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An Analysis of Human Motion Detection Systems Use During Elder Exercise Routines

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Abstract

Human motion analysis provides motion pattern and body pose estimations. This study integrates computer-vision techniques and explores a markerless human motion analysis system. Using human–computer interaction (HCI) methods and goals, researchers use a computer interface to provide feedback about range of motion to users. A total of 35 adults aged 65 and older perform three exercises in a public gym while human motion capture methods are used. Following exercises, participants are shown processed human motion images captured during exercises on a customized interface. Standardized questionnaires are used to elicit responses from users during interactions with the interface. A matrix of HCI goals (effectiveness, efficiency, and user satisfaction) and emerging themes are used to describe interactions. Sixteen users state the interface would be useful, but not necessarily for safety purposes. Users want better image quality, when expectations are matched satisfaction increases, and unclear meaning of motion measures decreases satisfaction.

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Keywords

geriatrics, silhouettes, human motion analysis, human computer interaction, exercise

Older adults make up the fastest growing segment of the American society. Elderly people participate in limited exercise, leading to decreased fitness, deconditioning of muscles, and reduced energy levels (Fletcher, Gulanick, & Braun, 2005). Conversely, regular physical activity is associated with better physical and psychological health outcomes. Thus, the promotion of physical activity is recognized as a high public priority (Humpel, Owen, & Leslie, 2002). Older persons can improve their cardiovascular, skeletal muscle, and metabolic functions by maintaining or initiating a lifestyle of physical activity, including exercise. Human motion capture and analysis (Moeslund & Granum, 2001) has important implications to help elders better understand their body posture and motion during exercise routines, leading to greater efficacy and safety of exercise regimens and eventually greater participation in these activities. In this study, we explore the use of a human motion analysis system to examine repetitive exercise motions performed by seniors 65 years or older on stationary machines (treadmill, stationary bicycle, and overhead pull machine) at a health club.

Human Motion Analysis

Human motion analysis is a well-researched topic that includes the capture and recording of human body movements for immediate or delayed analysis and playback (Kolahi et al., 2007). Poppe (2007) defines human motion analysis in terms of body pose estimations or the process where body configurations can be estimated from different types of technology. In motion tracking research, silhouette-based features have been used to recognize falls in monocular (single-camera) video of elders in the home environment (Anderson et al., 2009; Anderson, Keller, Skubic, Chen, & He, 2006). Zijlstra (2007) proposed a method to analyze human pose during exercise. This method has the strength that it is generalizable to any pose; however, as the author points out, it is very error prone. Also, the assumption is made that the background subtraction (silhouette extraction) is near ideal. Achieving an ideal silhouette in a gym environment is virtually impossible. Another assumption made by Zijlstra is that the subject is facing the camera and upright. In this research, we wish to measure postural angles of the spine, as seen from the side view in both upright (treadmill) and sitting (overhead pull-down and bicycle) poses. Therefore, Ziljstra's assumptions make this method undesirable for use in our research.

Human motion analysis is characterized by the capture and evaluation of continual repetition of motion patterns such as walking or cycling. Measured parameters for human motion include stride length, cadence, and walking speed. These parameters have been analyzed and could have important implications for the biomechanical examination of optimal walking speed combined with comfort levels, gait analysis, and metabolic costs of walking certain distances (Paroczai & Kocsis, 2006). In this article, we describe results obtained from qualitative interviews of participants who agreed to perform exercises and have images taken during controlled exercise routines (amount of weight lifted, walking or riding speed, steepness of incline, and number of repetitions). Processed images were shown to research participants during key informant interviews following the exercise routines to explore the usefulness of the motion tracking system to inform elders about their exercise routines.

Purpose

The aims of this research were to (a) identify human–computer interaction (HCI) issues with a custom technology interface designed to capture range of motion and provide feedback to elderly people using exercise equipment, (b) examine elder perceptions of a custom interface integrating human motion analysis methods, and (c) develop and improve on an interface designed to provide feedback about range of motion to elderly people using exercise equipment. The ultimate goal of our research is to discover how elderly people might use the feedback from the technology interface to alter their exercise routines.

Method

This research includes qualitative findings extracted from a combination of contextual interviews and usability testing with 35 elderly adults who participated in human motion capture methods conducted during exercises performed in a public gym. All methods used in this research were approved by the University of Missouri institutional research board (IRB) before any research was conducted.

