Human Pose Estimation, Anthropomorphism and Gamification in the Promotion of Physical Activity Among Breast Cancer Survivors

João P. Monteiro
Carolina T. Lopes
Nuno C. Duarte

INESC TEC / Faculdade de Engenharia
Universidade do Porto
Rua Dr. Roberto Frias s/n
4200-465 Porto, Portugal
jpsm@ieee.org
ee11101@fe.up.pt
up201502854@fe.up.pt

André T. Magalhães

Serviço de Cirurgia Geral
Centro Hospitalar de São João
Alameda Prof. Hernâni Monteiro
4200-319 Porto, Portugal
amag1976@gmail.com

Hélder P. Oliveira

INESC TEC / Faculdade de Ciências
Universidade do Porto
Rua Campo Alegre 1021/1055
4169-007 Porto, Portugal
helder.f.oliveira@inesctec.pt

Abstract—**As breast cancer survivors are living longer, the adverse effects impacting quality of life resulting from the cancer treatment are more frequent. Concurrently, an emergence of new technologies has led to major changes in society with hypothesized potential to automate and assist in otherwise time-consuming tasks while promoting engagement. In this context, technology from the video games industry has been used with emphasis in the recovery and follow-up stages to evaluate and motivate the patient after treatment. The present work aims to evaluate a set of graphical user interfaces that make use of data acquired with a colour and depth sensor to monitor and provide real-time feedback to a given user. Design guidelines from serious games are explored within the context of developing a system aid for physical follow-up care in the form of a set of exercises selected by the medical community. The proposed interfaces were evaluated in a clinical setting with a group of breast cancer survivors and the expressed preferences collected. Results are discussed under the light of future developments of anthropomorphization and gamification as means to promote engagement.**

***Keywords*–Computer vision; Computerized monitoring; Computer aided instruction; User interfaces; Medical services.**

I. Introduction

As previously observed [1], while contributing for improved overall survivorship, contemporary breast cancer treatment techniques may result in several impairments in women's upper-body function and, consequently, contribute to a decreased quality of life [2] that could potentially be monitored through the application of readily available low cost computer vision based sensing approaches.

On the subject of the adverse effects resulting from the cancer treatment, upper body morbidity (e.g., decreased range of motion, muscle strength, pain and lymphedema) can be recognized to be among the most prevalent side effects. Regarding lymphedema alone, a swelling condition resulting from lymphatic ablation commonly associated with breast cancer treatment, it has been estimated that over 1 million Breast Cancer Survivors (BCS) in the United States of America (USA) and 10 million women worldwide may meet the criteria for breast cancer-related variant of the condition [2]. Persistent postsurgical pain is also an increasingly documented problem, negatively impacting quality of life and affecting approximately 20% of new chronic pain patients. The reported incidence of persistent post mastectomy pain (PPMP) ranges from 25-60%, in an estimated total of around 2.5 million survivors in the United States. Among breast cancer patients, PPMP is rated as the most troubling symptom, leading to disability and psychological distress, and is notably resistant to management. While surgical factors, including more extensive surgery (total or partial mastectomy), axillary lymph node dissection and reconstruction have been suggested to serve as important risk factors for chronic pain, several studies do not support this association [3]. Adjuvant treatment, such as radiation, chemotherapy, and hormone therapy, has also been associated with persistent pain. Among demographic factors, younger age correlates with increased persistent pain incidence in some studies but not others. Pre-existing pain is also more frequent in those who go on to develop PPMP [4]. The most commonly cited theory for post mastectomy pain syndrome is the removal of the intercostobrachial nerves that run through the axillary region into the arm which provokes chronic post-operative pain in breast cancer patients, followed by chemotherapy and radiation therapy. The treatment involves physical therapy, topical agents, anticonvulsants, antidepressants, antiarrhythmic, nerve block and scar desensitization injections with dilute local anaesthesia and steroids [5].

While the assessment of the oncological outcome of the cancer treatment can be easily objectively quantified by disease-free and overall survival rates, the same does not hold for functional aspects closely related to quality of life within the target population. Assessment of BCS symptoms and health-related quality of life outcomes are usually made using Patient Reported Outcome (PRO) questionnaires that quantify significant outcome variables from the patient's perspective [2]. A prospective surveillance model for BCS has been proposed, highlighting the importance of monitoring for functional and physical impairment commonly associated with treatment [6]. Despite available methods for monitoring and assessing, an integrated approach able to achieve early detection, promote risk-reduction and self-management, while engaging the user in an adequate follow-up strategy, is still considered missing [7].

In Section II, an outline of topics related to the application of typical elements of game playing is presented in order to contextualize the proposed methodology, that is presented in Section III. The paper continues with a discussion of results in Section IV regarding key questions relating to the application of strategies of anthropomorphization and gamification as means to promote engagement to particular physical activities within the context of patient empowerment systems. Lastly, a discussion on future developments is presented in Section V.

II. Related Work

Engaging patients in their healthcare can be recognized as a paramount topic that has evolved through time also as a reflection of specific technological and societal contexts [8]. In this sense, growing trends of the quantified-self movement, personal health records tools dissemination and interactive video games that combine physical exercise with game-play and have a primary purpose other than entertainment present themselves as currently active research lines.

A. Gamification

Physical activity promotion programmes tested in patients with disabilities and impairment problems demonstrate that patients' functionality can improve with an intensive training split that is contextualised and oriented as a pursuit in the achievement of a well defined goal. However, this task division is prone to present a major set-back, which is the lack of interest of the patient in performing repetitive tasks [11].

On the other hand, it is possible to note that a game, overall, aims to offer the player a challenge of a physical or/and mental nature that can be completed using a set of rules, being able to install feelings of amusement or entertainment in the participant while returning feedback in a form of grades or scores, while possibly unlocking new challenges based on the feedback received. Video games have the same goals, only a computer is used as an intermediary [12].

The concept of serious games is one that is hard to define, but it usually refers to games used for training, advertising, simulation or education. A particular example of such a gamified approach, commonly referred to as exergaming or exergames, can be described as a type of video game, or multimedia interaction that requires the player to physically move in order to play [13]. With the evolution of video game acceptance by the general public, serious games have begun to surge, spreading into healthcare where they can eventually provide a more personalized experience to users, improving not just physical, but also mental aspects of care. This surge, and the evolution of visual computing, seems to enable the development of personalized home systems, which could objectively evaluate the patient's state, while motivating for continued physical activity [14]. Specifically for rehabilitation, game prototypes have been tested for specific circumstances, in particular scenarios, such as upper limb rehabilitation [15].

