Development of a Motion-Based Video Game for Postural Training: A Feasibility Study on Older Adults With Adult Degenerative Scoliosis

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***Abstract*—Forward sagittal alignment affects physical performance, is associated with pain and impacts the health-related quality of life of the elderly. Interventions that help seniors to improve sagittal balance are needed to inhibit the progression of pain and disability. A motion-sensing video game (active game) is developed in this study to monitor sitting and standing postures in real-time and facilitate the postural learning process by using optical sensors to measure body movement and a video game to provide visual feedback. Ten female subjects (mean age: 60.0 ± 5.2 years old; mean BMI: 21.4 ± 1.9) with adult degenerative scoliosis (mean major Cobb's angle: 38.1° ± 22.7°) participate in a 6-week postural training programme with three one-hour postural training sessions a week. Eleven body alignment measurements of their perceived "ideal" sitting and standing postures are obtained before and after each training session to evaluate the effectiveness of postural learning with the game. The participants learn to sit and stand with increased sagittal alignment with a raised chest and more retracted head position. The forward shift of their head and upper body is significantly reduced after each training session. Although this immediate effect only partially sustained after the 6-week program, the participants learned to adjust their shoulder and pelvis level for a better lateral alignment in standing. The proposed postural training system, which is presented as a gameplay with real-time visual feedback, can effectively help players to improve their postures. This pilot feasibility study explores the development and initial assessment of a motion-based video game designed for postural training in older adults with adult degenerative scoliosis, and demonstrates the usability and benefits of active gameplay in motor training.**

***Index Terms*—Active games, adult degenerative scoliosis, body alignments, pain management, posture training.**

I. INTRODUCTION

WITH the population ageing very quickly in most developed countries, health-care costs have been rising rapidly in parallel. Maintaining health-related quality of life (HRQOL) of the elderly population and extending their healthy life expectancy have become one of the most discussed issues in public health policies.

As demonstrated in medical research, sagittal imbalance, which generally refers to the forward displacement of the C7-S1 sagittal vertical axis (SVA), is correlated with physical function impairment [1], [2] and HRQOL [3] in the elderly population. This forward shift is found to be the greatest predictor of pain and disability in adults with spinal deformities [4]. As individuals age, they may lean forward progressively and develop kyphosis, a spinal degeneration due to the weakening of the spinal bones [5] and further worsen their health status. Therefore, educating seniors to actively self-manage their posture and maintain sagittal alignment habitually may increase their HRQOL as well as age in a healthy manner.

To improve postural alignment habitually, an individual must first develop postural awareness – the subjective and conscious awareness of body posture that is mainly based on proprioceptive feedback from the peripheries of the body to the central nervous system [6], and maintain a sense of "good" posture [7] which helps us to identify whether our posture is in good alignment, and hence, self-correct when necessary. Learning how to place the spine in "good" alignment, however, is not that easy and straight forward, but requires prolonged and frequent practice to internalize the perception of correct alignment and the corresponding muscle utilization pattern. Traditionally, healthcare practitioners would ask their patients to practice good sitting or standing postures in front of a mirror, or stand with their back against a wall. However, without objective measurements, the learning goal - "good" posture – is not well-defined. Moreover, like many rehabilitation exercises, the learning process could be very tedious.

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To monitor the sitting and standing postures in real-time and facilitate postural learning, an active game is developed in this study, which uses optical sensors to measure body movement and a video game to provide visual feedback to the user. Motion sensing technologies have long been used in developing active games that facilitate motor training during rehabilitation [8], [9], [10], [11] and physical training for the elderly [12], [13], [14]. However, little work has been done on using active video games in postural rehabilitation.

The proposed motion-sensing video game aims to allow players to learn the ideal sitting and standing postures through self-exploration, heuristic movement, and real-time continual feedback, yielding faster learning and more lasting results. This approach could be particularly beneficial to individuals with conditions like adult degenerative scoliosis (ADS), where learning and maintaining correct posture is not only therapeutic but also essential for managing symptoms and enhancing daily functioning.

Adult degenerative scoliosis (ADS), which is mostly due to age-related spinal degeneration such as asymmetric disc and facet joint degeneration, is typically found in older adults who are over 50 and clinically the most common form of adult scoliosis – a spinal deformity in a skeletally mature individual with a Cobb angle larger than 10 degrees in the coronal plane [15], [16], [17]. ADS patients usually suffer from progressive spinal deformity, sagittal imbalance, progressive lower back pain (LBP), and substantial disability. Measures to reduce the progression of sagittal imbalance would therefore help to inhibit the progression of pain and disability. However, due to spinal deformity and degeneration of body functions, the complexity and cognitive load of maintaining balance or controlling posture are increased for ADS patients, especially with the presence of LBP, which is found to be highly correlated with spinal proprioceptive deficits [18], [19], [20], [21], [22].

