A Game-based Training Approach to Enhance Human Hand Motor Learning and Control Abilities

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***Abstract*—This work presents a serious game designed to improve the performance in users' control abilities applied to pressure sensitivity. In particular, the aim of this work is part of a larger goal of providing medical students with further opportunities of palpation experiences and assistance as part of their education. Typically medical students are limited by the number of volunteers they can practice on and the amount of time they can interact with more experienced practitioners to further develop fundamental palpation skills. Correct palpation skills are crucial as they inform the diagnosis in a large number of healthcare fields and a skill required by most healthcare professionals. The ability to be able to enhance the educational process of healthcare professionals' palpation skills could lead to a more holistic student experience. This work presents a serious game in which one aspect of palpation, hand control ability through the correct application of pressure to a patient, is the target for user improvement. A serious game modelled on the infinite runner genre was designed to be controlled via an input device developed in-house with off-the-shelf components that translates real-world pressure to in-game movement. The game was tested in a participant trial involving a game-playing group ($n = 15$) and a control group ($n = 15$) and a significant improvement in a blind-folded pressure test was observed for the game-playing group. User feedback via a questionnaire also showed a positive response of the game.**

I. Introduction

The efficacy of serious games as a training approach has become widely accepted and as a consequence serious games are beginning to be used in a wide variety of domains. Immersion, pleasure and competition are key characteristics of games that enhance user engagement in training activities. Apart from research studies even commercial companies are now interested in taking part in the development and deployment of educational games [1].

One of the main domains demonstrating the fruitfulness of serious games is healthcare [2]. A number of reasons have lead to the success of serious games for healthcare. Ethical restrictions in medical training mean that certain procedures cannot be frequently tested and explored by practitioners. Similarly, a lack of available patients during training entails limited familiarity with the application of procedures across a varying number of ages, genders and body types. Furthermore, the demands for patients' growing thirst for health information has led to health professionals providing novel digital-based interventions.

Current challenges in medical education are particularly difficult when the possibilities of experiencing training in that activity are rare. Game-based solutions can provide an enhanced experience to the existing educational process for such cases [3, 4]. One of the most common medical processes which are carried out by most medical practitioners in a very large variety of conditions and for a diverse number of applications is palpation [5, 6]. Palpation plays an important role in the initial examination of patients and is a crucial initial diagnosis [7] based significantly on haptic sensory feedback. While visual and acoustic digital healthcare practices are becoming more common due to the ubiquitous nature of video and audio displays and their use in both entertainment and real-world applications, the lack of readily available haptic devices has meant very little progress has been made in the areas of motion and pressure sensitivity control within the healthcare domains.

This work is part of a larger project aimed at training medical students to become more proficient at palpation as part of their training process. Training in palpation is of crucial importance as during their training medical students are restricted to the number of hours they can spend with their tutors gaining hands-on experience and are also restricted on the number of body types and participants that they can engage with [8]. A goal of automating the process and providing palpation-based simulators will enhance current practices by allowing the students to practice by themselves or with each other while being guided via a digital tutor. This paper identifies and focuses on one aspect of an automated palpation framework; training of pressure sensitivity using the index finger, one of the crucial characteristics of palpation training, is provided via the use of a serious game in which the player controls an on-screen character via the use of an input device which is sensitive to pressure. Learning to apply the correct amount of pressure plays a significant role in providing the correct diagnosis and also in patient comfort; a too light touch may miss out on important physiological phenomena and a too heavy touch may cause significant patient discomfort further compounding potential diagnosis issues. While a number of novel input technologies beyond the traditional have recently begun to be applied to serious games [9, 10, 11, 12] no serious game, to the best of our knowledge, has targeted the correct application of pressure as its main goal. A study based on two groups composed of general public participants, one group that played the game and a control group demonstrates that there is reason to believe that such a serious game can help improve pressure sensitivity in individuals.

The following section presents background and related work. Descriptive information of the three technologies which are used in this study is discussed in Section III. The experimental design and results are discussed in IV. Finally future potentials for extending this study and conclusions are presented in V.

