Functional Case Study Evaluation of the SmartGym: An Anticipatory System to Detect Body Compliance

Arash Tadayon
Arizona State University
Tempe, Arizona
arash.tadayon@asu.edu

Troy McDaniel
Arizona State University
Tempe, Arizona
troy.mcdaniel@asu.edu

Sethuraman Panchanathan
Arizona State University
Tempe, Arizona
panch@asu.edu

ABSTRACT

Therapists and trainers often utilize training and exercise programs as a critical step within the rehabilitation process. Due to the inherent danger of injury while performing these exercises, they must often be performed under the supervision of skilled trainers to observe and provide feedback on body compliance during the motion. To address this safety risk, we've developed the Smart-Gym: an intelligent modification to the Total Gym Pro that monitors a user's body during exercise and provides feedback to anticipate non-compliance. The system was built to provide multimodal feedback for various body adjustments in the same way that a trainer would. Results from an initial case study involving an individual undergoing exercise rehabilitation for hemiparetic cerebral palsy are discussed.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile computing systems and tools**; *Information visualization*;

KEYWORDS

Anticipatory computing, Exercise compliance, Motion capture, Multimodal feedback

ACM Reference Format:

Arash Tadayon, Troy McDaniel, and Sethuraman Panchanathan. 2018. Functional Case Study Evaluation of the SmartGym: An Anticipatory System to Detect Body Compliance. In *3rd International Workshop on Multimedia for Personal Health and Health Care (HealthMedia'18), October 22, 2018, Seoul, Republic of Korea.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3264996.3265004

1 INTRODUCTION

Nearly every rehabilitative program includes an at-home component since the frequency of exercise required exceeds the availability of live trainers and therapists. While undergoing rehabilitative exercise programs, patients often neglect at-home workouts due to the inherent risk of injury in this unsupervised environment. The movements performed for these exercise programs require very specific posture and form to avoid further damaging affected structures. One study indicated that only 31% of people with motor disabilities perform the exercises recommended by their healthcare providers [11]. For individuals with impaired muscle control or issues with body compliance, this becomes especially dangerous since they often lack the ability to self-monitor and adjust in the middle of a movement.

In this paper, we evaluate the SmartGym: an anticipatory system used to detect non-compliance and intervene to provide multimodal corrective guidance [12]. Most prior work in the area has focused on reactive intervention to noncompliant body state; however, we aim to solve the problem more proactively by using anticipatory feedback for correction of non-compliance at an earlier stage than these solutions, thus decreasing the likelihood of injury.

As an initial application of the proposed system, the area of cerebral palsy is used to provide a context to demonstrate the effectiveness of the system in practice. We test the effectiveness of the designed multimodal cues for relevant behavioral patterns by conducting a single-user case study that aims to observe the intuitiveness and speed of the user's reactions. Due to the highly individually-variant nature of motor conditions, in this context, a case study was chosen as the design of a control group can be difficult and a case study better relates the design of the system to the unique aspects of the individual [3].

2 RELATED WORK

The concept of digital trainers to provide feedback to individuals to affect health outcomes has been well explored. Early examples include devices that monitor your daily health and activity levels and provide some interface to inform you of your progress [2, 4]. More recently, with the development of new sensors that have created cost-effective methods for body tracking, attention has shifted from providing rudimentary instruction to also including high fidelity feedback on motor performance. As an example, Kinerehab was a solution that was created to assist therapists in rehabilitating students in public school environments. The system automatically detects the student's joint position with the Kinect, and uses the data to determine whether the students' movements have reached the rehabilitation standard [1].

Virtual reality has also introduced a new generation of systems that provide virtual coaching for various motor impairments. Most prominently, the area of stroke rehabilitation has become a major topic of research since successful rehabilitation often requires consistent at-home sessions. Park et al. found that a Kinect-based VR intervention resulted in a statistically significant improvement in rehabilitation for patients with hemiplegic stroke [6]. Similarly, Tadayon et al. explored the design of serious games that provide

HealthMedia'18, October 22, 2018, Seoul, Republic of Korea

ACM ISBN 978-1-4503-5982-5/18/10…$15.00
https://doi.org/10.1145/3264996.3265004

Figure 1: Design of the system with the Balance Board at the base and the Kinect looking down at an angle.

adaptive game metrics to assess and improve rehabilitation outcomes for home therapy [13].

