Raising curiosity about open data via the 'Physiradio' *musicalization* IoT device

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Abstract

Open data is a technical concept and a political movement since datasets (on environment, businesses, etc.) can be used to verify/falsify (*ex ante* and *ex post*) governmental policies ("civic accountability"). But data analysis is not for the masses: the average citizen may not even know the existence of open data. Here the challenge is to raise interest, curiosity and the need for knowledge in the common person. Data physicalization may be of some help: by creating a familiar device (e.g., a radio) that 'physicalizes' some publicly available data, the authors are trying to raise curiosity about the source and availability of open data (e.g., weather status) and the techniques underlying data access, extraction and analysis.

This paper presents the prototype of a desktop 'Physiradio' that plays Internet streams according to a mapping between weather condition and musical genre, i.e., a *musicalization* process. The association (weather → musical genre) is subjective but understandable by non-technical people: this device internal workings can be almost fully grasped by the average citizen, thus it can be used as a conversation starter.

Physiradio was field-tested among coworkers, students and common people through a quanti-qualitative information gathering process. The field test data presented here can be useful to measure the efficacy in:

- conveying information (i.e., verifying the mapping)
- raising curiosity about internals and open data techniques

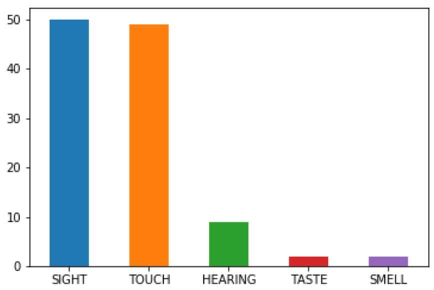
Keywords: data physicalization, open data, Internet Of Things, musicalization

1 Open data and its problems

Open data has become a worldwide movement involving governmental and non-governmental actors. The Open Knowledge Foundation (OKF, [14]) was one of the first organizations to define "openness" in this context, its definition can be quoted as: "A piece of data or content is open if anyone is free to use, reuse, and redistribute it - only subject, at most, to the requirement to attribute and/or share-alike" (i.e., data that can be used openly in terms of license). "HM Government's Open Data White Paper" [9] states that Open Government Data is "Public Sector Information that has been made available to the public as open data" and defines Public Sector Information (PSI) as "data and information produced, collected or held by public authorities, as part of their public task", data that should be accessible (ideally via the internet) at marginal cost and without discrimination, available in a digital and machine-readable format, and provided free of restrictions on use or redistribution. Berners-Lee [2] and Davies [7] defined open data ratings to highlight the importance of technical aspects of openness, for example through the use of open standards and non-proprietary file formats for open data publishing. Moreover, Berners-Lee and others [1, 3] promoted the concept of 'linked open data' to transform "data on the web" into "the web of data" by encouraging the linking of one's own data with other datasets.

Open data is a technical concept that is also becoming a political movement since datasets (on environment, businesses, etc.) can be used to verify/falsify (*ex ante* and *ex post*) governmental policies: open data can be a means to "civic accountability". Any citizen, **with enough knowledge**, can retrieve data (that can be better trusted if coming from third party sources) from public servers and study the effect of laws such as a change of tobacco taxation on number of smokers, the banning of some types of vehicles on air quality [19], the introduction of specific legislation to lower the number of unoccupied people, etc...

But data analysis is not for the masses [16]: the average citizen either does not know the existence of open data, or he/she is not able to extract information from a dataset. Here the challenge is to raise interest, curiosity and thus the need for knowledge in the common person. Even if he/she will eventually decide not to learn how to analyse datasets, at least he/she will have had the chance to reason about the possibility to leverage (with the help of a data scientist) his/her right to "civic accountability".



