# Virtual Coach Technology for Supporting Self-Care

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**Running Head:** Virtual Coach Technology

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## ABSTRACT

"Virtual Coach" refers to a coaching program or device aiming to guide users through tasks for the purpose of prompting positive behavior or assisting with learning new skills. This report reviews virtual coach interventions with the purpose of guiding rehabilitation professionals to comprehend more effectively the essential components of such interventions, the underlying technologies and their integration, and example applications. A design space of virtual coach interventions including self-monitoring, context awareness, interface modality, and coaching strategies were identified and discussed to address when, how, and what coaching messages to deliver in an automated and intelligent way. Example applications that address a variety of health-related issues are also provided to illustrate how a virtual coach intervention is developed and evaluated. Finally, we provide some insight into addressing key challenges and opportunities in designing and implementing virtual coach interventions. It is expected that more virtual coach interventions will be developed in the field of rehabilitation to support self-care and prevent secondary conditions in individuals with disabilities.

## INTRODUCTION

The term “Virtual Coach” appeared in the 1950’s and was used to refer to an athletic coach leading the team behind the scenes or over distance.  The earliest “Virtual Coach” was reported in 1997 when an electronic device (i.e., a laptop) was used to guide a rare surgical procedure in an operating room [6]. Now “Virtual Coach” has been used to refer to a coaching program or device aimed at guiding users through tasks for the purpose of prompting positive behavior or assisting with learning new skills[1,2,4,5,7,38].  “Cognitive Orthosis”, “Virtual Trainer”, “Occupational Enabler”, “Prompting Device” are some of the terms used to name the devices or programs having similar functions as a “Virtual Coach” [14,33,35].  “Virtual Coach” also shares similar features as persuasive technology defined as interactive computing systems intentionally designed to change people’s attitudes and behaviors [23]. However, “Virtual Coach” influences people by placing more emphasis on providing instructions on how to complete the target activity correctly than simply motivating them to start doing the activity if they have not done so.

One of the greatest areas of innovation for “Virtual Coach” is to support preventative health management and self-care. Healthy People 2010 emphasizes that a primary focus of health promotion for people with disabilities is on the prevention or reduction of secondary conditions[3]. The Institute of Medicine also identifies the use of assistive technologies for management and prevention of secondary conditions as one of the major areas in need of future research in the field of rehabilitation [22]. The current state of practice regarding preventing or managing secondary conditions among people with disabilities is to provide patient education during the rehabilitation process or service. However, with increased cost containment, the rehabilitation process or service continues to be compressed and limited time is available to provide such education. Information overload or feeling the information may not apply to them can interfere with retention or application of the education materials in their daily living environment [44]. Also forgetfulness, complexity of the regimen, and disruption of daily routines may contribute to poor adherence to clinical recommendations. Many people especially those having cognitive deficits rely on caregivers or family members to provide verbal reminders or instructions to complete target activities[25]. Virtual coach interventions ranging from simple time-based reminders to interactive web-based applications have been used to address these issues[7,15,39]. However, most of these interventions are designed to be used in a fixed space and cannot provide assistance as needed. They also generally operate open-loop or rely on self-report, and the information delivered is more generic and not suited to a user's context or situation.

In this paper we will focus on virtual coach interventions that incorporate sensor technologies, context-aware computing, and adaptive coaching strategies. Such interventions are able to infer elements of a person's context and activity, and reason about *when, how and what messages* to deliver based on the person's performance, progress, and context. They rely on extensive pervasive sensing of the person and his/her environment, and include powerful software engines that can process, mine, and send coaching messages tailored to the person's condition and context in an automated way.

This paper reviews virtual coach interventions with the purpose of guiding rehabilitation researchers to comprehend more effectively the essential components of such interventions, the underlying technologies and their integration, and exemplar applications. Our goal is also to provide insight by addressing key challenges and opportunities in designing and implementing virtual coach interventions, and promote such interventions in rehabilitation to support self-care and prevent secondary conditions in individuals with disabilities.

## COMPONENTS OF VIRTUAL COACH INTERVENTIONS

In order to systematically understand virtual coach interventions, we have identified four components that define the design space of such interventions and address when, how, and what message to deliver in an automated and intelligent way (see Figure 1).

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Insert Figure 1 here.

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### *Self-Monitoring*

Self-monitoring refers to observing and recording a target activity, such as medication usage, activity levels, and calorie intake, or an outcome of the target activity, such as weight. Self-monitoring is often achieved through self-report, which could be tedious, inaccurate, and relies on user cooperation. With the advance of sensor technologies and wearable computing, self-monitoring in virtual coach interventions can be achieved automatically and in real time using a variety of sensors such as heart rate monitors, accelerometers, GPS, and cameras. The sensors collect, store, and share relevant data with users and make it easier for them to know how well they are performing the target activity. Psychology research has shown that self-monitoring feeds the natural human drive for self-understanding and is an important strategy to motivate desired behaviors or avoid undesired behaviors [17]. More importantly, sensor-based self-monitoring enables the system to track user performance and progress over time, and makes sure the coaching messages will be triggered only when necessary and the message contents are more relevant to the user. Ijsselsteijn et al. used heart rate monitors to measure training intensity when participants cycled in a virtual environment with a stationary home exercise bike. The heart rate information was used to provide feedback to the participants via a virtual agent who could either encourage participants to do better or tell them to slow down if the heart rate became too high [24]. Mihailidis et al. developed a hand washing COACH device for people with moderate to severe dementia, where a ceiling-mounted video camera in the washroom and computer vision algorithm was used to track hands and task objects to monitor handwashing steps and guide users through the steps as necessary [34].