Sample

Participants were recruited through a variety of methods, including local live television spots, newspaper advertisements, and presentations at local society meetings targeting elderly citizens. Recruitment and sampling took place from January 2007 to August 2008. We conducted human motion capture methods at Health Connections, a community health and wellness center, on adults aged 65 or older. Participants were asked to complete a health status questionnaire that indicated if they had experienced any preexisting health conditions such as heart or lung problems, chest pain, loss of balance or dizziness, or bone and joint problems; if they were on any medication for high blood pressure or heart condition; or any other physical condition that might warrant physician approval. If participants indicated they had one of the conditions on the health status questionnaire, they were excluded from the exercise activities in the study until they provided information about the study to their physician and obtained written physician consent to participate.

Measures

Our methods included (a) the development of a computer interface consisting of a markerless human motion model including the participant's silhouette and a graph depicting posture measurements and motion patterns; (b) once interface models were developed, computer-vision techniques were used to capture exercise activities performed on each individual using an exercise treadmill, bicycle, and overhead pull machine; and (c) after exercises were performed each motion image for each exercise were displayed to participants using the computer interface. A standardized interview guide was used to elicit responses from participants. Each participant in our study completed all three exercise routines, which resulted in 105 processed motion capture images and silhouettes that were used during the user interactions.

Exercise Feedback System Intervention

Our human motion capture method tracks body contours in the video of exercising humans. The two contours we are interested in are the edge of the back (spine) as seen from the side view and the shoulders as seen from the rear or front view. The graphs in Figure 1 show the spine angle plots as seen from the side view. These indicate the degree of uprightness and forward or backward pitch derived from these two contours on example video frames of two research participants walking on a treadmill. Participant 1 shown in the top frames of Figure 1 has nearly a vertical upright pose, which is indicated on graph by the broken line being very near the zero mark. Conversely, Participant 2 shown in the bottom frames has greater than a 30-degree forward pitch from vertical as indicated in the graph. These pose estimations demonstrate potential risks that these subjects, especially Participant 2, might encounter when using exercise equipment, such as imbalance, unsteady gait, or falls.

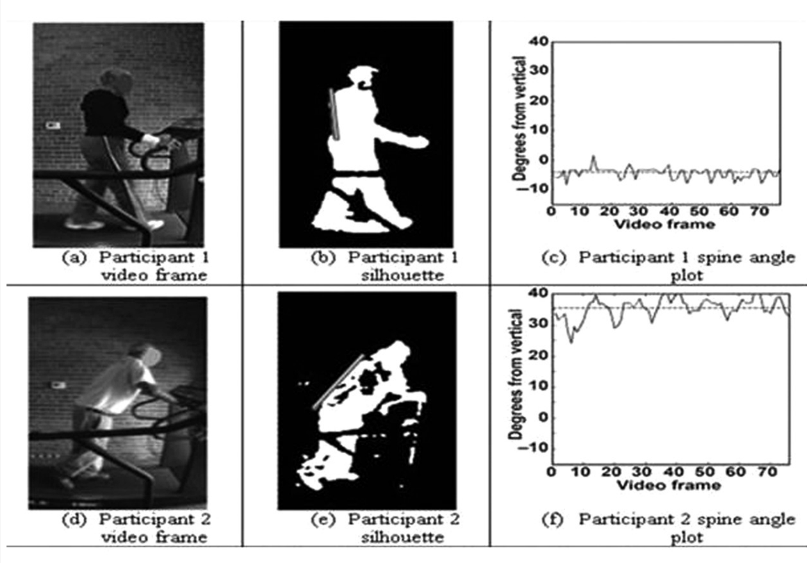

Figure 1. Silhouette contours

Figure 2 illustrates our approach in a step-by-step block diagram. We designed our approach to be both robust and flexible. The environment in which we performed this research study was a public gym. Therefore, our ability to control experimental conditions such as lighting conditions, background environment, and subject clothing, was very limited, but also highly generalizable. As a result, we chose simple, safe, and proven methods to perform the operations in our algorithm.

