THE "HARMONIC WALK" AND ENACTIVE KNOWLEDGE: AN ASSESSMENT REPORT

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ABSTRACT

The *Harmonic Walk* is an interactive, physical environment based on user's motion detection and devoted to the study and practice of tonal harmony. When entering the rectangular floor surface within the application's camera view, a user can actually walk inside the musical structure, causing a sound feedback depending on the occupied zone. We arranged a two masks projection set up to allow users to experience melodic segmentation and tonality harmonic space, and we planned two phase assessment sessions, submitting a 22 high school student group to various test conditions. Our findings demonstrate the high learning effectiveness of the *Harmonic Walk* application. Its ability to transfer abstract concepts in an enactive way, produces important improvement rates both for subjects who received explicit information and for subjects who didn't.

1. INTRODUCTION

A tonal composition is perceived by listeners as a sequence of discrete pitch-events [1], matched with an underlying harmonic background. As soon as the listeners recognize that pitches belong to the same chordal entity, they group them into subsequent musical units, which subdivide the melody after metrical and harmonic rules. This process is called "melodic segmentation" and represents the basis of tonal music knowledge. Research in the field of music psychology has offered wide evidence that unlearned adults and children from the very early age of 4-5 years [2] have an implicit knowledge of the elementary harmonic organization.

Thus, employing a geometric interpretation of the spatial qualities of melodic segmentation and harmonic chord space, we use enactive [1] and spatial knowledge to reach the heart of the complex domain of tonal music composition and to manipulate its contents in a creative way. A preliminary study for the *Harmonic Walk*'s environment and a thorough description of the system architecture and theoretical background can be found in a prior publication [3], while previous assessment sessions showed the application's success rate in simple orientation tasks or in more difficult cognitive assignements such as melody harmonization [4] and melodic segmentation [5].

[1] Enactive knowledge is deeply linked to the experience of doing something. It provides implicit information about a specific task, allowing the subject to perform also very complex actions without having an explicit knowledge about them.

Figure 1. The *Harmonic Walk* while being tested by a high school student at the Catholic Institute "Barbarigo", Padova.

1.1 Enactive learning in the *Harmonic Walk*'s environment

The *Harmonic Walk*'s design is grounded on the spatial characteristics of two fundamental features of the tonal harmony language: The melodic segmentation and the tonality chord space. This musical features are interpreted geometrically [6] and transformed into masks employed to partition the floor surface, which is the actual interface between the user and the application's contents. The melodic segmentation is interpreted as a sequence of square blocks put along a straight line (see Fig. 2), while the tonality chord space (see Fig. 3), formed by three primary and three parallel roots, is laid on a six partitioned circular ring [5].

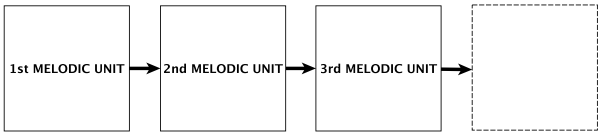

Figure 2. The geometrical representation of a tonal melody units sequence.

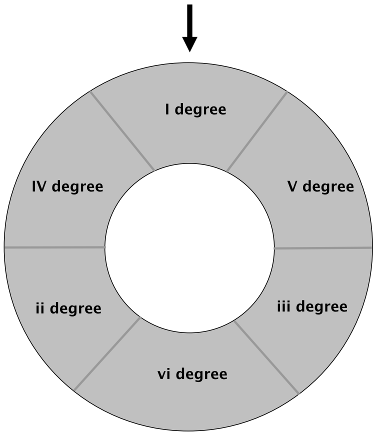

Figure 3. The geometrical representation of a tonality six roots harmonic space.

When following the first spatial schema (the straight line), locomotion is guided from block to block following the path displacement. The cognitive map of the path is easily understood, thanks to the fact that the sound file stops playing as soon as the melodic unit ends. The concatenative nature of the path invites the users to follow the melodic line and to move a step forward in time with the arrival of the next unit. But, in the second spatial schema the user is presented to the circular ring area, where only the starting point is marked and where various route possibilities are allowed. The first thing a user can do in this situation is to explore the sound of the six regions, containing the six roots of the tonality harmonic space. As soon as s/he discovers the chord of the first sounding area, s/he registers the first landmark, beginning so to feed the circular mask's cognitive map. Users can ignore every explicit notion about harmony, while they enactively learn how to move on the mapped interface. The sensorimotor information about the chords displacement coupled with the feeling of their harmonic functions guides them towards the accomplishment of the melody harmonization task.

