by the Canadian Association of Music Therapists, music therapy is the use of music to support an individual’s health, social development, and well-being and some of the techniques used include listening to music (Canadian Association of Music Therapists 2020). Hurwitz and Krumhansl conducted a study into how people’s listening habits throughout the pandemic and they found that the songs they listened to often were linked to an emotion such as sadness and/or invoking memories from the past (Hurwitz and Krumhansl 2021). However, this raises the following question, which we explored in our analysis: how are top songs prior to 2020 or the start of the pandemic different from the top songs during and after 2020? In our analysis, we defined hit songs before 2020 to be hit songs before the pandemic and hit songs during 2020 and afterwards to be hit songs during and after the pandemic.

In this paper, to investigate patterns and trends in music, we analyzed data from the Billboard Year-End Hot 100 singles list from 2014 to 2023 on music characteristics such as its modality (major or minor key), track duration, loudness, and tempo. Our estimand is the song characteristics from the Billboard Year-End Hot 100 singles such as its modality (major or minor), track duration, loudness, and tempo if a song was created before 2020 or during and after 2020. The list allowed us to gauge how preference in music characteristics has changed overall during and after the pandemic. Current studies give us a sense of how currently people are feeling based on surveys done. However, there is currently a lack of understanding and focus on the difference in musical characteristics of popular songs with the general population before the pandemic and during and after it. In our findings, our data showed that songs in a major key made up the majority of top songs before, during, and after 2020 and top songs were on average quieter, shorter, and had slightly faster tempos during and after 2020. [TODO: ADD RESULTS FROM MODEL]. Music can reflect the climate of society and understanding trends in music characteristics of hit songs can help provide insight on the overall feelings of different populations during and after the pandemic as well as before it. This can aid in improving treatments such as music therapy.

In the rest of this paper, the data section (Section 2) will cover the dataset used, how it was obtained, define the variables of interest that are used by our tables and graphs, and briefly explain the data cleaning process. The model section (Section 3) will explain our proposed causal model, which would explain potential relationships in our data, the setup of our model to understand these relationships, and justification for our model. In the results section (Section 4), we will reveal tables and graphs made on our datasets, explain what they show, and show our results from our model. In the discussion section (Section 5), we will connect back to the real world and explain what the results could mean, the implications of our results, potential areas of improvement for the paper, and suggestions for future works. Finally, the appendix section (Section A) will extra tables and graphs from our results as well, as additional information about the model, and a link to a Shiny application featuring interactive graphs of some of the results.

2 Data

2.1 Methodology

The dataset used in this paper was retrieved, simulated, cleaned, analyzed, and tested using the R programming language (R Core Team 2023), tidyverse (Wickham et al. 2019), knitr (Xie 2014), janitor (Firke 2023), dplyr (Wickham et al. 2023), ggplot2 (Wickham 2016), spotifyr (Thompson et al. 2022), usethis (Wickham et al. 2024), arrow (Richardson et al. 2024), ggcorrplot (Kassambara 2023), and testthat (Wickham 2011). Code written in the scripts was checked and styled with lintr (Hester et al. 2024) and styler (Müller and Walthert 2024). Accompanying the paper, a Shiny app (Chang et al. 2024) using shinyWidgets (Perrier, Meyer, and Granjon 2024) was created containing interactive visualizations. The packages that were

used for the model-related sections or used for the model itself are DiagrammeR (Iannone and Roy 2024), rsvg (Ooms 2023), magrittr (Bache and Wickham 2022), DiagrammeRsvg (Iannone 2016), png (Urbanek 2022), rstanarm (Goodrich et al. 2024), and modelsummary (Arel-Bundock 2022).

2.2 Data Source and Measurements

The data used for the model and analysis comes from the `playlists_analysis_data` dataset. This dataset was constructed by using an R wrapper for Spotify’s API called `spotifyr` (Thompson et al. 2022) to scrape playlists compiled by Spotify users `antoniomendoza` and `wickeddreamer96` of songs from the Billboard Year-End Hot 100 singles from 2014 to 2023 (Billboard 2024). User `antoniomendoza` created playlists for the years 2018 to 2023, inclusive, while user `wickeddreamer96` created playlists for the years 2014 to 2017, inclusive. The latest version of the data used was scraped on Tuesday March 26, 2024 at 9:46pm EDT. The Billboard Year-End Hot 100 singles list for the year 2014 onward was created based on data from Nielsen SoundScan (Manitoba Music 2024). Nielsen SoundScan collect data weekly from 39,000 retail outlets, venues, etc. in 19 countries such as Canada and the United States on in-store sales and digital sales (Manitoba Music 2024). They also track how often songs are streamed online and played on the radio (Manitoba Music 2024).

Initially, we had scraped playlists created by Spotify that they have compiled of the top songs on the app. However, we had an insufficient amount of observations from these playlists for our dataset since each only had around 50 songs and there were years where Spotify had not created a top song playlist for such as 2021 and 2022.

Each observation in the dataset belongs to a song from the Spotify playlist that we scraped compiled by `antoniomendoza` and `wickeddreamer96` for songs on the Billboard Year-End Hot 100 singles. For the duplicate songs that showed up in different years, they were kept as we wanted to analyze song characteristics. In total, there are 1000 observations in the `playlists_analysis_data` dataset, which equals to the number of songs on the Billboard Year-End Hot 100 singles lists from 2014 to 2023.

Table 1: Preview of dataset on Billboard Year-End Hot 100 singles from 2014 to 2023 provided by Spotify

hit_year	track_duration_ms	tempo	loudness	mode_name	key_mode	period
2014	232720	160.019	-4.662	minor	F minor	Before Pandemic
2014	215672	131.931	-6.122	major	F# major	Before Pandemic
2014	269560	119.930	-7.064	major	G# major	Before Pandemic

Table 1: Preview of dataset on Billboard Year-End Hot 100 singles from 2014 to 2023 provided by Spotify

hit_year	track_duration_ms	tempo	loudness	mode_name	key_mode	period
2014	199938	94.981	-4.141	minor	A# minor	Before Pandemic
2014	257840	122.017	-4.972	minor	C# minor	Before Pandemic
2014	177685	100.315	-7.321	major	F# major	Before Pandemic

Not seen in Table 1, before_pandemic, major, and minor are numerical versions of the mode_name and period columns. The variables that were originally the raw dataset that was scraped are track_duration_ms, tempo, loudness, mode_name, and key_mode. track_duration_ms describes the duration of the song in milliseconds (ms), tempo is the mean beats per minutes (BPM) of the song, and loudness is mean loudness of a top song in decibels (dB). mode_name represents the key the melody of the song is in, which is either “major” or “minor” and key_mode signifies the scale the song is in.