First, the silhouette of the human in each video frame was computed using a statistics-based background subtraction algorithm that is adapted from Wildenauer, Blauensteiner, and Kampel (2006). Second, the chamfer distance transform of each silhouette frame was computed to provide an error surface on which we can fit a contour template (Rosenfeld & Pfaltz, 1968). We used roach infestation optimization (Havens, Spain, Salmon, & Keller, 2008) to find the best position of the contour template, which is ideally located on the body contour of interest, either the back or spine. Roach infestation optimization is a biologically inspired algorithm based on the social and goal-seeking behavior of cockroaches that searches for the best solution to mathematically defined problems. The best position of the contour template is defined by a temporal fitness function that accounts for exercise

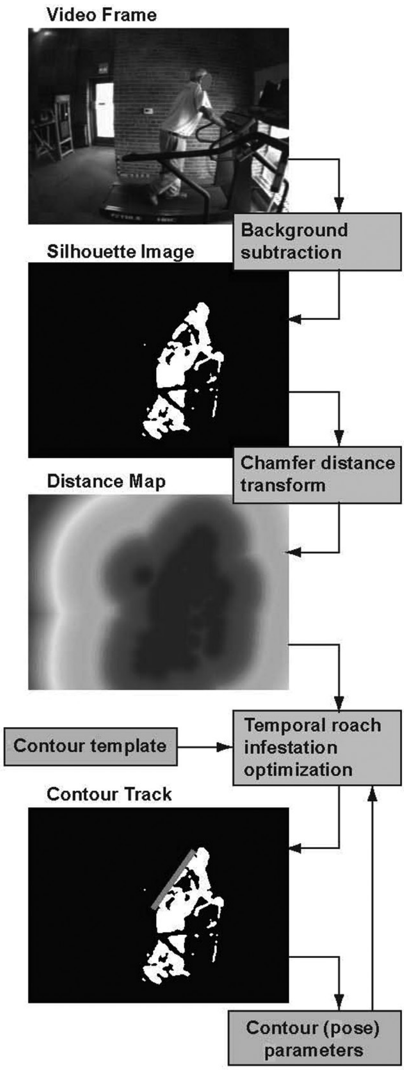

Figure 2. Block diagram of exercise-feedback system components—spine tracking on side view of treadmill exercise

dynamics, template translation, and rotation. More technical descriptions of our research method have been presented elsewhere; for reference, see the papers by Alexander et al. (2008) and Havens et al. (2009).

Exercise Regimens

Participation in the study required four separate site visits with study staff. Each visit lasted 30 to 60 minutes and included the activities described below.

Visit 1: Completed consent procedures including filling out an approved health status questionnaire describing any chronic illnesses participants may have. This was followed by a number of physical measurements taken from each participant's body (e.g., shoulder to elbow, hip to knee, base of neck to top of head). Each eligible participant was assigned a unique identification number used throughout the remainder of the study.

Visits 2 and 3: Participants were asked to perform exercise routines on the bicycle, overhead pull machine, and/or treadmill. Participants were asked to pull down the overhead pull machine one to two times using the least amount of weight available on the machine, 10 lbs; ride the stationary bicycle at the lowest setting, 10 RPMs, for approximately 30 seconds; and walk on the treadmill at the lowest setting, 0.8 mph with a 0% incline, for approximately 30 seconds. During these activities, digital cameras recorded the participant's body movements. These body motions were loaded onto a computer and processed images of the participant's silhouette were created. No identifiable features, other than crude body measures taken during the first visit, were included in the images.

Visit 4: Participants were shown the processed images that were recorded in earlier visits via a custom interface. They were asked a number of questions about each image to elicit responses about use of the images and usefulness of the interface. The same computer and interface were used with all participants. All interviews were conducted in a private office at the Health Connection. Interviews were tape recorded and data were aggregated, with unique identifiers eventually being stripped from the aggregated data.

Participants were asked to describe what they saw happening in each of their images, to explain how the images could be improved on, what type of information would be most beneficial to assist them during exercise routines, and to discuss how the images might be used to improve exercise routines. Pause-and-probe methods were used by facilitators to illicit further information from participants in situations where responses were unclear or vague.

To accomplish our research aims, a combination of methods were used to collect participant's interactions with their motion images. These included a detailed abridged transcript obtained from individual tape-recorded sessions and note-based analytics taken from field notes recorded by interviewers conducting the research. A matrix was created of the findings using common recurring themes and comments as one axis and HCI goals expressed as measures of effectiveness, efficiency, and satisfaction as the other axis (see Table 1). Table 2 contains direct quotes obtained during interviews to illustrate users' perceptions of HCI goals.