	INVOLVED
SIGHT	50
TOUCH	49
HEARING	9
SMELL	2
TASTE	2

Figure 1: Senses used in data physicalization. Total entries: 51

2 Help from 'data physicalization'

Data Physicalization is a recent area of research based on the physical representation of any nature and kind of data. While physical data representations have existed for centuries[1], recent creations of actuated tangible interfaces, advanced pervasive technologies and the increasingly widespread distribution of embedded systems and components, led to the development of a new research area: creating "modern" ways to (often dynamically and interactively) represent data through informatics tools coupled with sensors, actuators, etc.

The authors wonder if data physicalization may be of some help to solve the aforementioned "open data exploitation problem": can the creation of a familiar and unthreatening physicalizing device (e.g., a vintage-looking radio) be a vehicle of knowledge transfer? Could such an object be able to raise curiosity about the source and availability of some data (e.g., weather status) and the techniques underlying data access, extraction and analysis? Previous work is promising.

According to [11] data physicalization may:

- "help people explore, understand and communicate data using computer-supported physical data representations"
- make data more accessible/reachable
- foster cognitive benefits
- *democratize* data into the real world
- engage people

The democratization aspect is also proposed in [20] where 'Domestic Widgets' are used to successfully support household creativity and co-creation of data representations.

In [18] "DIY, hacking, and craft" are suggested as powerful democratizing tools.

IoT (Internet of Things) devices are exploited in [10] w.r.t. "the potential to democratize the access, use, and appropriation of data", since "most of the data is 'black box' in nature: users often do not know how to access or interpret data". These devices, "blended into homes", can be used to engage non-technical users.

For the project presented here, the authors were intrigued by data representations not mainly based on visualization (i.e., sight-based), that is the most used and maybe natural choice in the technical context, but also through physicalizations relying on other human senses. The preliminary work was an analysis of the papers listed in the bibliography on the official data physicalization website[2] to extract the ones describing a physical prototype/product that could give a real implementation of the data physicalization concept. Three main factors were analysed:

- human senses exploited
- interactivity level
- dynamicity level

This analysis resulted in a dataset[3] where useful information could be extracted from. Although the authors are aware that this analysis can be subjective w.r.t. the act of reading and interpreting articles, they tried to make it as "mechanical" as possible, by adopting the following criteria:

1. SENSES: boolean flags for every human sense (SIGHT, TOUCH, HEARING, TASTE, SMELL) where 1 = exploited and 0 =not exploited
2. INTERACTION: interaction level was described by 3 values:
   - 0 = no interaction
   - 1 = interaction with the prototype changes physicalization parameters (data remains the same)
   - 2 = interaction with the prototype changes the dataset or updates the physicalization
3. DYNAMICITY: a boolean flag (STATIC=0, DYNAMIC=1), where DYNAMIC means there is a constant connection between physicalization and data (real time), i.e., if data changes the physicalization is updated.

The results (Figure 1) show that the most used senses are **sight** and **touch**; while **hearing**, **taste** and **smell** are seldom exploited. With this in mind, the authors wondered if there was a way to take advantage of these "minor" senses. Acknowledging the technological difficulties in using smell and taste as senses for a physicalization, the remaining sense was hearing: this way the idea to use music, and genre in particular, arose.

In fact, music is part of everyone's life: willing or unwilling we all listen to it, and it manages to stimulate emotions and moods, which may be useful to canalize data. Although the perception of every song, of any

[1] See the list on `http://dataphys.org/list`

[2] `http://dataphys.org/wiki/Bibliography`

[3] Published in `https://doi.org/10.5281/zenodo.3612806`

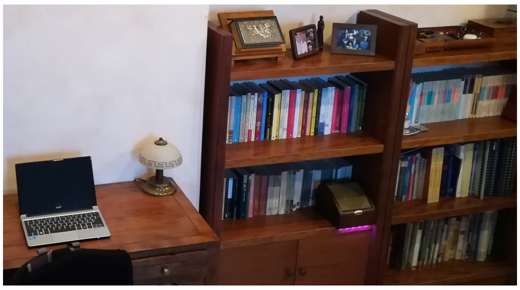


Figure 2: Can you spot the device? (hint: LEDs)

genre and artist, is different for each one of us, the thought of using music as a means of "physicalizing" data, obviously through hearing, was sound (pun intended). Of course, music can bring more subjectivity in the interpretation and it introduces several variables to consider, not least the fact that the field of psychology and psychoacoustics may also be involved.

