Developing a medical training game for visual assessment of head deformities in infants

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***Abstract*—Anatomical evaluation of an infant's head shape is an important task in clinical practice to diagnose cranial deformities. In the first stage of diagnosis, the current practice mainly relies on visual head inspection. However, this is a difficult task and subjective between physicians. Thus, medical training is paramount to correctly perform the visual head shape assessment to guarantee a safe diagnosis. The main goal of this work is the development of a prototype of a medical game called *Head Shape Inspector* to train individuals to perform head shape analysis. During the game, the player categorizes 3D surfaces of infants' heads according to their cranial deformity. Moreover, the game also allows the user to visualize anthropometric measurements of the head, required in clinical practice to quantify the deformities, to aid the categorization process. Preliminary experiments showed that playing the game can improve the visual inspection skills, suggesting the potential of the game to be used for medical training.**

Keywords—cranial deformities, head shape inspector, medical training game, visual inspection

I. INTRODUCTION

Cranial deformities are a condition characterized by an abnormal head shape of an infant caused by forces acting on the skull resulting from intrauterine restriction, premature birth, or supine sleeping [1]. The prevalence of cranial deformities has increased in the past decades, with studies suggesting that 1 in 5 infants suffer from this condition [2], [3]. The deformities can be divided into asymmetrical deformities, which refer to an asymmetric flattening of the skull, and symmetrical deformities, where the head is highly widened or elongated [1], [4]. Besides the cosmetic concerns related to the deformities, infants who present this condition can also experience developmental delay, and therefore, early diagnosis is crucial [5].

The first line of diagnosis relies on visual inspection of the head. Then, in case of suspicions of malformations, anthropometric measurements of the head are used to analyze the head. These cranial measurements allow estimating cranial indexes that are used to diagnose the type of deformity and to quantify its severity, according to clinical baselines. Thus, the correct evaluation of the head shape at the first line of the diagnosis is paramount to avoid misleading head shape evaluations that can hamper subsequent quantification of the deformity. However, the visual inspection of the head shape is not straightforward, being highly dependent on the observer's experience and prone to observer variability. In fact, subjective perception of the head shape is intrinsically associated with visual inspection. Thus, correct medical training in this task is mandatory to guarantee a safe diagnosis.

The main goal of this work is the development of an initial version of a game called *Head Shape Inspector*. It aims to train medical observers to perform head shape evaluations. During the game, the players must categorize 3D surfaces of infant's heads according to their deformity, receiving a score for each correct classification. Moreover, to aid in the categorization process, the observers have the possibility to visualize the cranial measurements used in the second stage of diagnosis, allowing to correlate the measurements with the head shape. Overall, this has the potential to improve the skills for visual head shape analysis evaluation.

The remainder of the paper is organized as follows. In section II, an introduction regarding serious games for medical training is given. In section III, the head shape inspector game is described. The experiments performed to verify the potential of the developed game are described in IV, being the present work discussed in section V. Finally, the main conclusions of this work are given in section VI.

II. SERIOUS GAMES FOR MEDICAL TRAINING

A serious game can be described as a computer application with a predefined goal that supplies the user with skills and knowledge while being engaging and fun to play [6]. This type of games are powerful tools for medical training, where the player can train their skills through a score-based approach that evaluate their performance and progress. Thus, to deal with the challenges associated with the diagnosis of medical conditions, serious games for medical training have been proposed in the literature for different medical fields, including pediatrics.

One of the works that used serious games for training medical professionals in the pediatrics field was proposed in [7], with the game *Jeopardy!*. This game is a question-answer quiz that allows that medical students to interactively complement their study, acting as a learning tool. In [8], a quiz-based game to teach medical students was also proposed, where theoretical questions are asked to the player, allowing to enhance the student's learning process. Besides quiz-based games, other types of serious games can be used for medical training, such as simulators or augmented reality-based games. One example is the pediatric game *e-Baby* that regards the evaluation of oxygenation in preterm infants [9]. For that, the game consists of a simulated environment of an incubator where the player must perform the clinical evaluation of the respiratory process of a virtual baby. Another example is the *PediatricSim* game proposed in [10]. The main goal of this game is to teach and assess the performance of medical professionals in critical pediatric emergency scenarios. In [11], pediatric emergency scenarios were also addressed, particularly focused on the assessment of the medical professional performance in cases of multi-patient care. Lastly, one framework based on augmented reality that had the goal of enabling the development of teaching, training, and monitoring pediatric healthcare applications was proposed in [12]. In such application, the visualization and interaction with virtual object enhanced the paediatric applications.