HCI goals including effectiveness, efficiency, and user satisfaction with the interface were used as a framework to develop a matrix to describe participant interactions with the motion tracking system (Staggers, 2002). In effectiveness research, usefulness and safety are important attributes. In efficiency research, attributes include cost, productivity (expenditure of resources to use the interface), and learnability. User satisfaction is measured by users' perceived effectiveness and efficiency, which are expressions of joy or frustration about efficiencies recognized or effectiveness of the interface.

Analysis

A transcript and note-based analysis approach was used to analyze interviews and observations. The analysis process included identifying phenomenon that emerged and reappeared across all interviews and observations. A process of axial coding described by Krueger (1994) was used, which consisted of placing labels in the margins of the transcription when recurring phenomenon emerged. This process enabled the data to be fractured and reassembled in new ways that the authors prepared in a statement of findings.

Emerging themes were identified and verified by one registered nurse certified in HCI methods and a doctoral student who had graduated in electrical and computer engineering, both of whom participated in all the interviews. Any inconsistencies or vagueness of statements made by participants were discussed by the two researchers until a consensus was reached.

Results

Health Status

Forty-one participants were recruited. Six subjects were lost to follow-up and never completed the entire study; our total sample size was 35 participants. A few more women (19) than men (16) participated in our study; on average

Table 1. User Interactions Stratified by HCI Goals

Effectiveness	Usefulness	Safety
	Body angulation Shows weakness Provides guidance for position changes Security and grip Stability Alignment Balance Pitch Performing exercise correctly Identifying bad habits Awareness	Posture Favoring left/right side Forward or backward lean Unevenness Straight Bad or good Slouching or drooping shoulders Position Danger Postural changes Head position Centered Symmetrical Motion Smooth Jerky Sequential movement Sway Limp Stillness Foot dragging Periodicity
Efficiency	**Costs and Productivity**	**Learnability**
	Would use image to maintain fluid motion Image problems clothing shape or color Lost tracking Need to track range of motion Processing images Black-and-white images helps see movement Quality of silhouettes Syncing silhouette algorithm and camera	Images Recognized posture changes Notices inefficient movement or poor posture Provides information on adjustments needed Would change walking motion What would a reasonable person look like? Graph Noted change in angulation on graph

(continued)

Table 1. (continued)

Efficiency	Costs and Productivity	Learnability
	Good information for trainer Needs ideal scenario for comparison Teach medical students how muscle groups work Need feedback mechanism comparing images and graphs	Need more explanation about how graph works Spikes and dips on graph not intuitive Notices variations in graph numbers/posture changes What is my optimum? How do I tell effectiveness of change Blue line helps indicate posture Red line gives average movement over time
Satisfaction	**Perceived Effectiveness**	**Perceived Efficiency**
	Positive statements Not offensive: not unpleasant Encouraged Images match expectations Interesting to watch Helpful for mature clients Realistic Presentation is excellent Graph consistent with movement	Positive statements More screen detail might be distracting Not looking at graph; focused on images Color contrast is good Zoom features are useful
	Negative statements Would not improve feeling of safety or comfort Images confusing Information not reassuring Turns pleasurable exercise into work	Negative statements Feedback or reminders would be useful Silhouettes more useful than graphs Bike is the least useful view

women were about 5 years younger (mean 70.5 years, range 65-82 years) than the men (mean 76.0 years, range 68-90 years). Men reported many more health status problems as identified on the health status questionnaire (26) than women (11). The majority of men (12) and women (5) in each group were

Table 2. User Comments Related to HCI Goals

Effectiveness

Usefulness

- "Would be useful. Would provide awareness when I was using the equipment to try to straighten shoulders and back."
- "Does provide enough information to know exactly how to do it and how they should adjust."
- "Not giving any information I wanted to know." Same participant stated, "It is interesting technology, but I am unable to make sense of it."
- "Would really help be aware and think about what I am supposed to be doing and how it shows up."
- "This way I don't know if I'm doing it right or wrong; I don't know how helpful it can be unless someone gives input: 'this is ideal' or 'this is the most efficient' or 'this is the least tiring position.'"