Finally, two more factors were considered: object interactivity and data dynamicity. The papers analysis shows low levels for both aspects: the majority of the devices use static data and allows little physical interaction. Thus, for this project, the authors devised a solution, named 'Physiradio', capable of managing data in real-time, where both the data to represent and the experience with which to interact, are dynamic and in continuous change.

3 *Blended* Internet of Things

IoT (Internet of Things) refers to (often) small devices directly connected to a network. In particular, they usually have the ability to transfer data back and forth without human intervention, they can be simple sensors/actuators or more complex devices like personal assistants to manage environmental conditions (e.g., air conditioning, kitchen, production lines, etc.).

To implement a device to be accepted by non-technical people, the Physiradio creators decided to build a couple of IoT appliances inside vintage wooden Magneti Marelli speaker boxes.

Why going with IoT instead of developing a mobile application? Because the authors thought about the use cases of this specific physicalization, and realized that the best idea was to create something that every person (regardless of age) could play with and represent data in the comfort of her/his own home, workspace, office, in the car, etc… A kind of blended[4] "smart home" device, which, in future developments, may be adapted to diverse situations.

Next, the problem of choosing an easy-to-grasp open data was addressed. The authors searched for some kind of data that can be interpreted and understood by anyone, not only by people coming from scientific/technical studies. Weather condition came out as the most natural choice because it is something within the reach of all; while it may seem a useless[5] information, nonetheless in the context of this experiment it was just a starter for conversations and stimulus for suggestions that in fact came in quantities (see below in 8). Physiradio relies on OpenWeather[6], an open data platform that provides many standard meteorological services. In addition, it supplies an API (Application Programming Interface) to allow software access to real-time meteorological data.

4 Music physicalization ("Musicalization")

Music is a huge world, with whole semantics. Music may also express a wide range of emotions, feelings and moods. When trying to analyze a song, there are a lot of parameters to consider: tempo (bpm), mode (major/minor), pitch, loudness, etc… Moreover, it is complicated to evaluate which song is more suited to a particular context as presented in [8] where an approach to music vs. emotion classification is described. Another fundamental aspect is that the lyrics of a song can convey information to the listener (if the words are understood, of course), but music and lyrics may be discordant for the mood that the song wants to canalize (e.g., 'Some Nights' by Fun is famous for this feature) thus causing problems to any classification effort.

There are specific techniques to transfer information via simple sounds generation such as the so called *sonification*[7], see for example [4] and [13] who present a face-tracking and sound-synthesis techniques to *sonify* facial expressions in order to help people with visual problems, and a reference system to interpret already-existing and future *sonification* models. A simple and steady sound cannot be listened to for a long period of time because it can be very annoying. So when a softer and more bearable (for the listener) technique must be used, *musification* comes to help.

Musification has been defined as the musical representation of data. It is designed to go beyond direct sonification and includes elements of tonality and the use of modal scales to build music compositions (see [6]). The resulting musical structures take advantage of higher-level musical features such as polyphony and tonal modulation in order to entertain the listener more than in the case of sonification.

Musification and sonification have a feature in common, namely the fact of being deterministic in the results: given the same input, the output sound/music sheet or track will always be the same. This determinism may also be somewhat boring.

Physiradio tries to get rid of this boring degree of determinism by broadening the association 'data → music' introducing the "musicalization" idea. Instead of

[4]See Figure 2 and [10] to read about the importance of device blending.

[5]Remember Robin Williams in the movie 'Good Morning Vietnam': "What's the weather like? You got a window? Open it!"