The variables constructed from the raw dataset are before_pandemic, period, hit_year, major, and minor. How these variables were constructed was that hit_year was obtained from check the name of the playlist and it represents the hit. From hit_year, the period column was constructed, which indicates whatever or not the hit year of the song was before 2020, which was when the COVID-19 pandemic started, or during 2020 onwards. Reading from the period column, the before_pandemic column was created, where 1 represents that the song was a hit song before the pandemic and 0 otherwise. The major and minor columns represents whatever or not the melody of the song is in a major or minor key and the value would be 1 if it’s that key and 0 otherwise. These columns were constructed from checking mode_name when it would indicate either “major” or “minor”.

2.3 Variables of Interest

As seen in Table 1, there are multiple columns however our main variables of interests are before_pandemic, track_duration_ms, loudness, tempo, and mode_name for our model. The major and minor columns were used initially to visualize potential relationships between variables as seen in Figure 14. period, hit_year, and key_mode were used to visualize our data prior to training our model and to understand the data.

3 Model

From our analysis of the data, we observed that there were trends between a song’s duration, loudness, tempo, and modality for top songs prior 2020 and 2020 onwards. We are interested in investigating if a song is likely to be a top song prior to 2020 or not based on what we know about the duration, loudness, tempo, and modality of a top song. We will do this by creating a model.

3.1 Model set-up

In order to predict a top song was a hit prior to 2020, we will make the assumption that there is a relationship between the outcome variable, if the song is a top song prior to 2020 and our variables of interests: duration, loudness, tempo, and modality. Our variables of interests will be the predictor variables for the model. We will define our model as a logistic regression model with a Bayesian approach as follows:

$$\begin{aligned}y_i|\pi_i &\sim \text{Bern}(\pi_i) \\ \text{logit}(\pi_i) &= \beta_0 + \beta_1 \times \text{duration}_i + \beta_2 \times \text{loudness}_i + \beta_3 \times \text{tempo}_i + \beta_4 \times \text{modality}_i \\ \beta_0 &\sim \text{Normal}(0, 2.5) \\ \beta_1 &\sim \text{Normal}(0, 2.5) \\ \beta_2 &\sim \text{Normal}(0, 2.5) \\ \beta_3 &\sim \text{Normal}(0, 2.5) \\ \beta_4 &\sim \text{Normal}(0, 2.5)\end{aligned}$$

We define y_i to be a top song, which if it is 1 represents a top song prior to 2020 and 0 if it is a top song from 2020 onwards. π_i is the probability that a top song i is a top song prior to 2020. Let duration_i be the duration of the top song in milliseconds (ms) and loudness_i to be the mean loudness of a top song in decibels (dB). Set tempo_i to be the mean beats per minutes (BPM) of a top song and modality_i to be the modality of the top song, where 1 means the melody of the song is in a minor key and 0 if it is in a major key.

We ran the model using the `rstanarm` package (Goodrich et al. 2024) and R (R Core Team 2023) with the default priors from the `rstanarm` package. Diagnostics related to the model such as a trace plot, Rhat plot, and posterior predictive check can be found at Section A.

3.1.1 Model justification

A logistic regression model was chosen because our outcome variable, if the song is a top song prior to 2020, is a binary outcome. However, alternative models were considered such

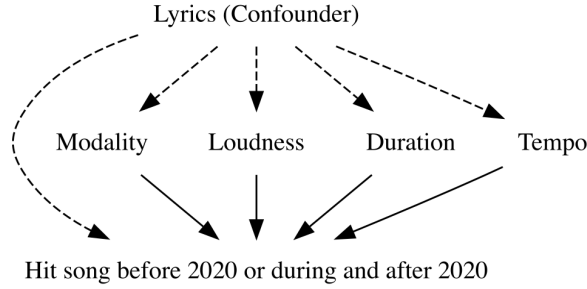


Figure 1: Causal relationship between song characteristics and hit song (before 2020 or during and after 2020)

as a multiple linear regression model since the model has multiple predictor variables. Other regressions models like negative binomial regressions were also considered but they were not chosen since we are not dealing with discrete counts for the outcome. Our logistic regression model describes the following causal relationship (Figure 1) where song characteristics predicts whatever a hit song was made prior to 2020, excluding a confounding variable, lyrics. The assumption we make is that there is a relationship between song characteristics and a top song being a hit prior to 2020. In Figure 1, the reason lyrics, if there are any, is a confounding variable is because lyrics can affect not only if the song was a hit prior to 2020 but also song characteristics from the way the lyrics are performed. However, we are unable to observe the effects of lyrics directly with our data. Weakness and further improvements to the model are discussed in Section 5.

4 Results

In this section, we visualized our data through graphs and tables as well as present the results from our model.

4.1 Difference in song characteristics before 2020 (the pandemic) and during and after 2020 (the pandemic) of songs from the Billboard Year-End Hot 100 singles