II. Background and Related Work

In general, applications of serious games in healthcare can be classified by their target audience [13] as follows:

- Medical education
- Patient intervention
- Public involvement

Games dedicated to medical education are those that help medical professionals to improve their skills while performing certain tasks. Patient intervention are targeted at patients rather than the medical professionals. Such patient-oriented training games help enhance individuals' knowledge about their condition and to also help improve their engagement in their treatment process. Public involvement applications are directed at the general public and are focused on raising awareness of public health issues and providing motivation for potential behavioural change. A large number of healthcare-related serious games have been developed [2] and we provide a small set of examples in the following.

In terms of medical education and awareness Graafland et al. [14] presented a survey on medical education and surgical skills across 25 publications which comprised 30 games. They explained that games developed for the purpose of such serious applications required the use of further validation before being deployed as there was a lack of robust evaluation for the surveyed games. Dunwell et al. [15] presented a serious game to help create awareness of healthcare-associated infections within wards. They provide feedback and findings on the deployment of the game across 13 hospital wards in the United Kingdom. The serious game we present in this paper could also be considered as part of the medical education sub-category of serious games.

An example of a patient intervention game was the Re-Mission game for cancer patients. Positive behavioral changes were reported on pediatric patients who were diagnosed with cancer by playing this video game [16]. Another patient intervention example was provided by Carmeli et al. [17]. The authors presented a serious game for the improvement of motor, sensory and cognitive performance in rehabilitation of stroke patients (with upper limb impairments) to conduct everyday functional tasks efficiently. An interactive tool was used as an input device for the game to measure range of motion and finger and wrist speed. Results demonstrated an improvement in movements for users.

An example of increasing public involvement was presented by Boulos et al. [18] environment to raise public awareness about sexual health. An online 3D virtual world such as Second Life (SL) with social networking capabilities has been surveyed to highlight positive impact on its audience. Brown et al. [19] also presented a serious game dealing with sex education in which an intervention mapping approach was used in the development and the design of the game. Scarle et al. [10] presented a serious game that had two main goals focusing on public involvement. Firstly, it was targeted at raising the awareness of poor eating habits at primary school children that has been becoming one of the main causes of the rising obesity epidemic and, secondly, through the application of motion controls that enabled the participant to reduce the amount of on-screen time in which the game player was physically inactive.

Figure 1. ParsGlove is an innovative wearable interface which is designed and developed to capture the human hands ergonomics and to provide this information as an interactive input both for the game and the application.

III. Serious Game and Input Device

This section presents the overall framework that has been used for this work. Three key technologies including a serious game were developed to improve pressure sensitivity learning. The input device is a glove developed in-house and can read pressure the amount of pressure applied accurately in Newtons. An application, DigiScale, was developed to help facilitate the input procedure via a user friendly interface. Finally, a serious game was implemented to facilitate the learning of pressure sensitivity for the user.

A. Input Device

A wearable measurement interface, ParsGlove (see Figure 1) has been developed under formal R&D discussions with with medical professionals. It is designed to capture the ergonomics of the human hand during dexterous interaction with the environment. It was essential in our main goals to use the full capabilities of the glove to capture applied pressures, orientations and location parameters although for this work the focus is only on the pressure input.

To provide more freedom the glove is equipped with Bluetooth connectivity and is composed of ultralight materials which help reduce weight and avoid fatigue when the glove is worn for long periods. Twelve force sensitive resistors are mounted in places which were defined by medical professionals. Sensors were also calibrated with a force gauge device to accurately map digital values to actual force.

B. Application

DigiScale is a Graphical User Interface (GUI) specifically developed for this experiment to deliver visual feedback for the force exerted by the tip of users' index fingers. DigiScale has two sections: an information panel providing visual information directly to the user and a toolkit panel for the research investigator. Figure 2 shows a screenshot of DigiScale demonstrating a target force set to 2 Newtons and a sampling timer having collected 3 seconds of data out of a total of 10 seconds (with 7 seconds remaining as shown in the figure).