The present study is a pilot investigation aimed at evaluating the feasibility of a newly developed motion-based video game for postural training in older adults with ADS.

II. METHODS

A. Subject Recruitment

Ten female subjects (mean age: 60.0 ± 5.2 years old; mean BMI: 21.4 ± 1.9) with ADS (mean major Cobb's angle: 38.1° ± 22.7°) were recruited for a 6-week postural training programme. All of the subjects have been experiencing chronic back pain for over a year. All subjects were required to self-report their medical conditions and histories. Cases of scoliosis diagnosed or identified before the age of 50 were excluded from the study. Written informed consent was obtained at intake. The study was approved by the ethics committee of the university of the authors before patient recruitment took place.

B. Game Design

A "maze runner"-style game was developed in which the game character (avatar) is controlled by the posture of the player. An optimal posture allows the avatar to run faster. While the player was playing the game, their body alignment and motion were recorded by a motion sensing system using six primary markers (Fig. 1). These markers include four attached to the pelvis to estimate its location and orientation, which are used to establish a subject-based coordinate system for postural measurements. Additionally, two spinal markers are placed on C7 (the 7th cervical vertebra) and T10 (the 10th thoracic vertebra) to estimate the orientation of the thoracic spine. The player can instantly adjust the posture, and hence control the avatar behaviour, which is displayed on a large screen in front of them.

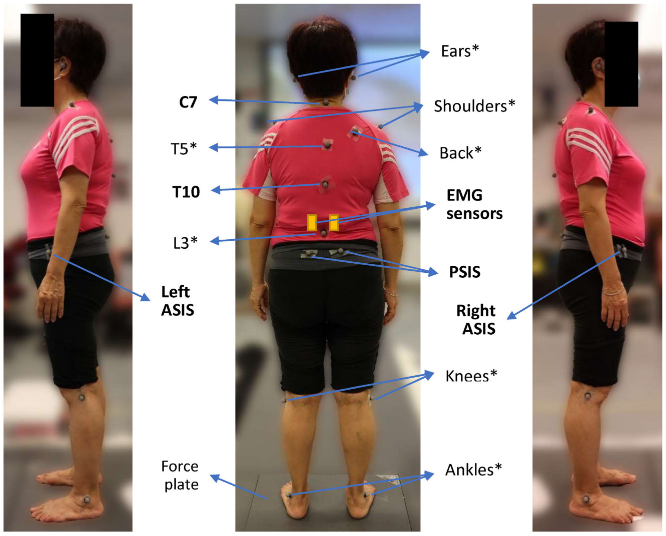
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Fig. 1. Locations of the 6 primary markers for game metrics computation, and 11 additional markers (indicated with asterisks) and 2 surface EMG sensors for postural evaluation.

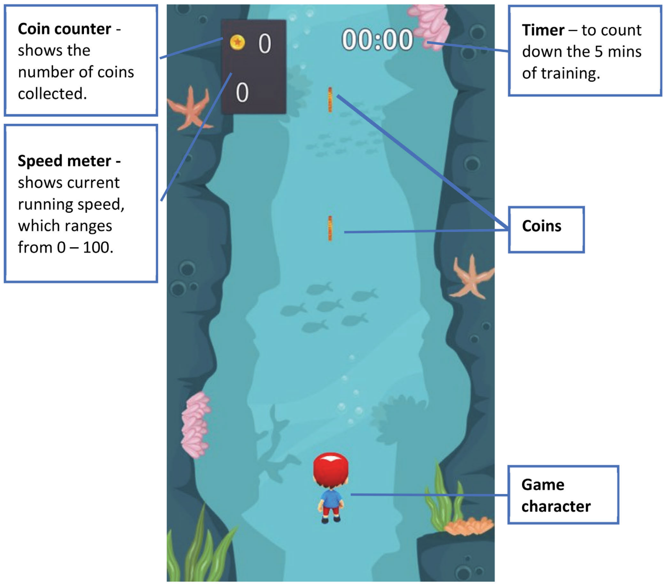

Fig. 2. GUI of motion-sensing video game.

In the gameplay, the player (subject) is required to sit (or stand) in front of a projector screen that shows the video game and controls the speed and path of the avatar based on the body posture. The avatar would pick up coins as it runs along a straight vertical road in the middle of the screen. The goal of the game is to collect as many coins as possible in the 5-minute gameplay. To do this, the player has to maintain a "good" posture to allow the avatar to run at maximum speed (thus denoting good sagittal balance) and remain along the path of coins in the middle (thus denoting good coronal balance). Fig. 2 shows the game user interface (GUI) of the video game.