[6]`https://openweathermap.org`

[7]`https://spdf.gsfc.nasa.gov/research/sonification/`

generating sounds/music *ex novo*, Physiradio chooses and plays categorized streams available on the Internet, these streams are *genre tagged*, i.e., “musicalization” is an association between data values and musical genre. This way a (potentially high, depending on the stream) degree of anti-boredom non-determinism is introduced in the system.

5 How to map weather conditions?

Physiradio gets weather condition values of a configured city (through the OpenWeather APIs), it elaborates them by extracting the main description and the relative humidity level only, and then it “physicalizes” them into a combination of music genre and colour, i.e., the mapping function is:

$$map(WeatherConditionDescription, Humidity) \rightarrow (MusicGenre, Colour)$$

To implement an initial mapping to experiment with, a reference study was examined: in [12] many parameters are taken into account to create a model of a music selector based on weather condition: mode, tempo, pitch, rhythm, harmony, and dynamics for music; temperature, humidity, pressure, wind, sunshine, cloudiness and precipitation for weather. But the main goal of Physiradio is just to increase curiosity about open data and data physicalization, so there is no need for a perfect mapping. Moreover, there is not enough metadata available through the freely usable Internet radio streams (more metadata is obtainable by connecting to paid services such as Spotify). So, the authors searched for previous studies on how musical genres inspire specific moods to people, such as [5]. In general, modern musical genres, such as LoFi, ChillOut, Smooth Jazz and various types of extreme metal, have never been mentioned in previous academic works. Nonetheless, these genres are very suggestive and extremely specific: most of the songs belonging to those genres will sound very similar to each other, which is useful if they want to convey the same information but with different songs.

The first two cases were associated as follows: the “Snow” condition seemed usefully and functionally, almost “naturally”, represented with Christmas songs. The second, of wider spectrum, is linked to dangerous weather conditions, such as “ThunderStorm”, “Tornado”, “Squall”, which can be represented with extreme metal songs, because the authors thought it is the most appropriate genre to define a chaotic and dangerous situation and a lot of songs belonging to this genre are really similar to each other. As for the other atmospheric conditions, the authors relied on the analysis mentioned above, since the most common weather conditions are also those with more difficult interpretation, consequently having a statistical basis, although small, can help.

During prototype development, the authors thought about adding an option to display coloured light (using RGB LEDs) to help device *readability*. Sight is the most common sense still used in data representation and this could be an interesting factor that, mixed with music, could bring semantics and help the user interacting with the device, to better interpret the data. To introduce colours, the authors relied on Robert Plutchick’s model [15], in particular the *wheel of emotions*, because even if it is a dated work (1980) it is still considered one of the most important psychological study on human emotions, with its useful mapping to colours, which is now part of this project.

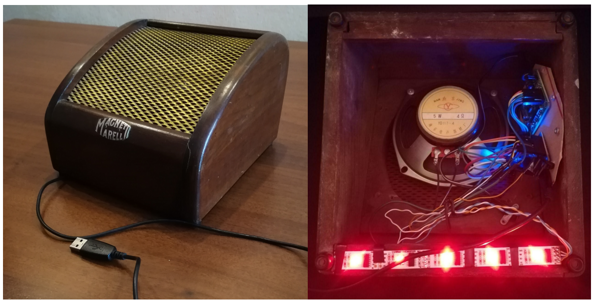


Figure 3: The Physiradio prototype: outside and inside

The field tested mapping is presented in table 1, `L#` refers to the listening number played during experiments.

6 The Physiradio prototype

Physiradio (see Figure 3) is a desktop streaming-based IoT radio built around the following components:

1. an ESP8266 (Wemos[8] D1 mini, an Arduino compatible MCU)
2. a VS1053 MP3 codec (LC Technology)
3. a WS2801 RGB LED strip with 5 LEDs
4. a “Vintage” (circa 1940) Magneti Marelli wooden speaker box mounted with a modern 4Ω loudspeaker

The main feature defining a device as IoT is the ’independent’ connection to the network, i.e., an IoT device does not need to be connected to a personal computer (after programming). In this prototype, this is achieved by the ESP8266 board thanks to its integrated WiFi chip that can easily connect to a local network, only a power supply must be provided (the whole device draws less than 100mA at 5V during normal use: a common USB power bank is enough for hours).