The usage of games as a rehabilitation tool is a rather young topic especially taking into consideration that these usually tend to depend on virtual/augmented reality and low-cost effective equipment that has only begun being available relatively recently, with early examples including applications of devices such as the Playstation EyeToy dating back to 2003. A selection of reference works related to rehabilitation games is briefly reviewed and presented in the following list:

- Esfahlani et al. [16], evaluated a system aiming to monitor kinematic activity of upper and lower limbs by using a group of capture devices (Xbox Kinect, Mya armband and Rudder Pedal), to create a game in which levels are proposed taking into account current and expected abilities of the user.
- Caurin et al. [17], tested a dynamic difficulty adaptation game, using an adapted version of the Pong game playable with a wrist rehabilitation system as an input mechanic for patients with motor deficiencies.
- Barzilay, et al. [18], proposed the usage of neural networks paired with a virtual reality platform, composed of a Vicon^{TM} motion capture system and a wireless Aurion^{TM} surface EMG ZeroWire, to create a neuromotor training system for upper-limb rehabilitation that proposes exercises based on the feedback from patient's initial usage as well as therapist input.
- Darzi et al. [19], studied a system that regulates the difficulty of a game by analysing the physiological responses of the users by measuring respiration and electromyography signals from the posterior deltoid.
- Ma et al. [20], assessed the use of a Microsoft Kinect in terms of quantification of maximum range for hand movement, peak velocity and mean velocity, through its integration in a rehabilitation game, validating it by comparing it to a Vicon^{TM} motion capture system.

From these latter mentioned studies we can observe that multiple capture devices can be used, although some of them represent not just custom made solutions but also high-priced solutions, with the Microsoft Kinect being identified as a relative accurate device at a relative low-cost price.

On the other hand, it is also possible to find multiple examples of studies more focused on the usability of such games and how the patients reacted to them and elements that should be taken into consideration when developing such games. Some examples are listed bellow:

- Alankus et al. [21], created multiple games that used two Nintendo Wii remotes attached to the user's arm in order to detect elbow and arm movement. The study mainly contributed by studying a set of game design elements proposed to be considered when attempting to create rehabiliation games.
- Seo et al. [22], measured stroke rehabilitation patients' expectations for virtual rehabilitation games before these engaging in three different games. After the gaming experience the patients are again asked to answer a survey in which they evaluate the games. The games were developed using the Microsoft Kinect and P5 Glove MIDI as capture devices.
- Burke et al. [23], conducted a study in which multiple games were tested, using different capture devices, such as the P5 Glove MIDI, Nintendo Wii remote or off-the-shelf webcams. The study focused on the usability of these games on able-bodied users before conducting it on stroke rehabilitation patients. This secondary study [24] eventually occurred in which the webcam games were tested at home by the stroke rehabilitation patients, proving to be successful both in usability and playability, with potential to be deployed for home usage.

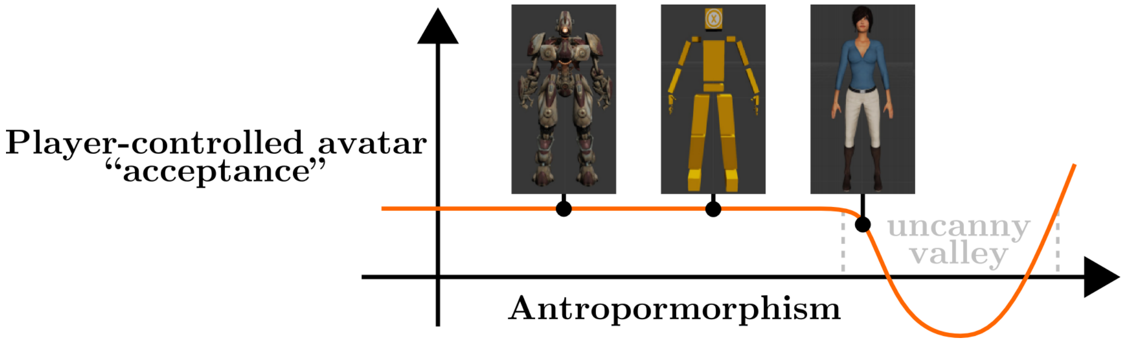


Figure 1. Example assessment of the strength of the IVBO in relation to the degree of anthropomorphism of a user controlled avatar, and the hypothesized uncanny valley effect [9], adapted from [10].

Previous studies seem to suggest that the evaluated systems are not just viable, but appreciated by its users. It is, however, important to note that although those games are graded as serious games, many of the principles being put to use were described for the creation of purely entertainment pastimes. On that perspective, it is possible to highlight that the ability to keep a patient engaged in a time-consuming repetitive activity is usually the biggest hurdle to overcome. Notwithstanding, in the case of [25], it has been noted that games that are created for the specific purpose of rehabilitation make the game effective, but end up lacking qualities traditional games possess, especially entertainment, thus leading to a less motivating experience, and thus resulting in the activity to be less likely to be repeated. The opposite can also happen when games that are designed purely for entertainment purposes are adapted to rehabilitation, in which the user with limited mobility expresses to have great fun with experience, but is unable to complete the level without help from a therapist [26]. These games also tend to focus on the individual recovery, thus lacking social qualities to it. As an additional variable to be taken into consideration, previous studies reinforce the need to create a social rehabilitation game for added motivation, suggesting the participation of a relative, or even multiple patients. An additional note to take from [21] is the consideration for the possibly older audience and the eventual need to hold their focus by the usage of colourful scenes and sound effects.

Overall, the ability of games to easily create fun challenges, be it for an individual or a group, seems to make them a good candidate for a rehabilitation aid tool. This, together with the existence of various input controllers, accessible systems and the possibility of such systems to be taken into the user's home, make it a very appealing candidate to help ease the problem of physical activity promotion. But still, does not yet seem to be settled how to exactly materialize such ideas.

B. Anthropomorphism

Different elements are being included in serious games as strategies to promote improved adherence [27]. Of those, it is possible to highlight virtual representations of the self, through which players are presented to the possibility of assuming the role of a character in the game [28]. On the topic of player controlled game characters, the Illusion of Virtual Body Ownership (IVBO) considers the effect of game players experiencing a sense of artificial body parts to be their own, within the context of an Virtual Reality (VR) setting [10]. Previous research [10] tends to suggest that the IVBO may result from an interaction of both synchronous visual, motor and tactile sensory inputs, as well as pre-existing visual and proprioceptive body representation factors. Another factor is the virtual body realism in terms of visual human resemblance, or anthropomorphism [29]. On a related note, the Uncanny Valley appertains to a theorized relationship between humans and robots [9] (e.g., Figure 1), that hypothesis that it should exist a positive relationship between how human a robot looks, and how comfortable people are with its appearance, up to the moment a robot would get too close to being human in appearance, without being fully human, at which point human reaction would became negative [9].

