METRICS FOR THE AUTOMATIC ASSESSMENT OF MUSIC HARMONY AWARENESS IN CHILDREN

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ABSTRACT

In the context of a general research question about the effectiveness of computer-based technologies applied to early music-harmony learning, this paper proposes a web-based tool to foster and quantitatively measure harmonic awareness in children. To this end, we have developed a web interface where young learners can listen to the leading voice of well-known music pieces and associate chords to it. During the activity, their actions can be monitored, recorded, and analyzed. An early experimentation involved 45 school teachers, whose performances have been measured in order to get user-acceptance opinions from domain experts and to determine the most suitable metrics to conduct automated performance analysis. This paper focuses on the latter aspect and proposes a set of candidate metrics to be used for future experimentation with children.

1. INTRODUCTION

Tonal harmony can be defined as an idiom, or system of rules, which *"... governs how melodies and chords are organized throughout the duration of a tonal musical composition"* [1, p.194]. Systematically defined by Rameau [2], tonal harmony has been employed in various musical styles, spanning from the Baroque period to contemporary popular songs [1,3]. It has been demonstrated that both children and adults who are not musicians have a strong feeling for harmony and are able to recognize the tonic chord [4], implicit harmonies [5], and chord progressions [6]. In this sense, the development of a harmony awareness extends beyond the boundaries of formal music education.

Many treatises and handbooks [7–11] describe the tonal system in terms of keys, chords and scales. Even though these concepts represent useful tools for analysis and theoretical pedagogy, they fail to explain the perceptual qualities of chord relationships that are peculiar to the tonal system [1]. Such a formal pedagogical approach has been severely criticized by some scholars [12], and it has been held responsible for failure and disaffection towards harmony studies. Eberlein, in particular, complains about the use of rules that are in contrast with practice and perception and about the absence of explicit stylistic references in tonal harmony treatises [13]. Therefore, it is not surprising that pedagogical approaches to tonal harmony have developed little outside professional music curricula, and that little attention has been paid to harmony education programs for children, high school students, and amateurs.

The work presented in this paper is part of an ongoing research on computer-based technologies applied to music-harmony learning. We have recently proposed a web-based tool that implements a set of experiences focused on harmonic skills and awareness form primary and middle school students [14]. Particularly for primary school children the use of the web interface should be complemented with a series of perceptual and physical activities - i.e. musical games - which focus on some fundamental concepts related to tonal harmony. The games, thoroughly described in [15] constitute the basis for understanding the tasks required in the various groups of experiences presented in the web interface. However in this context the current goal is to devise suitable metrics for objectively assessing children performance in the experiences, based on the recordings and analysis of their actions.

Objectively assessing musical abilities is a much studied – and controversial – problem. Musical aptitude batteries proposed in the second half of 20th century are now considered obsolete in several respects [16]. The concept of musical ability is multifaceted and includes various types of musical capacity (e.g., tempo, pitch, rhythm, timbre, melody perception) that are not easily separated. Building on previous research such as [17] and [18], more recent music games for education [19] have been developed. Commercial systems such as Smart Music [1] and Yousician [2] offer gamified approaches to music instrument learning, and academic research focuses on the development of objective descriptors for assessing music performances [20]. Although these works are mainly concerned with musical instrument performance rather than theoretical music abilities, they share some common traits with the experiences proposed in our web tool, namely a performative dimension and a gamified approach. As far as con-

[1] https://www.smartmusic.com/
[2] https://www.yousician.com/

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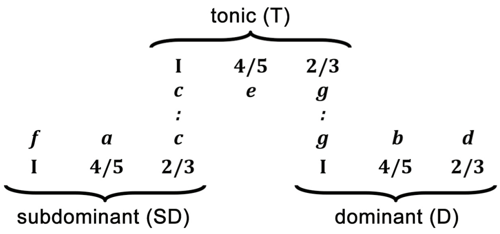

Figure 1. Chart of the relationships of the three tonal functions, also known as primary chords; picture adapted from [25, p. 7].