The software inside Physiradio is GPL[9] licensed (since the authors believe in the verifiability and reproducibility of Free Software) and can be downloaded at `https://github.com/simoneScaravati/Physiradio`. It was programmed using ArduinoIDE and uses the following libraries:

- Baldram’s library[10] implementing an SPI-based

[8] `http://wemos.cc`
[9] `https://www.gnu.org/licenses/gpl-3.0.en.html`
[10] `https://github.com/baldram/ESP_VS1053_Library`

L#	MOOD	GENRES	WEATHER	COLOUR
1	annoyed, frustated, irritated	classical, blues → classical music	smoke, haze, sand (annoying and polluted weather)	light red, light pink, magenta
2	angry, aggressive (happy with high humidity)	metal, rock, classical → metal	clear and high humidity	red
3	sleepy, bored, tired	folk, blues, classical, jazz → smooth jazz	rain, clouds , fog, mist, drizzle	blue violet
4	happy (feeling good, delighted...)	pop, rock, electronic (r&b, hiphop) → summer hits (mix of sun and popular music)	clear	yellow
5	fear	heavy/extreme metal	thunderstorm, tornado, squall, ash, dust (dangerous weather)	dark green
6	sad, depressed (sleepy with high humidity)	blues, jazz, slow music → lo fi	rain , clouds, fog, mist, drizzle and high humidity	dark blue
7	xmas is coming	christmas song	snow	white

Table 1: The current mapping table

protocol to send small audio chunks to the codec, to manage the VS1053 module;
- ArduinoJSON library[11] to interpret OpenWeather APIs return data (in JSON format);
- FastLED library[12] to interface with led strips;
- PubSub library[13] to implement basic functionalities of MQTT protocol;
- SimpleMap library[14] to implement associative arrays (Map) on Arduino.

Since Physiradio is an IoT device, the authors decided to use the most popular interaction protocol adopted for those kind of appliances, i.e., MQTT (MQ Telemetry Transport). It allows to interact with the object remotely from any endpoint device which is able to instantiate a MQTT message. Supporting MQTT is essential to add (a kind of) interaction with Physiradio: through MQTT commands it is possible to control the behaviour of the device, such as: changing volume, changing webradio station (stream), etc. Thus it will be easy to develop a "companion app" if/when needed.

At present, Physiradio connects to the OpenWeather APIs, gets the weather data (in JSON format) of the given city, maps (according to Table 1) them to a web radio stream, plays the stream and, at the same time, waits for commands (through serial port or MQTT).

The stream is buffered and sent to the VS1053 codec (to convert byte packets into sound) to be played through the speaker. At the same time, the WS2801 strip will light its LEDs with specific colours, according to the mapping explained in section 5.

[11]https://arduinojson.org
[12]http://fastled.io/
[13]https://github.com/knolleary/pubsubclient
[14]https://github.com/spacehuhn/SimpleMap

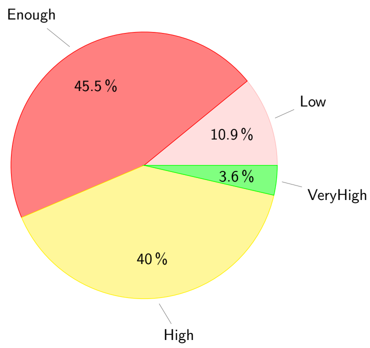


Figure 4: Response to the 'effectiveness' question

7 Field test

A survey was set up to test this "musicalization" idea. The authors prepared a two page questionnaire and organized many listening sessions where university students, colleagues (both teaching and administrative ones), friends, members of a local hacklab and a few relatives were invited. The anonymous survey contains the following sections:

1. personal data: age, sex, residency, work, studies;
2. listening habits: device, contexts, genres;
3. **Physiradio listening session**: the device plays seven mappings and the subject is asked to tick correspondences on a matrix;
4. **mapping suggestions**: the subject is asked to propose a mapping (genre+colour) according to seven weather conditions;
5. **opinion on effectiveness** (low, enough, high, very high);
6. **suggestion of other data to physicalize** (open

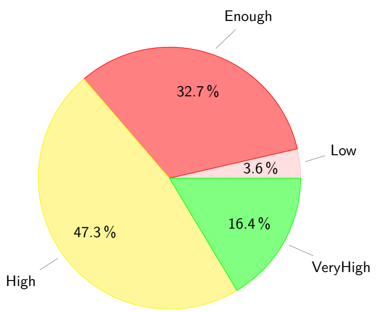


Figure 5: Response to the 'curiosity raising' question

question);

7. open data: a small abstract description of the device internals (get open data, map, get stream, play) prepares the subject for the next question;
8. **opinion on 'open data curiosity raising'** (low, enough, high, very high);
9. free remarks

The resulting set of data, available through Zenodo[15], is composed of almost 60 items, with the following stats:

- male/Female ratio: 78/22%;
- average age: 29.8yrs (stdev: 15.2);
- 'student' is the most represented class with 63.6%, next is 'clerk' with 24% and 'retired' with 4%;
- 36% lives in Milan (IT), the rest of the population in the Milan province, all in the Lombardy region;
- high school diploma: 70%, 'degree' 21%;
- habitual music listener: 96.3%;
- listening at 'home' (23%), in 'car' (18%), on 'public transport' (18%) and while 'walking/strolling' (12%);
- listening through: 'streaming app' (32%), 'mp3 player' (25%), 'radio' (18%), 'CD' (14%), 'vinyl' (6%) and 'webradio' (4);

Data elaboration was generated creating a jupyter[16] notebook using 'pandas', 'numpy' and 'matplotlib' libraries.

Figure 4 shows the pie chart of the responses to the subjective/perceived effectiveness. Figure 5 shows the pie chart of the responses to the subjective 'curiosity raising' effect. The **correlation index** between *curiosity raising* and *effectiveness* is 0.49 with covariance 0.27, between *age* and *curiosity raising* is -0.035 with covariance -0.41, between *age* and *effectiveness* is 0.052 with covariance 0.57.

Other than asking subject's opinion, mapping effectiveness can also be measured by verifying matches between listening and associated weather condition. Figure 6 lists and plots the matching frequencies[17] for every listening played , the values show that listening 4, 5, 6 and 7 were guessed correctly very often.

[15]https://doi.org/10.5281/zenodo.3627829
[16]https://jupyter.org
[17]Values range from 0 ('none guessed right') to 1 ('everybody guessed right').

8 Analysis and conclusions

Physiradio is a working prototype of an IoT device playing radio streams according to a mapping between weather conditions (accessed via open APIs) and musical genres. The main goal of this experiment is to test if such a device can be a conversation starter to raise curiosity about the open data world, the secondary is to test if musical genre can be used in a data mapping. The device was field tested and all gathered data is available through Zenodo[18].

Results show that Physiradio is well accepted (remarks such as "what a beautiful object!" were common) and that it effectively stimulates curiosity about the "internals" and open data: 64% (Figure 5) of the subjects declared *high* or *very high* "curiosity raising" effect, without age correlation (i.e., on all ages). The ones who found it interesting also assigned high effectiveness (correlation: 0.49). Only 43.6% (Figure 4) of the subjects declared the mapping between weather condition and musical genre coherent. This evaluation is confirmed by analysing the actual matchings in Figure 6 where four (namely 4, 5, 6, 7) listenings out of seven were often (between 56% and 80% of the times) guessed right while the remaining three (namely 1, 2, 3) where almost never (between 0% and 8% of the times) guessed right.