*Context awareness*

Location, time, identity, and activity have been proposed as the primary elements of context[19]. People usually take a great deal of context into account when they communicate. Previous research has shown that intervening at the right context will likely increase the chance of getting responses [31]. Studies in task interruption have also shown that responsiveness to an interruption depends crucially on what the user is doing at the time the interruption occurs in addition to many other factors such as the emotional state of the user and the modality of the interruption[11]. Sensor technologies and machine learning algorithms could enable machines to perceive certain elements of context such as location and user activity to determine levels of user interruptibility, and deliver prompting messages at the opportune moment when users are likely to respond. For example, if the user happens to be sitting idly when the prompting messages are delivered, these messages may result in a relatively high response rate. Siewiorek et al. designed a context-aware mobile phone that can modify its behavior such as ringer volume and vibration etc. based on its user’s state and surrounding environment using motion, light, and microphone sensors in a device worn on the body [41]. Kaushik et al. evaluated a proximity-based reminder system for home medical tasks in a 10-day case study where proximity to the location where the task must be completed was used to delay the reminder until execution of the task was convenient based on location. The study showed that 96% of the proximity-triggered reminders being acted upon within five minutes of being acknowledged compared with only 8% of timer-triggered reminders, and 25% of the proximity-triggered messages received the most favorable rating compared with 9% of the timer-triggered ones [25].

*Interface Modality*

A variety of modalities such as light, auditory, visual, and tactile interfaces can be used to present coaching messages to users. Within an interface modality, there are also different stimuli such as multiple sounds and text, graphics, or animation based displays. Research has shown that different modalities/stimuli or combinations have different effects on user perception, performance, and acceptance[11]. Mayer et al. found that participants performed better on a learning transfer test when the interface agent had a standard accent compared to foreign accent, and when the agent's voice was human rather than machine synthesized [30]. Bickmore et al. evaluated the impact of four different types of audio alert tones on the compliance of the target "wrist rest" behavior and found that compliance dropped off quickly with the very impolite alert tone[11]. Mihailidis used the pre-recorded voice of a professional male actor to prompt the correct sequence of hand washing for people with moderate to severe dementia [34]. However, some of the subjects did not like the male voice because it reminded them of "being in the army", and one subject even became agitated by the male voice.

Animated agents have recently become one of the most popular interface modalities with the advance in graphical user interfaces (GUI) and computing technology. These agents range from animated shapes to human-like entities including cartoon-like shapes and characters, talking animals, or a variety of other forms. A current trend is to design animated human-like agents with a wide variety of features such as visual appearance, fidelity, expressiveness, and social-emotional skills. There is well documented research showing the effect of an animated agent on user performance, perception, and acceptance [36]. Atkinson suggested that the dual mode of presentation (animated agent with narrated instructions) enhanced learning outcomes [9]. King et al. found that a dynamic 3D human agent whose eyes blinked was rated more intelligent than other forms such as 3D forms, caricatures, and geometric shapes [26]. Walker et al. found that people who interacted with a talking face spent more time on an online questionnaire, made fewer mistakes, and wrote more comments than those who answered a text questionnaire [43]. Bickmore et al. conducted a study comparing an animated health counseling agent on a mobile device to equivalent agents that had text only or text and static image representations, and found that the animated versions led to significantly better social bonding with users [10]. The same group of scientists also researched the role of emotional and relational skills in an animated human agent to support a behavioral intervention for physical activity adoption. They found that there was no significant difference between the amount of physical activity performed by subjects working with the agent equipped with emotional and relational skills versus those working with a non-relational agent. However, subjects working with a relational agent reported a significantly greater desire to continue working with the relational agent [13]. There are also negative effects reported with animated agents such as distraction and discomfort. Moreno et al. found that visual presence of the agent was no more effective than a voice-only condition [37]. Given the mixed results, it appears that a virtual coach intervention should consider the combined elements of physical characteristics of the user (such as personality, gender, background knowledge, capability etc.), attributes of the agent (such as appearance, fidelity, speech quality, expressiveness etc.), and the type of target task (such as intent, difficulty, complexity etc.).

