Towards an automatic version of the Berg Balance Scale test through a serious game

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Abstract

Considering the current pyramidal age of developed countries it appears that there is a need for tools that can automatically evaluate a person's ability to maintain balance. Proposed system, is a serious game running on the *Android OS*. It uses an augmented sole in order to measure movements realized by the user. For this evaluation, the same exercises proposed in the *Berg Balance Scale* are used; however they do receive a more motivating and engaging appeal through several events. When using the proposed system, a detailed analysis of the movements realized by the user can be done.

Categories and Subject Descriptors

H.4 [**Information Systems Applications**]: Miscellaneous; D.2.8 [**Software Engineering**]: Metrics—*complexity measures, performance measures*

Keywords

balance evaluation, Berg Balanace Scale

1 Introduction

Accidental falls are the combined result of several factors. Because of that, many programs dedicated to fall prevention have considered several factors ranging from medication to control of balance. Nevertheless, it was shown that problems related to gait and balance play a leading role in increasing the risk of falling. Furthermore, these two factors appear to be the most common in individuals at risk (elderly). On the other hand, developed countries are now facing an important demographic crisis. For example, the proportion of seniors (over 65 years old) in the Canadian population was 14.8% in 2011; representing an increase of 13.7% compared to 2006. However, Canada still has one of the lowest proportions of older people among the G8 countries [1]. Therefore, it seems essential to develop effective methods for the evaluation of balance and gait.

Traditionally, the evaluation of the ability of a person to maintain balance is realized through multiple exercises dictated one after the other by a specialist. The Berg Balance Scale (BBS) is a clinical test widely used in such a situation. Other tests such the Tinetti Balance Assessment Tool (TBAT) (as described in [13]) or even the Morse Fall Scale (MFS) [14] are also used. In these approaches, for each patient, the evaluation is realized in a clinical environment by a specialist. Although many effective results, one has to note that in such an implementation, patients have to deal with repetitive exercises. Moreover the healthcare cost is usually high, mainly because of the transportation cost to the clinic and the cost of this personalized service.

This paper targets these two aspects through a system dedicated to an automatic evaluation of a person's static and dynamic balance abilities. The proposed approach uses the ACHILE system [7] to implement an automatic version of the BBS. This system was previously used successfully for training balance control over different types of soil [6] and for learning some risk level of falling [5]. As opposed to traditional approaches, even through same exercises are exploited; they do receive a more motivating and engaging appeal through a gaming context. Exercises are integrated into a casual activity: the exploration of an uncommon museum.

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Moreover, the accuracy of each exercise is evaluated automatically by the system. Fig. 1 shows a user while experimenting the proposed system.

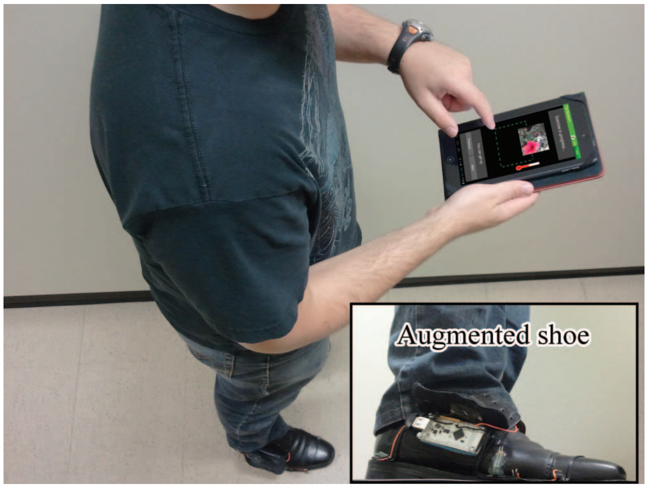

Figure 1. A user is experimenting the automtic version of the Berg Balance Scale.