4.1.1 Scale and Modality

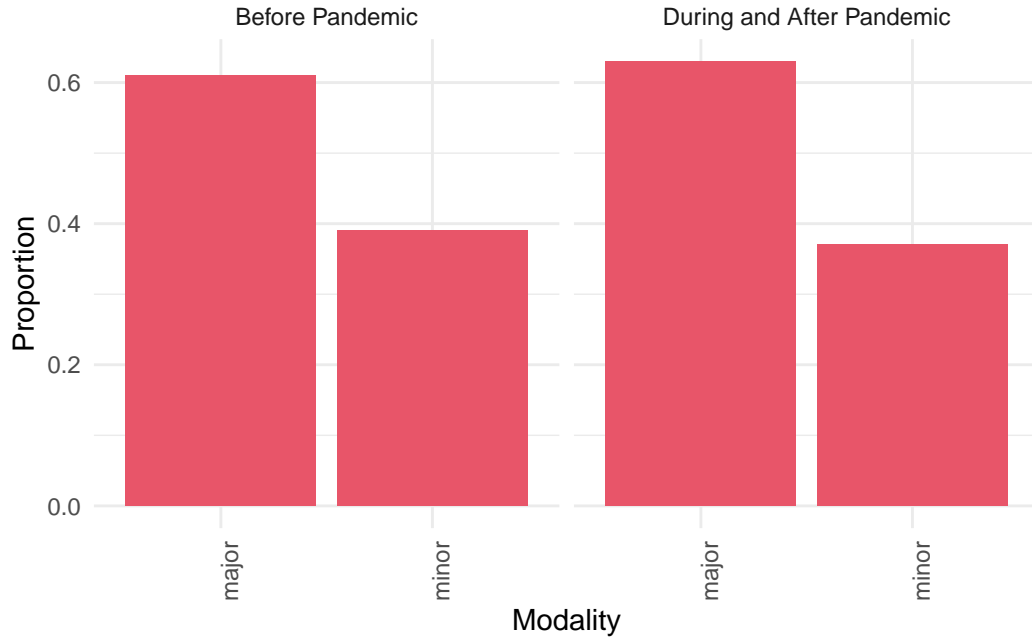


Figure 2: Proportion of songs whose modality is in a major or minor key before 2020 (the pandemic) versus during and after 2020 (the pandemic) from Billboard's Year-End Hot 100 singles

Table 2: Proportion of songs whose modality is in a major or minor key before 2020 (the pandemic) versus during and after 2020 (the pandemic) from Billboard's Year-End Hot 100 singles

Period	Modality	Count of each mode	Proportion of each mode
Before Pandemic	major	368	0.61
Before Pandemic	minor	232	0.39
During and After Pandemic	major	251	0.63
During and After Pandemic	minor	149	0.37

Figure 2 and Table 2 reveals that a proportion of hit songs before and during and after 2020 that had melodies in a major key was around ~60% (61% before 2020 and 63% from 2020

onwards). Songs in a minor key made up about 40% or less of songs (39% before 2020 and 37% from 2020 onwards) from 2014 to 2023 on Billboard’s Year-End Hot 100 singles list. There was a slight increase in songs in a major key from 2020 afterwards however songs in a major key making up a majority of Billboard’s Year-End Hot 100 singles stayed consist before 2020 and 2020 onwards.

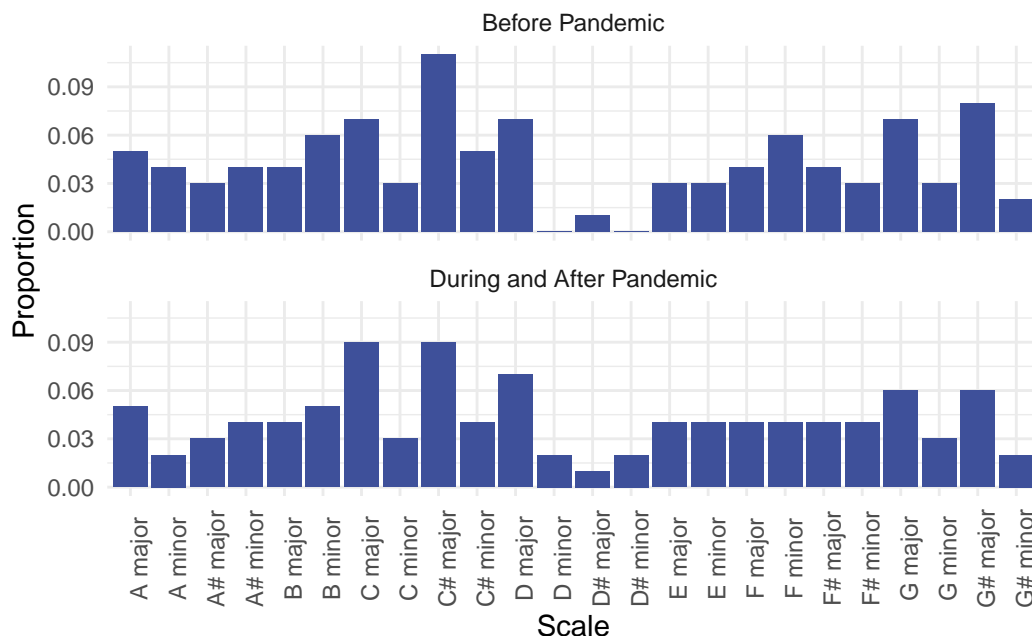


Figure 3: Proportion of songs in different scales before 2020 (the pandemic) versus during and after 2020 (the pandemic) from Billboard’s Year-End Hot 100 singles

When looking into the specific scales of the songs, Figure 3 and Table 10 shows that there was an increase in songs in C major during and after 2020 with C major and C# major made up a majority of songs from Billboard’s list from 2020 onwards at approximately 9% each. Prior to 2020, the proportion of songs in C major were at 11% however there was a decline in songs in C major after the start of the pandemic. There was a decline in songs in G# major from 8% of the list to 6% of the list as well as a an increase in songs in D minor and D# minor from less than 1% of the list to 2% each. There were also a decline in songs in F minor where they would make up 6% of Billboard’s list prior to 2020 to 4% during and after 2020.