Although some medical games have been presented to improve the skills of the medical individuals in pediatrics, no approach targeting the head shape analysis was already proposed. Thus, to the best of our knowledge, this work presents the first medical training game to address this task.

III. Methods

In this section, the *Head Shape Inspector* game to train the task of head shape analysis is explained. Figure 1 presents a simplified diagram of blocks of the initial concept of the proposed game. The game is composed of two layers, namely the data layer, which consists of the random assortment of a head and its category/measurements at each game iteration, and the gaming layer, which corresponds to the gaming experience where the player has to evaluate the head shape.

A. Clinical aspects of cranial deformities

To ensure its correct usage, the game starts by explaining the clinical characteristics of different cranial deformities to the players. Cranial deformities can be divided into asymmetrical and symmetrical deformities (Figure 2). One type of asymmetrical deformity is plagiocephaly. In this condition, a flattening of the skull occurs on one side of the head, causing the asymmetry [13]. During visual inspection, this condition can be diagnosed by evaluating if the head is flattened on one side of the head. Moreover, this condition can be also assessed by estimating a cranial index denominated Cranial Vault Asymmetry Index (CVAI). This index measures the absolute difference between two cranial diagonals measured at opposite angles (usually 30 and -30 degrees). Thus, high values of CVAI (*i.e.,* high differences between the two diagonal lengths), indicate a plagiocephaly condition.

Concerning symmetrical deformities, it includes brachycephaly and scaphocephaly. While brachycephaly corresponds to a widening of the head, patients with scaphocephaly present an elongated head. Thus, these conditions can be visually perceived by analyzing if the head is flattened in the occipital region, *i.e.,* brachycephaly, or if the head is long and narrow, *i.e.,* scaphocephaly. Quantitatively, these conditions are evaluated through the Cephalic Ratio (CR), which measures the ratio between the head width and length. In fact, if similar values of width and length are found, it means that the head is flattened and high values of CR are obtained. In opposite, if the head is elongated, the length of the head is much higher than the width, being obtained low values of CR. Finally, it is also possible to suffer from a combined deformity, which means the simultaneous presence of symmetrical and asymmetrical deformity (*e.g.,* the head can be widened in width while also presenting an asymmetrical flattening in one side of the head).

In this work, it is intended that the player categorize a 3D head surface into five different cranial deformities, namely: 1) no deformity (normal head shape); 2) plagiocephaly; 3) brachycephaly; 4) scaphocephaly; and 5) combined plagiocephaly and brachycephaly (Figure 2).

B. Game head surfaces database

To train the task of head shape evaluation during the game, 3D head surfaces of different infants are used. To create the database of the head surfaces, a set of Magnetic Resonance (MR) images of infants were processed to segment the head and create the 3D surface. The MR images were related to a population that included male and female patients with ages ranging from 3 days to 15 years. Moreover,

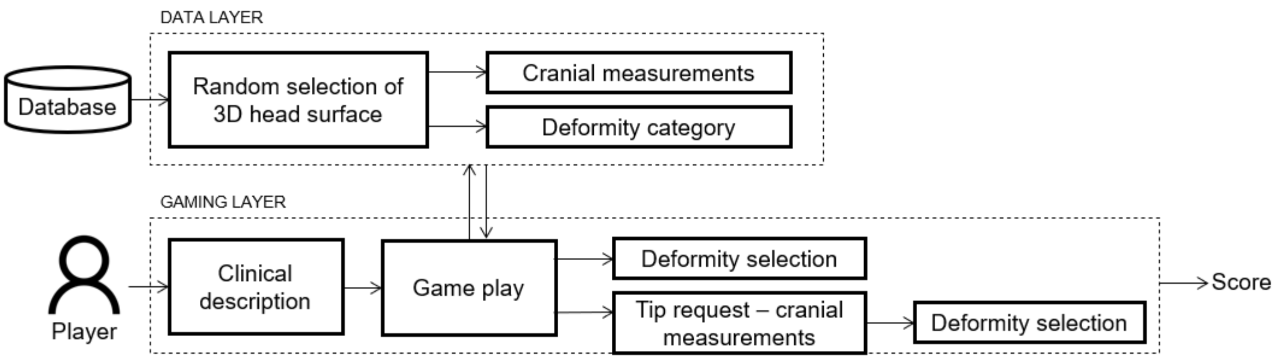

Figure 1 - Simplified diagram of the first conceptualization of the *Head Shape Inspector* game. The game is composed of two layers, namely the data layer and the gaming layer.