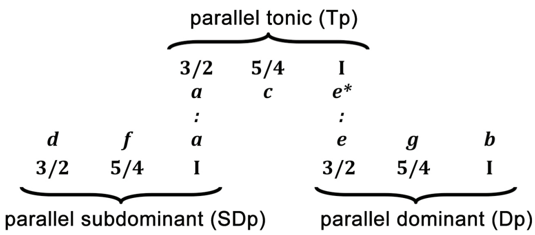

Figure 2. Chart of the relationships of the three parallel chords; picture adapted from [25, p. 7].

cerns the study of tonal harmony many computer interfaces and systems have been designed to help the understanding of musical chords and harmonic progressions [21–24], included *Mapping Tonal Harmony*, an innovative tool for visualizing the various shifts through harmonic regions in real time. [3] However all these systems are rather complex to use and are not finalized for use in primary or middle schools.

2. THEORETICAL BACKGROUND

Following Riemann's theory of tonal harmony [25], we divide the tonal space into primary and parallel chords. The primary chords are tonic (**T**), dominant (**D**) and subdominant (**SD**); the parallel chords are parallel tonic (**Tp**), parallel dominant (**Dp**) and parallel subdominant (**SDp**). Figure 1 depicts the three tonal functions **T**, **D**, and **SD** (primary chords, namely I, V, and IV degree). The Pythagorean relationships reported below the pitches show the origin of the major harmonic functions and chords starting from *c* (tonic).

Riemann considered the minor chords as the product of the inversion of the harmonic series. Thus, he derived the remaining chords (II, III, and VI degree) from the reversed harmonic series starting from *e* (marked with an asterisk in Figure 2). This is an abstract scheme from which much more complex harmonies can be derived. However, it can fit a number of popular songs as well as classic music harmonization patterns which can be a good starting point for understanding harmonic functions.

Building on this theoretical background, we designed a simple activity to be conducted with primary school children in order to assess and possibly improve their awareness towards tonal harmony. In general terms, we ask students to complete a number of tasks consisting in associating a single chord to each music tune. Chords are selected from the Riemann's scheme. Tunes are chosen (and sometimes modified) to best fit a single chord, typically the tonic one; this implies that all the notes of the leading voice occurring on beats belong to the pitches forming that chord.

But is there one right choice and five wrong options? Basically, the answer is: no. There is a more plausible chord in terms of tonal harmony, since the proposed music tunes are built on the notes forming the tonic chord. Besides, the themes selected for the experience are well known to listeners who are used to link them to a given harmonic accompaniment. Nevertheless, other options are possible. First, some of the proposed chords share one or more notes with the expected one (e.g., the minor triad on the VI grade has two notes in common with the major triad on the I grade), so a music tune insisting on the I and III grade of a major scale could be harmonized by a VI-grade triad as well, with no conflicting notes among the leading voice and the accompaniment. Moreover, chords forming seventh, ninth and even more complex intervals are common in many musical genres, so accompanying a tonal music tune through unconventional chords would be perfectly acceptable, and arguably also more interesting to some listeners.

To ease the navigation of the harmonic space and to enhance the perceptual differences between the primary chord zone (all major chords) and the parallel chord zone (all minor chords), we propose to place the chords along a circle with the tonic, dominant and subdominant in the lower part of the circle and the parallels in front of their relatives, as depicted in Figure 3 (white arrows).

3. THE WEB TOOL

Harmonic Touch is a Web platform for the study and practice of tonal harmony. [4] This application is conceived as a step-by-step wizard that leads users through three experiences towards the discovery of important features of tonal harmony by leveraging on chord perception, gestural interaction and gamification techniques.

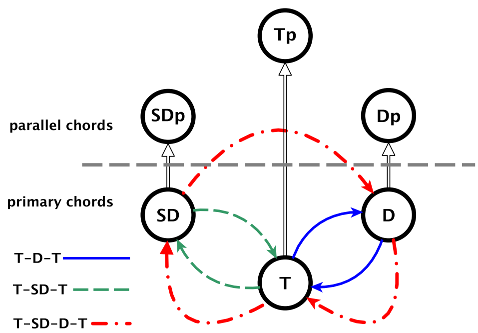

Figure 3. The spatial arrangement of primary and parallel chords with the route of three common chord progressions

[3] https://mdecks.com/mapharmony.phtml

[4] http://didacta18.lim.di.unimi.it/eng/

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Harmonic Touch implements a step-by-step process towards harmony awareness based on the administration of three groups of experiences, focusing on: 1) the recognition of the implicit harmony, 2) the timed recognition of harmonic changes, and 3) melody harmonization. These three types of experiences have been discussed in detail in [14]. In this context, we will focus on the first group of experiences. To this end, users are asked to match a short music tune with a single chord that, in their opinion, best fits the whole melody. The chord must be selected from the six primary and parallel chords discussed above.