4.1.2 Track Duration

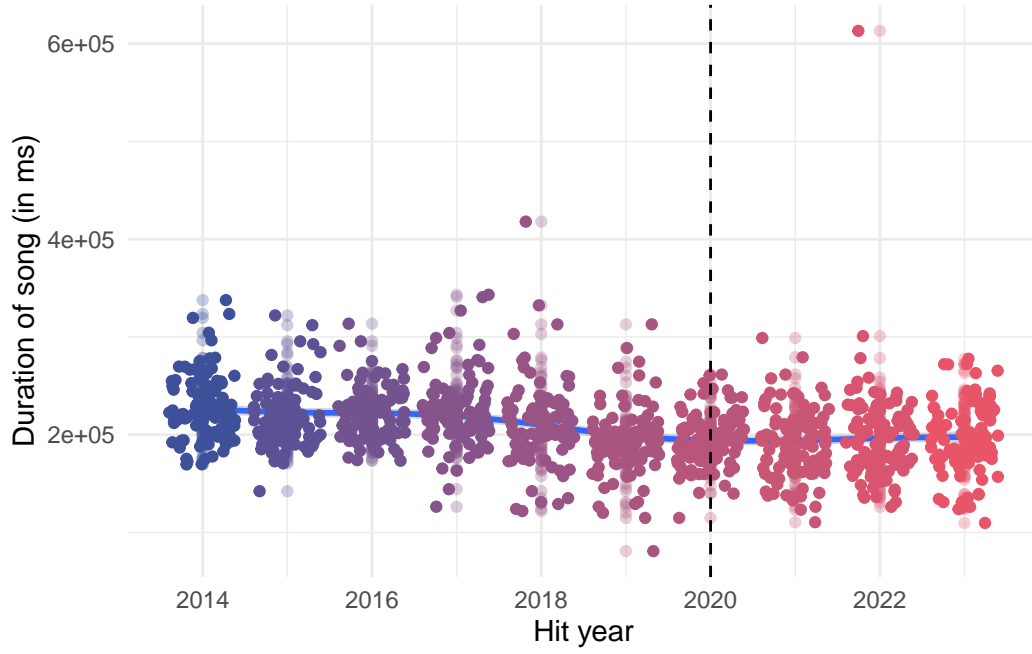


Figure 4: Relationship between the hit year and track duration of a song on Billboard's Year-End Hot 100 singles. Songs from the same year are grouped in the same colour and the horizontal, dashed line divides the hit tracks before 2020 and hit tracks from 2020 and beyond. Blue curve describes the overall trend.

Table 3: Minimum, quartiles, median, and maximum of track duration (in ms) before 2020 (the pandemic)

Duration of song (in ms)
Min. : 80927
1st Qu.:194600
Median :214070
Mean :216286
3rd Qu.:233087
Max. :417920

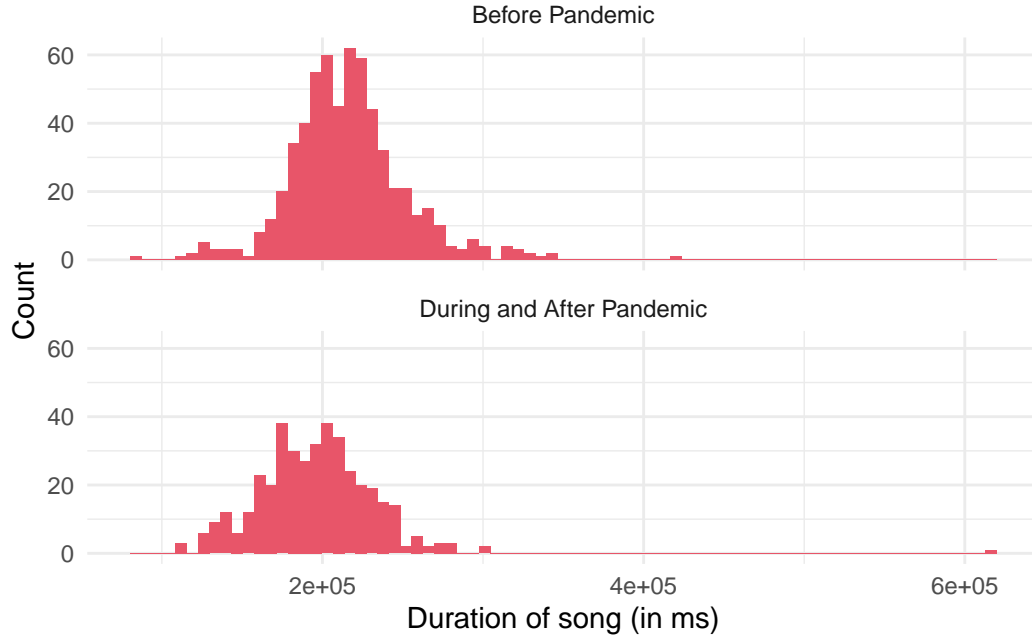


Figure 5: Distribution of track duration (in ms) before 2020 (the pandemic) versus during and after 2020 (the pandemic) from songs on Billboard’s Year-End Hot 100 singles list.

Table 4: Minimum, quartiles, median, and maximum of track duration (in ms) during and after 2020 (the pandemic)

Duration of song (in ms)
Min. :109750
1st Qu.:173369
Median :195120
Mean :195999
3rd Qu.:215336
Max. :613026

Figure 4 reveals that songs over the years from 2014 to 2023 decreased slightly in duration overall. Figure 5 shows that distribution in

Figure 6

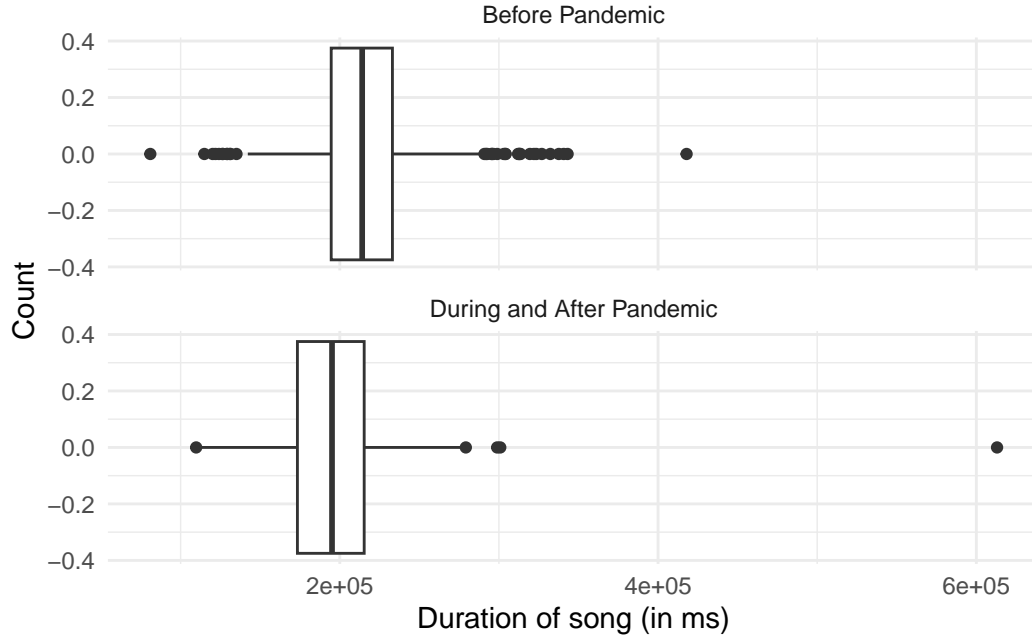


Figure 6: Track duration (in ms) before 2020 (the pandemic) versus during and after 2020 (the pandemic) from songs on Billboard’s Year-End Hot 100 singles list.

