A Serious Game to Improve Posture and Spinal Health While Having Fun

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Abstract—We present a serious game which we believe that has the potential to improve posture and spinal health while still having fun. In our game, we correct postural deviations and perform and memorize lengthening sequences. It operates in the single and multiplayer modes using haptic devices for game control and uses the Microsoft Kinect for gestural interaction. We also conducted user studies to evaluate our game. The results show that observations and experiences of posture correction and lengthening influence the behavior of the users, stimulating reflections and initiatives in their real lives during game play.

Index Terms—Serious game, Computer Vision, spinal health, RSI/WMSD, haptic devices, gestural control, user studies

I. INTRODUCTION

Posture is the position in which we hold our bodies while standing, sitting, or lying down. Your posture directly affects your health. The syndromes known as Repetitive Strain Injury (RSI) and Work-Related Musculoskeletal Disorders (WMSD) comprise a group of occupational diseases recognized worldwide, that affect nerves, muscles, joints and tendons [1]. Generally, these diseases result from poor working conditions, often caused by static or dynamic work overload in improper ergonomic position.

Commonly, the most affected body parts are the following: hands, wrists, forearms, elbows, arms, shoulders, neck and shoulder blade [1]. The deviations of posture are often influenced by improper settings in the environment of work, for example: chair height; positioning of the feet, arms and wrists; monitor height; viewing direction; among others. In particular, the professionals most affected are those who work with computers (bank employees, telephone operators, typists, secretaries, and professionals in the field of computing in general). Other risk groups are composed of people who work on assembly and production lines, machine operators, musicians, athletes, etc. The symptom has also been diagnosed in younger individuals who make excessive and continuous use of the computer or input/output devices to control electronic games, in endless moments of entertainment.

On the other hand, the quality of life can be enhanced through improving and maintaining a good range of motion in the joints. The level of flexibility of individual joints varies from one person to another. Besides that, loss of flexibility, age, gender, and genetics can be also predisposing factors for physical issues such as pain syndromes (RSI/WMSD). However, periodic exercises, including stretching, often improve the flexibility of joints and muscles.

Given the frequent occurrence of RSI/WMSD and aiming to contribute to the generation of preventive actions [2] that could alert individuals to the problems caused by occupational diseases, we have developed and evaluated a serious game in healthcare to correct postural deviations and to perform, memorize and fix stretching sequences.

More specifically, our game operates in both single and multiplayer modes using haptic devices (Novint Falcon [3] by Novint Technologies Inc, and Phantom Omni [4] by SensAble Technologies), which are computer peripheral devices that provide force feedback to the user. Haptic interfaces have been applied in an increasing number of domains, going from simulation-based training to entertainment. Due to their different characteristics, a force may be felt differently on different devices. Compared to game controllers, these devices provide in general more detailed and accurate force feedback. In our work, these devices work as control interfaces for correcting improper postures and generating greater sense of presence in the game. Our game enables the identification of various postural risk factors in the workplace, the posture correction of 3D characters, and the correct positioning of equipment and furniture in the environment, at a certain time limit. Additionally, it allows the memorization and practice of motion sequences for stretching the joints, respectively, through a puzzle and the Microsoft Kinect device [5]; and generates warnings stressing the importance of taking regular breaks from occupational activity, targeting the physical and mental well being of the individual.

II. PREVENTION MEASURES FOR RSI AND WMSD

Some preventive measures, with the aim of advising the ergonomic suitability of the worker’s body positions while performing a job, such as rest breaks have been recommended and established globally [1]. More specifically, the ergonomics recognizes that a person is in the correct posture when their major joints form angles of 90° between its upper and lower members, and the head and trunk are straight and perpendicular to the ground. The absorption of these recommendations in the daily tasks of people is not trivial, since there are many
people presenting postural problems. Often, it is necessary to redesign the work environment to maximize the elimination of the risks associated with poor posture. Aware of this scenario, for example, a correct posture in front of the computer implies some basic and continuing care, which is implicit in the act of sitting correctly [1]:

1) Occupy the entire chair seat, adjusting the backrest in a straight shape or slightly sloping;
2) Lean back on the chair until the lumbar spine fits comfortably in;
3) Keep the hip and knee joints at an angle of approximately 90°;
4) Fully support the feet on the floor or in a footrest;
5) Keep the shoulders and elbows relaxed and resting comfortably;
6) Adjust the forearm supports and the chair height so that the members form angles of approximately 90°;
7) Do stretching whenever possible; and
8) Take breaks of 2 to 5 minutes every 2 work hours.