Figure 2 – Head top view of different types of cranial deformities. Normal head – no deformity; Plagiocephaly – asymmetric deformity; Brachycephaly and scaphocephaly – symmetric deformity; Plagio + brachycephaly – combined deformity.

the database included both normal patients (without head deformity) and patients with the cranial deformities described in section III-A. The segmentation of the head in the MR images consisted of a semi-automatic approach that used a simple threshold strategy followed by mathematical morphology for refinement. Manual corrections of suboptimal segmented 3D models were performed if needed. An example of a 3D head surface can be visualized in Figure 3A. Since the 3D surfaces were directly retrieved from real medical images, the shapes showed during the game are realistic models, proving a virtual scenario close to the physical evaluation one. However, the texture information available at the physical exam (such as the hair or the skin) are not represented in the model.

To create the ground truth for the head classification (*i.e.,* the type of cranial deformity), the cranial measurements of each head were estimated, namely the two cranial diagonals, the head length, and the cranial width (Figure 3B). The estimation of the measurements was performed using anthropometric landmarks labeled in the 3D surfaces by experienced observers and using the estimation process described in [14]–[16]. Following the estimation of the measurements, the CVAI and CR were calculated to attribute a classification to each head, according to reference values found in the literature [17].

Finally, the estimated measurements were also included in the game database to provide additional information regarding the head shape to the player, allowing to perform its correlation with the head shape.

C. *Game workflow*

The *head shape inspector* is an interactive, three-dimensional, and single-player game where the player assumes the role of a medical professional that has to evaluate the head shape of an infant. The main goal of the game is that the player correctly classifies a given head shape according to its deformity. After the initial description of cranial deformities at the beginning of the game, the 3D surfaces of infants' heads are successively presented to the player. For each head surface, the player must evaluate its shape by selecting the type of cranial deformity. To facilitate this process, the user can freely rotate the head, allowing the analysis of the entire head surface and mimicking the traditional procedure of visual inspection where the entire head is visualized and evaluated. After analyzing the head surface and selecting the deformity, feedback is given to the player according to the accuracy of its answer. Thus, the player can correlate the head shape with the correct diagnosis.

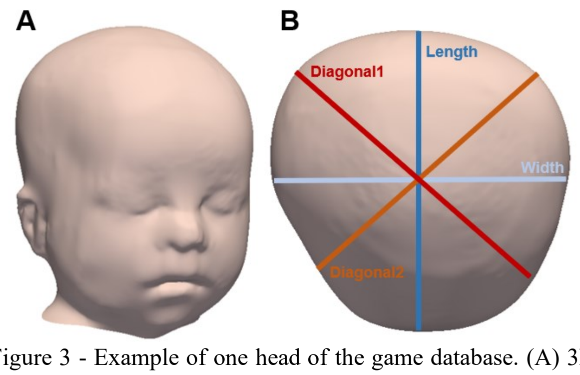

Figure 3 - Example of one head of the game database. (A) 3D head surface; (B) Top view with the cranial measurements.

Moreover, for each correct classification, a score is given to the player, allowing to analyze the performance of each player and consequently to evaluate their skills for the task of head shape analysis. Specifically, a score of +5 points is given for each correct classification and a score of 0 points is given for each incorrect one.