4.1.3 Loudness

Table 5: Minimum, quartiles, median, and maximum of loudness of song (in dB) before 2020

Loudness of song (in dB)
Min. :-18.071
1st Qu.: -7.051
Median : -5.700
Mean : -5.964
3rd Qu.: -4.705
Max. : -1.746

Table 6: Minimum, quartiles, median, and maximum of loudness of song (in dB) during and after 2020

Loudness of song (in dB)
Min. :-17.829
1st Qu.: -7.604

Table 6: Minimum, quartiles, median, and maximum of loudness of song (in dB) during and after 2020

Loudness of song (in dB)
Median : -6.151
Mean : -6.516
3rd Qu.: -5.109
Max. : -2.278

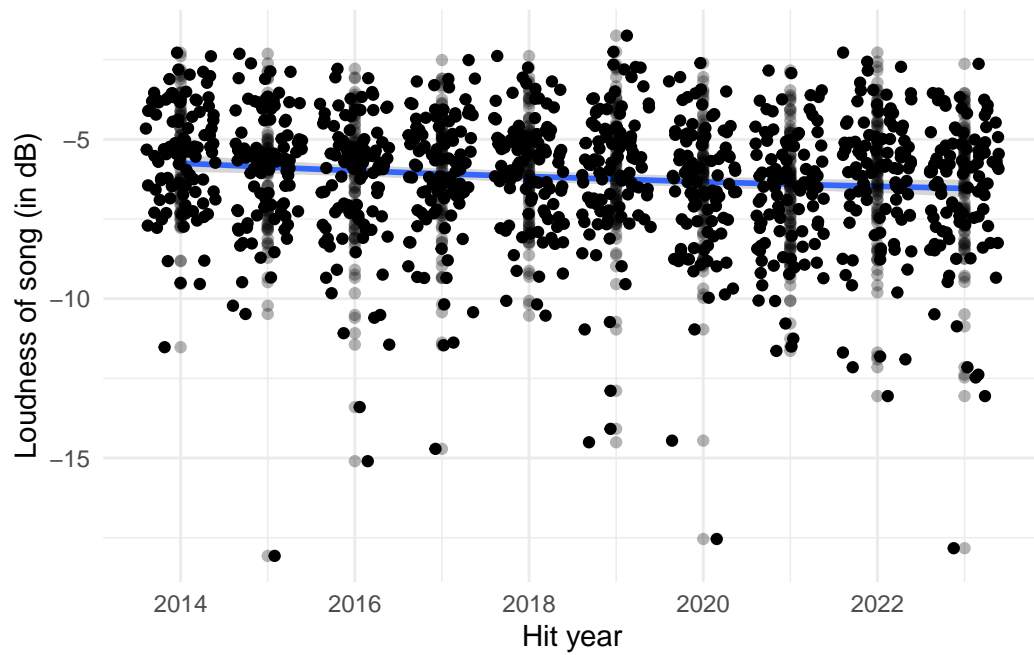


Figure 7: Relationship between the hit year and loudness of a song

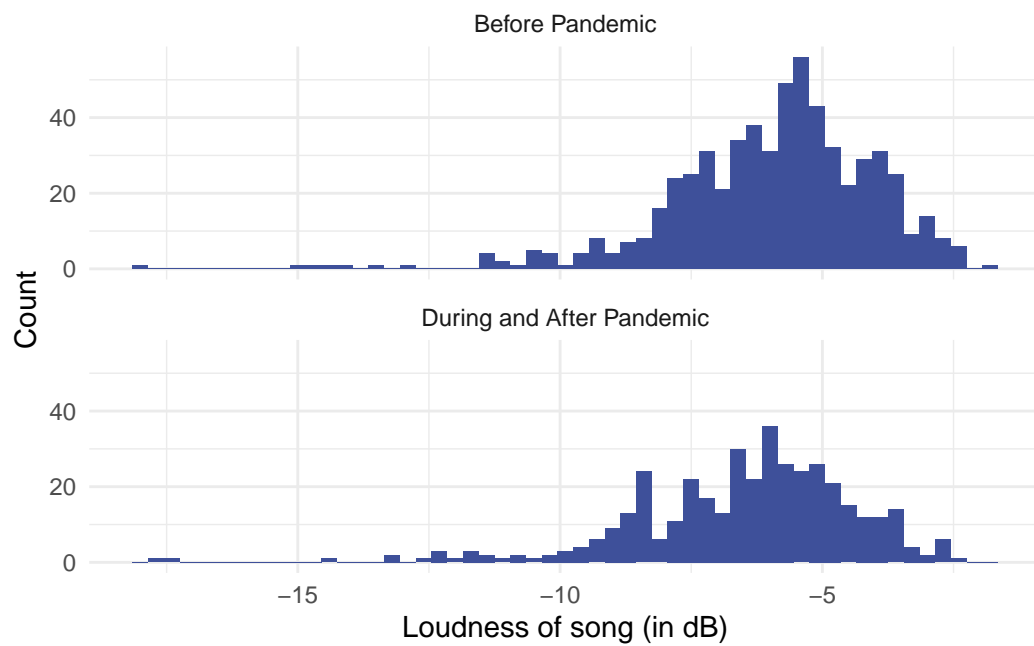


Figure 8: Distribution of loudness (in dB) before 2020 versus during and after 2020