2 Related work

To the best of our knowledge, no work has investigated the automatic evaluation of a person ability to maintain balance. Nevertheless several works have been focus on the automatic training systems. Indeed, during the last decade, growing interest has been focused on personalized training systems at home. In this way, several balance training programs have been designed.

The device used in such programs can be passive or active. For example, a force balance plate measuring the actions taken by the user is a passive system. On the other hand, a system that measures and drives back a signal to the user is active. Recently, *Standing Strong* [8] has been released. This program uses passive devices: two plates (one for each foot), elastic bands and a ball[1]. Some exercises consist in remaining balanced on the toe, to maintain balance on one foot (or one-leg stance test) or stepping in different directions. An interactive balance training program requires an active system comprising a component for the human activity measurement and another component for sensory feedbacks indicating the performance during the execution of the exercise. Sensory feedbacks can be visual, audible or haptic. The Nintendo Wii-Fit^{TM} Plus is a commercial device using such interactive systems. Several studies have been conducted on the use of the Nintendo Wii-Fit^{TM} Plus platform for balance training such as [4]. To validate the performance of using an interactive serious game platform at home, a recent study compared the impacts between the serious game and Tai Chi [9]. This study shows that the use of serious games in the balance training gives similar results to *Tai Chi* exercises.

However, these platforms, designed for balance training, do not allow to measuring the ability to maintain balance neither risk assessment of falls. Falls risk screening and assessment instruments are widely used by clinicians [2]. For example, one-leg stance test (OLST) is a good candidate for predictive measures of fall risks in frail elderly patients [12]. Other assessment instruments could be Falls Efficacy Scale (FES) [10]. Some systems may include an instrumented shoe with displacement actuators like in the *Smiling project* [11]. In this project, actuators are used to induce disturbances under the feet during balance training. The idea to include a shoe in the balance training program comes from the improvement in balance measures while using foot orthoses [3].

To the best of our knowledge, there is no interactive device using a serious game for fall risk assessment. This paper presents a new interactive system using a serious game for predictive measures of risks of falling.

3 The Berg Balance Scale test

Several tests have been created in order to determine a fall risk level. The Tinetti for example is splinted into two parts and each of them is thoroughly analyzed with the help of a clinician. Even though the clinician does not need special formation, he must take into consideration several posture factors. However, compared to other assessment tools, the Berg Balance Scale offers a more diversified range of exercises. This means a broader test that increases the chances to detect risks of falling. The BBS consist of 14 exercises all focused around daily life tasks. All exercises are rated from “0” to “4”. “0” stands for the instability whereas “4” represents no stability issue. A threshold is applied to the sum of scores from all exercises. A rating of “0-20” represent serious balance issues, “21-40” represents a stable balance whereas more than “41” represents an excellent balance. The test is performed with the help of a clinician that guides the patient through all exercises. The examiner is responsible of evaluating the patient and rating his total score. The BBS is estimated to last for 10-20 minutes. The test requires little specific equipment to perform, common things like chairs and canes can be used.

We selected the BBS to evaluate risks of falling since it takes into consideration a broader range of possibilities and it offers an easy evaluating process. This simple evaluation can be processed by a handheld device, removing the need for an clinician.

4 Proposed Game

Serious games have spread over several subjects of learning and training. Over the past two decades, subjects covered by such games have ranged from science learning to high class military training. In this way, serious games represent a proven way to learn and train about a specific subject in a pleasant process. This gives serious games an interesting step above formal training. Also, if the game itself can be operated without need of a supervisor, the exercise becomes more flexible over the users schedule.