*Coaching Strategy*

Coaching strategies determine what content is presented to the user such as general versus specific messages and incorporating different affects such as positive or emotional affects into the messages. Steege et al. evaluated two prompt strategies for teaching common household tasks to students with severe disabilities. One of the strategies used the least-to-most restrictive sequence where students received instructional prompts in the order of non-specific verbal prompt, specific verbal prompt, gesture and verbal prompt, partial physical and verbal prompt, and total physical and verbal prompt if they failed to initiate a response to the prompt with 5 seconds. The other prescriptive strategy was based on user progress, where the prompt was given at a level just above the prompt that had induced a correct response in the previous trial. The results showed both strategies were equally effective in increasing independent task acquisitions; however, the prescriptive strategy was more efficient [42]. Most-to-least restrictive sequence is another coaching strategy where the most specific message is provided at the beginning and the message specificity gradually decreases [32]. This strategy holds the most control over the user's behavior, but has a risk of message dependency.  Usually the most-to-least restrictive sequence is used to help establish the confidence in performing the target activity when a user just starts to learn the new task.  When the error rate decreases, the least-to-most restrictive strategy can take it over to help retain the learning outcome by gradually removing message dependency. Ideally, a coaching strategy dynamically adapts to the need, performance, and progress made by the user through self-monitoring and context awareness, which will help avoid 'nagging' effect and enabling a trustworthy relationship between the user and the system. The handwashing COACH for older adults with dementia developed by Mihailidis et al. used coaching messages with three levels of assistance including low-guidance verbal prompt, high-guidance verbal prompt, and verbal prompt with a video demonstration of the action [34]. The level of assistance was determined based on factors such as the error committed, sensory and cognitive status of the user, and past responsiveness to the previous coaching messages. This strategy gave the COACH the adaptive ability to select the most appropriate support for each individual's stage of dementia and overall responsiveness.

Coaching strategies also involve adding different affects to the messages. Coaching messages can be designed to minimize affect, or adopt a positive or negative affect. Positive messages may help reinforce the desired performance and increase comfort and interest in using the system. A study found that people who received computer praise after they played an experimental game felt the interaction was more engaging and more willing to work with the system again [8]. Also coaching messages that respond empathetically and encouragingly to users rather than state cold hard facts may appeal to the emotion of reaching a goal and help promote a trustworthy relationship between the user and the system [12]. Negative messages, on the other hand, should be used with caution and are generally not appropriate even when the purpose is to decrease the instances of errors or undesired behaviors.

## EXAMPLES OF VIRTUAL COACH INTERVENTIONS

The use of technologies to coach activities for supporting preventive health management and self-care has been an active domain for research. Table 1 summarizes some typical virtual coach interventions including those mentioned in previous sections. We will also discuss our preliminary work in developing a wheelchair seating virtual coach in this section.

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Insert Table 1 here.

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*Wheelchair Seating Virtual Coach*

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Insert Figure 2 here.

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Power seating functions (PSFs) including tilt-in-space, backrest recline, and elevating legrests (see Figure 2) are usually prescribed for power wheelchair users who are often unable to adjust their body positions independently, and therefore predisposed to secondary conditions related to prolonged sitting such as pressure ulcers, spasticity, edema, orthostatic hypotension, and chronic pain[20,27]. However, power wheelchair users who have these seating functions may not use them as prescribed and frequently come back to clinics for problems such as fatigue, pain, or pressure sores that could be improved or solved by changing seating positions. While client education on proper use of PSFs is part of the clinical evaluation process in assistive technology clinics, these clinics have limited time and resources to devote to extended periods of client training. Users may know that using PSFs is good for their conditions, but simply may not remember when they should use them, and how to operate them. In a previous survey study, the majority of individuals used the PSFs for comfort rather than the specific medical reasons for which they are provided [28]. We have also tracked actual PSFs use of 11 subjects with a suite of sensors and a datalogger for two weeks. It was found that subjects did not adjust seating positions frequently and seldom used large tilt angles (>30º) which was found to provide sufficient weight shift in previous laboratory studies [21]. Given the fact that a full complement of PSFs can double the cost of a power wheelchair, and many wheelchair users are not using the technology in an appropriate and effective way, it is important to develop interventions that address this problem. We are currently developing a wheelchair seating virtual coach (see Figure 3). Figure 4 shows the system diagram of the seating coach which is comprised of a suite of sensors that monitor the actual PSF use and elements of a user's context such as location and activity, a single board computer that synthesizes sensor information to determine the appropriate coaching protocol to assist wheelchair users to use PSFs for effective pressure relief and other activities of daily living such as transfers, and a touch screen that delivers the coaching messages to the user via a multi-modal interface. The seating coach can also transfer actual PSF use and compliance information to clinicians to assist further client education and decision making with PSF prescription [18].

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Insert Figure 3 here.

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We instrumented a Permobil C500 power wheelchair with a suite of sensors to monitor the actual PSF use. User access to PSF is detected by three encoders coupled to the shafts of three actuators for tilt-in-space, backrest recline, and elevating legrests, respectively. Nine pressure sensors underneath the cushion are used to detect wheelchair occupancy and activate the seating coach and other sensors. All sensor data is processed by a single board computer attached behind the backrest to track actual PSF use such as duration of maintaining the same seating position, frequency and duration of accessing pressure relief positions, and sequence of using three PSFs etc. The actual PSF use is also compared with clinician recommendations to determine user compliance status. The sensors, computer, and touch screen are powered by the wheelchair battery, making the seating coach simple always available when the power wheelchair is in use.