4.1.4 Tempo

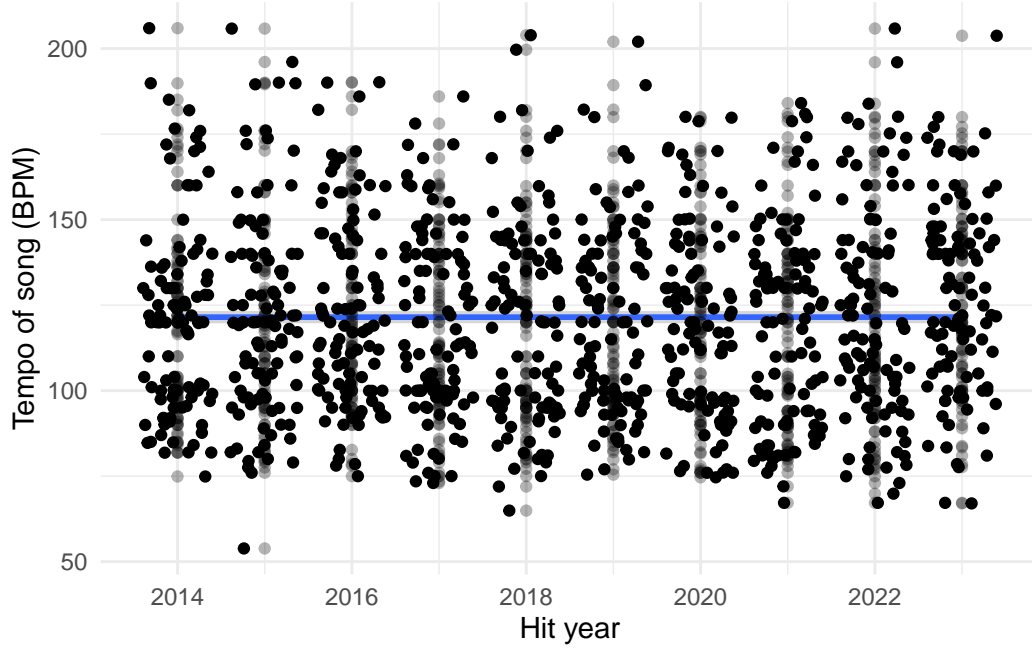


Figure 9: Relationship between the hit year and tempo of a song

Table 7: Minimum, quartiles, median, and maximum of tempo of a song (BPM) before 2020

Tempo of song (BPM)
Min. : 53.86
1st Qu.: 98.03
Median :119.98
Mean :121.11
3rd Qu.:140.00
Max. :205.97

Table 8: Minimum, quartiles, median, and maximum of tempo of a song (BPM) during and after 2020

Tempo of song (BPM)
Min. : 67.03
1st Qu.: 98.02
Median :120.03

Table 8: Minimum, quartiles, median, and maximum of tempo of a song (BPM) during and after 2020

Tempo of song (BPM)
Mean :122.06
3rd Qu.:142.31
Max. :205.86

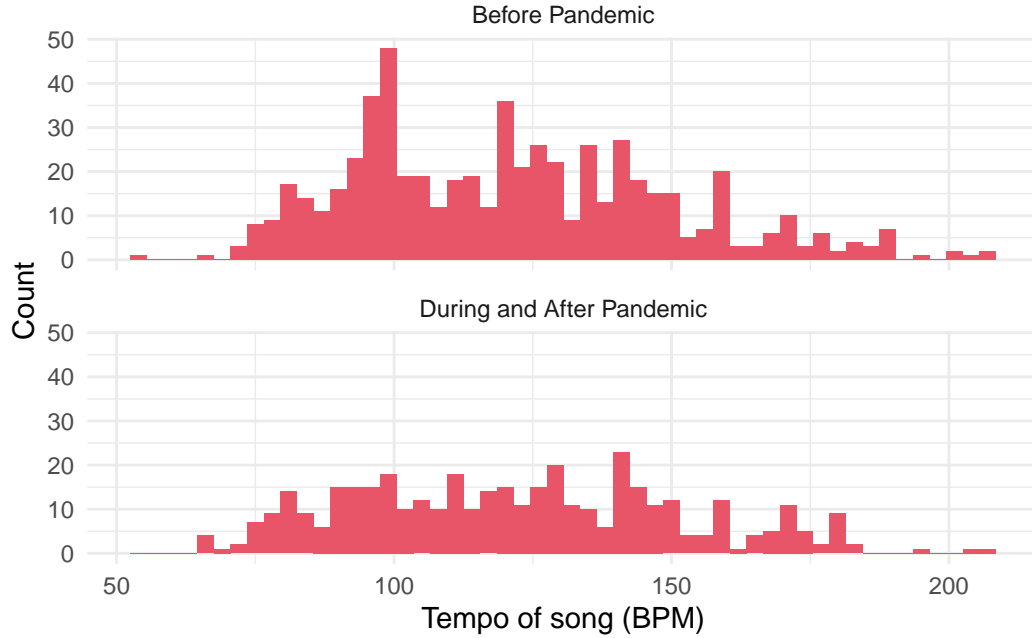


Figure 10: Distribution of tempo (BPM) before 2020 versus during and after 2020

4.2 Model Results

Table 9 and Figure 11 shows the results of our logistic regression model. Table 9 shows the coefficient estimates obtained for our model with their mean absolute deviation (MAD) while Figure 11 showcases the coefficient estimates (the dot) alongside their 90% credible interval (the line). Coefficient estimates represents....(Minitab 2024). Mean absolute deviation is....

Table 9 indicates that the y-intercept is -2.002, this however has no meaning in this situation since we only have two outcomes, 0 and 1 to represent a hit song from 2020 onwards and a hit song prior to 2020, respectively. Table 9 and Figure 11 reveal that the coefficient of track duration is 0.000 when tempo, mode, and loudness remains constant and its credible interval..... [The credible interval means.....] This indicates there is no relationship between a song being a hit before 2020 and the duration of the song.

Table 9: Relationships of a hit song is a hit before 2020 / the pandemic with its tempo, song duration, loudness, and modality with their mean absolute deviation (MAD) values in parenthesis.