III. GAME DEVELOPMENT PROCESS

The development process of our game followed the five phases shown in Table 1: Game Concept, Analysis, Design, Implementation and Testing [6]. After the pre-production phase in which we discussed the basic concepts and defined the storyboard and the main characteristics of the game core, we started the game production phase.

A. Analysis and Design

According to a set of requirements of our gameplay (playability level, forms of user interaction, types of characters and 3D scene, punctuation mechanism, etc.), we generated the number of menus and the type of information to be displayed during the game’s execution, and constructed a generic activity diagram for the game as a whole [7], [8], [9].

Due to its educational aspect, the game provides to the users the opportunity to learn how to fix and assimilate the main improper postures that cause pain to try avoid them in their daily life tasks. There are two game modes: “play with help” or “play without help”. When we enable the option “play with help”, a shadow effect of the character in the correct posture is inserted under the original game character with incorrect posture, serving as a guide for the player. This shadow effect is not enabled in the option “play without help”. Initially, new dynamic 3D characters with different individual characteristics (age, gender, body anatomy, levels of flexibility in the joints, and postures) appear randomly on the screen. The user task is to help strengthen and improve their postures. Basically, the characters are sitting in a chair facing a table with a notebook, having a common scenario in the background (Fig. 1).

Our game can be played by a single player or by two different people at the same time. In the single player mode (top image of Fig. 2), the game starts with the character in an improper posture. The committed joints are indicated to the player, as shown in the red circles in Fig. 1. Using the input device, the player starts the correction of the elements in the scene, with a focus on improving the posture of the character, according to the following priority: spine, legs, feet, arms, forearms, hands and gaze direction in relation to the notebook screen.

In the multiplayer mode, shown in the bottom image of Fig. 2, the viewing screen of the game is divided vertically in half: the left side is relative to the player 1 and the
right one, to the player 2. The players compete with each other and interact through their respective devices (Novint Falcon, Phantom Omni or conventional mouse), via network. Both players share the vision of their own game and the opponent’s game, on their respective computer monitors. In addition, during the game, a player may interfere with the other player’s game, for example, taking out the character of the opponent player from its correct position, in order to hinder the fulfillment of the task of correcting the other player character’s posture. However, before being allowed to interfere with the opponent’s game, it is necessary to obtain a special item, available when the player makes a correct sequence of postural adjustments on their characters in less than 35s (this value was used based on empirical testing involving an expert user). Each pair of characters remains in the game scene, available for postural correction, up to 130s. After this time limit, randomly, another pair of characters enters the game scene, continuing the multiplayer round.

Additionally, suggestions for body stretching are included in our game in the form of a set of two-dimensional sliding puzzles [10] (shown in the left side of Fig. 3) to encourage the memorization of lengthening sequences. The pieces cannot be lifted out or rearranged in any way, except by sliding them into an empty space. The goal of our sliding puzzle is to arrange the pieces in a particular pattern (i.e., lengthening sequences). Movement of pieces is restricted so that you have to move one piece in order to shift another. Bonuses are activated when solving these puzzles, showing a 3D animation of an articulated character doing the stretching exercises concluded in the puzzle (right side of Fig. 3).

Finally, during the game, from times to times, the Kinect device mode is activated, in which the player should be positioned in the center of the screen to replicate the stretching exercise superimposing his/her image on the projected image displayed on the computer screen (Fig. 4).

B. Modeling Tools

There are several tools that can assist in the production process of games. We chose Blender computer graphics software [11] to produce all the 3D contents (geometric modeling, texturing, rigging of characters and animations) and Unity [12], an engine for 3D games which supports scripts written in C# and Javascript. The scripts allow the developer to add customized logic to the game components, as well as to implement plug-ins developed in native C language, which integrate external resources to the game engine.