We also plan to add more sensors such as accelerometers, light, and audio sensors for context detection to determine opportune moments or avoid inappropriate moments for delivering coaching messages. As prior research suggested time-shifting interruptions that coincide with changes in posture and mobility, or happen in a location where the task is likely to be completed might reduce reminder burden, locations and changes in mobility state will be detected in the seating coach to help increase user responsiveness to coaching messages.

As appropriate feedback features can be varied according to the intervention purpose and the target audience, we are conducting a user preference study to determine the appropriate interface modalities and coaching strategies. A survey program (see Figure 5) was created which allows participants to select different interface modalities/stimuli for four types of coaching scenarios including reminding (e.g., when a user forgets to change the seating position for an hour), warning (e.g., when a user accesses PSF in a wrong sequence), guidance (e.g., when a user attempts to access pressure relief positions), and encouragement (e.g., when a user responds to the message with appropriate actions). For example, Figure 5 shows that a participant is to select preferred interface modalities/stimuli for the reminding scenario on Page A. Page B lists a combination of modalities/stimuli for the reminding scenario. Page C shows a number of icons if the participant selects "Static Sign" as the preferred visual modality on Page B. Page D displays the combination of selected modalities/stimuli and allows the participant to review the final interface for the reminding scenario. Participants can either go back to Page B to choose a different set of modalities/stimuli, or go back to Page A to repeat the selection process for another scenario. Figure 6 shows four animation characters if the participant selects “Animation” as preferred visual modality on Page B. Genie and Merlin are from Microsoft Agent Animations, and the female and male faces represent an average face developed by Braun et al. Figure 7 shows the final interface for the warning scenario if the participant selects “Instruction” as preferred visual modality on Page B. An animated power wheelchair figure is used to illustrate the instruction.

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Insert Figure 5 here.

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Insert Figure 6 here.

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Insert Figure 7 here.

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Our preliminary data with 6 participants who use power wheelchairs equipped with PSFs showed that participants preferred to have the cartoon animation to inform them of the task they need to do, as they are funny and entertaining. They also preferred to have the animated power wheelchair figure to illustrate the instructions for the specific task, which not only conveys the essential point of a message, but makes them feel it is important to follow the instructions. The participants did not show specific interest in either one of the human agents. This is partly due to the static faces instead of animated faces being used in the study. The participants also commented that they would like to work with a human agent whose face is someone they know or someone who is significant to them.

Currently the virtual seating coach provides specific coaching messages when detecting conditions when a user forgets changing seating positions or uses the seating function inappropriately. However, the messages remain the same no matter how many times the same condition occurs. We intend to implement an adaptive coaching strategy where the content specificity, frequency, and affect of coaching messages will change dynamically based on user compliance, responsiveness, and context.

One of the unique components of the virtual seating coach is the clinician interface. Feedback on user compliance to clinicians should be easy to understand. Traditionally, feedback is provided in the form of daily, weekly, or monthly graphs which may be difficult to comprehend at a glance. We use Kiviat Graphs (often used in computer system performance analysis) which summarize high dimensionally data. Figure 8 shows a Kiviat Graph of a wheelchair user's overall compliance (left) where the shape of triangle should be shifted towards the right side for good compliance, and individual activity compliance  where the shape of the triangle should be uniform and large for good compliance [40].

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Insert Figure 8 here.

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## OPPORTUNITIES AND CHALLENGES

Although virtual coach technology has shown promising results, we identified some key challenges and opportunities that need to be addressed as the technology matures and help shape future directions.

*Evaluation*

Evaluating a virtual coach intervention can be complicated. Hardly any user studies are available that have looked at the long-term acceptance and effectiveness of virtual coach interventions. All the studies presented in this paper are pilot projects involving a short period of time with a small number of subjects. Given the complex nature of designing a virtual coach intervention, it seems reasonable and necessary to use iterative pilot testing to refine the design until the intervention is field-ready for large-scale long-term evaluation. Mihailidis et al. developed three versions of their handwashing COACH for older adults with dementia over 10 years [33-35]. Each version was tested with a small number of subjects (<=10) and had significant advances in the sophistication and versatility compared to those in the previous version. For example, the first version of their COACH used an accelerometer-based wristband to track user performance and only used audio prompts with one prompt for each step of handwashing. While the third version used a camera and computer vision algorithms to detect performance and dynamically determined the level of assistance with audio and audio-video prompts. Perhaps one way to speed up the evaluation process is to use participatory action design which emphasizes user involvement from the very beginning. For example, users can review the design space of a virtual coach intervention with the design team and discuss tradeoffs for each component during the project planning phase. "Wizard of Oz" (the main behind the curtain) approach could also be used for preliminary usability testing before a system is fully operational, thus enabling observation of potential end-users' responses to the planned interface and functionalities as the system evolves from proof-of-concept to prototype. Nonetheless, large-scale longitudinal user studies such as clinical trials are needed to determine the ultimate efficacy of a virtual coach intervention.