3 PROPOSED APPROACH

The proposed approach aims to map the feedback of the device to the feedback that the trainer would give under normal circumstances in order to anticipate when the user is going to potentially injure themselves. For the purposes of this case study, we have chosen to focus on a single exercise (jumping squat) that the trainer performs with his client. The subject begins in a squatted position with her feet against the landing plate. She then pushes off to slide up and must land back on the plate as shown in Fig. 1.

To monitor balance, we are using the Wii Balance Board to determine center of gravity and warn the user if they are off balance before the start of the exercise. Due to the complexity of measuring postural stability, we are using pressure sensors embedded into the exercise equipment as well as a Microsoft Kinect camera that will monitor the individual and provide postural information through joint and skeletal tracking. The pressure sensors were needed in parallel with the Kinect due to the possibility that the user moves out of frame from the camera while jumping.

In a previous study [12], we observed trainer/subject interaction to determine modalities used for trainer provided feedback on various aspects of non-compliance. We have mapped the feedback of our system to the same modalities that the trainer uses while instructing the individual.Examples of feedback protocols for intended behaviors are shown in Table 1.

4 IMPLEMENTATION

Our system has been built and integrated with the Total Gym Pro (a commercially available piece of exercise equipment). The system consists of a Wii Balance Board, a laptop with Bluetooth communication, a Microsoft Kinect, an array of pancake motors, an array of pressure sensors, an Arduino Uno and a webcam. The laptop serves as the central communication device between the various sensing and actuating elements.

The Wii Balance Board is positioned at the bottom of the platform in line with the user and gives pressure information while the user has her feet against the platform. The board contains pressure sensors in each of the four corners that give distinct values to

Figure 2: Positions of the pressure sensors located inside of the Wii Balance Board.

differentiate between pressure being applied from the ball versus the heel of the foot as shown in Fig 2. This pressure information is extrapolated to determine center of balance for the individual and is visualized through a ball that is displayed on screen as shown in Fig 3. The user must keep this ball inside of the target circle (outlined in white) to be considered compliant in balance. A heatmap is also displayed on the screen to give the user more insight into their center of balance. The heatmap is split into four quadrants that represent the amount of pressure being applied by each foot with the intensity of the color darkening when the user applies more pressure on a quadrant. The user's goal is to get all four quadrants to match colors before the start of the exercise.

The Microsoft Kinect is mounted on a tripod and pointed down at the user at a slight angle that is fixed to the same angle as the Total Gym Pro. This allows the user to appear on the camera perpendicular to the viewing angle. The camera tracks a total of 14 points (shoulders, elbows, wrists, trunk hips, knees and feet) to provide feedback on body compliance as shown in Fig 3. The system monitors for a set of requirements that are defined by the trainer which include: knees kept in line with one another, shoulders in line with knees, back straight and feet in line with knees. Feedback from the kinect is displayed to the user within the visual interface where we use different colors on the points to denote various levels of non-compliance.

There are a total of 12 pancake motors and 12 pressure sensors that are embedded in pairs along the outside of the Total Gym Pro board with 6 pairs on each side as shown in Fig 4. These sensors

Table 1: Feedback protocols

Behavior	Trainer Feedback	System Feedback
Uneven feet	Tell the subject and demonstrate correct positioning	Show heat map with differentiating colors to show which foot is uneven. Camera on the user's feet to augment lack of proprioception
Imbalanced center of gravity	Tell the subject to align their body	Circle shown which changes to green once the user is properly balanced
Improper posture	Tell the subject to move back to the center of the board. If that doesn't work, physically help the subject by pushing the non-compliant limbs back onto the equipment	Red points shown on body map to signify which joints are out of position. Tone played until body is compliant. Haptic signals on the subject's back to guide the user into position.