This type of experience can be proposed to learners in a physical space, namely moving across different spots on a floor, as well as through a web-based interface that simulates the mentioned setting. The former approach implements a real embodiment of a harmonic path, whereas the latter presents advantages in terms of ease of use and computer-based performance, for both the leading voice and underlying chords. A mixed approach is also possible, thus applying to music education the principles of *algomotricity* learning methodology defined in [26].

In the Web interface, available chords are represented as shown in Figure 4, with positions randomly rotated and no explicit indication of tonal functions. These are made explicit in the visual representation of the harmonic space of the third group of experiences, where the user has to explore the harmonic space to find the chords for melody harmonization (see Figure 5). Understanding the relative layout of chords is left to the user, who can explore them freely during an initial training phase. This spatial arrangement carries some important peculiarities:

- The user can get acquainted with the sound of the various chords by simply clicking or touching a set of buttons that follow this arrangement: an important facility for people who cannot play a polyphonic instrument or for children [27];
- The user can intuitively couple the chord qualities with their relative location, which can help the memorization of the sound of the various chords as well as the routes of the most important harmonic progressions, as shown by the colored arrows in Figure 3.

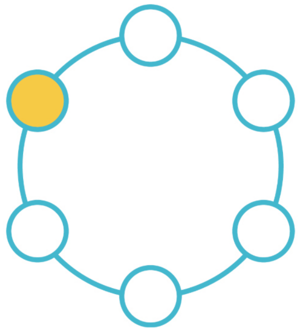

Figure 4. The interface for the recognition of the implicit harmony of a music tune. No indication is provided to the user about harmonic functions and their spatial disposition, that can be reconstructed only through exploration.

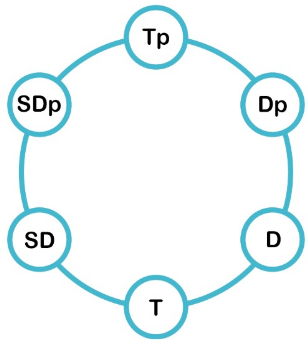

Figure 5. The interface for melody harmonization with explicit indications of the harmonic functions employed in the third group of experiences.

4. RESEARCH QUESTIONS

There is a clear distinction between the research questions that brought us to develop *Harmonic Touch* and to test it in different contexts on one side, and those investigated in this paper on the other.

Concerning the former questions, the general goal of the project is to engage learners through playful physical and computer-supported activities in a topic often considered too abstract and difficult for young students or amateurs. As mentioned before, harmony awareness is trained firstly by making the user recognize the implicit harmony in a music tune, then focusing on the timed detection of harmonic changes in a theme, and finally inviting the learner to perform melody harmonization (i.e., selecting a sequence of chords and playing them at the right time while listening to a tune). The research questions addressed by the *Harmonic Touch* project deal with the efficacy of an embodied approach to harmony learning and with the educational support offered by technologically enhanced tools.

In this paper, conversely, we focus on a specific aspect: how can we analyze the large amount of data recorded during the experimentation phase, with respect to the first group of experiences only?

From a terminological point of view, in the following we will call *test* each experience completed by a user, *session* the group of experiences performed by a single user, and *activity* the collection of sessions completed by all users. Consequently, the assignment for each test is: “Associate one chord out of the six available to this music tune”; the assignment for a user session is: “Complete 4 tests”. Music tunes have been proposed in the same order to all participants.