*Usability*

The usability of a "Virtual Coach" to a large extent determines user acceptance and possibly performance. Self-monitoring and context-awareness are important to improve the usability by delivering relevant just-in-time messages. However, this benefit is crucially dependent on the quality and relevance of the machine sensing and inference algorithms. As the physical world and human behavior are both highly complex and ambiguous, reliable activity inference is a difficult problem. It is important to understand how tolerant will the target audience be to incorrect inferences, improper feedback, and bad timing, and strike a balance between the level of intelligence and reliability of a "Virtual Coach".

Few existing virtual coach interventions incorporate adaptive affect into their coaching strategies. The handwashing COACH is the only study we found that can adapt the level of prompting assistance to each subject's performance, cognitive status, and overall responsiveness [34]. Ideally, a virtual coach intervention should reduce the number of and level of detail in the cues it provides as a user learns and his/her ability changes, which could enable a trustworthy relationship between the user and the system, leading to better usability and coaching effectiveness.

*Virtual Coach on a Mobile Device*

With mobile devices such as smart phones and PDAs becoming more plentiful and powerful, and the fact that they become an integral part of our everyday life, one of the further directions is to use mobile devices to deliver virtual coach interventions [16]. Mobile devices are always with their users and stay on most of the time, which enables a virtual coach to be consulted whenever and wherever a user needs help and proactively intervene in real-time. The time and frequency of contact with a mobile device could also help build greater social bonding between the user and the virtual coach. Context awareness is essential in mobile applications to avoid annoying users and maximize coaching effectiveness. The ability to actively interrupt and help a user in a situation that is automatically sensed by a virtual coach could lead to increased perception of trust and caring by the user.

## CONCLUSIONS

Prevention and self-care play an increasingly important role in the overall health of an individual. Virtual coach technology can potentially enable a new class of intelligent devices and applications that facilitate self-management and improve compliance to clinical regimens. The ability to provide coaching messages in a way that is tailored both to the user and the situation will likely enable a trustworthy relationship between the technology and the user, improving technology acceptance and effectiveness. Future work should focus on improving technology reliability, usability, and portability, and conducting large-scale longitudinal evaluations.

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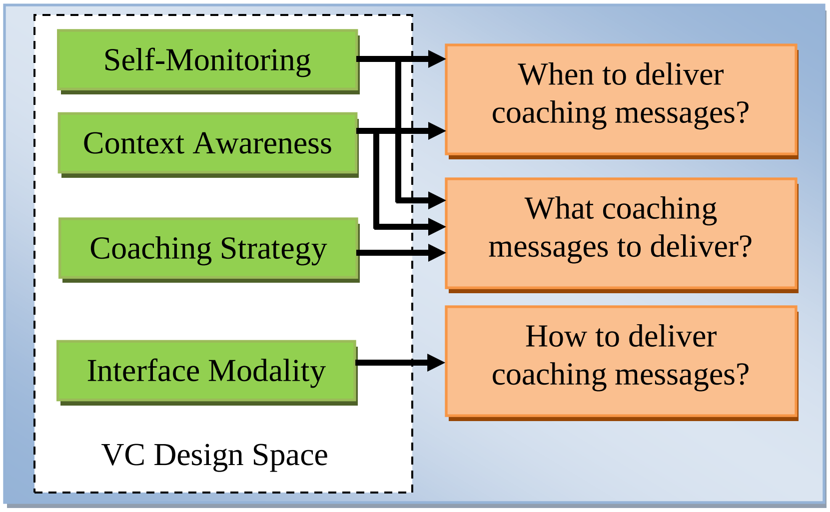


Figure 1: Design Space of a Virtual Coach Intervention.

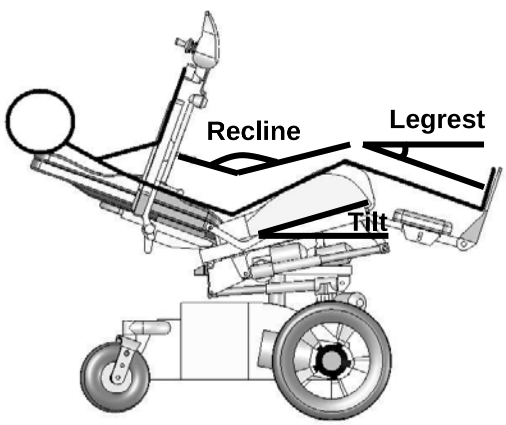


Figure 2: Power Seat Functions.