Our serious game objective is to combine the effective Berg Balance Scale and the appeal of a serious game without sacrificing the results reliability of such a test. All exercises of the BBS test are adapted to a particular context and are evaluated through our ACHILE system and collected data. The serious game introduces the user to a visit of a partic-

[1] http://www.standingstrongprogram.com/

ularly strange museum. There, the user explores the museum and executes exercises in order to find puzzle pieces. At the end of the visit, the user is granted the optional task to complete the puzzle. The game provides an interesting process on the randomized exercises which create the path to the mysterious puzzle which is also randomized. The museum visit scenario was selected since it contains several pleasant factors as exploration and puzzle solving. On the other hand, this scenario offers many opportunities to adapt exercises of the BBS. Proposed exercises range from typical painting sighting to the process of helping someone who lost something. The main advantage of proposed game is the ease of completion of exercises with the help of the augmented shoe. Moreover, by separating an exercise into several steps, we get a deep analysis on the user's skill. Such an analysis can give the accurate results required by the BBS in order to provide appropriate advices to the user.

4.1 The ACHILE system

ACHILE stands for ACtive Human-Computer Interface for Locomotion Enhancement. This is an intelligent system, recently developed; it aims at preventing accidental falls related to conditions of the physical environment of the person (slippery ground, steep slope, etc.), or abnormalities of its gait. This system is centered on an augmented shoe (see Fig. 2). This device counts, on one side, a set of sensors that serves for characterizing the dynamics of walking, the posture of the user and the physical properties of the environment. For example, they measure the velocity and acceleration of the foot, bending of the sole and forces applied at five points under the foot. All these sensors are exploited to compute the risk level associated to physical characteristics of the environment. On the other hand, this device brings together several actuators aiming to transmit vibrotactile signals to the user. These signals intend to attract the attention of the user towards situations deemed dangerous by the control system running on a *Android* device (tablet or smartphone). For more details on this system, one can refer to [7]. In the context of current game, these sensors (acceleration, sole bending, applied force by the user, etc.) are used in order to assess the correctness completion of some exercises.

4.2 Playing of the game

The serious game contains a series of exercises which are all based around BBS exercises. Each of these exercises represents a situation where the user has to complete a challenge in order to proceed through the game. All exercises are randomly ordered with the exception of the first and last one. This provides an interesting new way to complete the game on each walk-through. The completion of an exercise grants the user with a puzzle piece. Once the game is completed the player will have the opportunity to solve a puzzle. This is where the user will spend his gathered pieces.

To facilitate the usage of the game, each exercise is splinted into several steps (*Introduction, Instructions, Execution, Conclusion* and *Reward*). The introduction step describes what is happening in the game world to the player as he starts an exercise. The instruction step tells the player what he should actually do in order to complete the exercise. The execution step informs the user about the completion of the current exercise. At this step, the completion of an exercise is analyzed in real-time by the system. The conclusion step (right side of Fig. 4) thereafter concludes on what happened in the game world and then starts the reward step where the game presents a reward in function of the score. There can be several occurrences of introduction and instruction type steps in order to give detailed explanations on more complex exercises. This allows the game to be quite flexible.

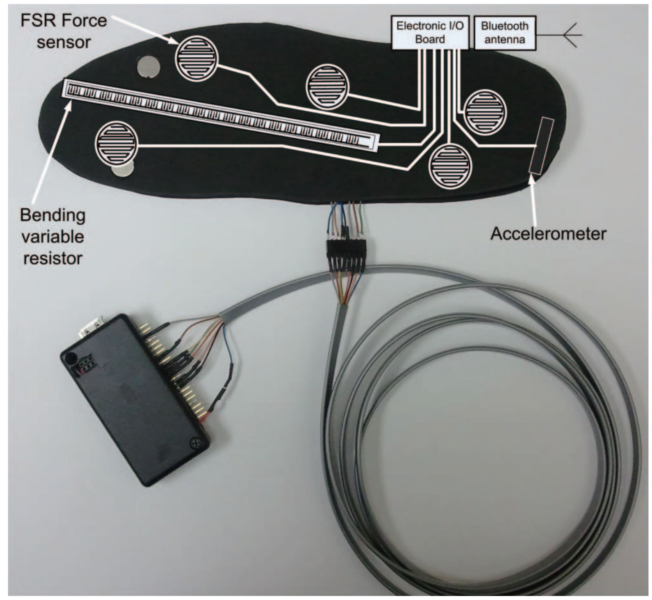

Figure 2. Current version of the interactive sole.