Safety

- "Using this piece of equipment [treadmill] would not make me feel more safe, because I didn't feel unsafe before."
- "Core is balanced"

Efficiency

Cost and productivity

- "Not aware before I had tilt in shoulders/swaying. Can see it in image. . . . Didn't feel image could be improved upon."
- "Side view does not give better image."
- "I wouldn't expect the bottom of me to joggle around that much when I'm doing it, but I don't even recall what I was sitting on when I was doing it."
- "I have a hard time processing three images at once. . . . All three are helpful, but would rather have them sequential than all at once. Too much information."

Learnability

- "Was standing straight up, but were forward. Knew from other image that I was leaning forward in that one, but in this one was steady."
- "A trainer might be able to use this information in some way and then provide feedback to me."
- "This one is better (provides more information) because it's in black and white, you can see it better; can see movements a lot easier."
- "Needs more explanation to interpret meaning of graph and movement around the center of the axis of the line."

Satisfaction

- "Needs the graph, the images to go with the graph; the graph alone would not give enough information, but the graph and image is fine."
- "Looking at the graph and the image, there's more movement which I would expect with the bike because of the arms. It moves you back and forth more."
- "It turned what was a reasonably pleasurable exercise into work, and that turns me off."

taking medication for blood pressure or heart rhythm/rate control. More men (3) reported having a chronic imbalance because of dizziness or have experienced loss of consciousness in the past; no women reported being treated for this problem at the time of the study. More men (3) also reported having chronic bone, joint, or back problems, which could be made worse with physical activity. No women reported having any bone, joint, or back problems. No personal information that could be used to identify the participants individually was aggregated with the transcription data, which maintained confidentiality.

User Interactions and HCI Goals

The goals for HCI are useful for determining the effectiveness, efficiency, and user satisfaction during users' interaction with computer interfaces (Salvendy, 1997; Staggers, 2002). These goals have been used recently to identify important design issues in clinical technology (Alexander & Staggers, 2009). For example, in HCI effectiveness research (usefulness and safety), user interactions with newly developed clinical software, inflexibility of computer interfaces, and poor navigation caused users to get lost in the application; in efficiency studies, learnability (the capability of a software product to enable users to learn how to use it) and productivity was improved by increasing the screen density or amount of information on each screen; finally, satisfaction (user-perceived effectiveness or perceived efficiency) was greatly improved when graphics were included in the interface and were found to be very important for better navigation across applications.

Effectiveness

Eighteen participants explicitly discussed the usefulness of the interface, with 16 of them indicating it would be useful. Only 8 participants mentioned anything about using the interface during exercise routines for safety reasons, with 3 participants indicating it would provide a safer means of exercising and 5 indicating it would not make a difference. For example, users who indicated it would provide safer exercise stated the interface could assist users' awareness of weaknesses in extremities, identify potential safety issues (e.g., foot dragging, noticeable limp, or sway in stagger), and determine if users were using equipment correctly (see Tables 1 and 2). In addition, participants said that the interfaces could be used to identify misalignment of the core of the body or extremities, which is a good indicator of balance, pitch, and stability during use of exercise equipment. Those who did not feel that it would provide a safer environment stated the interface did not provide enough information for comparison of good or bad exercise activities.

Efficiency

Across all users, 12 items of efficiency that could affect costs or productivity were discussed as part of the human motion interface. In regards to further development of the interface, 11 users indicated that the quality of silhouettes needed to be improved on. For example, neck posture needs better visualization and representation. Furthermore, clothing interference, such as a hooded sweatshirt, could falsely indicate poor spinal posture measures in images. Four users suggested that an ideal exercise scenario with images and range-of-motion measures should be incorporated into the interface to allow users to draw comparisons between their actual processed human motion images and ideal postures that should be maintained during exercise. All users on their first interactions with the interface were able to describe some personal attributes related to their motion during exercise. However, the graph and the measures related to the graph were not intuitive to the users (see Table 2). Users were interested in how to use the graph to tell whether their exercise regimen was effective, especially if they were to make changes in their routines in response to the feedback. All users noted variations in the graph numbers and simultaneous posture measures; however, 8 did not know how to correlate the spikes, dips, and movement occurring on the graph with the processed images.