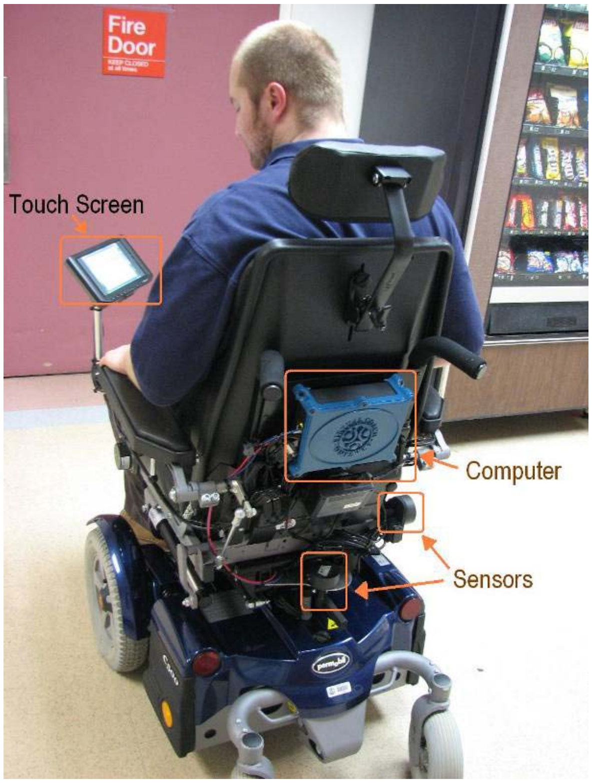


Figure 3: Virtual Seating Coach.

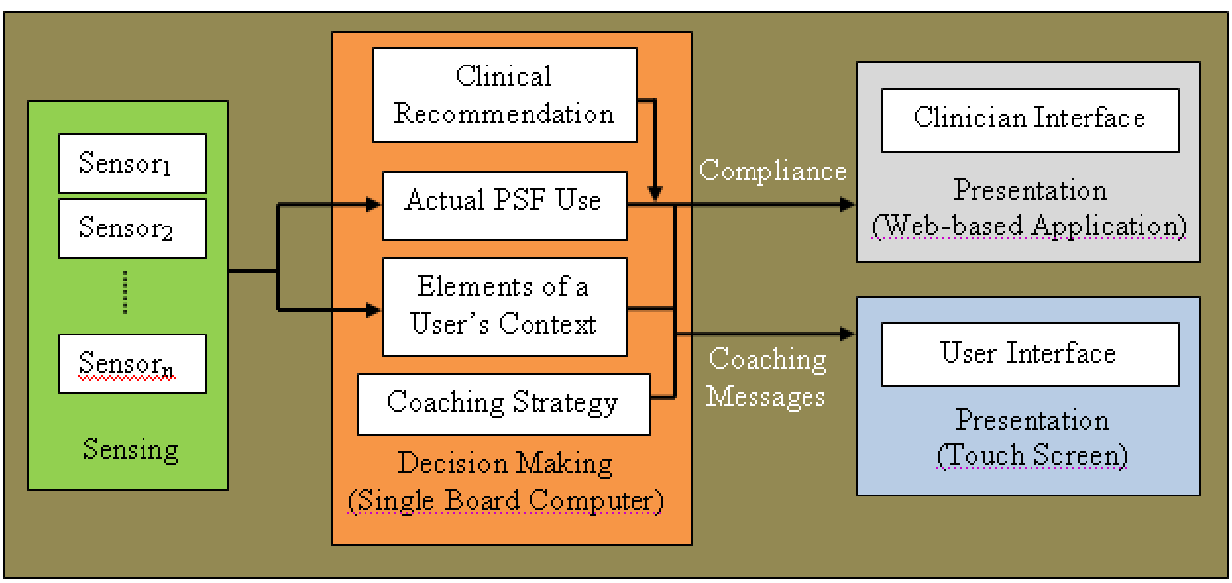


Figure 4: System Diagram of the Virtual Seating Coach.