The aim of this paper is twofold. Firstly, we want to test if the application is really efficient to drive the users to harmonize a tonal melody with and without explicit explanation from the teacher; secondly, we point to the cognitive aspect of the experience in the *Harmonic Walk* environment, trying to discover what users actually learn after one or more trials and training sessions. Assuming for true that users are endowed with some degree of implicit knowledge about tonal melody and harmony, we wonder: Is it possible to make this unconscious knowledge to emerge and to become a real ability? How important is the role of explicit, previously delivered information? Is enactive experience stronger than explicit information? And if so, in what domain? These are crucial points to foster the full body interaction style in learning environments, to make it really useful in educational curricula and to try to integrate it in the actual teaching practice.

1.2 Related Work

The *Harmony Space* project of the Music Computing Lab (University of Stanford), was elaborated in 1993, not only on a desktop interface [7] but also in a physical environment, employing a floor projection and a camera tracking system [8]. More recent systems like *Isochords* [9] or *Mapping Tonal Harmony* [10], are very complex environments which improve musical structure consciousness at a very high degree of knowledge. Other more intuitive approaches are offered by the *PaperTonnetz* [11] and the *Harmony Navigator* [12], where the chord selection, supported by a corpus based statistical model, is operated by hand gestures in the 3D space around the user.

The authors of [13] present some results from assessment sessions in the *SMALLab* environment, [2] a semi-virtual learning environment where users move freely producing visual and audio output. Their results suggest that receiving regular instruction before the exposure to the application's environment, significantly improves the learning of content. Moreover, they tried to test if an embodied experience in a reality based physical environment could lead to greater learning gains if compared to the same learning session in a desktop environment. Their findings confirmed a significant, but equal improvement for both groups, without the expected enhancement in favor of the embodied experience group. An interesting survey about augmented reality learning applications is presented in [14], where researchers try to measure the learning gain achieved by the use of augmented reality applications in education. They reported an effect size to student performance expressed by a Cohen's d value of 0.56. [3] Anyway, this result is subject to a wide variety due to the many important differences in the ways of use of augmented reality as well as in experimental design.

This article is organized as follows: In Section 2 we describe the system architecture, with the *Zone Tracker* application and the *Max/MSP* modules for sound production. Section 3 presents the test's aim and organization, while quantitative results, data gathering and meta-analysis are discussed and compared between the two assessment test sessions in Section 4. Conclusion and further work follow in Section 5.

[2] *SMALLab* (Situated, Multimedia Arts Learning Laboratory `http://smallablearning.com/`) has been developed by and a transdisciplinary group at the Arizona State University School of Arts, Media and Engineering in 2010.

[3] Cohen's d is defined as the difference between the control and treatment means divided by the pooled standard deviation (root mean square of the two standard deviations). After Cohen's (`http://en.wikipedia.org/wiki/Effect_size#Cohen.27s_d`) effect size table (`http://www.uccs.edu/lbecker/effect-size.html`), we define an effect size small if $0 < d \leq 0.2$, medium if $0.2 < d \leq 0.5$, and large if $d > 0.5$.

2. SYSTEM ARCHITECTURE

The *Harmonic Walk* architecture combines two software modules: The *Zone Tracker* application with video analysis algorithms and masks for surface division, and the *Max/MSP* patch containing audio files for sound output.

A camera mounted on the ceiling follows the user while moving on the underlying surface within the camera range. These data arrive to the *Zone Tracker* application, which subtracts the background obtaining a well shaped image blob. Comparing the blob's position with a previously stored mask, the system identifies the zone occupied by the user and sends this information through the *OSC* protocol [15] to the *Max/MSP* patch.

For our tests we use two different masks, corresponding to the straight path of the musical unit sequence and to the circle of the six chords of the harmonic space. The first mask subdivides the tracked zone in 5x5 squares, each one with a side of about 60 cm, roughly corresponding to the distance of a human step; the second is the circular ring mask depicted in Fig. 3.

For each tonal composition the *Max/MSP* patch stores :

1. the music audio file, segmented according to the harmony changes;
2. 6 audio files reproducing the chords of the song's tonal space, played with the same rhythm and timbre of the original composition.