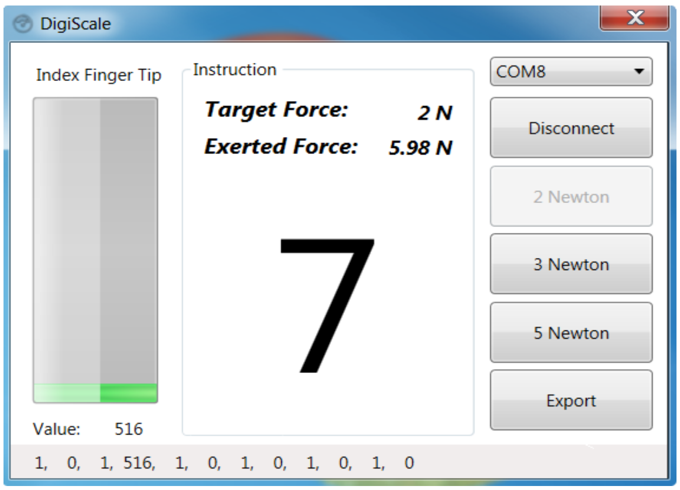

Figure 2. The DigiScale application is designed to deliver visual feedback on the exerted force by the user and to collect samples form the user performance.

The information panel is designed to provide visual feedback of applied forces by the user, the target force level in each task and a countdown timer. The toolkit panel is designed to provide connectivity options to pair ParsGlove with DigiScale, three buttons to set the target force levels in each task and finally an export button to persist recorded samples at the end of each session. The application has capabilities to read continuous data streams over the Bluetooth standard which permits communication with the glove. The application could be run on any normal PC without any specific hardware or software requirements. The only requirement for this application is a Bluetooth receiver.

C. Game

To provide game-based training to help improve performance, a 2D game was developed in the Unity 3D game engine. The game assets were adapted from free assets made available from the Unity store. The game was designed to interface with the ParsGlove playing the role of the game controller. Figure 3 illustrates a number of screenshots of the game in action. Figure 4 shows the game as it is being developed.

The goal of the game is to help users improve their pressure sensitivity by controlling a flying bird that soars higher based on the amount of pressure applied by the index finger of the user. The pressure applied is the only form of input. The gameplay is inspired by the infinite runner genre of games; although the play sessions have been limited in the interest of time. The objective of the game is for the bird to collect coins that appear randomly at three possible heights within the environment. The coins are randomly generated in different quantities from 5 to 15. Auditory feedback is also provided on successful coin collection.

The heights chosen correspond to the application of three levels of force. The three force levels are 2, 3 and 5 Newtons coinciding with very light to medium pressure. These forces were established through a pre-study with medical professionals in a process discussed further in Section IV-A. It is crucial for a medical student to control his hand in a dexterous manner to perform different abdominal palpation tasks. Hence, a very light amount of force such as 2 Newtons could be extremely challenging for a novice. Design of different tasks in game-based and application-based approaches were established on these guidelines.

A collision detection function is implemented to detect if the bird avatar hits a coin. The box collider used for coin to bird intersection has a buffer equivalent to ± 0.25 Newtons along the height dimension. Players should collect more coins in order to achieve a better score at the finish line. A slight increase in the flying speed during the game as well as random generation of coins makes it more challenging for the player and has the goal of keeping the game interesting. An information panel is placed on the top right corner of the game screen to show which the next coin level is. This is demonstrated in Newtons for the user to form an association with the amount of pressure to be applied and the numeric value of the force. The information panel also provides a final score at the finish line. The screen height is normalised to represent 0 to 10 Newtons from bottom to top. Although, the player could reach higher levels of force by pressing harder, the limitation of 10 Newtons was chosen to meet safety regulations.