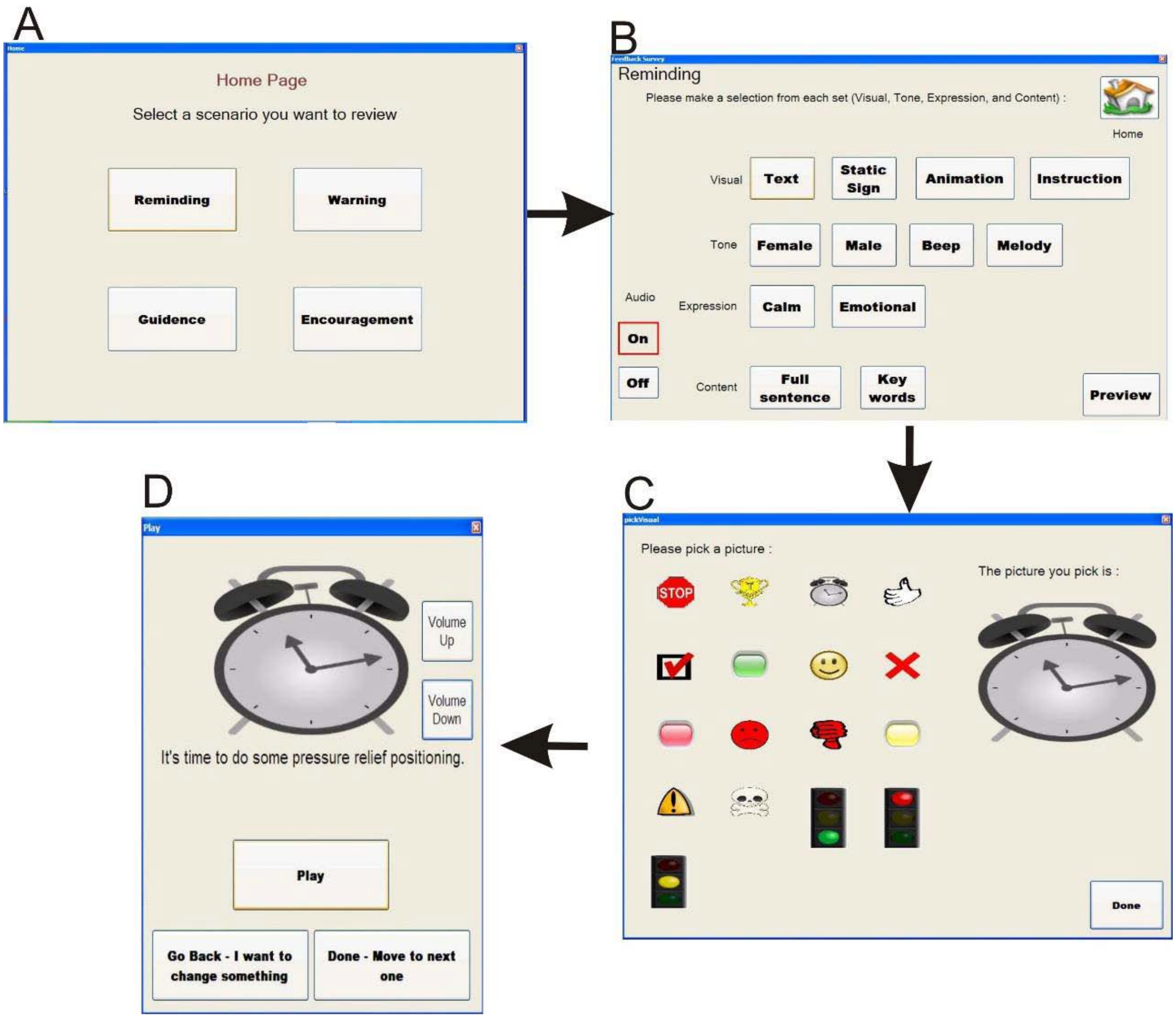


Figure 5 Survey Program for the User Preference Study

Figure 6: Four Animated Characters.

(From Left: Genie, Merlin, Average Female Face, and Average Male Face)

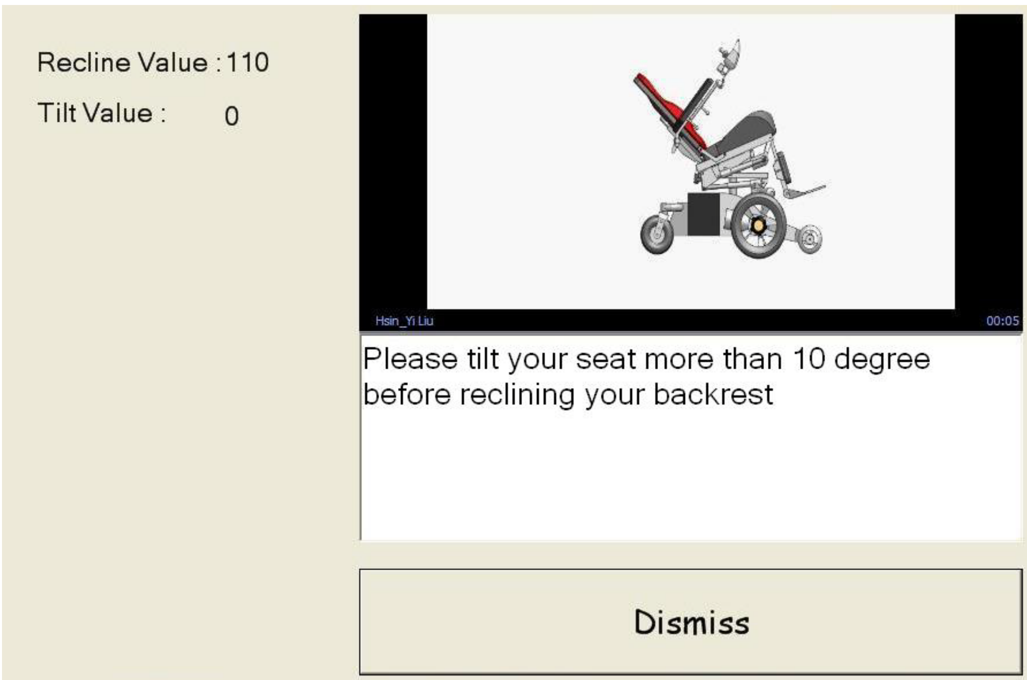


Figure 7:An Example Interface for the Warning Scenario.