If the sagittal alignment of the player is within a pre-set threshold, the avatar will start to run, and the trail will move backward compared to the avatar. The running speed is indicated to the player through (1) the value displayed in the speed meter and (2) the speed of the trail motion relative to the avatar. If player's sagittal alignment is beyond the pre-set threshold, the avatar will stop running.

C. Game Metrics: Avatar Control and User Posture

1) Transforming Output of Motion Sensing System to Local Coordination System: The output of the motion sensing system is a series of 3D coordinates that denote the position of the markers in a world coordinate system pre-determined during system calibration, and is updated for every frame. To better describe the body alignment, a local coordinate system that originates at the centre of the pelvis of the user is established for each set of marker coordinates recorded in each frame according to the following equations:

$$\begin{aligned} Origin_{local} &= \frac{ASIS_L + ASIS_R + PSIS_L + PSIS_R}{4} \\ VectorX_{local} &= \text{Vector}(\frac{\text{ASIS}(x, y)_R + \text{PSIS}(x, y)_R}{2} \\ &\quad - \text{Origin}(x, y)_{local}) \\ VectorZ_{local} &= \text{Vector } Z_{global} \\ VectorY_{local} &= VectorZ_{local} \times VectorX_{local} \end{aligned}$$

The origin of the local coordinate system is defined as the mid-point of the four pelvis markers. It moves along with the player and defines the frontal (XZ-), sagittal (YZ-) and traverse (XY-) plane frame by frame. The running speed and lateral displacement of the avatar, and all body alignment variables described in the next section, are determined based on the transformed coordinates throughout the gameplay.

2) Running Speed: After transforming the marker coordinates to the local coordination system, the running speed of the avatar was determined based on the sagittal displacement of C_7 to $T_{10}(D_{Yspine})$. The equations are:

$$\begin{aligned} D_{Y_{spine}} &= Y_{C7} - Y_{T10} \\ Speed &= \frac{Tolerance - Abs\left(D_{Y_{spine}} - D_{Y_{ref}}\right)}{Tolerance} \end{aligned}$$

where $Speed$ is clamped to the range between 0 and 1, representing a percentage of the maximum running speed. $Tolerance$ defines allowable deviation of D_{Yspine} from $D_{Y_{ref}}$ to maintain the avatar's running ($Speed > 0$). The default value for $Tolerenc$ is set at 50 mm. D_{Yspine} refers to the sagittal displacement of C7 against T10 vertebrae. This measurement is chosen over the commonly recognized parameter for determining one's sagittal balance — the C7-S1 sagittal vertical axis (SVA) — because players typically open their chests and straighten their kyphotic curves more in response to changes in D_{Yspine}. In contrast, using SVA tends to result in players swaying their upper bodies forward and backward without significant adjustments to thoracic spinal alignment. The initial value of $D_{Y_{ref}}$ is the D_{Yspine} measurement taken during the pre-training stage. This value can be adjusted based on the user's spinal conditions and is adapted according to the user's performance within the game.

Upon completion of each 5-minute game session, the player's average D_{Yspine} and $Speed$ are calculated. On the one hand, $Speed$ should remain above 50% throughout the 5-minute game session to maintain encouragement. On the other hand, $Speed$ should not consistently be at 100% (max. $Speed$) to keep the game challenging. Therefore, $D_{Y_{ref}}$ will be revised if the average $Speed$ of the latest training session is either (1) below 50% or (2) above 98%:

$$D_{Y_{ref}}(new) = D_{Y_{ref}} + \frac{D_{Y_{spine}}(mean) - D_{Y_{ref}}}{2} \tag{1}$$

$$D_{Y_{ref}}(new) = \frac{D_{Y_{ref}}}{2} \tag{2}$$

3) Lateral Displacement: The horizontal displacement of the avatar to the centre line of the trail (D_x) is determined according to the lateral displacement of C_7 to the midpoint of the posterior superior iliac spine (PSIS) markers (D_{XSpine}).

$$\begin{aligned} Mid_{PSIS} &= \frac{(PSIS_L + PSIS_R)}{2} \\ D_{X_{spine}} &= X_{C_7} - X_{Mid_{PPIS}} \\ D_x &= \frac{D_{X_{spine}} - D_{X_{ref}}}{Sensitivity} \end{aligned}$$

where D_x is clamped to the range between -1 and 1, representing the avatar's maximum lateral displacement on the trail. When D_x is within ± 0.1, the avatar is centered on the trail and can collect coins along the trail. A negative D_x value indicates a leftward shift of C_7, while a positive value indicates a rightward shift. The reference value of $D_{X_{ref}}$ is the $D_{X_{spine}}$ measured during the pre-training stage. $Sensitivity$ dictates the extent of the avatar's displacement in response to the player's actual lateral movement, with a default value of 50 mm.