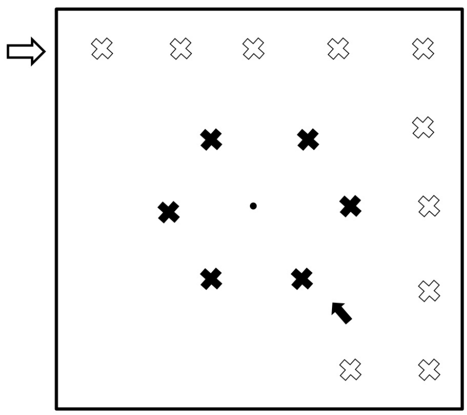

Figure 4. Visual tags of the straight and circular path of the *Harmonic Walk*.

The *Harmonic Walk* user interface appears to the user as depicted in Fig. 4. Along its borders there is the straight line of the musical unit sequence, while the circular ring is put at the center of the rectangular area. [4]

The user's paths are identified respectively through white and black crosses, with an arrow marking the beginning of each path. [5]

[4] We represent the masks as square and circular ring also if, due to camera pixel shape, the actual masks are respectively distorted in a rectangle and in an oval ring.

[5] The tags both in the straight line and in the circular ring are not descriptive, i.e. they are not marked with the syllables of change or with the chord names, but they have the function to indicate to the user the right position to be occupied on the application's surface.

3. THE *HARMONIC WALK*'S ASSESSMENT

The *Harmonic Walk* assessment tests were organized at the Catholic Institute "Barbarigo" in Padova, the seat of a music high school, as well as of various other kinds of schools. The assessment test was organized in two subsequent stages (December 2014 and January 2015), with the aim of collecting experimental data about the impact of the application's utilization with respect to four different subject categories selected among high school musicians and non-musicians students (see Table 1). In the first stage the subjects experienced the application's tasks without any information about the music contents; in the second stage one half of the group could get some information in a 1 hour demonstrative lesson, while the other half not. We considered the first test's results as control and the second test's results as experimental data. The results comparison is presented and discussed with respect to the success in the main application's task (the melody harmonization) and to the level of knowledge acquired in three selected aspects of the application's musical content.

3.1 Subjects

A total number of 22 high school students between 16 and 20 years old, took part in the first and second test. In the first test the students were equally subdivided into two different groups: one musically trained and the other not. The first group was taken from classes belonging to the music high school, with specific instrumental and music theory programs. The second was chosen from classes belonging to various kinds of high schools with no music programs in their curricula. In the second test we randomly divided each group into two subgroups of 5 and 6 subjects. Then, we selected one subgroup of musicians and one subgroup of non musicians to assist to a 1 hour demonstration lesson and we called them respectively "instructed Musicians" and "uninstructed Not Musicians". At the end, we obtained the following four groups of subjects and denominations:

instructed Non Musicians (iNM)	5 subjects
instructed Musicians (iM)	6 subjects
uninstructed Non Musicians (uNM)	6 subjects
uninstructed Musicians (uM)	5 subjects

Table 1. Subject distribution among the 4 groups.

3.2 Materials

For our two tests we choose a very popular, old style song, written in 1966 and interpreted by the Italian singer Adriano Celentano. The song (*Il ragazzo della via Gluck*) is very clear and easy in the melodic structure. The harmonic rhythm is not too fast and allows easy body movements in the physical space. The first musical phrase of the song is composed of 11 segments and includes 10 chord changes and a total number of 3 different employed chords, two primary and one parallel (I, V and VI degree), all belonging to the same key.

3.3 Scenario

The *Harmonic Walk*'s test, both the first and second, is subdivided into three phases. In the first phase the user is presented to the straight path along the borders of the mapped area (see Fig. 2). Every step through the mapped regions produces the sound of the portion of the audio file corresponding to one melodic unit. If the user fails to step to the next zone in time, the audio file ends and the performance is interrupted. This feedback shows to the user the right harmonic rhythm, which represents a fundamental knowledge for melody harmonization, and makes her/him aware of the exact place where harmonic changes occur. In the second phase of the experience the user enters the circular ring containing the six roots of the tonality harmonic space, with the aim to explore it and to practice the right positions for a precise performance. When ready, s/he begins the third final phase: the harmonization task. Here the user can try to find the chords useful for the melody accompaniment of the composition, remembering the points of the song where the harmonic changes occurred and searching for the right chord to match. To achieve such a successful result implies a certain number of abilities like remembering the melody of the tonal composition, locating the chords in the circular mask and being able to reach the right place at the exact time requested by the melody.