To deal with the repetitive aspect of the BBS, our focus was on integrating each exercise into engaging tasks. We also added an optional puzzle game at the end of the whole exercises. This game is a puzzle slider of randomized paintings. The user is not in the obligation to complete it and it does not affect his scores.

As an example, we can consider the second exercise of the BBS. In this case, the user is invited to stand still and then to rise to his toes for a period of 3 seconds. Traditionally, as in other exercises, to evaluate the level of completion of this exercise, a clinician is required. In the context of the proposed serious game, we created a simple process where the user is automatically guided and thus does not require the help of an examiner. After brief Introduction, Instruction and Execution screens, the Execution step displays a painting that the user needs to stabilize into a target marker for a period of 3 seconds. Then the user is presented with the Conclusion screen to learn what happened before receiving a puzzle piece at the reward screen in the case of a success. Fig. 3 and 4 are screen copies at these steps.

As shown, the game takes form into several screens. Each exercise is created with this process. When an exercise is completed, the game sends the user to a next one. As mentioned earlier, the order is randomized, so the next exercise cannot be predicted. This allows a more engaging repetition of the game.

The third exercise of the BBS invites the user to stand on

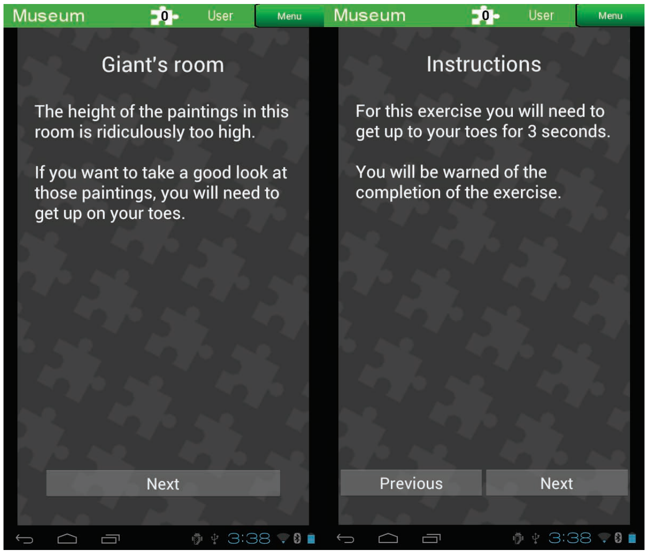

Figure 3. Introduction and instruction screens of an exercise.

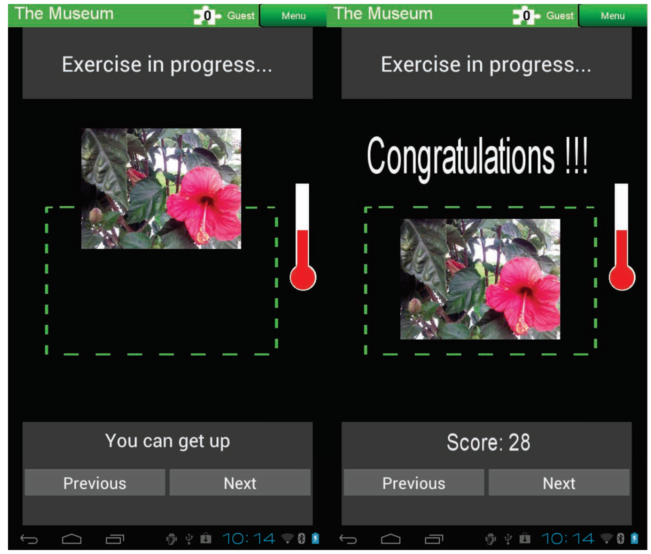

Figure 4. Execution and Conclusion screens of an exercise.