Similar to $D_{Y_{ref}}$, $D_{X_{ref}}$ is adjustable and adapts to the player's performance in the game. It will be revised if the average D_x of the latest game session is (3) greater than ± 0.2 or (4) less than ± 0.05:

$$D_{X_{ref}}(new) = D_{X_{ref}} + \frac{D_{X_{spine}}(mean) - D_{X_{ref}}}{2} \tag{3}$$

$$D_{X_{ref}}(new) = \frac{D_{X_{ref}}}{2} \tag{4}$$

These self-adaptive features allow the game to accommodate various conditions, including both inter- and intra-subject variations, thereby keeping the game engaging for all users and enabling them to learn at their own pace.

D. Training Protocols

As observed in the literature, a training period of 4 to 8 weeks with 2-3 sessions per week is typically necessary to observe changes in motor learning and postural control in similar interventions [23], [24], [25], [26] Accordingly, a 6-week postural training programme, consisting of two 1-hr sessions each week was provided to the subjects. They were required to play the game in a laboratory setting.

There are three stages of the laboratory gameplay: pre-training, training, and post-training. Pre- and post-training were used to obtain the profile of the participants to be used for evaluating effectiveness of the experiment, while the training stage involved playing the game.

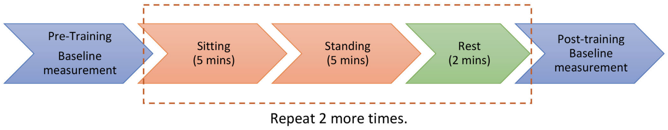

Fig. 3. Three stages of a training session.

1) Pre-Training Stage: In this stage, 17 spherical retro-reflective markers — 6 primary and 11 additional — were attached to the participant's body for postural monitoring, along with 2 surface electromyography (EMG) sensors for muscle activity detection (Fig. 1). In addition to the 6 primary markers which calculate the running speed and lateral displacement of the avatar, 11 extra markers are utilized to compute 8 postural measurements for evaluation (Table I). The positions of the markers were recorded at a sampling rate of 100 Hz by an 8-camera motion sensing system (Vicon Motion Systems Ltd, UK).

The imbalance in the use of the between-side paraspinal muscles is a significant issue for patients with scoliosis [27], [28]. Therefore, restoring muscular symmetry is one of the primary goals of scoliosis-specific exercises [29], [30], [31]. To better understand how the gameplay might influence the utilization of the paraspinal muscles, surface EMG signals of the erector spinae on both sides of the lumbar region were recorded using two Noraxon Ultium® EMG sensors at a sampling rate of 4000 Hz. A pair of electrodes (3M Red Dot 2228) was positioned 2 cm apart on the muscles, in line with muscle fibre direction.

After attaching the markers and sensors, the participant was instructed to sit in his/her best perceived posture for 10 seconds, followed by standing on the floor in his/her best perceived posture for another 10 seconds. The data collected during this stage served as the baseline measurements.

2) Training Stage: After the participant completed the pre-training stage, the main training began. Each training session consisted of six 5-minute rounds (three of sitting and three of standing) of video gameplay. Before the gameplay, the research team assisted the subjects to sit or stand with a better posture with reference to the body alignment calculated real-time from the markers. To upkeep an ideal standing posture, the subject should distribute the body weight evenly on both feet, and maintain a natural lordosis without excessive forward or backward pelvis tilt [32]. Minimal muscular effort should be used to maintain an optimal posture. The chest should be raised while keeping the thorax and hips relaxed. The hips and shoulders should be level [33]. Photos of the required sitting and standing postures, verbal instructions and manual manipulation might be provided prior to each 5-minute gameplay if needed.

3) Post-Training Stage: After the training was completed, another baseline measurement was taken in the post-training stage. The participants were asked to sit and stand in their best postures (posture they learnt from the gameplay that allowed the avatar to run at the highest speed) for 10 seconds respectively.

E. Outcome Measurements

The mean positions of the 17 markers were calculated for the pre- and post-training sessions, each with a duration of 10 seconds. The raw EMG data were root-mean-squared (RMS) at a time window of 100 ms and the mean RMS EMG values were calculated for each pre- and post- training session. To examine the changes in body posture following each training session, and hence the effectiveness of the gameplay in improving awareness and perceived control of body posture, 11 variables were calculated from the sensor data and marker locations. Table I shows the measured variables along with their definitions.