C. Human Pose Estimation

In vivo measurements of body mechanics have been typically acquired with optical motion capture or inertial sensor-based methods in a laboratorial setting [30]. Most commonly applied techniques employ optical systems that use high-speed cameras to capture the 3D motion of reflective markers that have been placed on anatomically relevant landmarks of the subject's limbs, trunk, and pelvis, being the supportive assumption that these markers' motion represent the movement of the rigid bony segments observed during the movement (Kernozek et al., 2013). It is possible to verify that an increasing number of studies have been focused on monocular mark-less approaches based on visual data. Accordingly, it is possible to recognize that the visual data streams, acquired by cameras, present the benefit of allowing a person to be monitored without the need of additional markers to be employed. From the several types of data that can be captured, RGB and depth, are, as already recognized, two of the most commonly used modalities being used. This approach tends to be much less expensive compared with those specialised opto-electronic apparatuses for acquiring motion data [31], and can also be considered to be used in most natural, everyday life settings. Commercial products include Microsoft's Kinect or Intel's Realsense that also provide an application programming interface (APIs) to acquire said depth data.

Range of motion is an important element to be taken into account when evaluating body mobility [32] that can be challenging for a patient to self report. Despite associated performance compromises, the Microsoft Kinect has been previously evaluated as a tool that could easily be used to monitor such measures without assistance from a trained examiner [33].

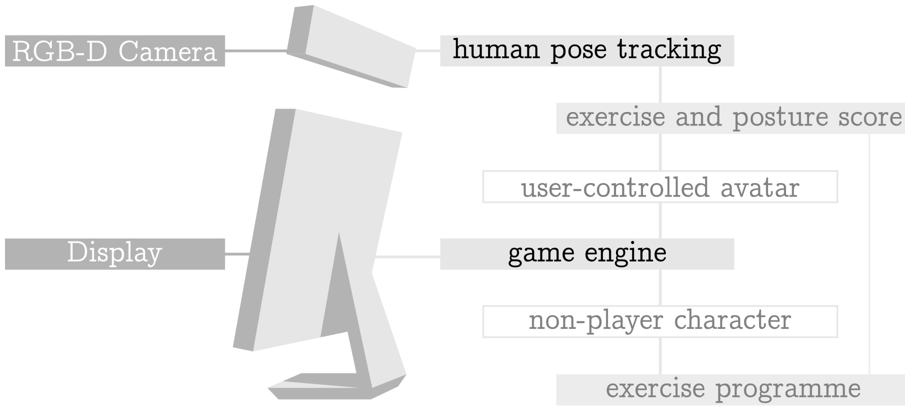


Figure 2. Overall architecture of the proposed system, comprising the use of colour and depth data to monitor, and provide real-time feedback to, a user in the context of a physical activity promotion for breast cancer survivors.

III. Proposed Research Approach

While there are several games that include serious topics, the inclusion of serious game elements is not yet enough to induce learning or real-world action [35]. Overall, despite engagement being considered a valuable resource, research on patient engagement technologies regarding impact on health outcomes has been limited [36]. Given this, this work's main goal is to develop and assess a game to promote an adequate exercise routine for BCS, to be used independently, as a self-management system to support breast cancer survivorship while monitoring one's physical status. The overall architecture of the proposed system is outlined in Figure 2.

We consider the Microsoft Kinect as an easily accessible, Color and Depth (RGB-D) sensor-device that enables to monitor a user's movement and provide feedback through the usage of an avatar, so that the user is aware of the performed movement, aiming at promoting adherence to exercise [37]. Both versions of the Kinect range sensor, i.e., the $\text{Kinect}^{\text{SL}}$, which is based on the Structured Light principle, and the Time-of-Flight variant $\text{Kinect}^{\text{ToF}}$, were considered [38]. To create the game environment, Unity was selected as the game engine, given its accessibility and widespread use.

In this paper, we pursue the following main topics:

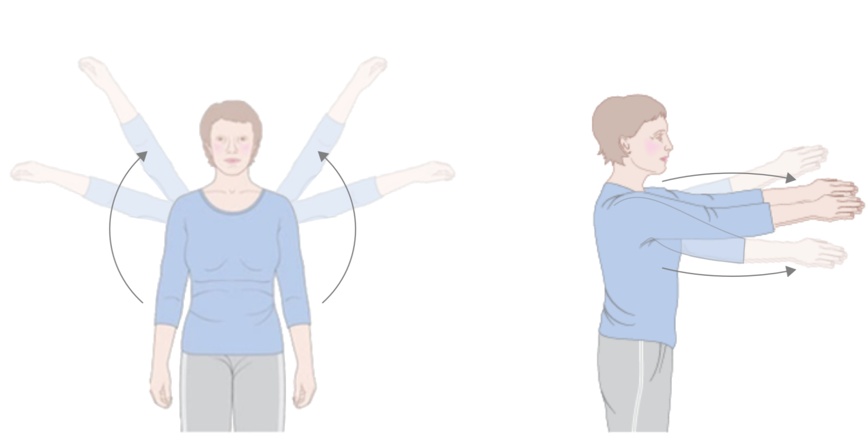
1) anthropomorphism as a strategy to engage, and
2) gamification as a mean to promote physical activity,
3) evaluation of RGB-D based human pose estimation systems for shoulder and elbow angle measurements

about which we present a body of exploratory work, with particular interest on the investigation of expressed preferences of the target user population to evaluate the developed demonstrators in a clinical setting.

A. Exercise programme selection

A standardized exercise programme consisting of shoulder flexion, abduction, and horizontal adduction was selected in accordance to the National Institute for Health and Clinical Excellence (NICE) guidelines [34]. The individual exercises comprised in the programme are illustrated in Figure 3.

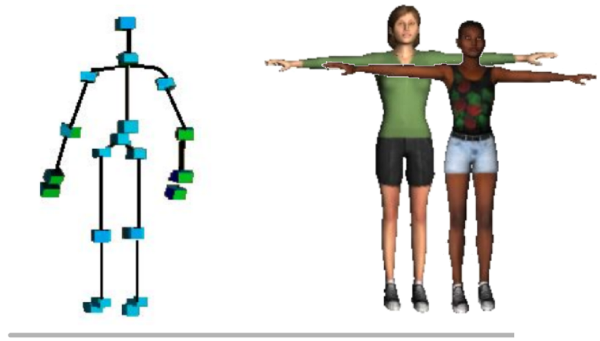
The exercise routine is composed of three sets, each comprising ten repetitions of one of the three exercises included in the programme, and small breaks between sets.



(a) (b) (c)

Figure 3. Illustration of the elements of the exercise programme considered for BCS physical activity promotion intervention, consisting of shoulder flexion (a), abduction (b) and horizontal abduction (c). Adapted from [34].