IV. Experiment

In order to evaluate whether the game discussed in the previous section improves pressure sensitivity a participant-focused experiment was run. This experiment intends to explore if visual and auditory feedback of applied forces in the form of a game-based training approach could improve motor learning and control abilities on non-medical participants.

A. Method

A between participants design was chosen for the experiment. Participants were divided into two groups: Group A ($n = 15$) to be trained by the serious game and group B (n=15) a control group. All participants had been asked to apply force from their index finger tip while sat (in the stand up position kinesthetic help from shoulder may produce variation in the exertion of force) on a table as rigid surface. The exerted force values were sampled for each target force level for 10 seconds with 10 millisecond intervals resulting in 100 samples per each target force level. The three forces of $2, 3, 5$ Newtons that were the target goals where the coins were set in the game (as discussed earlier) were based on a pre-study in which medical tutors' pressure while palpating patients was captured. These studies involved the use of four medical professionals examining five different participants acting as patients composed of both genders and three body types. The data capture consisted

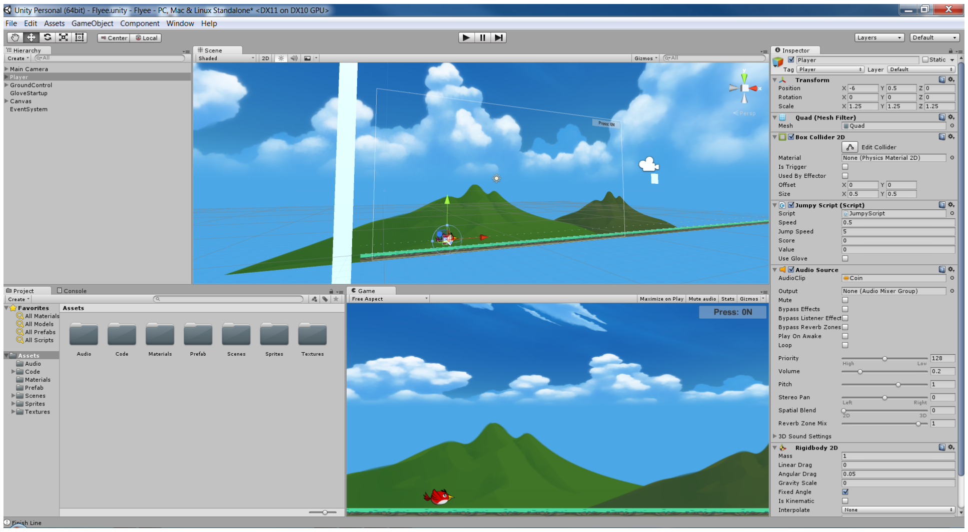

Figure 4. The game being developed within the Unity environment.

of all the medical professionals completing three palpation tasks (liver edge, deep and superficial) for all the patients. All data was captured and analysed and the goals of $2, 3, 5$ Newtons were identified based on the mean force across the medical professionals in each task across the body types.

Table I shows an overview of the experimental design and training methods for each group. The familiarisation phase allowed the participants to acquaint themselves with the equipment and saw the actual value they were pressing on DigiScale. In the final test (no visual feedback) the participants could not see how much pressure they were applying on the display and had to rely only on their pressure sensitivity training. The difference between the target value and the recorded value (in Newtons) for the no visual test was used as the dependent variable. The null hypothesis H0 in this experiment was that there is no difference between the two groups in the accuracy of the exerted target force for the no visual feedback test session. The software used for the familiarisation DigiScale was significantly different from the environment found in the game to avoid any bias of familiarisation that may have led to the game playing group to have an unfair advantage during the testing phase.

Table I. EXPERIMENTAL DESIGN

	Group A	**Group B**
Training	Visual Feedback (GUI)	Visual Feedback (Game)
Familiarisation	Visual Feedback (GUI)	Visual Feedback (GUI)
Test	No Visual Feedback	No Visual Feedback

B. Materials

The primary materials used correspond to the three technologies discussed in Section III. DigiScale was used to convert the raw sensor value from the glove to force in Newtons and to provide visual feedback on the exerted force by the user for the Training and Familiarisation phases. Two TFT displays were used in duplicate mode to provide visual feedback for each participant and to let the research investigator monitor the experiment's progress. An ultra thin powder coated polyvinyl glove was used to meet hygiene requirements prior to provide the measurement glove to participants.