During each test, users could:

- play the leading voice with chord accompaniment (action P);
- rewind the music tune and play it back as many times as they wanted (action R);
- make subsequent choices selecting the current chord

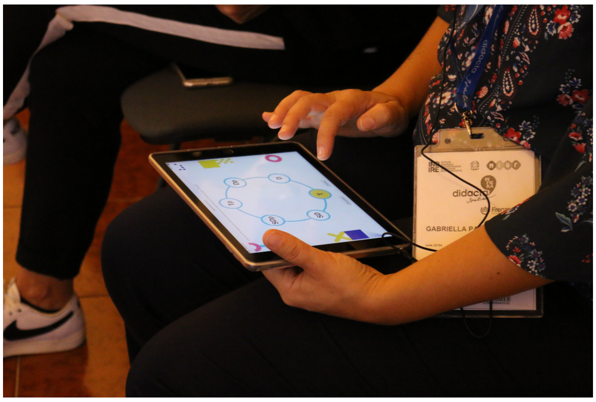

Figure 6. Users experiencing *Harmonic Touch* at Didacta 2018.

from the mentioned circle, and keep it playing under the leading voice (actions $C_1 \ldots C_n$);

- confirm the final choice and exit (action X).

In order to measure the abilities in the recognition of implicit tonal harmony, actions P, R, C_n, and X have been recorded user by user for each test, thus generating a considerable set of information to be investigated along different axes.

5. GATHERING THE DATA SET

Harmonic Touch was presented to primary and middle school teachers in occasion of the 2nd edition of Didacta Italy, Florence, October 18-20, 2018.[5] This initiative is the most important Italian fair focusing on education, vocational training and relation among school and work.

Specifically, *Harmonic Touch* was presented during a workshop on music education and digital languages, with the aim to involve music teachers in the use of the interface (see Figure 6). But, as a side effect, we were interested also in analyzing teachers' performances, consequently we tracked their results on a set of increasingly difficult harmony experiences and profiled them through anonymous questionnaires administered before and after the experimentation in order to obtain more accurate indications from tests. Finally, we also gathered user observations and suggestions about content and technology-related issues, through a set of questions about the whole experience.

The workshop was attended by an audience of 45 educators, mainly teaching in middle (57%) and in primary school (25%). Sixteen percent of the audience were males; mean age = 49.8 (median = 51); mean working age = 22.7 years (median = 20 years). The employed melodies are all well-known tunes, as confirmed by 44 participants out of 45. The complete data set of answers to pre-activity and post-activity surveys is publicly available.[6]

Concerning user performances for the first activity, i.e. the battery of 4 tests for the recognition of implicit harmony, results are publicly available, too.[7] For each test, 2 diagrams are available (see Figure 7):

1. The path that was followed in the chord circle. In this diagram, positions are reported in the same form (e.g., **T** is always the bottom chord) in order to ease the comparison of paths, but remember that users experienced random rotations for each test;

2. The time of chord changes, including clicks on the same chord. Time scale is the same for all users, with the exception of User 25 who was discarded from time scale calculation due to the very long time employed in the answer. This diagram carries also information about actions R and X. The former action was often invoked by users since, at the end of the piece, music stopped with no looping. This diagram presents a dark background when music is playing; chord changes occurring on a white background are chords played after the end of the melody.

Blank spaces indicate tests with no saved results, as the complete session of User 6 or single tests of Users 8, 16, 31, etc.

6. ANALYZING THE DATA SET

The experimentation at Didacta 2018 was not conducted on the intended final users for such an experience, who should be primary school students. In this sense, gathered data cannot be analyzed to assess the pedagogical effectiveness of the proposed approach. Rather, the goal of the analysis is to discover and fine-tune the most suitable metrics to extract significant information about user awareness of tonal harmony.

6.1 Analysis Dimensions

Going back to the definitions of *test*, *session* and *activity* provided in Section 4, we can identify the following dimensions to analyze:

- Horizontal axis – The goal is to track, user by user, the behavior and improvements from one test to another. This effort can bring to the identification of well-defined user profiles, e.g. the "frantic explorer" or the "self-confident listener" (see below);

- Vertical axis – The purpose is to recognize similar behaviors across users when approaching the same test. An aspect evaluated vertically is the average time to complete the n-th test, or the distribution of answers about the final chord for a given test;

- Global dimension – The data collected during the whole activity, namely in each test of each session, are evaluated globally in order to assess general aspects. Prototypical behaviors may emerge from a joint analysis of the horizontal and the vertical axes.