Levels of user controlled avatar anthropomorphism (while exercising)	
no visual feedback	
skeleton	a_1)
humanoid avatar	a_2)
mirror	



a_1) a_2)

Figure 4. Illustration of the user controlled character: avatar based characters animated with the user's tracked movement with different levels of anthropomorphism a_1) and a_2).

B. Expressed acceptance assessment

Analysis of engagement can be considered valuable in providing insights into game mechanisms that can then be applied to games for learning, or physical activity promotion [39], although not trivial to measure. In order to assess the acceptance of particular contexts of a given physical activity promotion intervention, a criteria set, based on [40], was used as basis for user expressed acceptance assessment. The criteria comprised the following aspects of testing:

c_1) suitability for the task,
c_2) information accessibility,
c_3) continuity correction,
c_4) visual pleasingness,
c_5) self-descriptiveness,
c_6) adequacy of user workload.

Based on that criteria, a questionnaire composed of six questions was formulated in Portuguese, and a five point scale, ranging from strong disagreement (1) to strong agreement (5), considered for range of response options.

C. Study on anthropomorphism

1) Participants and design: Following the approval by the clinical service direction, seventy-two adults (mean age of the cohort was 57.79 $\pm$ 11.16 years, all female) participated in the study. Participants were recruited via personal invitation from surgeon-led follow-up consultations of BCS. Participants were informed that the study was voluntary and part of the development of an aid designed to promote physical activity recommend for BCS within the context of an academic dissertation work. Written informed consent granting permission to the use of the anonymously collected data was obtained from all participants. All participants were fluent in Portuguese and did not get paid for their participation.

2) Procedure and materials: Participants were invited to participate in this study via personal invitation at the end of a follow up consultation at the Breast Center of São João Hospital during the period from the end of October until the beginning of December, 2016. The recruited participants were prompted to use the system in an adjacent room to the consultation room.

The architecture illustrated in Figure 2 was adapted so that it would entail a Non-Player Character (NPC) in the form of a virtual assistant that exemplified the movements to be performed according to the established exercise programme while the user was exercising. The same programme would be repeated four times, considering additional breaks between routines, one for each of the considered levels of the user controlled avatar anthropomorphism (illustrated in Figure 4).

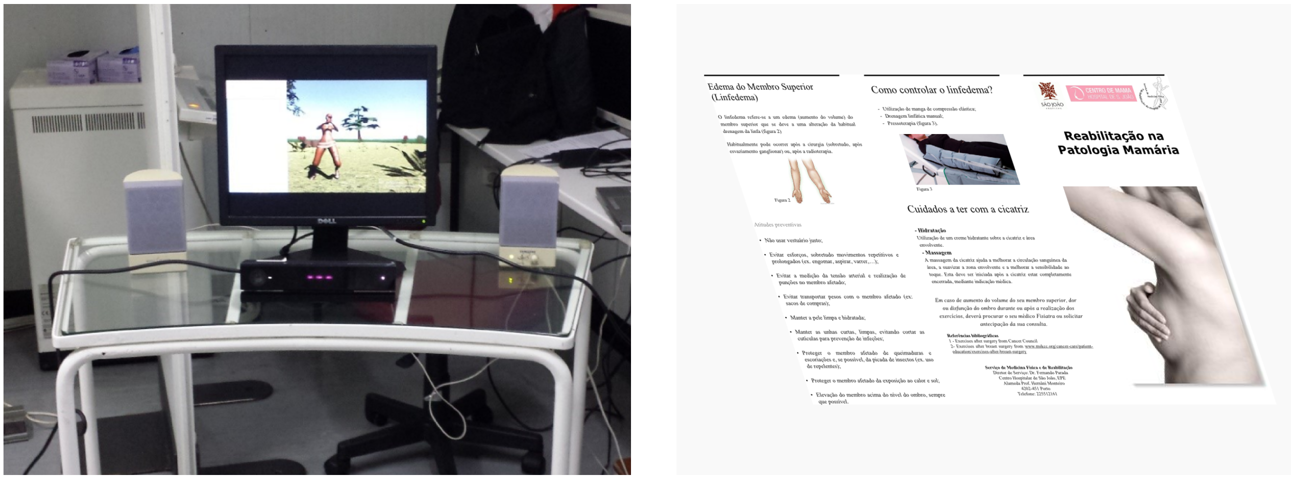
After using the system, each patient was inquired of its satisfaction level of the usage of the system through a questionnaire that required the user to rate each of the tested interfaces according to a five point scale ranging from least preferred (1) to most preferred (5). Each session took approximately 30 minutes, comprising the usage of the system for the proposed exercise programme and the filling of the questionnaire.

3) Results: Each of the four interfaces were evaluated using the aforementioned score in a five point scale after the user completed the exercise programme using all of the proposed interfaces. Table I presents the mean expressed preferences for the user controlled character variations.

Although it seems to not exist an abrupt drop on the collected expressed preference between evaluated interfaces with different levels of user controlled avatar anthropomorphism, both skeleton and humanoid examples seem to be preferred over the alternatives with either no visual feedback, or mirror-based feedback.

TABLE I. AVERAGE AND STANDARD DEVIATION (SD) OF EXPRESSED PREFERENCES OVER THE DIFFERENT USER CONTROLLED CHARACTER TESTED BY SEVENTY-TWO BCS IN A CLINICAL SETTING.

		avatar		
	no visual feedback	skeleton	humanoid	mirror
Average	4.10	4.22	4.22	4.19
SD	0.77	0.88	0.77	0.82



(a) Experimental set-up

(b) Printed pamphlet

Figure 5. a) Acquisition environment for the study on gamification for the tested system comprising a Kinect$^{\text{ToF}}$, laptop and additional screen; b) Printed pamphlet produced at the Breast Center of São João Hospital and distributed to BCS.

D. Study on gamification

1) Participants and design: Sixty-eight adults (mean age of the cohort was 59.09 $\pm$ 10.92 years, all female) participated. The same recruitment method mentioned in Subsection III-C (Study on anthropomorphism) was used. A sub group of 22% of participants (15 out of 68) were randomly assigned to receive printed information resources, in form of a pamphlet produced at the Breast Center of São João Hospital.

2) Procedure and materials: As in the study on anthropomorphism, participants were invited to participate after a surgeon-led follow-up consultation at the Breast Center of São João Hospital. The recruitment took place from the beginning of November until the end of December, 2017. Participants were informed about the study being part of the development of an aid to promote physical activity recommend for BCS, and prompted to use the system, in an adjacent to the consultation room (as illustrated in Figure 5).

The architecture used for the study on anthropomorphism, was considered, including the NPC virtual assistant exemplifying the exercise programme to be performed. To provide real-time feedback of the user's own movement only a human avatar was used. Differently from the previous study, the user controlled avatar was animated with the human pose provided by a Kinect$^{\text{ToF}}$. A novelty introduced by the second Kinect version (through its corresponding SDK and respective tools) is the gesture builder tool.