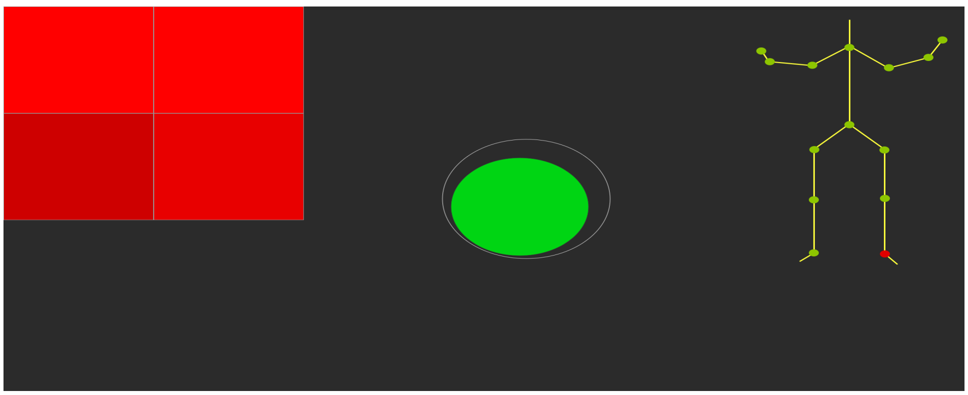

Figure 3: Interface that is used to provide visual feedback to the subject.

serve to determine if the subject's back is aligned with the equipment before starting the exercise. This gives information on both balance and postural stability to augment the information from the Kinect and Balance Board. The haptic patterns were designed using a push metaphor as explored by McDaniel et al., such that the motors will vibrate when their paired pressure sensor hits a threshold value to gently push the subject back into the middle of the board [5].

Figure 4: Location of the pressure sensor and pancake motor pairs along the outside of the Total Gym Pro.

5 CASE STUDY

5.1 Procedure

Our aim is to test the effectiveness of our proposed system in affecting non-compliant behaviors to avoid injury in the home environment. We worked with a female participant undergoing a rehabilitative exercise program for hemiparetic cerebral palsy and her trainer. The participant had limited motor control on the left side of her body and is using a strength building program that incorporates a variety of exercises to rebuild muscle strength. For the purposes of this study, we have chosen to focus on a specific exercise (jumping squat) as an initial proof-of-concept for the system.

The participant was first given an overview of the study and then asked to complete an informed consent form. The participant then underwent a 10-minute familiarization phase during which the interface and feedback pattern were described. The participant then completed two trials with each trial consisting of a five minute session doing the exercise without any feedback, a five minute session doing the exercise with just trainer feedback and a five minute session with just system feedback. Breaks were given between sessions and trials to control for fatigue. The session times were determined by the trainer as this was a standard session time assigned to the subject during regular workouts. The system tracked two main values: the amount of time spent in a non-compliant state and the cumulative pressure applied by each foot. We used threshold values for variability of position that were defined by the trainer to determine when a joint or bone would be considered non-compliant. Cumulative pressure was tracked as it is a measure of compensatory behavior which the system aimed to reduce.

After the two trials, the subject was given a questionnaire with eight Likert-scale questions as shown in Table 4 and one open-response question asking for feedback on improvements.

5.2 Results and Discussion

Overall, the subject seemed to report a positive response to the use of the SmartGym, but did show a faster response rate to the feedback given for upper body versus lower body compliance as shown in Table 2. For upper body compliance (waist and above), the subject spent on average 10 seconds less in a non-compliant state when using the system versus getting the feedback from the trainer. Some potential factors that could have affected this are that the system's feedback was much more immediate than the trainer's in instructing the subject that their body was misaligned. Secondly, the system's feedback was persistent until the behavior was fixed whereas the trainer would take pauses between commands.