TABLE I
DEFINITIONS OF THE MEASURED VARIABLES

Measured variable	**Definition**
Length of spine (cm)	The vertical distance between C7 and mid-point of the right and left PSIS markers.
C7 forward shift (cm)	The displacement of the C7 markers from the mid-point of the right and left PSIS markers along the sagittal plane.
Head forward shift (cm)	The displacement of the mid-point of the ear markers from the mid-point of the right and left PSIS markers along the sagittal plane.
C7 lateral shift (cm)	The distance of the C7 marker from the mid-point of the right and left PSIS markers along the frontal plane.
Shoulder obliquity (°)	The angle between the vector that connects the two shoulder markers and local X-axis on the frontal plane.
Shoulder rotation (°)	The angle between the vector that connects the two shoulder markers and local X-axis on the traverse plane.
Pelvis obliquity (°)	The angle between the local X-axis and the horizontal line on the frontal plane.
Pelvis rotation (°) (only for standing trials)	The angle between the local X-axis and the vector that connects the ankle markers on the traverse plane.
EMG (lower side)	RMS (time window = 100 ms) EMG values (uV) which denote the muscle activity of the erector spinae on the concave side of the spine.
EMG (higher side)	RMS EMG values (uV) which denote the muscle activity of the erector spinae on the convex side of the spine.
Muscle symmetry ratio	EMG (higher side) / EMG (lower side). Value of 1 denotes perfect muscle symmetry between the left and right erector spinae.

III. RESULTS

Ten ADS subjects were invited to participate in a 6-week postural training programme carried out at the university of the authors. A full spine x-ray with both anterior and lateral views was acquired before the training programme to have more accurate information on the spinal conditions. Spinal deformities in the sagittal plane were found through the X-ray measurement of the thoracic kyphosis (TK) angle. While the normative value of the TK angle is 20°-40°, it has been found to increase with age. Our X-ray measurements showed that only 3 subjects have a TK angle smaller than 30°. Five of them have a TK angle larger than 40°, which is beyond the normative range. A summary of their demographic information is presented in Table II.

The 11 variables obtained in pre- and post- training stages of all sessions of all subjects were calculated and statistically evaluated. A non-parametric Wilcoxon signed-rank test was performed to compare the median difference between the pre- and post-training measurements to examine the immediate training effect of each session. Table III shows the descriptive statistics and the statistical test result of the sitting and standing postures respectively.

TABLE II
DEMOGRAPHIC INFORMATION OF ADS SUBJECTS

ADS subject (N = 10)	Range	Mean (S. D.)
Age	53 – 65	60.0 (± 5.2)
Height (cm)	147 – 164	156.8 (± 6.0)
Weight (kg)	46.0 – 61.7	54.8 (± 6.8)
BMI	18.13 – 25.38	21.4 (± 1.9)
Major lateral Cobb Angle (°)	12.5 – 67.9	38.1 (± 22.7)
Thoracic Kyphosis (TK) Angle (°)	19 – 58	36.8 (± 13.2)

From the direction of change of these 11 variables after training, we can determine whether the posture has "improved" after each training session. When compared to a slouched posture, a good posture [34], [35] should lengthen one's spine; have a smaller forward and lateral shift of the head and upper body; and have minimal obliquity and rotation of the pelvis and shoulders. Moreover, minimal and balanced between-side muscular effort should be used to maintain the optimal posture. The results assessed the immediate training effects of separate training sessions. It is shown that the participants generally learn to sit and stand with improved sagittal alignment with a raised chest and more retracted head position. The C7 and head forward shifts of the post-training measurements are significantly reduced when compared to their pre-training values. The medians of C7 forward shift and Head forward shift is decreased by 0.67 cm ($Z = -2.803$, $p = .005$) and 1.22 cm ($Z = -2.805$, $p = .005$) respectively for sitting, and 0.81 cm ($Z = -2.803$, $p = .005$) and 0.96 cm ($Z = -2.652$, $p = .008$) respectively for standing. However, the subjects cannot lengthen their spine during sitting and standing. Instead, the length of the spine is found to be slightly shortened after training. A reduction of 0.28 cm ($Z = -2.705$, $p = .007$) and 0.14 cm ($Z = -2.705$, $p = .007$) is observed in sitting and standing respectively. This might be due to fact that they are asked to use minimal muscular effort to maintain the ideal postures. Also, an increased sagittal balance does not does not necessarily reflect a balanced use of the erector spinae muscles. As Table III demonstrates, no significant changes were observed in the EMG readings of the lower and higher sides, nor in the Muscle Symmetry Ratio. An imbalanced use of the lumbar erector spinae muscles between sides was present in both pre-training and post-training assessments. Subjects appear to adhere to their habitual muscle utilization patterns and rely on the stronger paraspinal muscles when maintaining an improved posture.