The gesture builder tool was used to create a database containing the set of considered movements, and to assess the completion of a given movement being performed. After building a library of the selected exercises, this was used to score the performance of the user. The normal scoring of the game attributed 1 point for every 1% of progress in each repetition, and a final score was presented as a percentage of the routine completed (the complete routine corresponds to 3000 points).

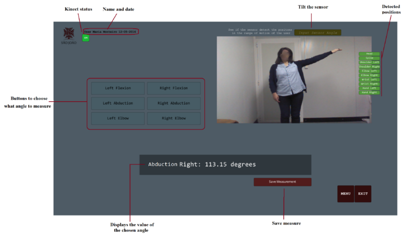
After the usage of the system, each patient was inquired to express level of acceptance that required the user to rate each of the previously identified criteria according to a five point scale ranging from strong disagreement (1) to strong agreement (5). Each session took approximately 10 minutes, which comprised the usage of the interface for the proposed exercise programme by the user and the filling of the questionnaire.

3) Results: Table II presents the mean expressed acceptance for the proposed Gamified Aid for Monitoring Exercise (GAME) with a humanoid player controlled character and an NPC virtual assistant, against an informative printed pamphlet. Of the total cohort of sixty-eight BCS, fifty-three were randomly assigned to use the GAME and fifteen assigned for being shown the printed pamphlet.

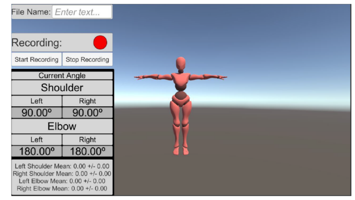
In the context of the evaluation, it seems to exist a stronger agreement, across considered criterion, for the proposed GAME being a preferred medium over printed materials.

TABLE II. AVERAGE AND STANDARD DEVIATION (SD) OF EXPRESSED ACCEPTANCE FOR THE PROPOSED GAME AND A PRINTED PAMPHLET CONTAINING INFORMATION ABOUT THE SELECTED EXERCISE PROGRAMME.

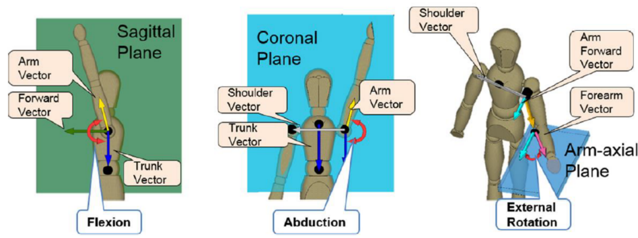
	GAME		pamphlet	
Criteria	Average	SD	Average	SD
c_1)	4.60	0.74	4.00	1.11
c_2)	4.72	0.50	4.08	1.27
c_3)	4.92	0.32	5.00	0.00
c_4)	4.88	0.29	4.60	0.84
c_5)	4.96	0.19	4.60	0.84
c_6)	4.88	0.39	4.00	1.11



(a) Interface for Kinect^{SL} virtual goniometer



(b) Interface for Kinect^{ToF} virtual goniometer



(c) Reference measurments of shoulder and elbow range of motion angles

Figure 6. Snapshots of the developed interfaces for the virtual goniometer for both Kinect^{SL}, (a), and Kinect^{ToF}, (b), and illustration of the measured postural angles, adapted from [41], (c).

E. Study on postural angles from RGB-D

1) Participants and design: Due to time constraints from the clinical setting this study of validation of the Kinect sensors for the task of measuring joint angles was performed in an academic setting, having participated seven adults (mean age of the cohort was 27.6 ± 5.44 years, 5 male, 2 female) recruited via personal invitation from a group of post graduate students from the Faculty of Engineering of Porto with no known shoulder impairments. All participants were fluent in Portuguese and did not get paid for their participation.

2) Procedure and materials: Participants were invited to participate in this study via personal invitation at two moments: December, 2016 and December 2017. Participants were informed that the study was part of the development of an aid designed to promote physical activity recommend for BCS. The recruited participants were prompted to use the system, in an indoor room of the Faculty of Engineering of Porto.

An application for measuring range of shoulder and elbow motion using input data from both Microsoft Kinect RGB-D sensors was developed using the cross-platform game engine Unity. Furthermore, the results are compared against the data acquired with a clinical gold standard goniometer. The goniometer used to register the values of postural angles of the shoulder and elbow has a range between 0 and 270 degrees, with a minimum scale value of 2 degrees.

Each subject was recorded performing a shoulder flexion with the instruction of obtaining a 90 degree angle. For the shoulder abduction and elbow rotation exercises, the same procedure as the shoulder flexion has considered. In the case of shoulder rotation the vectors can be seen as the vector defined by the points consisting of the chest and the hip, against the vector defined by the points consisting of the shoulder and elbow. In the case of elbow rotation, the angle is obtained by the vector defined from the shoulder to the elbow and the vector from the elbow to the wrist. These vectors can be visualized in different planes in Figure 6.

3) Results: Table III presents the mean absolute difference (disagreement) between the readings of a trained annotator using a goniometer, and the computed angles from the three-dimensional location of the anatomical landmarks detected by both versions of Kinect. The results suggest that despite an improved design regarding depth estimation of the Kinect^{ToF} over the Kinect^{SL}, the difference to the goniometer measures is smaller for the older version of the RGB-D camera, that seemed to deal better with the partial occlusion of body parts in the range of view of the acquisition device in the context of this study. Despite constituting a limitation to the present study, it does not seem evident to the authors whether a different result could have been observed would have been possible to have access to BCS to perform this technical validation.

TABLE III. AVERAGE AND STANDARD DEVIATION (SD) OF SHOULDER AND ELBOW RANGE OF MOTION ABSOLUTE ANGLE DIFFERENCE IN DEGREES BETWEEN GONIOMETER MEASURES BY A TRAINED ANNOTATOR AND ESTIMATIONS BASED ON THE HUMAN POSE RECOVERY METHODS PROVIDED WITH BOTH STRUCTURED LIGHT (SL) AND TIME-OF-FLIGHT (TOF) VARIANTS OF KINECT ($|\theta_{KINECT_V} - \theta_{GONIOMETER}|, V = SL, TOF$).

	Absolute Disagreement [°]					
	Shoulder abduction		Shoulder flexion		Elbow flexion	
	Kinect^{SL}	Kinect^{ToF}	Kinect^{SL}	Kinect^{ToF}	Kinect^{SL}	Kinect^{ToF}
Average	0.936	3.190	0.532	5.170	1.034	7.080
SD	0.630	2.205	0.421	2.200	0.603	7.305

IV. CONCLUSION

The present work investigates the impact of providing real-time feedback to BCS within the context of a physical activity promotion intervention. A system comprised of a RGB-D sensor with a processing pipeline to monitor the user, and in that way animate a user controlled avatar, was considered.