Very low	Low	Medium	High	Very high
0.02236	0.03886	0.04403	0.12269	0.13456

Table 1. Standard deviation associated to each level of oscillation.

one leg. The patient must stand on one leg for a maximum of 30 seconds on both sides. In the proposed version, the user is in front of a magic mirror (a video clip is played) where he must mimic his own reflection in order to complete the exercise. The reflection will guide the user on both legs. This exercise can be easily validated by the game with accurate results without the need of an examiner.

4.3 Safety issue

Proposed system is dedicated to fragile users (elderly or persons who are facing balance problems); therefore it is crucial for us to insure its safeness. For this goal, several constrains have been incorporated in the game in order to guaranty the safety of the player.

Firstly, the system should be used only under medical supervision. Namely, only a specialist can decide whether a person can use it or not. For this, a first utilization supervised by the specialist is required. In the case that the specialist estimates that the person may use the application, for all subsequent usages, results of the first evaluation will serve as a reference by the system in order to detect whether the person is still eligible to use the system.

Moreover, because of the dangerousness of several exercises (for example standing on one leg) the system invites the user to realize them only in the presence of another person. Indeed, at the "Instruction step" of such exercises, the system invites the user to confirm that there is a person ready to assist him in case of an accident. At current version of the game, we rely on the user to validate that aspect; nevertheless we plan to incorporate an automatic detection aspect in future versions.

5 Case of study

To analyze the effectiveness of the proposed serious game in the automatic evaluation of a person ability to maintain static balance, here we present the implementation of the second exercise of the BBS into our serious game. In the traditional test, for this exercise the patient has to rise on his toes for a period of 3 seconds, a clinician has to check the patients behavior and rate it. As described above, in the context of our serious game, this exercise is incorporated in a scenario depicting someone who enters a room where all the paintings are hanged too high. The user has to rise on his toes in order to get a good look at the painting.

For this, we exploit the typical process of Introduction, Instruction, Execution and Conclusion. This allows the user to get a good idea of what he must do at its own pace so that he can complete the exercise without the need of a specialist. In the Execution step, the user has to move a painting on a wall and then moves it into a dashed square for 3 seconds. This simple task allows the system to realize a deep analysis on the users balance through the bending variable resistor placed into the sole (see Fig. 2). This bending variable resistor is located along the middle of the foot toward toes. This position provides usefull information about the users progress.

5.1 Exploitation of the ACHILE system

To evaluate the ability of a user to stand on toes, we have to evaluate the level of oscillation of its foot and ankle. For this, standard deviations of the bending variable resistor have been used to trace down a pattern in the user oscillations. Based on a pretrial test, we defined five levels of oscillation, ranging from *Very-low* to *Very-high* oscillations, based on observed standard deviation. Table 1 presents these oscillation levels.

5.2 Results of an initial study

Nine male participants, mainly university students, took part to this study. Participants reported being accustomed to technological devices. We created a profile for each of them which allowed each test to be recorded on the device separately. The record process of this exercise is divided into three parts: *feet on ground*, *user on toes* and *feet on ground*. This separation allows a detailed analysis of the users balance.

Raw data coming from the bending variable resistor are shown in Fig. 5. For the clarity of the presentation, this figure does only exhibit five of the nine users; this shows the functionality of the sensor. Measures are acquired during three stages of the game: Instruction, Execution, and Conclusion. During the instruction step, the algorithm measures the rest position of the user. This allows displaying the initial position of the picture on the screen. Thereafter, at the execution step, the variation of measurement moves the image on the screen. The red dots in Fig. 5 show the Execution step for user "D" and "G" when the picture is located inside the dotted box. User "D" has a very stable behavior unlike the user "G" which has some oscillations. These data (red dots) are used to compute the capacity of the person to maintain balance. These results are based on the stage where the user is on his toes. Table 2 presents all the data recorded during this experiment. Fig. 6 represents the standard deviations (σ) of each user over the three second period of the exercise (standing on toes). In this figure, the standard deviation is for each point computed from the start of the exercise (from $t = 0$) since we want to evaluate the stability over the three second period.