Apart from the immediate training effect, the overall training efficiency of the 6-week program of all subjects was also evaluated by comparing the pre-training baseline measurements obtained in the first and last training sessions by a Wilcoxon signed-rank test. The results are summarized and presented in Table IV.

While a significant reduction of 0.39 cm ($Z = -2.293$, $p = .022$) is observed in the C7 forward shift of standing postures, no significant change is identified in sitting postures. The immediate training effects in sagittal alignments described previously is only partially sustained to the end of programme. Interestingly, the participants learned to place their shoulders and pelvis in a more levelled alignment, even though the obliquity of the shoulders and pelvis is not involved in the game metrics computation. For standing postures, the median of pelvis obliquity is reduced significantly from 1.75° to 0.53° (Diff = $-1.23°$; $Z = -2.090$, $p = .037$); and the median of shoulder obliquity is reduced from 1.79 to 0.49 (Diff = $-1.3°$; $Z = -2.497$, $p = .013$). A decrease from 3.08° in the first session to 2.17° in the last session (Diff = $-0.91°$; $Z = -2.497$, $p = .013$) is also observed in the pelvis obliquity for sitting.

IV. DISCUSSION

This pilot test on ADS patients demonstrated both the immediate and a 6-week training effect of the proposed active video game in posture training. After each training session, participants learned to sit and stand with better sagittal alignment without recruiting excessive muscular effort of the erector spinae. No significant improvements, however, are seen in the lateral shift of the upper body, where a more complex adjustment mechanism is involved. Apart from spinal alignment, levelling of the pelvis and shoulders also contribute to this lateral shift. As mentioned earlier, ADS patients with chronic LBP may have lower sensitivity to body position and difficulties in coordinating different body parts to correct their posture due to poor proprioception. Additional feedback mechanisms on the shoulder and pelvis levels might be required to help them learn to adjust various body parts separately for better postures.

Although the immediate training effects on sagittal alignment only partially sustained after the 6-week training, the participants developed a higher awareness of their postures and would actively adjust the shoulder and pelvis level for a better lateral alignment. The gameplay encourages repetitive and regular practice in maintaining good posture. This reinforces perceived ideal postures in terms of body alignment and muscle utilization. Patients will have a better understanding of their own habitual posture and become more aware of their postures. These would have a positive effect on self-observation and personal competencies, which nurture the ability to achieve the ultimate goal of the training – active self-correction.

The idea of self-correction for ADS patients is to place the spine in a scoliosis-reduced posture during normal daily activities such as sitting, standing, and walking, in the hopes of stabilizing the spinal curvature for more permanent changes. These self-corrective maneuvers have to be performed by the patient independently and continuously throughout the day [36], [37]. Its success, therefore, lies in the ability of the patient to remember and adjust the spine to the correct posture. If the training frequency is not enough for patients to learn and internalize their perception of ideal postures, a home-based training program with a mobile application and accelerometers might be more beneficial as more frequent training sessions can be arranged.

Our proposed active game provides accurate body alignment measurements through immediate visual feedback, which assist players to visualize how their current posture is deviated from the ideal posture, hence quickly providing an understanding of the direction and magnitude of the corrections to be made.

In contrast to traditional methods such as practicing in front of a mirror, our game introduces a dynamic and engaging