To aid in the classification task, the player may request help during the game, which results in a small penalization in the game scoring of -2 points. The help consists of a tip where the cranial measurements of the head shape are shown, namely, the cranial diagonals, the head length, and the width (Figure 3). The player can analyze these measurements to have a better understanding of the head shape, guided by the knowledge provided by the information of the clinical aspects of the cranial deformities. Specifically, the user can analyze the differences between the cranial diagonals and have a perception of the relation between the head length and width. These tips are also useful for the player to train how to correlate a given head shape with the showed measurements, allowing to improve their skills of performing the visual inspection. Thus, once each head has defined measurements that are showed to the users, the subjective analysis of the head shape is minimized. The summary of a game iteration can be described as follows:

1. Random assortment of a head surface;
2. Game-player interaction for visual assessment of the head shape;
3. Requirement of the tip to visualize the anthropometric measurements (optional);
4. Selection of the deformity;
5. Feedback to the player;
6. Score attribution (+5 points if the analysis is correct, 0 points if not, and penalization of -2 points if the tip is used).

Concerning the gaming structure, this initial version of the game is divided into three different difficulty levels. In the first level, head surfaces with severe deformities are used. Since the severity of the deformity is high, distinguishable head shapes are foreseen, and thus, the task of classifying the head is eased. In the subsequent level, head shapes with moderate deformities are used. Finally, in the final difficulty level, mild deformities are explored. In this severity level, smooth deformities are expected, increasing the complexity of choosing the correct category for the head models. At each level, a star-based scoring approach is used to increase the engagement of the player to the game and to allow advancing to the subsequent level. Specifically, three stars can be gain at each level, each one gain by correctly classify one-third of the head shapes of the level. To advance to the next level, a minimum of two stars must be collected.

D. *Initial conceptualization of the game design*

The design of a serious game presents an important component for its success, since it is intrinsically related to gaming engagement and pleasure, consequently having a high impact on the training process. In this subsection, an initial concept for the game design is presented. The initial version of the game was developed for Windows applications, using Qt framework and C++ programming. Moreover, the VTK framework was used to allow the visualization and manipulation of the 3D head surfaces.