A hit song before 2020	
(Intercept)	−2.002 (0.550)
track_duration_ms	0.000 (0.000)
loudness	0.148 (0.033)
tempo	−0.002 (0.002)
mode_nameminor	0.095 (0.139)
Num.Obs.	1000
R2	0.096
Log.Lik.	−624.867
ELPD	−630.3
ELPD s.e.	12.9
LOOIC	1260.6
LOOIC s.e.	25.7
WAIC	1260.6
RMSE	0.46

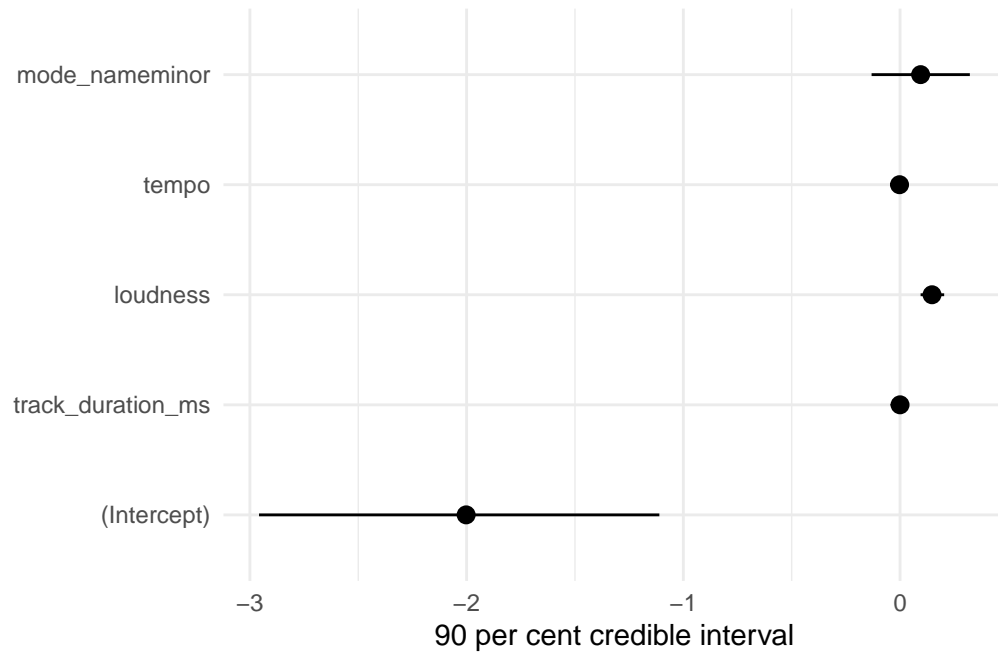


Figure 11: The credible intervals (line) for coefficient estimates (dot) of predictors of a hit song before 2020

5 Discussion

[To Do]

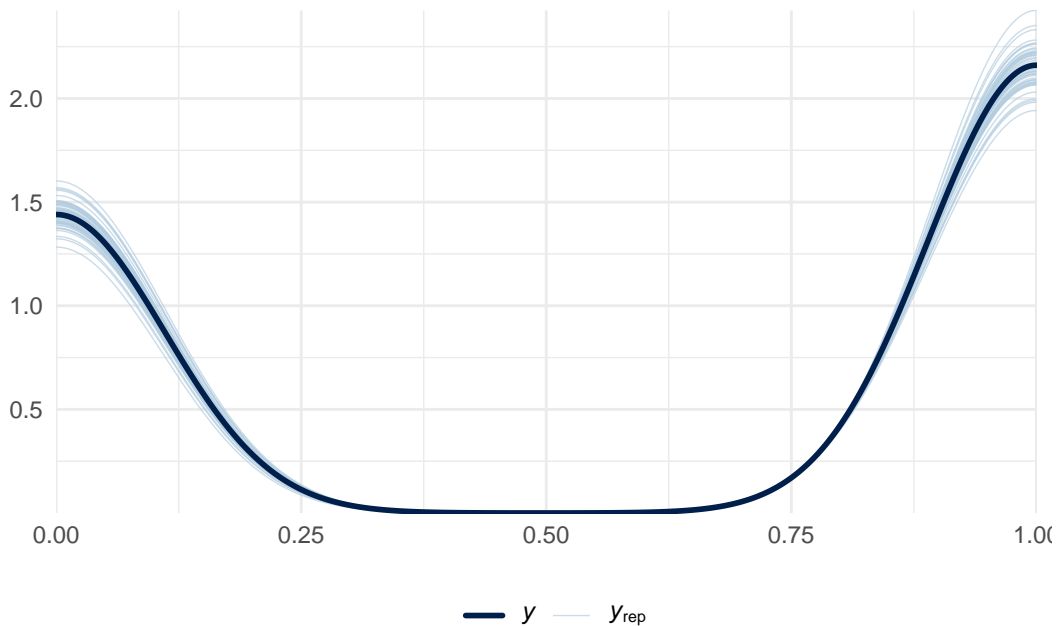
A Appendix

A.1 Shiny application

A Shiny application featuring interactive graphs from the paper can be found here: <https://49z7k8-emily-su.shinyapps.io/top-songs-characteristics-app/>

A.2 Posterior predictive check for model

Figure 12 shows that the posterior distribution of the fitted model is consistent with the actual data.



(a) Posterior prediction check for the model

Figure 12: How the data impacts how the model fits

A.3 Diagnostics for model

Figure 13 shows that the sampling algorithm used, the Markov chain Monte Carlo (MCMC) algorithm, did not run into issues as the posterior distribution for the model was created. Both graphs do not show anything abnormal.