1) Characters and Environment: We have used a 3D public domain articulated character, as the reference to the modeling of the games’ characters. From this base model we derived four other customized characters, in accordance with the original art concepts we created for our game. Own visual attributes of each character, including textures, were subsequently modeled. The motion controls of the joints and animation, the customization of the characters’ visual attributes, and the 3D scenarios were generated by the authors using Blender. The static elements of the game correspond to the geometric inanimate objects that do not move or change their visual attributes throughout the game, for example, some of the furniture or objects that compose the scene (table, cabinet, etc.), whereas the dynamic elements match the lively geometric objects that have motion or ability to change their visual attributes via user interaction (humanoid characters, chair, footrest and notebook).

The joints of the characters, compromised by improper posture or stress (caused by occupational exercise), are visually emphasized in the game by “pulsing” red circles. The goal is to ensure the correct posture of the characters within a time limit, which decreases as the number of completed postural
corrections increases. That is, as time passes, the postural correction of a character becomes an increasingly difficult task to be accomplished. In our implementation, based on some functional testings we conducted, values for the angular rotation of the joints with a deviation of $3^\circ$ are considered acceptable and within the solution space that represents the correctness of a particular posture.

2) Input Devices: As mentioned before, besides the mouse device used for handling 3D characters and objects, our game offers the possibility of using the haptic devices [13] Novint Falcon [3] and Phantom Omni [4]. In particular, the positions of the haptic cursors are controlled by the device’s movements and are used by the device’s software to determine the forces that will be applied on the player character. We also used the Microsoft Kinect device (Fig. 5) [5] for gestural interaction to control the game tasks and to perform lengthening sequences [14].

We chose the C# as the programming language due to its high compatibility with the available libraries for the Kinect device. We used the Kinect for Windows Software Development Kit (SDK) v1.8 [15] and the Kinect for Windows Developer Toolkit v1.8 [16], in order to access the three major physical Kinect components (Fig. 5) and its main features [17].

Fig. 5. Kinect and its three main physical components.

The main functionality of the Kinect is tracking the joints of the human skeleton. An integration with the Kinect Toolkit 1.8 is required to access this information. In total, 20 joints (Fig. 6) can be identified and mapped spatially in real time by the device’s depth sensor.

The level of the gameplay takes into account the interaction process of the user with the haptic interfaces (or with the mouse). We have modeled three different modes of interaction with the 3D characters using the haptic devices to represent the level of flexibility in their joints: low flexibility, normal flexibility, and high flexibility. In the low flexibility mode of interaction, the forces are increased to make it harder for the user to correct the positions of the character’s joints; in the normal flexibility mode they are set to default values; and in the high flexibility mode they are decreased to make it easier for the user to correct the positions of the character’s joints and the positions of objects in the game scene. This can be achieved by locating a geometric element on the game scene, clicking on the central button of the Falcon grip or on the button relative to the end-effector of the Phantom Omni device to select the item. This item is then highlighted to show that it has been successfully selected. The user can drag the device’s grip to the left or right side to move the character’s joint to another point on the 3D scene, and drop the character’s joint in the new desired location by releasing the button. Whilst the manufacturers provide some basic specifications on workspace size and forces that these haptic devices are able to perform, they do not describe these values in sufficient detail (and based on user studies), for example, for control purposes.

3) Interfaces and Integration Layer: The outgame interface we have created corresponds to the available menus outside of the game, such as the home menu, new game and options; and the ingame interface, corresponds to the displaying information to the user in playtime.

The integration of the haptic devices with the Unity engine was possible by developing a plug-in to send the 3D position of the grip controllers of each input device to the game and receive the respective feedback data on the strength. This plug-in we have implemented has four components and is shown in Fig. 7.

We classified the data sent/received in two groups: position and force. The former represents the 3D position data of the grip, which are sent to the Unity to be processed continuously; whereas the latter, represents the information on the forces acting on the grip, which generates a perception of response forces in the user’s hand. The force generation is handled in the layer represented by the script written in C#. The DLL to control the haptic devices is responsible for providing an interface of functions that interact with the haptic devices.

Since we use all our senses to construct a reliable percept
representing the world with which we interact and to enrich the user experience even more, we also included in our game an interface that activates the “Kinect device mode”. Our goal was to offer the players an additional option to put into practice the stretching exercises more effectively. Each player has a Kinect device connected to the computer to track the lengthening movements of the user. More specifically, we used a plug-in that interfaces the official Microsoft Kinect SDK [5] with the Unity engine [12]. This plug-in was used to capture the following data: the RGB camera image of the Kinect, the image that represents the depth of the scene (captured by the infrared camera), and a list containing the locations of 20 joints in the human body from up to two players.