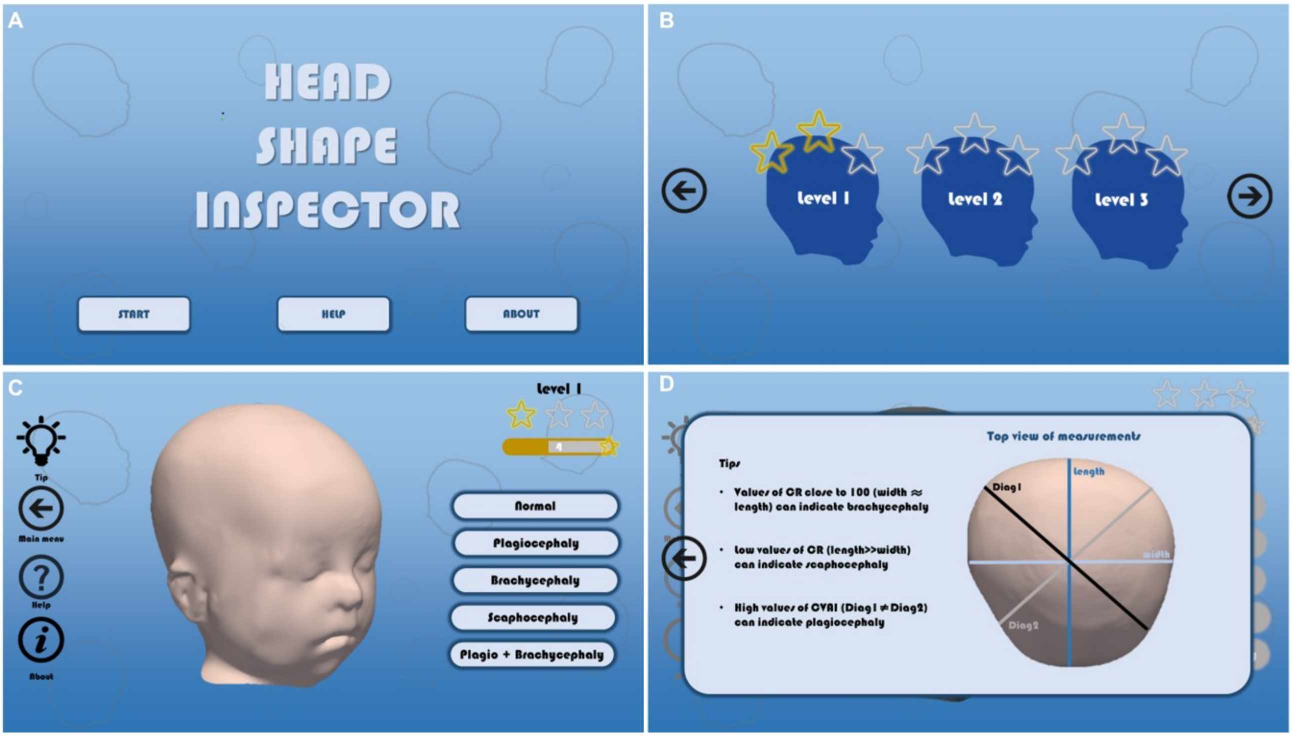

Figure 4 – Illustration of the first conceptualization of the *Head Shape Inspector* game. (A) Main menu; (B) Level selection menu; (C) Main game window with the 3D head surface and the options for the deformity classification; (D) Tip window that allows the visualization and evaluation of the cranial measurements.

The first interface of the *Head Shape Inspector* game relates to the main menu where the game is introduced to the player. In this interface, illustrated in Figure 4A, there are three buttons, being two of them used to provide information to the player regarding the main goal of the game and how to play. The remaining button is used to start the game. If the player is playing the game for the first time, a window appears with the clinical information required to perform the head shape classification. After reading the clinical information, the player must select the difficulty level (Figure 4B). Note that at the beginning of the game, the player can only choose the first level, due to the absence of a previous score. However, if the player has already a good result in the initial level, the player can select another level if the rules related to the star gain are satisfied (section III.C). After level selection, the interface related to the game environment is presented to the player (Figure 4C). This interface includes the elements needed for the gaming playing process. The main element of the window is the central region, which relies on a 3D render window, where the head surface is displayed and can be manipulated. The clinical evaluation is performed by clicking on one of the five buttons presented at the right side of the windows, each one corresponding to a given cranial deformity. In the right upper corner, information regarding the difficulty level, the number of stars collected, and the player score is shown. Plus, a bar containing the progress until the next star is reached is also displayed. Finally, there is a bar on the left of the screen with the necessary utility tools. One of these tools is related to the requirement of a tip to aid the classification. Here, an interface with a top view of the head and the respective measurements are shown (Figure 4D). By correlating the measurements relation with the head shape, the training process is enhanced.

IV. Experiments and Results

To validate this first approach of the *Head Shape Inspector game*, a preliminary experiment was performed. This experiment consisted of an exploratory study to verify the potentialities of the proposed game to improve the head shape evaluation task. For that, a small study population composed of four observers was used. The study population was divided into two different groups: 1) the players; and 2) the non-players. To the players' group, it was asked to play all three levels of the proposed game. For this specific experiment, a database of 90 head surfaces was used, 30 for each difficulty level (corresponding to severe, moderate, and mild deformity severities). During the game, the feedback regarding the performance of the player was constantly given through the interface, and the tips to allow the correlation of the head shape with the respective head measurements were allowed if requested by the player. The observers in the non-player group did not play the game, but they had access to the initial clinical description regarding the head shape evaluation. Both groups were afterward asked to classify a new set of 15 head surfaces, *i.e.,* head surfaces not included in the game database. Thus, a comparison of the performance of both groups for the task of head shape analysis was performed.

Table I depicts the performance of the observers in the 15 testing head surfaces. Two evaluation metrics were used. The first consisted of the accuracy that measures the percentage of correct classifications. The second one was the Cohen's kappa coefficient (k) that was used to determine the agreement between deformity classifications answered by the observers and the ground truth. For this coefficient, it is considered that a value between 0 and 0.4 corresponds to a poor agreement, between 0.4 and 0.6 corresponds to a fair

TABLE I.
PERFORMANCE OF DIFFERENT OBSERVERS IN THE TASK OF HEAD SHAPE CATEGORIZATION

Group	Observer	Accuracy (%)	k-coefficient
Players	Obs_1	86.7	0.83
	Obs_2	80	0.75
Non-players	Obs_3	60	0.49
	Obs_4	66.7	0.57

agreement, between 0.6 and 0.8 corresponds to a substantial agreement, and finally values higher than 0.8 corresponds to perfect agreement.