User Satisfaction

Participants commented both positively and negatively about their experience with the human motion analysis system. Their expectations were met and they were encouraged by the processed images. For example, one participant emphasized this tool could be helpful for maturing clients because it is important to maintain proper core body alignment as you age; these images help identify bad habits. Participants who were less enthusiastic about the motion analysis system were confused by the meaning of graphs and motion measures and how to interpret them. Two participants never felt unsafe using exercise equipment in the first place so they did not see any benefit in this tool.

Discussion

To design more usable technologies, users of the systems must be included in their manufacture and development. Technologies helping elderly people to maintain more active lifestyles are critically important for achieving healthier physical and psychological outcomes. Our sample provided insights into how motion detection technology can be used to effectively and efficiently support exercise regimens performed by elders with some degree of satisfaction. For example, users of the interface expressed many degrees of usefulness the system could provide during exercise regimens to improve awareness and guidance for changes in body positions to avoid dangerous and unsafe situations.

The benefits of these systems must outweigh the costs. The majority of our end users were enthusiastic about the motion sensor system; however, many of them still recommended further development toward a more efficient and usable system. Developers of these types of systems must consider recommendations of end users carefully. Our end users recommended additional development time to add ideal exercise scenarios to the interface so that they could make comparisons between ideal scenarios and their images. This type of development requires more resources, such as input by other disciplines including experts in physical and exercise therapy, whose knowledge is important for understanding the evidence base. Expert input increases development costs as more professional expertise is required, but could also lessen unexpected costs of future redesign of the interface. Our development team included an expert physical therapist certified to care for aged people in the early prototype stages of our interface. These contributions led to better design elements in the interface that enabled developers to more closely match the expectations of the end users, resulting in greater user satisfaction and perceived effectiveness.

Future development of the motion detection system will include better end user instruction for how to use the graphs and correlate images with measures captured via the motion-tracking system. The creation of feedback loops and reminders would prove beneficial to elder users so they can better maintain consistent, recommended physical activities and use of exercise equipment. For example, users expressed their desire to have reminder systems built into the interface to help them remember settings, such as weight lifted during exercise on equipment they had previously used. In addition, users wanted to have automated messages to remind them to adjust their posture if they were not meeting expectations for their age or physical limitations. An automated reminder system could be used by any health care provider responsible for monitoring progress or range of motion of participants. The system could be designed to allow providers to communicate via customized messages delivered through the motion-capture interface anytime the participant was exercising and viewing image poses. Subsequently, user responses to these messages and altered exercise routines could be used as outcomes for further study.

Future research will include focusing on how this system can be used with clinicians who prescriptively authorize exercise regimens for their elderly patients as part of rehabilitation therapy after medical interventions. For example, motion detection systems would be beneficial in cardiac rehabilitation following a cardiac event; use of a motion detection system such as this would provide better accessibility to follow-up and perhaps quicker intervention as health status changed. As cardiac rehabilitation progressed, if cardiac endurance and strengthening did not improve as expected through recommended home exercise regimens, including stretching and squatting, further evaluation might be necessary. Another example includes physical rehabilitation after joint replacement surgery, when range of motion is so important to maintain flexibility and strength of the joint and musculature. Often this therapy is initiated in the hospital and continues long after the patient is dismissed to another setting where physiological monitoring of progress toward desired outcomes is more challenging. A motion analysis interface could provide greater flexibility and access for health care providers to reach and monitor patients after discharge from the hospital. In turn, more frequent monitoring and earlier intervention could improve their patient's outcomes.

Although this study has a relatively small sample size, the sample was adequate for the purpose of this study. Adequate representation of end users in HCI evaluations have been recommended to include between seven and eight participants (Nielsen & Landauer, 1993) to reach saturation and enabling emergence of all important HCI issues while maintaining costs of testing.

Human motion analysis methods are becoming an important tool to assist nurses, physical therapists, rehabilitation specialists, and other health care professionals in monitoring progress of elders who want to maintain active lifestyles. These tools also have important implications for these providers beyond just assessing for range of motion, including evaluating depression and potential risks of falls in elderly persons. The aims of this research were achieved by involving elderly end users in the software development process, which facilitated important discoveries about how this technology could be used to improve the lives of aging people who want to exercise but who are concerned about their body posture and safety.

Authors' Note

This article is reporting on the RAND pilot project 1 (principal investigator: G.L.A.) titled "Developing Interfaces to Provide Range of Motion Feedback to Elderly People Using Exercise Equipment."

Declaration of Conflicting Interests

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