Table 2: Non-compliance times measured in seconds

Feedback	Upper Compliance		Lower Compliance	
	Trial 1	Trial 2	Trial 1	Trial 2
None	123	157	93	120
Trainer	41	35	25	24
System	34	22	40	38

However, for lower body compliance, we observed that the subject on average reacted 13 seconds slower than when receiving instruction from the trainer. Part of the limitation here was that the Kinect would sometimes lose tracking and attempt to re-track the joints, potentially causing a slight delay in the feedback. In all areas where feedback was provided (either from the system or from the trainer) the subject performed better during the second trial, suggesting that there might be a slight learning effect between trials. However, because we ran feedback methods for the first trial before the second, this learning effect didn't change the trainer-versus-system comparison. Also, it is important to note that no feedback was given regarding the amount of time spent in non-compliant states between sessions.

Table 3: Cumulative pressure (in lbs) placed against the Wii Balance Board.

Feedback	Left Leg		Right Leg	
	Trial 1	Trial 2	Trial 1	Trial 2
None	130	120	240	275
Trainer	180	174	300	311
System	243	296	297	320

Cumulative pressure also increased significantly for the affected leg relative to the unaffected leg when using the feedback provided by the SmartGym as shown in Table 3. Some of the difference between the trainer and system feedback in this category can be attributed to the observation that the trainer often misses moments when compensation occurs that are not easily discernible to the eye. Throughout the two trials, there were only two explicit instances in which the trainer told the subject to make sure to land on both feet at the same time. During these trials, the system identified 12 instances in which compensation was occurring. Therefore in total, the system identified 10 instances of compensation missed by the trainer over the observed sessions.

Table 4: Questionnaire responses based on Likert-scale: 1(Low) to 5(High)

Question	Score
How comfortable was the gym equipment without any embedded sensors?	3
How comfortable was the gym equipment with the embedded sensors?	3
How well do the vibration patterns represent the intended movements?	5
How well did the visualization of the ball represent your center of balance?	4
How well did the color quadrant visualization represent your center of balance?	2
How easy was the interface to understand?	5
How well do you feel the interface helped in your ability to complete the exercise?	4
How well do you feel you can complete the exercises independently using the feedback provided by the system?	5

In the post-experiment questionnaire, the system was evaluated for usability, intuitiveness and overall functionality. We found trends in the subject's responses that seemed to match what was shown in the data. Overall, the subject seemed to prefer the feedback that was given on upper body compliance to the feedback that was given on lower body compliance. She rated the vibration patterns as being very representative of the intended motions but added comments about the visualizations that the Kinect provided, noting that they often seemed incorrect. This was an interesting point of feedback as it provides evidence that the external tracking of the subject's body did not map well to her internal and impaired proprioception and thus created a conflict. Results from the questionnaire are shown in Table 4.

6 CONCLUSION AND FUTURE WORK

This paper presented an evaluation of an anticipatory system to detect body compliance in the at-home environment. Our case study revealed that there is great potential for the application of anticipatory computing through detection to provide proactive feedback. The results of our experiment show potential for augmenting proprioceptive systems and providing at-home monitoring to improve outcomes in rehabilitative exercise programs. We were able to detect and provide more consistent feedback to greatly reduce the potential for injury.

Our future work includes exploring haptic feedback for fine grained adjustments since visual feedback seemed to contradict the internal image of body alignment. Similarly, we aim to shift more of the information given on lower body compliance to tactile channels. We also plan to conduct a larger study to test the variability and generalizability of our findings to other domains of rehabilitation since a case study is not sufficient to draw conclusive results.

REFERENCES

[1] Yao-Jen Chang, Shu-Fang Chen, and Jun-Da Huang. 2011. A Kinect-based system for physical rehabilitation: A pilot study for young adults with motor disabilities. *Research in Developmental Disabilities* 32, 6 (Nov. 2011), 2566–2570. https://doi.org/10.1016/j.ridd.2011.07.002

[2] Sunny Consolvo, David W. McDonald, Tammy Toscos, Mike Y. Chen, Jon Froehlich, Beverly Harrison, Predrag Klasnja, Anthony LaMarca, Louis LeGrand, and Ryan Libby. 2008. Activity sensing in the wild: a field trial of ubifit garden. In *Proceedings of the SIGCHI conference on human factors in computing systems*. ACM, 1797–1806.