V. DISCUSSION

Head shape analysis is an important task in clinical practice to diagnose cranial deformities. The first line of diagnosis concerns the visual inspection of the head. However, this task is highly subjective and dependent on the observer's experience, which can mislead the diagnosis. The proposed medical training game aims to empower clinicians with skills to deal with this visual clinical inspection task. Indeed, as abovementioned, medical training games can present important added value to improve trainee's skills.

Analyzing the results presented in TABLE I, it is possible to verify that the observers that played the game achieved high accuracy for the head shape analysis, namely 86.7% and 80%, respectively. k -coefficients obtained by this group correspond to a strong agreement, corroborating the good performance of the observers in this group. In opposite, the performance of the observers that did not play the game was worst than the performance of the players. In fact, accuracies of 60% and 66.7% were obtained, with k-coefficients that only indicate a fair agreement between the classifications and the ground truth. Thus, this initial experiment may suggest that the game enhanced the performance of the players group. In fact, since feedback was constantly given to the players regarding the head shape analysis, they were allowed to verify their mistakes, improving the analysis performance. Moreover, since the game has the option of using the tips to show the cranial measurements, the players learn how to correlate a given head shape with the cranial measurements, and consequently, with the correct diagnosis. Thus, the finding of this preliminary study can indicate the potential of the game.

Regarding the performance of the players during the game execution, it was verified that the level corresponding to mild deformities had higher difficulty. This was expected due to the fact that mild deformities are usually confused with normal heads since the flattening (symmetric or asymmetric) and the elongation of the cranial cannot be fully perceived in such cases. Thus, adding more head surfaces with mild deformities in the game can enhance even more the visual perception of it. Interestingly, was also observed that combined deformities were also less perceived by the players, which can suggest that the observers only focused on the most prominent condition.

Despite the described preliminary experiment, further and stronger validation must be conducted, namely using a defined evaluation protocol including different medical professionals groups. Firstly, a total of four groups will be used to validate the game, including, medical students, pediatricians, medical doctors (not pediatricians), and laypersons. For each group, a division into two subgroups will be performed, namely the players and non-players. Thus, the experiment conducted in the present paper to compare the performance of head shape analysis between players and non-players will be replicated at a larger scale. Moreover, the players will also evaluate the proposed game in terms of its engaging to it, where questions will be asked regarding the game design, its easiness to use, the fun and motivation during playing, its impact on the learning process, and also improvement suggestions. Overall, this study to be conducted will allow verifying the educational function of the game and its contribution to the learning process.

Improvements are also envisiooned for future versions of the game. Firstly, game design will be discussed with the expected target players, allowing to have feedback concerning the visual aspects of the game. A modification will also be performed in the classification task. Here, instead of only categorizing the head according to five deformity types, it will be also required that the players select the severity of the deformity (mild, moderate, or severe). This can be important since the severity of the deformity is used in clinical practice to decide the best treatment option, and thus, it must be included in the visual inspection process. Moreover, to improve the realism of the head shape analysis process, texture information will be added to the 3D head surfaces. Although the 3D head surfaces used in the current version of the game are representative enough to allow the medical training, the absence of textures can ease the game since the textures can hide features of the cranial shape, hampering the assessment of head shape. Thus, these features will be added.

Additional tasks related to the head shape analysis are expected to be implemented. The first one consists of the task of anthropometric landmark labeling, where the player will learn to accurately label the landmarks required to perform the estimation of the cranial measurement. The second one will be related to the placement of measurement planes in the head that allows the computation of several cranial indexes. The last task that will be implemented consists ofquiz-based task where the knowledge of the players regarding the different cranial deformities will be tested, namely its causes, treatment options, or consequences. Finally, it is also enviosioned the implementation of the game for mobile and web applications, broadening the game to a higher number of players.

VI. CONCLUSION

In this work, an initial conceptualization of a medical training game to evaluate the head shape of infants is presented. Specifically, the head shape evaluation performed in this work regards the diagnosis of different cranial deformities. Initial experiments suggested the potential of the proposed game to be used for medical training. However, future work will be developed in different strands of the game, namely, in the improvement of the game design and in the addition of other training exercises that will increase the learning process for visual head shape evaluation. For that, continuous feedback from the expected target players will be sought during game improvement. Furthermore, a feasible validation protocol that includes the participation of medical students and professionals is envisioned.

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