A major difference can be clearly observed among the participants. Fig. 8 shows the best and the worst cases observed within the tested population. Looking at the user "I" (worst case), we observe that he had trouble in standing on toes whereas the user named "D" (best case) did performed the required standing perfectly. Results observed with user "I" may be explained by two reasons. Maybe the exercise has been tiring for him or maybe he had lost balance during the exercise. To get a deeper understanding of difficulties the user did faced during the exercise, we have analyzed the standard deviation observed for each period of 0.5 second (see Fig. 7). Looking at this figure, it appears that the observed result is due to a sudden loss of balance occurred in period starting from 1.5 to 2 seconds. Indeed, after some sudden increasing of the standard deviation in this time frame, it has decreased over the two other periods. ($[2, 2.5]$ and $[2.5, 3]$). It is interesting to note that such a detailed analysis would be difficult to realize without recorded data namely in a traditional approach.

We also noticed that all participants gave great feedbacks about the game. They commented it as being intuitive and engaging. More particularly, we noticed that the user named "I" reported the ease he had to complete the exercise despite his obvious instability. Such a comment highlights the fact that the proposed serious game is accessible moreover it focuses more on evaluation rather than pure entertainment.

5.3 Score

Within the application itself there is a method that analyzes results from each stage of an exercise in order to provide feedbacks to the user of how well he did during the test. These results can be browsed from a scoreboard page accessible from the main menu of the application. There are three types of scores that are calculated separately.

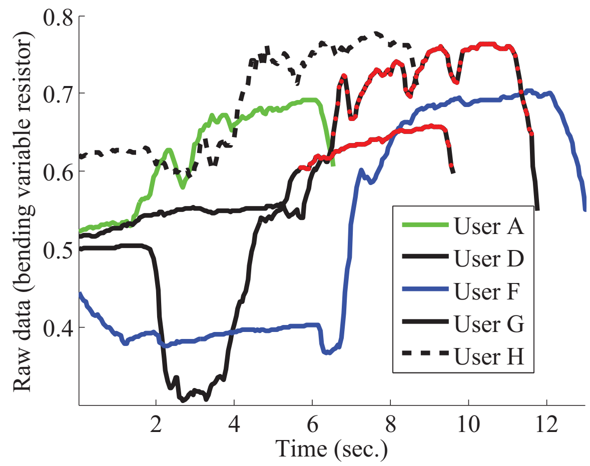

Figure 5. Raw data coming from the bending variable resistor.

User	Min	Max	Average	σ	level
A	0.578	0.680	0.652	0.030	Very low
B	0.503	0.721	0.662	0.058	Low
C	0.566	0.750	0.674	0.048	Low
D	0.616	0.672	0.649	0.015	Very low
E	0.636	0.703	0.683	0.017	Very low
F	0.675	0.699	0.689	0.006	Very low
G	0.647	0.739	0.703	0.02	Very low
H	0.698	0.765	0.744	0.016	Very low
I	0.225	0.739	0.536	0.183	Very high

Table 2. Data recorded for all users during the exercise.

The first score is calculated after each stage of an exercise; it is named *stage score*. As an example, in the *stand on your toes* exercise, there would be three *stage scores*. One for the stage of standing still, one for the stage of being on toe tips and the last one for the stage after dropping back on the ground. Each *stage score* aims at informing about the difficulty that a user had face for a given step. This score is computed using data coming from sensors of the augmented shoe. It uses the average of the readings, the standard deviation and correcting factors. The correcting factors are dependent of the standard deviation. Let X and A_r represent respectively the standard deviation and the average of all the data recorded by the system during the completion of a stage. The *falling factor* (F_f) and the *correcting factor* (C_f) are computed using table 3. The *stage score* is defined

σ	Falling factor (F_f)	Correcting factor (C_f)
$X < 0.04$	1	1.5
$0.04 < X < 0.06$	2	3
$0,06 < X < 0,1$	3	4.5
$X > 0,12$	5	6.5

Table 3. Standard deviation associated to each level of oscillation.