TABLE III

DESCRIPTIVE STATISTICS AND STATISTICAL TEST RESULTS OF ALL PRE- AND POST- TRAINING MEASUREMENTS

Variables	**Sitting**						**Standing**					
	Pre-training		**Post-training**		**Post - Pre**		**Pre-training**		**Post-training**		**Post - Pre**	
	Median	**Mean (± S. D.)**	**Median**	**Mean (± S. D.)**	**Z**	**Asymp. Sig. (2-tailed)**	**Median**	**Mean (± S. D.)**	**Median**	**Mean (± S. D.)**	**Z**	**Asymp. Sig. (2-tailed)**
Length of spine	43.83	43.86 (± 1.86)	43.55	43.69 (± 1.91)	-2.705^{a}	**.007***	42.64	42.93 (± 1.67)	42.50	42.77 (± 1.59)	-1.040^{a}	**.041***
C7 Forward Shift	6.04	6.22 (± 2.20)	5.37	5.30 (± 2.11)	-2.803^{a}	**.005***	4.19	3.99 (± 1.76)	3.38	3.37 (± 1.64)	-2.803^{a}	**.005***
Head Forward Shift	4.04	3.70 (± 1.79)	2.82	2.64 (± 1.66)	-2.805^{a}	**.005***	2.24	1.75 (± 1.34)	1.28	1.00 (± 1.26)	-2.652^{a}	**.008***
C7 Lateral Shift	1.10	1.22 (± 0.51)	0.88	1.08 (± 0.65)	-1.275^{a}	.202	0.91	1.28 (± 0.83)	0.97	1.32 (± 0.87)	-.415^{b}	.678
Shoulder Obliquity	1.35	1.45 (± 0.68)	1.20	1.18 (± 0.47)	-1.599^{a}	.110	1.19	1.51 (± 0.78)	1.17	1.21 (± 0.39)	-1.718^{a}	.086
Shoulder Rotation	2.08	2.75 (± 1.65)	2.24	2.76 (± 1.68)	-.459^{b}	.646	3.13	2.86 (± 1.27)	2.94	3.09 (± 1.35)	-1.070^{b}	.285
Pelvis Obliquity	2.02	2.08 (± 0.81)	2.24	2.23 (± 0.65)	-1.020^{b}	.308	1.51	1.64 (± 0.88)	1.37	1.58 (± 0.82)	-.765^{a}	.444
Pelvis Rotation							2.66	2.97 (± 1.35)	2.97	3.08 (± 1.33)	-.561^{b}	.575
EMG (lower side)	72.10	73.90 (± 31.40)	68.40	76.52 (± 38.42)	-.153^{b}	.878	64.46	82.52 (± 49.20)	61.21	81.32 (± 48.89)	-.459^{a}	.646
EMG (higher side)	113.75	186.25 (± 164.85)	91.75	176.19 (± 145.67)	-.764^{a}	.445	91.29	214.69 (± 196.54)	89.65	214.10 (± 198.87)	-.357^{a}	.721
Muscle Symmetry Ratio	0.71	0.59 (± 0.23)	0.71	0.66 (± 0.28)	-1.380^{b}	.168	0.63	0.61 (± 0.25)	0.67	0.62 (± 0.27)	-.593^{b}	.553

^{a} Post < Pre

^{b} Post > Pre

* indicates statistically significance (2-tailed asymp. significance $p < 0.05$)

environment by setting clear and challenging goals for players. It intelligently adjusts its difficulty levels according to the individual's current abilities and progress. This personalized approach not only promotes better engagement but also facilitates more effective learning of postural control [38]. Additionally, the achievable goals enhance players' enjoyment and motivation, which are crucial in encouraging sustained participation in the postural training program, potentially leading to better adherence and improved outcomes.

Apart from body alignment, the proposed system also monitors paraspinal muscle activity. In doing so, the player could avoid excessive effort to maintain erect postures, where disc pressure is significantly higher than that with normal sitting [39]. Similarly, the system could prevent over-correction, where players might lean backward rather than maintain a neutral sagittal balance while correcting their forward slumped sitting posture. While sitting slumped forward (anterior sitting) increases disc pressure, slumping backwards (posterior sitting) further increases intervertebral pressure. This muscle activity monitoring feature could be exceptionally beneficial to ADS patients, or those who suffer from imbalanced paraspinal muscles. Many scoliosis patients have stronger paraspinal muscles on the convex side of the lateral spinal curve. They also tend to rely more on the stronger muscles when maintaining body posture. The system could be improved by providing feedback from sEMG measurements, through which the patients would become familiar with their current paraspinal muscle recruitment pattern and learn to adopt a more balanced pattern by recruiting more of the weaker muscles on the concave side of the spinal curvature. The higher intensity of the isometric contractions used during postural control would help to train the weaker muscles. Sitting in a better posture might change habitual unbalanced use of the paraspinal muscles, and hence help relieve lower back pain in the long run.

As suggested by previous research studies, video games can induce neuroplastic reorganization which leads to long-term retention and transfer of skills [40]. Well-designed game mechanics can augment patient engagement and motivation in rehabilitation. Positive effects have been identified in the use of video games in rehabilitation with respect to behavioral, physiological, and motivational factors [41], [42]. Also, active video games are found to be beneficial for cognitive and motor skill learning in rehabilitation science [43]. Throughout the