In the first exploratory study the effect of different levels of anthropomorphism of the user controlled avatar was investigated. Seventy-two BCS participated in the cohort. The results seem to agree with the hypothesised Uncanny Valley effect, in the sense that a more anthropomorphised representation of the self (a mirror), seems not to be the preferred interface. Although not possible to assess from the presented results, but also supported considering previous research, i.e., [10], subjectively constructed proprioceptive body representations of the self, seems to be an apparently worth considering factor in the context of BCS, with potential impact to adherence to systems using anthropomorphised avatars.

In the second study a gamified approach considering an humanoid avatar and an NPC assistant was evaluated against a printed pamphlet. From a total of sixty-eight participants, a subgroup of 15 was randomly assigned to be shown the pamphlet containing information about appropriate care following breast cancer treatment, including the recommendation to perform simple exercises to be repeated throughout survivorship. The remaining participants played a game where an NPC assistant would exemplify the recommend exercise programme, while a humanoid avatar would replicate the user's movements, and in real-time provide feedback of the exercise being executed. Overall, the collected expressed acceptance suggests that the proposed gamified aid for monitoring exercise seems suitable for the task, informative, visual pleasing, self-descriptive, and providing an adequate workload to the user.

For the third study the accuracy of both versions of the Microsoft Kinect RGB-D capture device in calculating angles of the shoulder and elbow in specific poses and the possibility of using it instead of a tradition instrument the goniometer was evaluated. A control group of 7 healthy adults was considered and two separated sessions were performed for the distinct Structured Light and the Time-of-Flight based depth sensors. The results compared to the goniometer seem to suggest that the Microsoft Kinect can be considered as an auxiliary virtual goniometer in order to facilitate frequent measurement taking, specially if in coordination with individualized monitoring context. It seems also possible to recognize a higher disagreement with the gold standard measures for the Kinect$^{\text{ToF}}$ that can be related with a more frequent interference from detection errors associated with occluded body parts.

Overall it seems possible to recognize that in the context of physical activity promotion interventions target at particular populations monitoring particular measures of physical status trough automatic methods based on human pose estimation is feasible. Moreover, the application of gamified strategies to promote engagement seem to be well perceived by users, even though the mid to long term adhesion is yet to be properly characterized. Furthermore, for the particular context of breast cancer survivors, the hypnotized relation between humans and virtual characters in which users would experience higher levels of comfort when interacting with more anthropomorphic looking avatars, does not seem to hold.

V. FUTURE WORK

The considered prospective surveillance model for breast cancer survivors highlights the importance of monitoring for functional and physical impairment commonly associated with breast cancer treatment. Low cost device-based methods have been studied, and its potential to "enable a continuum of time scale from a summary of entire interactions to second-by-second dynamics" continuously highlighted in a myriad of application scenarios [42]. Notwithstanding, from the presented work, various topics seem to still present themselves as pertinent to be explored in future work. Among several, the problem of recovering the spatial pose of the human body during dynamic movements, from mark-less set-ups of acquisition is highlighted bellow.

Computer vision and pattern recognition fields present recent insightful research that is constantly innovating. Even if, at the very front end of development, progress may look a lot like long-lived methodologies as may be the case of variations of perceptron inspired learning approaches [43] or related weights estimation method of back-propagation [44], rediscovered through a new context of parallel computation capabilities and extensive data availability [45]. And despite all that, or even the recent explosion of deep convolutional neural networks (DCNN), *general purpose learning algorithms that improve themselves in provably optimal ways* still seem a distant future [45]. By the same token, human pose estimation still remains with several challenges, especially in the 3D space as reviewed by [46]. One of the challenges arises from the ill-posed nature of the 3D pose estimation task itself, especially from a single monocular image. Similar image projections can be derived from completely different 3D poses. In such cases, self-occlusions result in ambiguities that limit the applicability of existing techniques. Furthermore, recent research primarily focus on frontal views with few occlusions despite the abundance of occlusion and partial-poses in object detection in natural environments.

Besides a trend of deep neural networks-based methods, the existence of prominent publicly made available datasets [47], [48], [49], recurrently used to stablish benchmarks for the task of recovering the tri-dimensionality of the human pose from bi-dimensional visual data, seem to contribute to advances in the respective field. Despite the recent trend of methods outperforming feature learning strategies in a myriad of applications [50], the challenging tasks of establishing a proper learning approach and parameters tuning for a given task [51], as well as, a compromised interpretability [52] of the resulting models, still remain relevant open challenges that gain special importance in clinically related applications. On that regard, recent regulation in the European Union proposes that individuals affected by algorithmic decisions have a right to explanation [53], despite not being completely clear on how a clinician treating a patient who is aided by a machine learning algorithm may be expected to explain decisions that use the patient's data [54]. The need for less opaque ways to explain algorithms outcomes, has also motivated the recent DARPA's Explainable Artificial Intelligence (XAI) program [55].

ACKNOWLEDGMENTS

The authors would like to thank the direction, members, and users of the Breast Center of São João Hospital, that, valuably, supported and participated in the research.

This work is financed by the ERDF - European Regional Development Fund through the Operational Programme for Competitiveness and Internationalisation - COMPETE 2020 Programme within project POCI-01-0145-FEDER-006961, and by National Funds through the Portuguese funding agency, FCT - Fundação para a Ciência e a Tecnologia as part of project UID/EEA/50014/2013; and also by FCT within the Ph.D. grant number SFRH/BD/138823/2018.

REFERENCES

[1] J. P. Monteiro, C. T. Lopes, N. C. Duarte, A. Magalhães, and H. P. de Oliveira, "Investigations on the impact of anthropomorphism and gamification on breast cancer survivors' expressed preferences in a physical activity promotion intervention," in Proceedings of the eTELEMED 2019 : The Eleventh International Conference on eHealth, Telemedicine, and Social Medicine. IARIA, 2019, pp. 139–143.

[2] V. M. Boquiren, T. F. Hack, R. L. Thomas, A. Towers, W. B. Kwan, A. Tilley, E. Quinlan, and B. Miedema, "A longitudinal analysis of chronic arm morbidity following breast cancer surgery," Breast Cancer Research and Treatment, vol. 157, no. 3, 2016, pp. 413–425.

[3] R. Gärtner, M.-B. Jensen, J. Nielsen, M. Ewertz, N. Kroman, and H. Kehlet, "Prevalence of and factors associated with persistent pain following breast cancer surgery," Jama, vol. 302, no. 18, 2009, pp. 1985–1992.

[4] K. G. Andersen and H. Kehlet, "Persistent pain after breast cancer treatment: a critical review of risk factors and strategies for prevention," The Journal of Pain, vol. 12, no. 7, 2011, pp. 725–746.