The Kinect mode in our game operates in accordance with the following steps: (1) Initially, the player should be positioned in the center of the screen area and keep the waist aligned with the marker on the screen (in (a) of Fig. 8); (2) Then the player must replicate the stretching exercise shown on the screen, fitting his/her own image in the outline of the drawn image shown on the game screen (in (b) of Fig. 8); and (3) If this stretching position is held for 25s (a valid time range for all stretching exercises), the task is considered correct and the corresponding score is credited to the player. The next task is to perform the next stretching exercise that composes the sequence, and so on, until all the exercises from a particular sequence are completed.

In order to verify whether the stretching positions of the player are actually conform to the outline of the drawn images, we have defined objects called colliders and used them as references of the ideal stretching posture for that player in the game. These colliders have “invisible” display attributes and were created in both graphical representations of the player (i.e., in the joints of the actual image of the player, captured by the kinect device, and in the joints of the outline image generated by the game, representing the ideal stretching position for that player).

Every time the collision areas (colliders in the player’s joints and in the reference image) overlap each other (in (b) of Fig. 8), this means that that the player is positioned correctly, consequently, the countdown of the game starts from 25s to 0s to score the player’s points (i.e., the player should hold this stretched position during this period of time, otherwise, no points are earned).

4) Synchronization: In the multiplayer mode, our game requires an additional component for synchronizing the state of the two game players. This enables the visualization of the game scenes of each player on their respective computer monitors, as well as the interference of a player in the game of the other (for example, player 1 corrects the position of the chair of his/her character and player 2 interferes on this action, by modifying the position of the chair of the character, controlled by player 1, to an improper position). We included in the game a synchronization feature of the game states in the characters’ joints and other dynamic objects that compose the scene (notebook, chair, footrest, etc.). For example, when a player fixes the position of the joints of his/her character, the current state of the game automatically is transferred via network to the screen of the other player’s game.

5) Computer Animations: The interaction between player and characters on the game screen is visually displayed through a cursor, which can be controlled by the haptic devices or mouse, representing the player in the 3D game environment.
To change the posture of the characters, collisions between the cursor and the target joint are first identified. So, when a collision happens, geometric elements represented by “pulsating” red circles involving the joints, change their colors to green, indicating to the user that the joints are active. The basic tasks that the player can do to properly position the characters during their posture corrections are directly linked to the ideal postures, related to the major joints of the human anatomy. In the game, the articulated character has two basic states: Typing or Stretching. At intervals of predetermined time, the game character changes its state from Typing to Stretching and vice versa. More specifically, in the Stretching state, the character performs some movements to lengthen the muscles linked to some of their major joints.

From time to time, a new character appears randomly. A clock appears on the screen to represent the screen time of each character, i.e., the time of his/her occupational activities, to account for the need of rest breaks. When a break is identified as necessary, the character enters Stretching mode. In this mode, the user will have the opportunity to assimilate and perform a series of stretching exercises. More specifically, in the Stretching phase, the player must solve various puzzles (one example is given in Fig. 3), moving the pieces that contain images of the characters, so to order the sorting sequences of stretches. If the sequence is correct, the 3D character who is standing on the right side of the puzzle will perform the computer animation corresponding to that sequence of stretching movements, as a bonus to the user. The puzzle is finally resolved when all the characters have completed their stretching exercises. In the game’s puzzle we have implemented three levels of difficulty. These levels contain four different characters and twenty-eight stretching sequences. In the puzzle, each character’s pose is represented with a specific card. A timer is used to account for the time spent by the player to solve each of the proposed puzzles. The player’s score is inversely proportional to the time spent in solving the puzzle, so that players with the highest scores are the ones that account for the lowest times.

The variation in the level of perceived pain of the character is represented graphically in the game screen by a system of indicators based on emoticons. This system has five decreasing levels of pain, as follows: 100%, 75%, 50%, 25% and 0%. When a character’s joint is not in the correct posture and is suffering some discomfort, the pain level of the character increases proportionally. The reverse occurs when the player corrects the joint position of the character.