TABLE IV
DESCRIPTIVE STATISTICS AND STATISTICAL TEST RESULTS OF THE FIRST AND LAST PRE-TRAINING MEASUREMENTS

Variables	**Sitting**						**Standing**					
	First pre-training		**Last pre-training**		**Last - First**		**First pre-training**		**Last pre-training**		**Last - First**	
	Median	**Mean (± S. D.)**	**Median**	**Mean (± S. D.)**	**Z**	**Asymp. Sig. (2-tailed)**	**Median**	**Mean (± S. D.)**	**Median**	**Mean (± S. D.)**	**Z**	**Asymp. Sig. (2-tailed)**
Length of spine	43.51	43.79 (± 2.97)	44.77	44.90 (± 1.68)	-1.784[b]	.074	42.97	42.99 (± 2.09)	43.15	43.49 (± 1.34)	-1.274[b]	.203
C7 Forward Shift	6.79	6.85 (± 2.26)	6.71	6.51 (± 3.13)	-.255[b]	.799	4.57	4.37 (± 1.51)	4.18	3.69 (± 2.00)	-2.293[a]	**.022***
Head Forward Shift	3.48	3.83 (± 1.97)	4.36	4.15 (± 2.75)	-1.580[b]	.114	1.81	1.80 (± 1.41)	1.77	1.58 (± 1.53)	-.764[a]	.445
C7 Lateral Shift	1.08	1.32 (± 0.81)	1.16	1.09 (± 0.69)	-.459[a]	.646	1.43	1.44 (± 1.04)	0.65	1.17 (± 1.22)	-.968[a]	.333
Shoulder Obliquity	1.40	1.93 (± 1.49)	2.63	2.21 (± 1.20)	-.357[b]	.721	1.79	2.02 (± 1.64)	0.49	0.78 (± 0.61)	-2.497[a]	**.013***
Shoulder Rotation	2.13	2.60 (± 1.78)	1.78	2.65 (± 2.84)	-.051[b]	.959	1.86	2.04 (± 1.36)	2.36	2.50 (± 1.62)	-.255[b]	.799
Pelvis Obliquity	3.08	3.04 (± 0.92)	2.17	1.98 (± 0.92)	-2.497[a]	**.013***	1.75	2.47 (± 1.98)	0.53	1.26 (± 1.35)	-2.090[a]	**.037***
Pelvis Rotation							2.26	2.50 (± 1.48)	1.64	2.26 (± 2.38)	-.459[a]	.646
EMG (lower side)	69.58	76.46 (± 31.26)	62.92	82.71 (± 68.87)	-.051[a]	.959	62.17	82.30 (± 51.77)	63.43	80.46 (± 53.94)	-.357[b]	.721
EMG (higher side)	128.25	154.97 (±123.67)	94.10	182.58 (± 186.87)	-.764[b]	.445	89.39	197.39 (± 195.03)	85.26	190.86 (± 187.42)	-.968[a]	.333
Muscle Symmetry Ratio	0.74	0.70 (± 0.34)	0.77	0.67 (± 0.30)	-.968[a]	.333	0.71	0.64 (± 0.28)	0.71	0.66 (± 0.34)	-.051[a]	.959

[a] Last < First

[b] Last > First

* indicates statistically significance (2-tailed asymp. significance $p < 0.05$)

gameplay, the players are required to stay focused on the visual cues. This might enhance attention, problem solving skills, perceived control, and memory capacity [44], which are particularly beneficial to ADS patients.

A. Limitations of the Study

The primary limitations of this study include a small sample size and lack of a designated control group, in which traditional postural training methods could be adopted for comparison purposes. The focus of this article is to describe and document the design and development of the video game with the use of optical motion sensing and sEMG sensors, and demonstrate its effectiveness in assisting the learning of older ADS patients of good posture. Considering the diversity of symptoms of ADS patients, more in-depth analysis in respect to various factors such as age, severity of spinal deformity, degree of back pain, training frequency, etc. can be carried out in future studies with a larger sample size.

B. Future Work

Active videogame play has its own unique values and benefits in the learning process of older adults. Future studies could be focus on the efficiency of transferring the benefits obtained in the video gameplay training to postural control in daily life. More effort could also be placed in developing easy-to-use home-based biofeedback training systems by adopting wearable technologies and mobile applications.

V. CONCLUSION

Habitual postural patterns are of equal importance as regular exercise to spine health. This study has demonstrated that the developed postural training system, embodied as an engaging game with real-time visual feedback, is effective in enhancing players' perception of sagittal alignment, thereby improving postural kyphosis. The system's ability to capture physiological measurements enables players to "visualize" deviations from ideal postures in the moment, allowing for immediate corrective action. By offering an immersive human-computer interaction experience, the game not only makes the training program more appealing but also encourages consistent participation, hence optimizing the effectiveness of the intervention. This research demonstrates the practicality and benefits of integrating active gameplay into motor training for patients with ADS. It is anticipated that such an approach can be adapted for a wider population, benefiting a diverse group of individuals with similar or related postural challenges.

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