C. Participants

Thirty participants took part in this experiment in two groups of fifteen with seven females and one left handed participant. Participants all had normal or corrected to normal vision. Participants were members of staff or students contacted via internal university email. A Participant Information Leaflet and related ethics documentation were attached to the invitation email before the experiment day to debrief the participants about details prior to the experiment. Participation in this experiment was entirely voluntarily with the right to withdraw at any point.

D. Procedures

Each participant had been debriefed about the experimental steps by research investigators and via email prior to data collection. Each participant was asked to wear a powder coated ultra thin polyvinyl glove and confirm if the sensor on the index finger tip was positioned correctly.

Group A had 5 minutes training with DigiScale application. Group B had the same duration of training with the game in three rounds with one minute intervals between them. The reason for repeating the training for three attempts for the game group was to provide the player with variety within the game environment as aspects of the game are randomised.

In the familiarisation phase, which occurred soon after the training session, participants were asked to attempt to meet target force levels with the aid of a dedicated display that provided visual feedback via the DigiScale application. In the final no visual feedback test, the display was switched off and results collected for each participant. There was a one minute interval between training and tests to avoid human fatigue. For

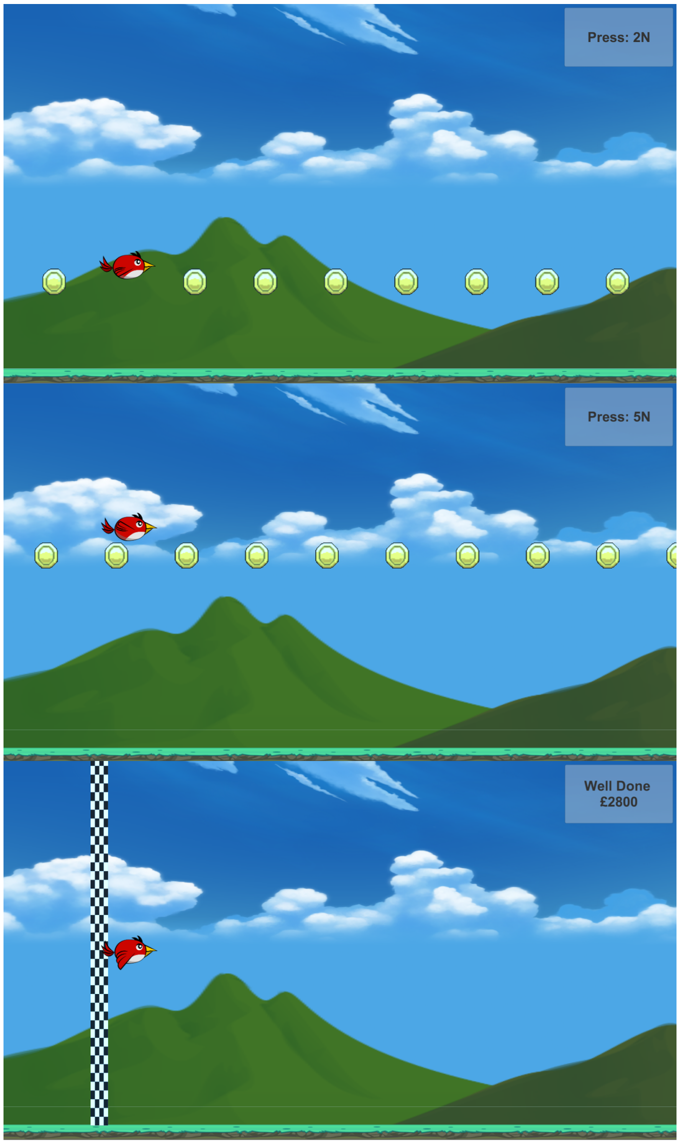

Figure 3. A game-based training approach is proposed by this experiment to help users improve their pressure sensitivity by controlling a flying bird that soars higher based on the amount of pressure applied by the index finger of the user. The final figure demonstrates the score that is displayed at the end of a run. Each captured coin is worth 100.

each target force the following objectives need to be achieved by each participant in each test.