[5] http://fieradidacta.indire.it/
[6] http://www.lim.di.unimi.it/data/didacta_survey/
[7] http://didacta18.lim.di.unimi.it/results/index_results.html

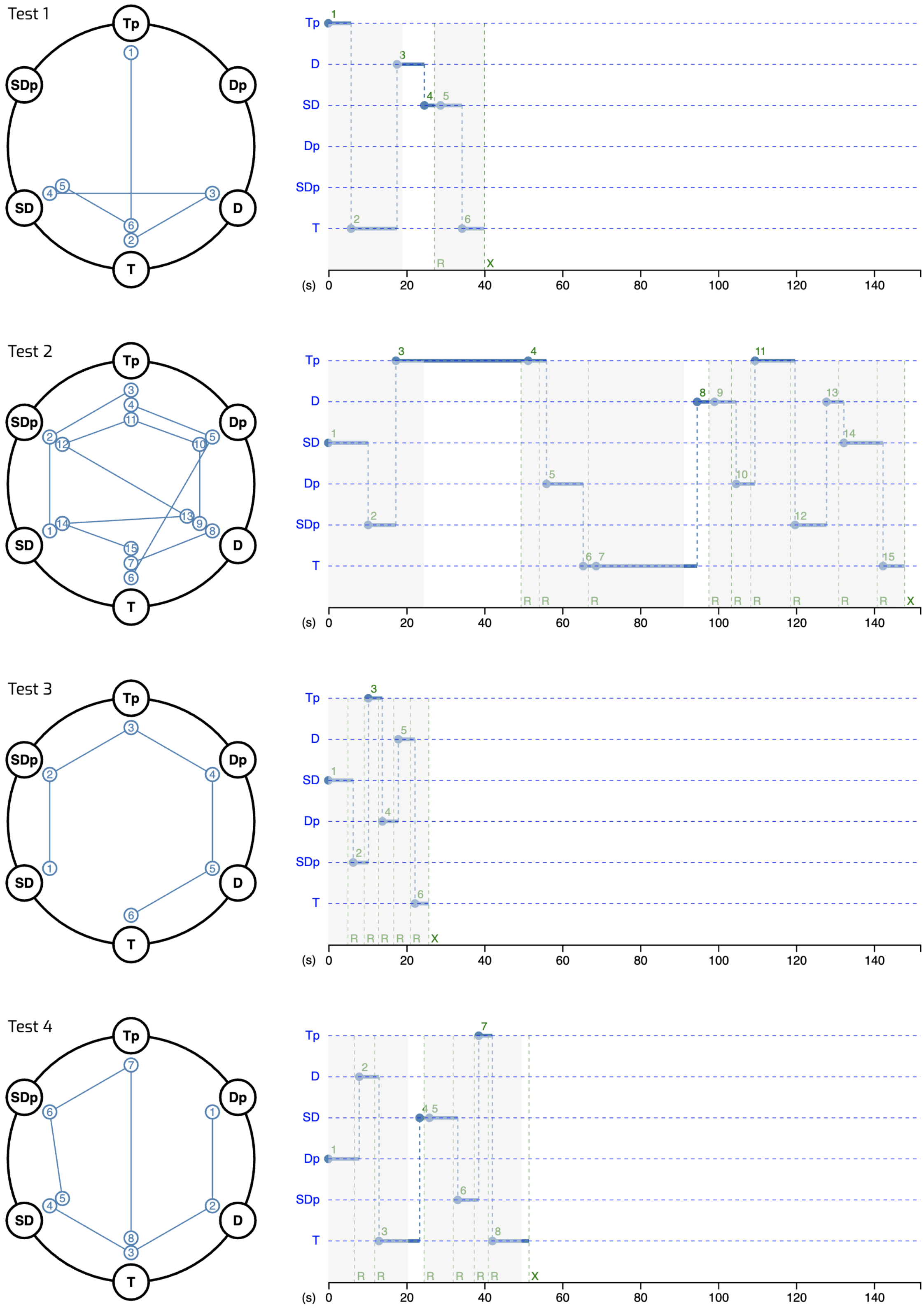

Figure 7. Diagrams tracking the performances of a randomly selected user (35). The left part of the image represents the chord circle with the path followed by the user. In the right part information about the times of chord changes is provided, including clicks on the same chord