3.4 Method

The high school students were always tested individually, in private sessions where only the test conductor and the music teacher were present.

3.4.1 First test (common to all the 22 subjects)

1. no previous information about the employed song is provided to the subjects

2. each student is presented with some written instructions about the tasks s/he had to accomplish, while a short demonstration about the environment and its interaction modalities is provided by the test conductor

3. the student undergoes the three phases of the test, lasting respectively a maximum of 5, 3 and again 5 minutes

4. after the time is expired or the last task is accomplished, the student fulfills a questionnaire for both quantitative and qualitative feedback about the test.

3.4.2 Second test (different for instructed and uninstructed subjects)

1. the 11 chosen subjects take part to a 1 hour demonstrative lesson where the test conductor and the teacher explain the aim of the test and show how the applications works. The conductor shows the meaning of the three phases of the test and how the required tasks could be accomplished (only for instructed subjects)

2. each student undergoes the three phases of the test, lasting respectively a maximum of 5, 3 and 5 minutes

3. after the time is expired or the last task is accomplished, the student fulfills a new questionnaire identical to that of the first test.

Instructed subjects follow the second test schedule from the beginning, while uninstructed subjects skip point n. 1.

4. RESULTS AND DISCUSSION

4.1 Quantitative Assessment

Also if the questionnaire fulfilled by the test subjects is very rich in both quantitative and qualitative information about the experience with the *Harmonic Walk* application, for the analysis of control and experimental data we concentrate only on quantitative assessment results. In particular, beyond the evaluation of the success with respect to the main application's task, the melody harmonization, we measure the knowledge acquired in the following three fields of the application's musical content:

1. the detection of the syllables of harmonic changes. The identification of the right syllables indicates that the subjects felt the right points where the harmonic changes occurred and that they are able to remember them. We postulate that this knowledge originates directly from the enactive experience acquired in the first phase of the test.

2. the number of harmonic changes involved in the harmonization task. To provide the correct answer, the subjects need to detect the harmonic changes and to count exactly how many they are. Actually, the number of the harmonic changes is the same of the syllables of change; but realizing this implies further memorization, musical reasoning and awareness from the subject.

3. the total number of chords (tonal functions) employed in the harmonization task. This is the most difficult answer, because it requires that subjects identify the harmonic functions and recognize them when they return in the song's first phrase. This ability is closely related to the enactive experience of the second and third test phases, where the subjects had to find the right chordal route in the circular ring of the song's tonality harmonic space.

4.2 Data Gathering

For the harmonization task data, we rely on the test conductor's reports, where a full success (FS) is recorded when the subject can produce in the assigned time a clearly defined version of the melody harmonization that s/he considers valid. When the subject succeeds in harmonizing only the first part of the melody, where only tonic and dominant chords are employed, a partial success is reported (PS). If the subject, also after many trials, cannot provide an ultimate harmonized version, a failure is reported (NS). For the detection of the syllables of harmonic change, we provided the subjects with a grid where the syllables of the first song's phrase were reported. We asked them to cross those syllables corresponding to the harmonic changes, remembering the exact point where they stepped in through the melodic unit's blocks during the test's first phase. Only the right checked syllables are computed in the means showed in Table 3, while for the other two musical elements knowledge, we source our data directly from explicit subject's answers.

4.3 Meta-Analysis Methods

We consider the 1^{st} test results as the control and the 2^{nd} test results as the treatment. [6] After collecting the two test's records about the full success (FS), partial success (PS) and unsuccessful (NS) subjects in the harmonization task, we obtain a 2x3 contingency table (see Table 2) for each of the 4 subject categories. For each table the Fisher's exact probability [7] (P-value) is calculated, in order to express the degree of statistically significant association between the control and treatment results, assuming a P-value < 0.05 as the significance threshold.

Effect size [8] and Cohen's *d* are calculated on the basis of mean and standard deviation for the syllables of harmonic changes, number of harmonic changes and of employed chords in the harmonization task (see respectively Tables 3, 4 and 5).

4.4 Data Meta-Analysis

In this Section we analyze our data and organize them in 4 Subsections and Tables, depending on the musical content. For each assessed ability, we provide data interpretation based on the appropriate meta-analysis methods.