[5] Y. Briskin and T. Odinets, "Improvement of upper limb's condition of women with post mastectomy syndrome with the help of problem–oriented program of physical rehabilitation," Pedagogics, psychology, medical-biological problems of physical training and sports, vol. 19, no. 11, 2015, pp. 20–25.

[6] N. L. Stout, J. M. Binkley, K. H. Schmitz, K. Andrews, S. C. Hayes, K. L. Campbell, M. L. McNeely, P. W. Soballe, A. M. Berger, A. L. Cheville, C. Fabian, L. H. Gerber, S. R. Harris, K. Johansson, A. L. Pusic, R. G. Prosnitz, and R. A. Smith, "A prospective surveillance model for rehabilitation for women with breast cancer," Cancer, vol. 118, no. S8, 2012, pp. 2191–2200.

[7] L. Lai, J. Binkley, V. Jones, S. Kirkpatrick, C. Furbish, P. Stratford, W. Thompson, A. Sidhu, C. Farley, J. Okoli, D. Beech, and S. Gabram, "Implementing the prospective surveillance model (PSM) of rehabilitation for breast cancer patients with 1–year postoperative follow–up, a prospective, observational study," Annals of Surgical Oncology, vol. 23, no. 10, 2016, pp. 3379–3384.

[8] W. Tauxe, "A tumour through time," Nature, vol. 527, no. 7578, 2015, pp. S102–S103.

[9] M. Mori, K. MacDorman, and N. Kageki, "The uncanny valley," IEEE Robotics & Automation Magazine, vol. 19, no. 2, 2012, pp. 98–100.

[10] J. Lugrin, J. Latt, and M. E. Latoschik, "Avatar anthropomorphism and illusion of body ownership in vr," in Proceedings of the 2015 IEEE conference on Virtual Reality (VR), 2015, pp. 229–230.

[11] M. Simon, "Gamification and serious games for personalized health," Studies in Health Technology and Informatics, vol. 177, 2012, pp. 85–96.

[12] F. Laamarti, M. Eid, and A. E. Saddik, "An overview of serious games," International Journal of Computer Games Technology, vol. 2014, 2014, pp. 1–15.

[13] S. Wüest, N. A. Borghese, M. Pirovano, R. Mainetti, R. van de Langenberg, and E. D. de Bruin, "Usability and effects of an exergame–based balance training program," Games for Health Journal, vol. 3, no. 2, 2014, pp. 106–114.

[14] B. Lange, S. Koenig, E. McConnell, C.-Y. Chang, R. Juang, E. Suma, M. Bolas, and A. Rizzo, "Interactive game–based rehabilitation using the microsoft kinect," in Proceedings of the 2012 IEEE Conference in Virtual Reality (VR). IEEE, 2012.

[15] R. Moreira, A. Magalhães, and H. Oliveira, "A kinect–based system for upper–body function assessment in breast cancer patients," Journal of Imaging, vol. 1, no. 1, 2015, pp. 134–155.

[16] S. S. Esfahlani, S. Cirstea, A. Sanaei, and G. Wilson, "An adaptive self–organizing fuzzy logic controller in a serious game for motor impairment rehabilitation," in Proceedings of the 2017 IEEE 26th International Symposium on Industrial Electronics (ISIE), 2017, pp. 1311–1318.

[17] G. A. Caurin, A. A. Siqueira, K. O. Andrade, R. C. Joaquim, and H. I. Krebs, "Adaptive strategy for multi–user robotic rehabilitation games," in Proceedings of the 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2011, pp. 1395–1398.

[18] O. Barzilay and A. Wolf, "Adaptive rehabilitation games," Elsevier Journal of Electromyography and Kinesiology, vol. 23, no. 1, 2013, pp. 182–189.

[19] A. Darzi, M. Goršič, and D. Novak, "Difficulty adaptation in a competitive arm rehabilitation game using real-time control of arm electromyogram and respiration," in Proceedings of the 2017 International Conference on Rehabilitation Robotics (ICORR), 2017, pp. 857–862.

[20] M. Ma, R. Proffitt, and M. Skubic, "Quantitative assessment and validation of a stroke rehabilitation game," in Proceedings of the 2017 IEEE/ACM International Conference on Connected Health: Applications, Systems and Engineering Technologies (CHASE), 2017, pp. 255–257.

[21] G. Alankus, A. Lazar, M. May, and C. Kelleher, "Towards customizable games for stroke rehabilitation," in Proceedings of the Special Interest Group on Computer-Human Interaction (SIGCHI) Conference on Human Factors in Computing Systems, 2010, pp. 2113–2122.

[22] N. J. Seo, J. K. Arun, P. Hur, V. Crocher, B. Motawar, and K. Lakshminarayanan, "Usability evaluation of low-cost virtual reality hand and arm rehabilitation games." Journal of rehabilitation research and development, vol. 53, no. 3, 2016, pp. 321–334.

[23] J. W. Burke, M. McNeill, D. Charles, P. Morrow, J. Crosbie, and S. McDonough, "Serious games for upper limb rehabilitation following stroke," in Proceedings of the 2009 Conference in Games and Virtual Worlds for Serious Applications, 2009, pp. 103–110.

[24] J. W. Burke, M. McNeill, D. K. Charles, P. J. Morrow, J. H. Crosbie, and S. M. McDonough, "Optimising engagement for stroke rehabilitation using serious games," The Visual Computer, vol. 25, no. 12, 2009, p. 1085.

[25] E. Flores, G. Tobon, E. Cavallaro, F. I. Cavallaro, J. C. Perry, and T. Keller, "Improving patient motivation in game development for motor deficit rehabilitation," in Proceedings of the 2008 International Conference on Advances in Computer Entertainment Technology, ser. ACE '08. ACM, 2008, pp. 381–384.

[26] D. Rand, R. Kizony, and P. Weiss, "Virtual reality rehabilitation for all: Vivid gx versus sony playstation ii eyetoy," in Proceedings of the 5th Intl Conf. Disability, Virtual Reality and Assoc. Tech (ICDVRAT), 2004, vol. 4, pp. 87–94.

[27] D. Thompson, "Designing serious video games for health behavior change: Current status and future directions," Journal of Diabetes Science and Technology, vol. 6, no. 4, 2012, pp. 807–811.

[28] M. Rice, R. Koh, Q. Lui, Q. He, M. Wan, V. Yeo, J. Ng, and W. P. Tan, "Comparing avatar game representation preferences across three age groups," in Proceedings of the 2013 ACM SIGCHI Conference on Human Factors in Computing Systems CHI. ACM Press, 2013.