Besides the limitation of time for each individual correction, there is a time limit for the task to be completed. If this time is reached and the character is not with level 0% of pain, the game ends, displaying a message pointing out that the player failed to complete the task. After that, another message is displayed asking if the player wants to restart the game. If not, the game is ended. Continuous sound effects throughout the game and musical notes are also activated (for example, when striking objects, to get bonuses, etc.).

IV. TESTS AND EVALUATION

We have conducted users tests to verify the functional aspects of our game and to qualitatively evaluate the use of the haptic interface, the navigation menus, the quality of the conceptual art in general and of the 3D modeling and textures, the level of difficulty of the game, the effect of stretching activities using the Kinect which was included in the general evaluation, the sound effects and the gameplay [18], [19].

A. Procedure

We created an evaluation form with twenty specific questions about the game and eight on the general user profile. Among the sixteen people who participated in the evaluation, all of them use the computer for long periods of time (at least 8 consecutive hours per day), six have had RSI/WMSD and only one person has reported that has never played any kind of digital game. The mean age of the participants ranged between 20 and 30 years. All participants were right-handed and used their dominant hand during the tests. We started the user tests with a free exploration phase. After this accommodation phase was over, the participants were grouped in pairs and had 15 minutes to play in the single and multiplayer modes, initially using the conventional mouse and then using the Falcon and Phantom devices. They corrected postures of the characters, solved the puzzles and performed stretching sequences. After playing, individually, the participants were asked to complete the evaluation form, classifying the quality level of various items related to the game development process. In order to do so, they could choose one of three options available: Very Good, Medium and Low. The final grades of each recommendation were used to generate the diagrams of Figs. 9 and 10. Before starting the user studies, we have carefully calibrated both haptic devices used in our experiments.

B. User’s Preferences Analysis

In Fig. 9, among the sixteen participants, 81.3% and 18.7% considered the gameplay quality level Very Good and Medium, respectively. This indicates that our game demonstrated a good level of playability.

As for the quality of game graphics and finishing of the scene (3D modeling and textures), 62.5% and 37.5% of the participants found these aspects Very Good and Medium, respectively (nobody scored them as Low). As for the sound effects, 68.8% thought they helped to generate greater dynamism and better interaction in the game (for example, by alerting the points and bonuses earned by the players, when the player gets enough points to interfere in the posture of the character of the opponent, etc.) and 31.2% found their quality Medium. This means that there are still ways for improving these two aspects of our game. The concept art (original drawings of the boy, the girl, the old man and the teenager) was very well evaluated (81.3% found their quality Very Good and 18.7%, Medium). The diversity of menus and navigation between them was judged more heterogeneous by the group, reaching the following indices: 56.3% Very Good, 37.4% Medium and 6.3% Low. We realized that there is also
room for improvements of these aspects. As for the difficulty level, participants felt the game in general Very Good (62.5%), i.e., it presented challenges in both the control and adjustment of the joints, as well as in solving the puzzles. One of the participants failed to solve the initial puzzle, but got the bonus in the multiplayer mode by adjusting the joints of the characters before a time limit, classified the difficulty level as Medium. The rest of the participants, 31.2%, scored it as Low.

Overall, using the evaluation form, 93.8% of participants rated our game as a serious game in healthcare that provides an important educational aspect to be transmitted between computer users, arousing the general interest. Among them, ten people claimed to have fixed at least five fundamental postures when sitting in front of the computer and twelve reported that they were able to memorize at least three of the main stretching sequences and enjoyed using the Kinect device. Nobody evaluated its contribution as Low. Joints of the elderly character are less flexible than the joints of the other characters and 12.5% felt that the joints of the boy are quite flexible (the rest did not notice the difference).

As for the mapping of the haptic bounding box that defines the edges of the virtual environment of the game in which the grip can act (from the real world to the 3D game scene), this was only clearly noticeable by 43.8% of the participants (50% perceived more or less the maneuver area of the device and one of them failed to do the mapping). On the ease of use of the device to control the tasks for correction of the character’s postures, 62.5% of the participants found Very Good (easy), 6.3% Medium (partially easy), and 31.2% felt Low (i.e., difficult). That is, in this regard, the user’s opinions were somewhat divided.