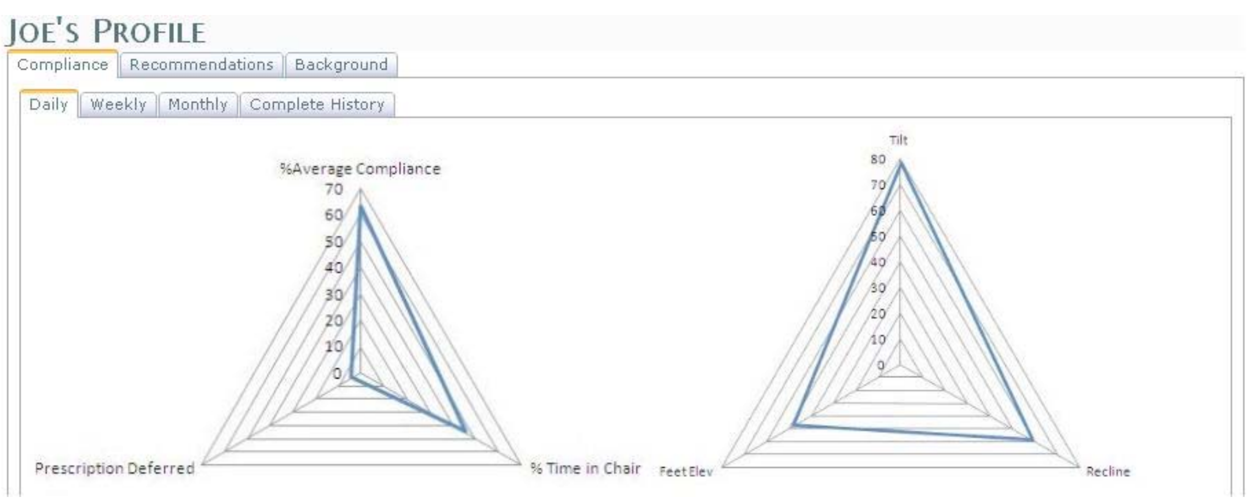


Figure 8 Feedback to Clinicians by Kiviat Graphs

Table 1: Summary of some typical virtual coach interventions.

| **Reference** | **Target Activity** | **Portability** | **Interface Modality** | **Coaching Strategy** | **Evaluation** | **Outcome** |
|---|---|---|---|---|---|---|
| The COACH prompting system to assist older adults with dementia through handwashing: an efficacy study [34] | Hand washing | Fixed station with an video camera to monitor handwashing performance | Pre-recorded male voice, video demonstration | Three levels of instructions determined based on the error committed, user conditions, and past responsiveness | Pilot test with six older adults with dementia using single subject design | More steps completed independently, fewer interactions with caregivers. 23% false alarm or miss detection |
| Virtual fitness: stimulating exercise behavior | Physical exercise | Fixed bicycle station with virtual environment | Female virtual agent with prerecorded voice and synchronized lip movements, text in a | Feedback based on heart rate | Test with 24 subjects who do not do regular | Significantly lowered the perceived control and pressure, but |

| | | | | | | |
|---|---|---|---|---|---|---|
| through media technology [24] | | and heart rate was monitored | cartoon like text balloon | | exercise using within subject design | did not affect enjoyment |
| Bringing mobile guides and fitness activities together: a solution based on an embodied virtual trainer [14] | Physical exercise | PocketPC with GPS that monitors the trial and user speed | Annotated trail map with prerecorded voice to support navigation, and embodied virtual trainer to provide motivation support and exercise demonstration | Positive feedback based on user speed on the trail; location aware exercise demonstration | Test with 12 users using within subject design | More useful for navigation than trail maps and more effective to teach how to correctly perform exercise |
| Lifelogging memory appliance for people with episodic | Memory | Wearable camera, audio recorder, and GPS logger | Visual and audio cues in a slideshow narrative on a Tablet PC | Self-guided review based on automated heuristics to exact meaningful | Pilot test with three subjects with EMI and their caregivers, | Support the memory of people with EMI better and reduce the burden placed on |

| | | | | | | |
|---|---|---|---|---|---|---|
| memory impairment (EMI) [29] | | to record personal experiences | | memory cues | compared with two other strategies | their caregivers |
| Context awareness in a handheld exercise agent [10] | Walk | PDA with an integrated 2D acceleromete r to detect if walking at a moderate intensity | Animated agent in a close-up shot with a range of nonverbal behaviors such as head nod, eyebrow raise etc. and text display (no speech) | Positive feedback based on accelerometer readings | Pilot test with eight subjects using within subject design (sensor-based feedback on and off) | More perceived awareness and closer relationship with the agent, but less walking when feedback based on accelerometer |