[29] T. Waltemate, D. Gall, D. Roth, M. Botsch, and M. E. Latoschik, "The impact of avatar personalization and immersion on virtual body ownership, presence, and emotional response," IEEE Trans. on Visualization and Computer Graphics, vol. 24, no. 4, 2018, pp. 1643–1652.

[30] L. Donath, O. Faude, E. Lichtenstein, C. Nüesch, and A. Mündermann, "Validity and reliability of a portable gait analysis system for measuring spatiotemporal gait characteristics: comparison to an instrumented treadmill," Journal of neuroengineering and rehabilitation, vol. 13, no. 1, 2016, p. 6.

[31] A. Patrizi, E. Pennestrì, and P. P. Valentini, "Comparison between low-cost marker–less and high–end marker–based motion capture systems for the computer–aided assessment of working ergonomics," Ergonomics, vol. 59, no. 1, 2016, pp. 155–162.

[32] S. H. Lee, C. Yoon, S. G. Chung, H. C. Kim, Y. Kwak, H. won Park, and K. Kim, "Measurement of shoulder range of motion in patients with adhesive capsulitis using a kinect," PLOS ONE, vol. 10, no. 6, 2015, p. e0129398.

[33] M. Huber, A. L. Seitz, M. Leeser, and D. Sternad, "Validity and reliability of kinect skeleton for measuring shoulder joint angles: a feasibility study," Physiotherapy, vol. 101, no. 4, 2015, pp. 389–393.

[34] J. Yarnold, "Early and locally advanced breast cancer: Diagnosis and treatment national institute for health and clinical excellence guideline 2009," Clinical Oncology, vol. 21, no. 3, 2009, pp. 159–160.

[35] K. Starks, "Cognitive behavioral game design: a unified model for designing serious games," Frontiers in Psychology, vol. 5, 2014, p. 28.

[36] J. E. Prey, J. Woollen, L. Wilcox, A. D. Sackeim, G. Hripcsak, S. Bakken, S. Restaino, S. Feiner, and D. K. Vawdrey, "Patient engagement in the inpatient setting: a systematic review," Journal of the American Medical Informatics Association, vol. 21, no. 4, 2014, pp. 742–750.

[37] J. Han, L. Shao, D. Xu, and J. Shotton, "Enhanced computer vision with microsoft kinect sensor: A review," IEEE Transactions on Cybernetics, vol. 43, no. 5, oct 2013, pp. 1318–1334.

[38] H. Sarbolandi, D. Lefloch, and A. Kolb, "Kinect range sensing: Structured–light versus time–of–flight kinect," Computer Vision and Image Understanding, vol. 139, oct 2015, pp. 1–20.

[39] E. A. Boyle, T. Hainey, T. M. Connolly, G. Gray, J. Earp, M. Ott, T. Lim, M. Ninaus, C. Ribeiro, and J. Pereira, "An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games," Computers & Education, vol. 94, 2016, pp. 178–192.

[40] K. S. Park and C. H. Lim, "A structured methodology for comparative evaluation of user interface designs using usability criteria and measures," International Journal of Industrial Ergonomics, vol. 23, no. 5-6, 1999, pp. 379–389.

[41] S. H. Lee, C. Yoon, S. G. Chung, H. C. Kim, Y. Kwak, H.-w. Park, and K. Kim, "Measurement of shoulder range of motion in patients with adhesive capsulitis using a kinect," PloS one, vol. 10, no. 6, 2015, p. e0129398.

[42] C. Leclère, M. Avril, S. Viaux-Savelon, N. Bodeau, C. Achard, S. Missonnier, M. Keren, R. Feldman, M. Chetouani, and D. Cohen, "Interaction and behaviour imaging: a novel nethod to neasure mother–infant interaction using video 3d reconstruction," Translational psychiatry, vol. 6, no. 5, 2016, p. e816.

[43] F. Rosenblatt, "Principles of neurodynamics. perceptrons and the theory of brain mechanisms," Cornell Aeronautical Lab Inc Buffalo NY, Tech. Rep., 1961.

[44] D. E. Rumelhart, G. E. Hinton, R. J. Williams et al., "Learning representations by back–propagating errors," Nature, vol. 323, no. 3, 1986, pp. 533–536.

[45] J. Schmidhuber, "Deep learning in neural networks: An overview," Neural networks, vol. 61, 2015, pp. 85–117.

[46] N. Sarafianos, B. Boteanu, B. Ionescu, and I. A. Kakadiaris, "3d human pose estimation: A review of the literature and analysis of covariates," Computer Vision and Image Understanding, vol. 152, 2016, pp. 1–20.

[47] L. Sigal, A. O. Balan, and M. J. Black, "Humaneva: Synchronized video and motion capture dataset and baseline algorithm for evaluation of articulated human motion," International journal of computer vision, vol. 87, no. 1-2, 2010, p. 4.

[48] M. Andriluka, L. Pishchulin, P. Gehler, and B. Schiele, "2d human pose estimation: New benchmark and state of the art analysis," in Proceedings of the IEEE Conference on computer Vision and Pattern Recognition, 2014, pp. 3686–3693.

[49] C. Ionescu, D. Papava, V. Olaru, and C. Sminchisescu, "Human3.6m: Large scale datasets and predictive methods for 3d human sensing in natural environments," IEEE transactions on pattern analysis and machine intelligence, vol. 36, no. 7, 2013, pp. 1325–1339.

[50] R. Miotto, L. Li, B. A. Kidd, and J. T. Dudley, "Deep patient: An unsupervised representation to predict the future of patients from the electronic health records," Scientific reports, vol. 6, 2016, p. 26094.

[51] Y. Guo, Y. Liu, A. Oerlemans, S. Lao, S. Wu, and M. S. Lew, "Deep learning for visual understanding: A review," Neurocomputing, vol. 187, 2016, pp. 27–48.

[52] B. J. Lengerich, S. Konam, E. P. Xing, S. Rosenthal, and M. Veloso, "Towards visual explanations for convolutional neural networks via input resampling," arXiv preprint arXiv:1707.09641, 2017.

[53] B. Goodman and S. Flaxman, "European union regulations on algorithmic decision–making and a "right to explanation"," AI Magazine, vol. 38, no. 3, 2017, pp. 50–57.

[54] T. Ching, D. S. Himmelstein, B. K. Beaulieu-Jones, A. A. Kalinin, B. T. Do, G. P. Way, E. Ferrero, P.-M. Agapow, M. Zietz, M. M. Hoffman et al., "Opportunities and obstacles for deep learning in biology and medicine," Journal of The Royal Society Interface, vol. 15, no. 141, 2018, p. 20170387.

[55] M. T. Ribeiro, S. Singh, and C. Guestrin, ""why should i trust you?": Explaining the predictions of any classifier," in Proceedings of the 22nd ACM SIGKDD international conference on knowledge discovery and data mining. ACM, 2016, pp. 1135–1144.