- To reach the given target force level
- To maintain that target force level for 10 seconds.

E. Results

Results for each target force was obtained via the difference in target and recorded force for each observation. The mean exerted force (μ_i) for each target force level (f_i) is calculated from collected samples for each participant. The absolute difference from the target force is calculated as:

$$\delta_i = |\mu_i - f_i|$$

The mean of the delta values for all three target force levels f_i (2, 3 and 5 Newtons) were computed as a final result for each participant. A non-parametric Mann-Whitney test has been selected to analyse the results due to the non-parametric nature of the data.

The accuracy in the exerted target force for the no-visual test for participants in group B, who were trained using our game approach ($Mdn = 0.86$), differed significantly from the participants in group A, who trained using the application only approach ($Mdn = 1.56$), $U = 61$, $z = -2.137$, $p < .05$, $r = -0.36$ and thus H0 is rejected.

This result may highlight the potential role of game-based training on cognitive and control motor learning abilities. One possible reason for this achievement is an improvement in the understanding of the approximate force and sensitivity for the required pressure instilled while playing the game. Another potential advantage of game-based training is the competition factor characteristic of games. It was observed during the experiment that participants in group B were keen to beat their previous best score in each round which may have led to better focus and concentration on the requested test.

F. Qualitative Feedback

In order to form an understanding of whether the game was considered an enjoyable experience, and whether it was well designed and engaging a number of questions were asked to the group that played the game. An electronic questionnaire was sent via email to each participant in the game group (n=15) to collect their reflective feedback on their experience when playing the game. A total of six questions were asked to rank key features of the game from 1 to 5 (e.g for first question the answer is made from Not at all, Slightly, Moderately, Very, Extremely "Enjoyable"). Fourteen out of fifteen participants replied and a mean scores for each question are reported in Table II.

Table II. QUESTIONNAIR

Questions	Score
Did you enjoy playing this game?	3.85
Did you engage with this game?	3.85
How would you rank this game in terms of design?	3.85
Did you feel any improvement in controlling your force level each time you have played this game?	3.77
Would you play the game again in future?	3.46
Would you recommend this game to a friend?	3.54

Using rounded mean scores for a general evaluation the game can be deemed to be very enjoyable to play, very engaging, well designed, and with the ability to provide a perceived increase in motor ability. Participants also considered that they were likely to play the game again given the opportunity and would very much recommend it to a friend. On the whole, based on this feedback, the game design seems to have been for the most part successful.

V. Conclusions and Future Work

This work has presented a serious game that attempts to teach participants the correct application of pressure by controlling a virtual character on screen via a pressure sensitive input device that rewards players with accurate and controlled input. The results demonstrate that those players that played the game performed significantly better than a control group in a subsequent no-visual task within a very different environment from the game itself. Moreover, questionnaire responses indicate that the game is enjoyable and engaging. It is important to indicate that while this game has appeared to have been successful it is part of a larger framework that is required in order to make automated or assisted palpation training successful.

Future work will look into enhancing this experience by using all the input sensors on the glove, and the capability of the system to capture location and orientation data. This can be then used for the development of a serious simulator or serious game. Furthermore, palpation is not the only application that requires pressure sensitivity and modifications to the main game to adapt to the range of sensitivities of various applications can aid pressure sensitivity training in other fields eq. training for musical instruments.

Acknowledgment

Grateful acknowledgement is made to members of staff and students in WMG for their participation and support. We would like to thank Unity and Creepy Cat for making available the 2D Game Starter Assets used to prepare the game used in this publication. Debattista is partially supported by a Royal Society Industrial Fellowship.

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