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Concerning the horizontal axis, first it is possible to compare the duration of each test in a session. The expected effect is a decreasing amount of time to determine the final chord. In the analysis of the total time spent on each test, it is important to underline that music themes have different lengths (19, 25, 17, and 9 seconds respectively), and present increasingly difficult harmonic situations. In any case, results do not confirm the initial prediction, and the time spent on each test does not follow a common trend. For the horizontal axis, one of the most interesting aspects to highlight is the evolution of the path followed by single users from test to test. Since the relative chord positions were kept unaltered across the activity, we could expect a learning effect. The first choice of each test can be considered random, since circles are rotated; but, after a training phase, previous experience should bring users to quickly jump to the desired chord. Conversely, from test to test we often noticed the replication of an exploratory behavior. The learning effect, if any, pushed some users to stop at the first occurrence of the tonic chord, or to minimize the number of attempts after that, but not to jump towards the final destination with confidence. In this sense, one of the rare counterexamples is the performance of User 1 in Test 4, which was the last one of the session: after randomly performing action C_1 and selecting **SD**, in about 5 seconds he/she moved to **T** through action C_2 and stopped.

The vertical axis investigates the common characteristics of each test. For example, it is possible to compute: the mean and the variance of the total amount of time spent by users on a given test; the distribution of the chords selected as the final choice; the number of chords listened before fixing the last one; and so on. Considering common behaviors of users test by test, the first experience, presented as a trial to get acquainted with the interface, has been considered exploratory by most of them. In this case, a number of wrong behaviors emerged, for example the choice of new chords with no music playing; conversely, later tests showed a general improvement in performances. Another behavior common to many users when passing from early tests to the last ones is the tendency to restart the piece more. In this way, users can compare the fitness of each chord against the first notes of the leading voice, limiting the experience to the initial part of the tune, whereas, at the beginning, most of them played the entire piece and changed chords while music was advancing. Since these actions can be found in many users, such a consideration brings us to the global dimension.

Concerning the whole activity, we evaluated the average time spent on each chord selection, test by test and user by user. The expected learning effect should bring to a gradual decrease of listening times, and, actually, this is noticed in many user sessions. Moreover, the analysis makes another aspect emerge: users tended to rest on the chord they considered correct, even in the middle of the experience, namely before confirming it as the final choice.

The analysis of dark-colored areas in time diagrams often justifies the repeated selection of the same chord: this happens when music stops and clicking on a new chord does not restart the performance, thus users manually invoke action R and immediately re-select the chord. For instance, this effect occurs in Test 1 (actions C_4, C_5), Test 2 (actions C_3, C_4; actions C_8, C_9), and Test 4 (actions C_4, C_5) in Figure 7.

Finally, a comprehensive analysis of the whole activity lets us determine mainly two well-defined user profiles:

1. the “frantic explorer”, who wanders around the circle, usually following a clockwise or counterclockwise path and going on until the whole circle has been covered, even multiple times. Although this behavior could be associated to a casual way to explore, actually we did not retrieve many examples of random patterns;

2. the “self-confident user”, who stops almost immediately after choosing the expected chord.

In this specific case, it would be interesting to study the correlation between self-declared music skills and all the aspects we have mentioned before, e.g.: the final choice, the total time spent on each test, the number of trials before selecting the final chord, the average listening time for each chord, and so on. Nevertheless, please remember that such an experience has been conceived for young learners, who probably have no prior music education.

6.2 Metrics

Concerning the metrics to automatically assess the educational efficacy, a first point regards the learning curve. This aspect can be investigated through different numeric values: the amount of time and/or the number of trials to find the final chord after its first listening, the number of waypoints to reach the expected chord after listening to the first one. For each of the mentioned values, we can consider the minimum, maximum, mean and variance.

Another indicator regarding the learning curve is the evolution of aggregated times spent on each chord, both the selected one and those considered wrong by the user. The distribution of final choices could also redefine the concept of right vs. wrong chords, even if in a tonal context it is possible to rank chords on the base of the pitches in common with the leading voice.

For each of the mentioned aspects, we can investigate the horizontal as well as the vertical axis, thus focusing on user-specific or test-specific analysis respectively. Global considerations emerge from a comprehensive insight involving both dimensions. Figure 8 shows the distribution of chords selected by users at the end of each test. The convergence of answers towards the tonic chord **T** seems to demonstrate the existence of a harmonic awareness, at least in the context of tonal harmony. The distributions of results in the first three tests (all pieces in major key and taken from music literature) are very similar, with **T** chosen by about 80% of the participants; the fourth test (in minor key) differs from the previous ones, with **T** chosen by only 57% of users.