4.4.1 Harmonization task

The harmonization task contingency tables (Table 2), show statistically significant improvement results only in the category of instructed subjects (Musicians and Non-Musicians), with a very good result for the category of instructed Musicians (iM's P-value = 0.007), while uninstructed Musicians and Non Musicians are well beyond the significance threshold (respectively, P-value = 1 and 0.437).

Harmonization task

	1^{st} TEST			2^{nd} TEST			P-value
	FS	PS	NS	FS	PS	NS	
iNM	0	0	5	4	0	1	0.047
iM	1	2	3	6	0	0	0.007
uNM	1	0	5	0	1	5	*1.000*
uM	0	2	3	2	2	1	*0.437*

Table 2. Contingency tables of 1^{st} and 2^{nd} test results for the harmonization task for each of the 4 subject groups. FS is the number of fully successful subjects, PS is the number of partially successful and NS is the number of non successful subjects.

4.4.2 Syllables of change

Table 3 shows more uniform results among the various subject categories for the detection of the syllables of change, as all Cohen's *d*s are comprised in the same range of values, with a medium improvement for all the 4 subject categories.

Syllables of change

	1^{st} TEST		2^{nd} TEST		Effect size	Cohen's *d*
	Mean	SD	Mean	SD		
iNM	4.25	2.872	5.2	3.114	0.156	0.317
iM	5	2	6	3.464	0.174	0.353
uNM	3	2.944	3.75	1.258	0.163	0.331
uM	6	3.082	7	1.825	0.193	0.394

Table 3. Table of mean, standard deviation, effect size and Cohen's *d* of the results of the 1^{st} and 2^{nd} test for the number of correct syllables of change detected by the 4 subject categories.

4.4.3 Number of harmonic changes

The results for the detection of the right number of harmonic changes show a large improved level for the category of instructed subjects, while for uninstructed subjects we have a small improvement ($d = 0.176$), if not a negative effect in the category of uninstructed Non Musicians.

No. of Harmonic Changes

	1^{st} TEST		2^{nd} TEST		Effect size	Cohen's *d*
	Mean	SD	Mean	SD		
iNM	5.5	2.121	9.2	1.095	0.738	2.192
iM	7	2.549	10	0.408	0.634	1.643
uNM	4.3	1.528	4	0.816	*-0.121*	*-0.244*
uM	8.25	2.872	8.8	3.347	0.087	0.176

Table 4. Table of mean, standard deviation, effect size and Cohen's *d* of the results of the 1^{st} and 2^{nd} test for the number of correct harmonic changes detected by the 4 subject categories.

[6] Usually, in learning environment analysis, the control is given by the results obtained during a traditional lesson, without the help of any technology, while the treatment is given by the results obtained during sessions where the application is used to convey the same contents. In the case of the *Harmonic Walk* this was an impractical assessment condition, at least for the Non Musicians category of subjects. Indeed the melody harmonization is a rather difficult task, which requires a great amount of practice and musical knowledge, well beyond the level also of a music high school student.

[7] The Fisher's test is used in the analysis of contingency tables when sample sizes are small. Its results are always exact also if the frequency of values is less than 5 (the frequency validity limit for Chi-test).

[8] Effect size measures the magnitude of a treatment effect. By convention, it is a positive value if it is in the direction of improvement, otherwise it is negative.

4.4.4 *The number of employed chords (tonal functions).*

The results for the number of employed chords show a good improvement in the categories of Non Musicians (both instructed and uninstructed), while showing a negative value for instructed Musicians and a very small effect size for uninstructed Musicians (d = 0.054).

No. of Employed Chords (tonal functions)

	1 st **TEST**		**2** nd **TEST**		**Effect size**	**Cohen's *d***
	Mean	SD	Mean	SD		
iNM	3.67	1.527	3	0	0.296	0.620
iM	3.4	1.673	3.75	0.957	*-0.127*	*-0.258*
uNM	5.4	3.714	3	0	0.415	0.913
uM	3.3	1.204	3.25	0.5	0.027	0.054

Table 5. Table of mean, standard deviation, effect size and Cohen's d of the results of the 1^{st} and 2^{nd} test for the number of employed chords (tonal functions) detected by the 4 subject categories.