We also noticed a close empirical relation between the participants with a greater habit in practicing different modalities of games on different platforms, with a greater ease of use of the haptic devices (many of them were familiar with joysticks that provide vibration when shooting or with steering wheels that shake when driving over rough terrain). Nonetheless, those who found the haptic device difficult to control proved to be competitive and interested and immediately chose to use the conventional mouse to try to end the game round. The level of accuracy required for the selection of joints, was considered by 43.8% of the participants as Very Good (high) and 56.2% found Medium (medium accuracy). Most likely these percentages are associated with the selection process of some of the “pulsating” red circles involving the character’s joints. Due to the fact that these circles have a small radius, especially those drawn around the wrist, elbow and shoulder of the characters, they are difficult to be selected and hence delay the completion of the task of postural correction.

C. Falcon Versus Phantom

A subjective experience with respect to these both haptic devices was reported by the users, as shown in Fig. 10. During the gameplay they felt that the Phantom device’s damping effects were smaller than the Falcon’s. Probably this difference in perception has an influence on the device’s control. Users also perceived different behaviors between these two input devices, especially during the selection of the character’s joints. In particular, they described that the Phantom device appears to be faster to control than the Falcon device. This may be correlated to the observation that the Phantom seems to offer greater freedom and precision in the execution of movements and force generation than the Falcon device. On the other hand, fast movements can also generate some control instabilities. Also, users reported that the Falcon workspace seems to be smaller than the Phantom workspace, which was basically what we expected since for those who are new in 3D digital space and haptics, working with different haptic devices may take a little getting used to.

V. General Results and Discussion

Our game demonstrated good gameplay. Moreover, the participants expressed interest in playing it again, manifesting that they felt the game helped in learning the proper postures and sequences of stretches. In particular, in a quite spontaneous way and without realizing they were being watched, almost all the participants, more precisely 93.8%, did the stretching exercises for their wrists and tried to sit on the chair with their lumbar spine properly positioned while they played. Also, the Kinect device experience showed how important is to do stretching whenever possible and take breaks from times to
times, as well as to be aware of the work-life balance, by creating and maintaining a healthy work environment.

Mostly users preferred the multiplayer mode, rather than the single player one, most likely because it is more exciting and challenging since it is more competitive. The use of the haptic devices contributed to the perception of different interaction forces via haptic interface, and improved significantly the user interaction with the game, bringing a new level of immersion and control to the game experience. However, we noted that the mapping of the haptic bounding box used for the maneuver of the device, from the real world dimensions to the 3D game scene is not always very intuitive, adding an extra level of difficulty for some game players.

During the user testing study, we observed that the experience, reflection, thought and activity elements were always interrelated and sometimes depended on the individual preferences, generating differentiated results in terms of the learning level of each person. We could also identify which experiences of postural correction and stretching stimulated observations, reflections and natural and immediate initiatives on the users during the game. This showed, therefore, that this type of experience through a serious game can be assimilated into abstract concepts that the user can actively test and experiment playing the game.

VI. CONCLUSIONS AND FUTURE WORK

This paper covered the components of building a computer game that focuses on proper positioning of spinal health and posture. While this type of health can be covered in many areas, this developed game paid close attention to perform and memorize both stretching exercises and correct joint placement of users that sit at a computer desk for prolonged periods of time.

During playing our serious game, we also noted that alternative input devices can increase the sense of immersion (perception of different forces acting on the characters) and fun (user reaction caused by force feedback perception). Comparing use of the Novint Falcon and Phantom Omni devices has also shown some limitations of each device.

As future work, we plan to focus our efforts on the improvement of the graphical quality of the game and on experimenting with new input devices. For example, the 3D visual realism can be improved using Unreal Engine 4 [20] for generating instantaneous feedback from changes to global illumination light maps or even much more realistic visual effects. Another simpler extension is to adjust the proportions of the circles involving the characters’ joints that are continuously selected during postural corrections. Also, continuing research on the Kinect will be further explored. While it is good to instruct game players on proper way of joint placement for posture, it would be interesting to have the user to do this themselves (outside of stretches). The Kinect sensor could be utilized to also evaluate the player while they are trying to correct joint placement as well. Finally, we also aim to detail the game menus and conduct systematic tests with a larger number of participants.

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