Table 1 illustrates some additional metrics computed on the Didacta 2018 sample. Let c be the chord selected by the user at the end of the test, and $t_0(c)$ the time when

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Table 1. Minimum m, maximum M, mean μ, and standard deviation σ of elapsed time and number of explored chords.

	Time				Chords			
	m	M	μ	σ	m	M	μ	σ
Test 1	0.55	211.65	65.01	49.38	0	22	5.78	5.49
Test 2	1.25	577.71	75.18	90.82	0	27	7.66	5.82
Test 3	1.03	185.91	38.43	38.32	0	18	4.73	4.53
Test 4	2.06	174.36	43.38	38.00	0	32	7.18	7.56

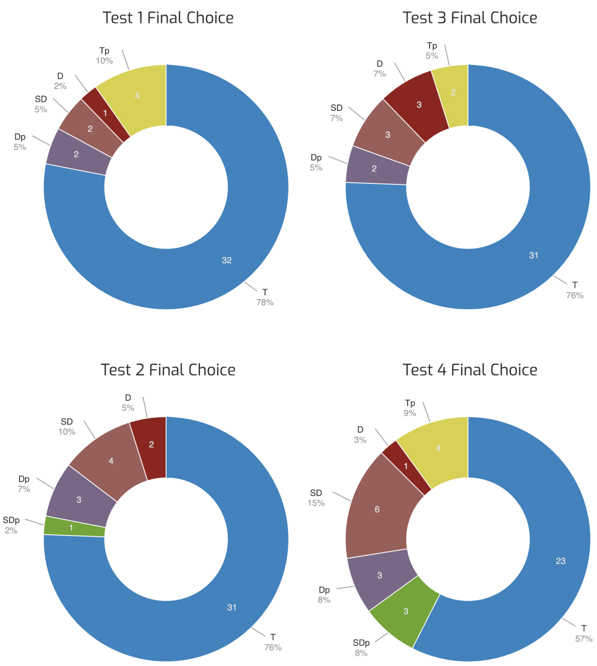

Figure 8. Distribution of the chords selected at the end of each test.

c is first clicked, $t_1(c)$ the time when the user confirms its final choice; the table shows the minimum, maximum, mean, and standard deviation of $t = t_1(c) - t_0(c)$ and of the number of selections occurred between time $t_0(c)$ and $t_1(c)$. An analysis of such values on one side demonstrates a tendency towards an exploratory behavior by users, who go on navigating through chords also after listening to the one they consider correct; on the other side, the evolution of times across tests shows a trend of decreasing, which could imply an improvement in self-confidence and harmonic awareness. We can expect that a more noticeable learning effect may emerge only after a number of administrations and may be observed across a long timespan.

A global indicator of the harmonic awareness is necessarily based on multiple metrics, sometimes coming from already available data, sometimes involving additional features that we will implement in the future. For example, in the current version of *Harmonic Touch* there is no way to assess consistency, namely to test coherence of user choices when a music tune is administered multiple times.

Even if the computation of values for the mentioned indicators could be easily extracted from the data reported above, it would make little sense to provide this kind of information on the sample involved at Didacta 2018, since domain experts could behave very differently from young learners.

7. CONCLUSIONS

The main goal of this work was paving the way for the analysis of big amounts of data coming from an extensive experimentation of *Harmonic Touch*, to be conducted on primary school children instead of domain experts. In this sense, the Didacta 2018 experience was the occasion to present the educational approach and test the functionality of the software framework.

A critical analysis of gathered data, little significant with respect to the educational valence, allowed us to identify different dimensions to be investigated when the experimentation campaign will involve the expected final users, i.e. children. To each dimension we associated a number of indicators useful to assess the educational activity.

As a side effect of the experimentation occurred at Didacta 2018, some change requests emerged, both in the general pedagogic approach and in the implementation. Concerning the former, teachers asked the possibility to customize contents and to adapt them to their educational goals. In addition, the corpus of experiences should provide a more gradual evolution from very clear tonal situations to more complex pieces. The familiarity of children with music themes may also have an impact on user performances, so this aspect could be better assessed in the future.

As for implementation issues, some recurrent wrong behaviors will push us to improve the usability of the interface. An example is to restart music when a new chord is selected and the leading voice is no more playing, instead of explicitly request the user to push the Play button.

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