4.5 Discussion

4.5.1 *Test data evaluation*

We submitted our subjects to various assessment conditions to discover what is the weight of the simple test repetition (for uninstructed Musicians and Non Musicians) and of the test repetition after a 1 hour lesson, where the test's musical content was explained and showed by the test conductor (instructed Musicians and Not Musicians). Our results show that, for the harmonization task, the lesson was very important, as instructed subjects (Musicians and Not Musicians) could achieve a very good result in the second test's session, while uninstructed subjects performed rather poorly. Anyway, the lesson didn't provide any technical detail about the harmonization task, but, rather, showed to the subjects how it could be practically done in the application's environment. Thus, the necessary information was transmitted to the subjects only by the observation of the test conductor's movements and interaction style and not by theoretical explanations, thereby proving the high power of knowledge communication of the *Harmonic Walk* learning environment. But the results of the harmonization task do not always coincide with the findings in the three musical content knowledge acquisition tests. For instance, in the detection of the syllables of change we observe a general uniform improvement among the 4 subject categories, ranging from a minimum of Cohen's d value of 0.317 for instructed Non Musicians, to a maximum of 0.394 for uninstructed Musicians. In any case, it is a medium difference, but it indicates a clear improvement in the musical knowledge, independently from the success in the harmonization task. The explanation of such a result can simply be the memorization of the song's words, which improved with a second trial. In any case, the information was explicitly provided to the instructed group during the lesson, but this didn't seem to affect significantly the test's results. The number of harmonic changes is again much better detected by the instructed group, with great Cohen's d values. This information, explicitly provided during the lesson, was clearly much easier to remember than the list of the syllables of the harmonic changes and, consequently, most of the instructed subjects could produce a better answer in the second test. In the perception of the number of the tonal functions employed in the song's first phrase harmonization, we record a right answer in all the non musician subjects. This is probably due to suggestions shared among the group components, and, consequently, this part of the test cannot be considered valid.

4.5.2 *General results evaluation*

We have now some element to answer the questions we pose at the beginning of this paper.

1. *It is possible to make implicit knowledge about tonal melody and harmony to emerge and to become a real ability?*
   If we consider the results obtained in the assessment of the only two available fields of musical knowledge (detection of syllables of change and number of harmonic changes), we see a general middle level improvement for the syllables of change and a limited to the instructed category low improvement for the number of harmonic changes. So, inside the boundaries of this experiment, the answer is yes, it is possible to make implicit knowledge to emerge, especially when the application's practice is matched with supporting explanatory lessons.

2. *How important is the role of explicit, previously delivered information?*
   When the information is easy to remember and has been given explicitly, as in the case one the number of harmonic changes, it actually affects the results, as shown in Table 4. Such kind of answers are also easy to be suggested, as in the case of the detection of harmonic functions (see Subsubsection 4.4.4). As a matter of fact these two answers are meaningful as a product of a reasoning, but are not meaningful as a mere repetition. This seems to ask for a better control in the communication during the lesson and for better refinements in the assessment method.

3. *Is enactive experience stronger than explicit information?*
   The enactive experience has been crucial in the performances registered for the harmonization task and for the detection of the syllables of change, as it has been able to transmit only by imitation and in a very short time a lot of information to the test subjects. Thus the answer is yes: Enactive experience is stronger than explicit information, at least in the case of the musical task we choose for our test.

4. *And if so, in what domain?*
   The authors of [13] tried to answer this question referring to a learning experience in the field of physics. They found that embodied physical learning leads to the same grade of improvement as a mouse-operated learning experience. Also, if we didn't yet perform a similar test for the *Harmonic*

Walk environment, we can say that music education has a lot to do with embodied knowledge also without the use of technologies. In our design policy, we included a lot of abstract concepts, but these were always acted through acquired or implicit embodied knowledge. Thus, we were not surprised by our test's results, and we consider the difficulty of translating the same communicative power in other fields of knowledge different from music, a challenge that requires more control and refined research methods.

5. CONCLUSION AND FURTHER DEVELOPMENTS

We submitted a group of musicians and non musicians high school student to a two phase assessment test under different conditions, with the aim to measure the educational power of the *Harmonic Walk* application. We found that a lot of information could be conveyed by simple imitation, skipping other forms of explicit knowledge transmission, like traditional class sessions. Moreover, explicit information content could improve the student's performance at some extent, but we could not prove if this major results were due to mere information memorization/suggestion or to actual knowledge and content awareness. The big challenge of test method refinement has to be faced in next assessment sessions, to try to better control the test conditions. Moreover, we missed a post-test assessment session, where we could outline the concepts acquired by our subjects and cause further reasoning and awareness.

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