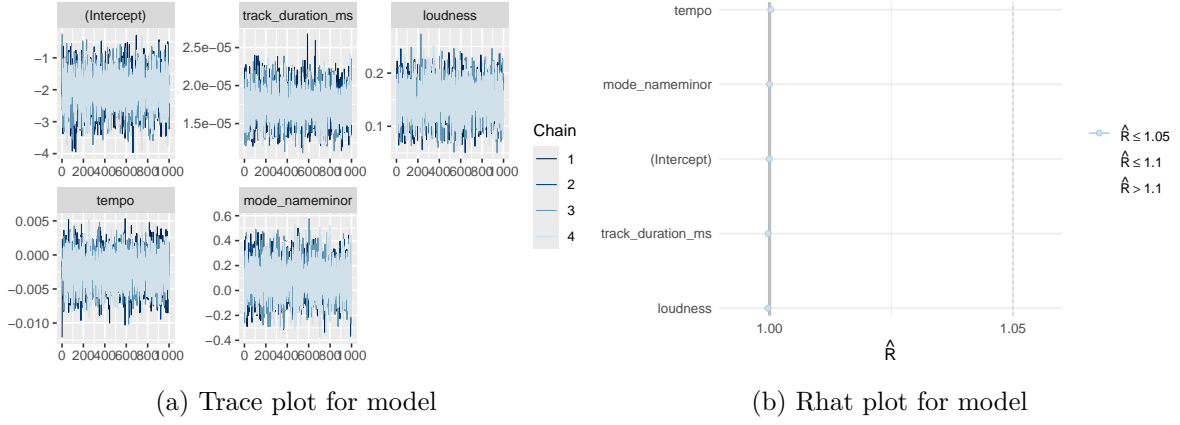


Figure 13: Checking the convergence of the Markov chain Monte Carlo (MCMC) algorithm for hit song model

A.4 Additional Figures

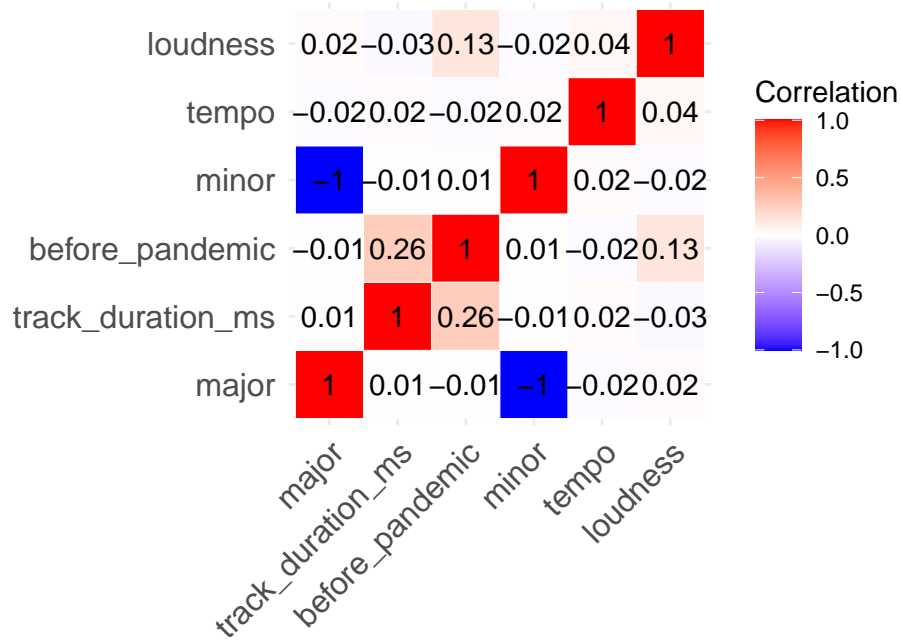


Figure 14: Correlation between numerical characteristics of songs from Billboard Year-End Hot 100 singles list and if song was a hit before 2020/the pandemic

A.5 Additional Tables

Table 10: Proportion of songs in different scales before 2020 (the pandemic) versus during and after 2020 (the pandemic) from from Billboard’s Year-End Hot 100 singles

Period	Scale	Count of each scale	Proportion of each scale
Before Pandemic	A major	28	0.05
Before Pandemic	A minor	23	0.04
Before Pandemic	A# major	18	0.03
Before Pandemic	A# minor	23	0.04
Before Pandemic	B major	22	0.04
Before Pandemic	B minor	38	0.06
Before Pandemic	C major	41	0.07
Before Pandemic	C minor	17	0.03
Before Pandemic	C# major	64	0.11

Table 10: Proportion of songs in different scales before 2020 (the pandemic) versus during and after 2020 (the pandemic) from from Billboard’s Year-End Hot 100 singles

Period	Scale	Count of each scale	Proportion of each scale
Before Pandemic	C# minor	30	0.05
Before Pandemic	D major	41	0.07
Before Pandemic	D minor	2	0.00
Before Pandemic	D# major	5	0.01
Before Pandemic	D# minor	2	0.00
Before Pandemic	E major	15	0.03
Before Pandemic	E minor	19	0.03
Before Pandemic	F major	21	0.04
Before Pandemic	F minor	33	0.06
Before Pandemic	F# major	24	0.04
Before Pandemic	F# minor	17	0.03
Before Pandemic	G major	41	0.07
Before Pandemic	G minor	18	0.03
Before Pandemic	G# major	48	0.08
Before Pandemic	G# minor	10	0.02
During and After Pandemic	A major	19	0.05
During and After Pandemic	A minor	8	0.02
During and After Pandemic	A# major	13	0.03
During and After Pandemic	A# minor	14	0.04
During and After Pandemic	B major	14	0.04
During and After Pandemic	B minor	20	0.05
During and After Pandemic	C major	36	0.09
During and After Pandemic	C minor	12	0.03
During and After Pandemic	C# major	36	0.09
During and After Pandemic	C# minor	15	0.04
During and After Pandemic	D major	29	0.07
During and After Pandemic	D minor	8	0.02

Table 10: Proportion of songs in different scales before 2020 (the pandemic) versus during and after 2020 (the pandemic) from from Billboard’s Year-End Hot 100 singles

Period	Scale	Count of each scale	Proportion of each scale
During and After Pandemic	D# major	6	0.01
During and After Pandemic	D# minor	7	0.02
During and After Pandemic	E major	17	0.04
During and After Pandemic	E minor	14	0.04
During and After Pandemic	F major	16	0.04
During and After Pandemic	F minor	14	0.04
During and After Pandemic	F# major	16	0.04
During and After Pandemic	F# minor	18	0.04
During and After Pandemic	G major	23	0.06
During and After Pandemic	G minor	11	0.03
During and After Pandemic	G# major	26	0.06
During and After Pandemic	G# minor	8	0.02

References

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