One problem emerged very soon: 'musical genre' is a definition too wide[19] to be usefully *inverted*, i.e., extrapolate the original weather condition. In addition, the association between music, mood and weather is, of course, subjective. While this mapping satisfies the precondition to be a formal 'sonification' (i.e., same weather condition in $\rightarrow$ same genre out) it is also true that genre may not be enough for everyone to associate to a specific weather condition, even with the help of colour[20]. In fact, any webradio available on the Internet may even be genre-centric but nonetheless it usually plays a vast range of songs belonging to the genre itself, so the actual experimental sessions were somewhat influenced by the song currently playing. A very important suggestion received from a colleague is: "instead of using a genre-centric webradio for every streaming channel it would be better to create specific playlists, best if user-defined". I.e., every Physiradio user, in the long term, should be able to customize its configuration in terms of:

- what data should be taken as input, mapping to an enumeration of values;
- creating playlists;
- associating playlists to values.

Actually, this option was forecasted in the design, the adoption of MQTT as an interfacing language to con-

[18]https://doi.org/10.5281/zenodo.3627829
[19]E.g., a "latin" webradio may play "salsa", "bachata", "reggaeton", "chacha", etc. that are very different between one another. In fact, in musical terms, there is no universally accepted definition of specific genres.
[20]Not every subject noticed/used the coloured LEDs, sometimes because the environment had not proper lighting (e.g., too much ambient light) and sometimes because the subject decided (and declared) not to pay attention to both music and light.

trol the device was chosen to ease the integration with systems such as IFTTT[21] or NodeRED[22]. Physiradio can be fully controlled via an MQTT API with commands such as 'volume', 'station', 'city' (to get specific weather data), etc. This way, even a semi-technical[23] user could implement a suitable configuration.

Of course, the simplest solution to the 'subjectivity problem' would be to describe the mapping in the documentation (or via a small display) so that once assimilated any user would not need to look at the device later.

More suggestions (to address the subjectivity) received were:

- using music from 'formal' dancing (e.g., 'salsa', 'tango', 'can can', 'tarantella', etc. not general dance/disco music), these are more canonized and recognizable
- exploiting lights better, e.g., by pulsating the LEDs according to tempo

During experimental sessions, many subjects were genuinely inspired by the device and started suggesting other mappings based on their work and life experience, such as:

- overall CPU load (in a server farm);
- network traffic, not only in terms of volume but also in terms of type of traffic (denial of service attacks, mail spamming with many repeated messages);
- city traffic conditions;
- train timings/delays[24];
- cooking times[25];
- call center waiting times (music representing time to wait for an operator);
- an outsourced (i.e., probably very far away) call center operator could "listen" (in background) to the current weather condition at the caller's location thus adapting the style of the call according to the weather experienced by the caller;
- in general, any situation where the need to continuously monitor a 'variable' (data) cannot be represented with simple and very annoying tone/sound, to take advantage of the "superior" discerning[26] power [17] of hearing over sight;
- in general, contexts where children may be involved, they are more sensitive to music and colours.

To summarize, these field experiments were very satisfying: subjects became very talkative and asked many questions, the mapping is far from perfect but that is not the goal, the device stimulates curiosity and imagination and that was the authors' goal. Last but not least, the vintage wooden box design chosen for the Physiradio prototype proved to be a very successful key to acceptance by subjects.

listening 1	0.0
listening 2	0.018
listening 3	0.0
listening 4	0.78
listening 5	0.56
listening 6	0.8
listening 7	0.58

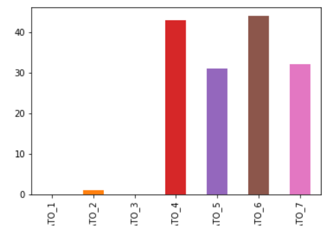


Figure 6: Relative matches per listening

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