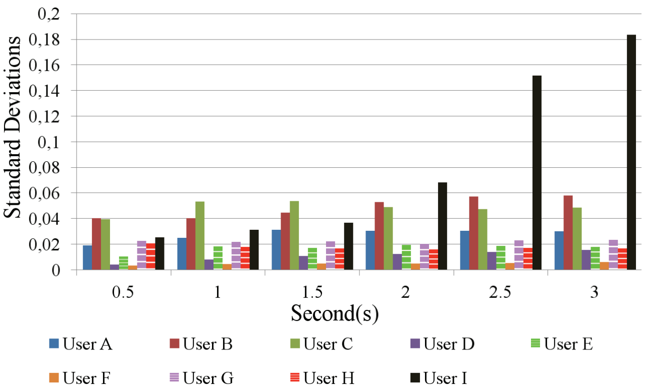

Figure 6. Variation of the Standard Deviation over the 3 seconds period.

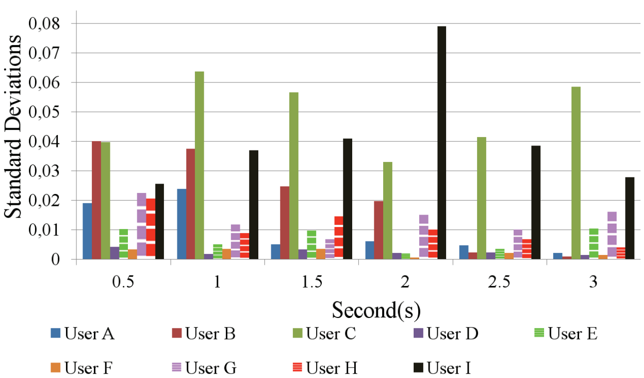

Figure 7. Variation of the Standard Deviation for each step of 0.5s over the 3 seconds period.

by (1).

$$Score = \frac{A_r}{\sigma} \times F_f \times C_f \tag{1}$$

The second score is computed after each exercise so that it provides an overall feedback for the exercise. It defines the average of all the stage scores of an exercise. The last score represents a global score. It gathers the whole exercise score that the user has ever completed. All these scores are stored in the applications database and are associated to a user profile. Each entry in the database has a timestamp to help keeping track of the user's progress.

6 Conclusions

This paper described a serious game for the automatic evaluation of the ability of a person to maintain balance. The same exercises proposed in the Berg Balance Scale are used, however they are integrated into casual activities, namely the sightseeing of a museum, in order to guaranty the engagement of the user. With the proposed system, the intervention of the clinician is limited. Although one has to note, that the clinician still plays a central role in the process. In this perspective, the system appears as a tool that can help a clinician in offering a better service. Indeed, when using the system, a more detailed evaluation can be made about the users' ability to maintain balance. Realized experiments confirmed the effectiveness of the system.

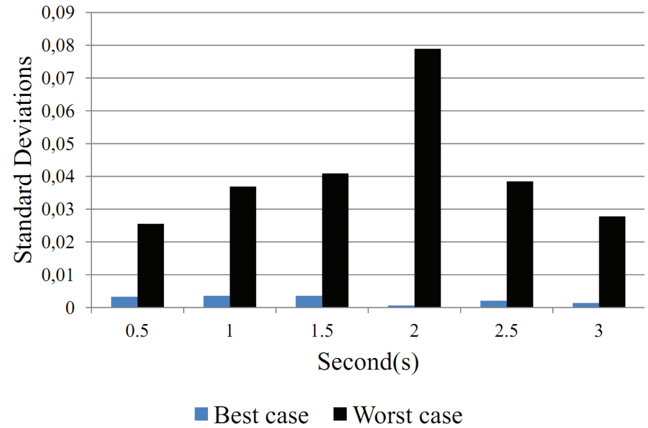

Figure 8. The minor and major oscillations observed within the participants.

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