[3] MPJM Dijkers. 2009. When the best is the enemy of the good: the nature of research evidence used in systematic reviews and guidelines. *Austin, TX: SEDL* (2009).

[4] Nicholas D. Lane, Mashfiqui Mohammod, Mu Lin, Xiaochao Yang, Hong Lu, Shahid Ali, Afsaneh Doryab, Ethan Berke, Tanzeem Choudhury, and Andrew Campbell. 2011. Bewell: A smartphone application to monitor, model and promote wellbeing. In *5th international ICST conference on pervasive computing technologies for healthcare*. 23–26.

[5] Troy McDaniel, Morris Goldberg, Daniel Villanueva, Lakshmie Narayan Viswanathan, and Sethuraman Panchanathan. 2011. Motor Learning Using a Kinematic-vibrotactile Mapping Targeting Fundamental Movements. In *Proceedings of the 19th ACM International Conference on Multimedia (MM '11)*. ACM, New York, NY, USA, 543–552. https://doi.org/10.1145/2072298.2072369

[6] Dae-Sung Park, Do-Gyun Lee, Kyeongbong Lee, and GyuChang Lee. 2017. Effects of Virtual Reality Training using Xbox Kinect on Motor Function in Stroke Survivors: A Preliminary Study. *Journal of Stroke and Cerebrovascular Diseases* 26, 10 (Oct. 2017), 2313–2319. https://doi.org/10.1016/j.jstrokecerebrovasdis.2017.05.019

[7] Veljko Pejovic and Mirco Musolesi. 2014. Anticipatory mobile computing for behaviour change interventions. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct Publication*. ACM, 1025–1034.

[8] Veljko Pejovic and Mirco Musolesi. 2015. Anticipatory Mobile Computing: A Survey of the State of the Art and Research Challenges. *ACM Comput. Surv.* 47, 3 (April 2015), 47:1–47:29. https://doi.org/10.1145/2693843

[9] Robert Rosen. 2012. Anticipatory Systems. In *Anticipatory Systems*. Springer, New York, NY, 313–370. https://link-springer-com.ezproxy1.lib.asu.edu/chapter/10.1007/978-1-4614-1269-4_6

[10] ZsÃşfia Ruttkay, Job Zwiers, Herwin van Welbergen, and Dennis Reidsma. 2006. Towards a Reactive Virtual Trainer. In *Intelligent Virtual Agents (Lecture Notes in Computer Science)*. Springer, Berlin, Heidelberg, 292–303. https://doi.org/10.1007/11821830_24

[11] Marianne Shaughnessy, Barbara M. Resnick, and Richard F. Macko. 2006. Testing a Model of Post-Stroke Exercise Behavior. *Rehabilitation Nursing* 31, 1 (Jan. 2006), 15–21. https://doi.org/10.1002/j.2048-7940.2006.tb00005.x

[12] Arash Tadayon, Ramesh Tadayon, Troy McDaniel, and Sethuraman Panchanathan. 2017. SmartGym: An Anticipatory System to Detect Body Compliance During Rehabilitative Exercise. In *Universal Access in HumanâĂŞComputer Interaction. Human and Technological Environments (Lecture Notes in Computer Science)*. Springer, Cham, 98–107. https://doi.org/10.1007/978-3-319-58700-4_9

[13] Ramin Tadayon, Sethuraman Panchanathan, Troy McDaniel, Bijan Fakhri, and Miles Laff. 2014. A toolkit for motion authoring and motor skill learning in serious games. In *2014 IEEE International Symposium on Haptic, Audio and Visual Environments and Games (HAVE) Proceedings*. 59–64. https://doi.org/10.1109/HAVE.2014.6954332