ReadySteady: App for Accelerometer-based Activity Monitoring and Wellness-Motivation Feedback System for Older Adults

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Abstract

Increased physical activity and exercise have been found to reduce falls and decrease mortality and age-related morbidity in older adults. However, a large percentage of this population fail to achieve the necessary levels of activity needed to support health living. In this work, we present a mobile app developed on the iOS platform that monitors activity levels using accelerometry. The data captured by the sensor is utilized to provide real-time motivational feedback to enable reinforcement of positive behaviors in older adults. Pilot experiments (conducted with younger adults) performed to assess validity of activity measurement showed that system accurately measures sedentary, light, moderate and vigorous activities in a controlled lab setting. Pilot tests (conducted with older adults) in the user setting showed that while the app is adept at capturing gross body activity (such as sitting, walking and jogging), additional sensors may be required to capture activities involving the extremities.

Introduction

Daily physical activity and exercise have broad implications to both the physical and mental wellbeing of older adults (+65 years). Regular exercise has been shown to reduce the risk of mortality and age-related morbidity[1,2,3,4]. In addition to reducing the risks of falls and fall-related fractures[5,6], studies have also shown that older adults, even those with chronic illnesses, such as heart failure, can benefit from carefully designed exercise programs[7,8]. Aside from benefits to physical well being, increased activity has been found to be associated with lower risks of cognitive impairment, Alzheimer disease and dementia[9]. With so many known advantages, the fact that more than 70% of older adults are inadequately active[10] is indicative of a larger problem; the limited attention to research on behavioral processes central to adopting and maintaining activities over time.

Physicians, nurses and family members play a critical role in fostering motivation among older adults for increased physical activity and exercise[11]. The absence of a strong support structure may be one of the many reasons for the lack of motivation to achieve the recommended levels of activity. There is a need for theory-based tools that enable adults to monitor their physical activity, set their own goals and obtain motivational feedback. In this paper, we describe an accelerometer-based activity monitoring application that provides feedback based on the concepts of Wellness Motivation Theory[12,13].

The WMT promotes the emergence of new and positive health patterns by conceptualizing motivation as a complex and dynamic process of individual growth based on personal values and resources[14]. It focuses on how individuals develop personal goals, assess opportunities for improvement and initiate the required change[13]. Translating the concepts of WMT to feedback involves providing users information about the intensity, duration and frequency of physical activity, in a social context, as a way to enhance motivation for health related behavioral change.

There have been a number of persuasive tools developed to promote physical activity through initiating a change in everyday behavior[15,16,17,18]. Consolvo, McDonald and Landay[17] designed a mobile application that emulates a garden. The application, UbiFit Garden, encourages people to be active by associating the "health" of the garden to their daily activity. The system includes a display on a mobile device, an interactive application for viewing everyday performance and a fitness device for gathering data about activity. The fitness device automatically transmits information about activities to the display, which then modifies the representation of the garden. The display of the garden is a novel representation of activity behavior and goal-attainment status. The persistent and positive reinforcement was found to support the goals of promoting physical activity though persuasion. The system, however, is targeted towards a younger population. It may be difficult for older adults, many of who may not tech-savvy, to utilize a system with multiple functional components. In addition, icons and text sizes would need to be sufficiently large to ensure readability and ease of use.

Another persuasive tool developed is Flowie[18], an application designed specifically for older adults. Flowie is a graphical representation of a flower that "emotes" its state of health i.e. the flower transitions between states of happiness and sadness depending on activity levels. While this is a similar concept to UbiFit Garden, Flowie's emotive states help users feel socially connected to the representation. Flowie is similar to UbiFit in that it is a composite system. A pedometer is used to accumulate data about physical activity. This data is communicated to a centrally located laptop (via Bluetooth), which in turn controls a digital photo frame that displays Flowie and other information about history of activity. As Flowie is designed with older adults in mind, the display is legible and user friendly. However, similar to UbiFit, it uses multiple components to function. Another drawback is the centrally located feedback. Users can obtain feedback at only one location. They would need to return to this location to visualize the impact of their activity, as opposed to being able to check it on the go. In addition, it would be difficult to share their progress with people outside of their household.

Other pedometer based systems include Chick Clique[15] and Fish'n'steps[16]. Chick Clique is a mobile application that capitalizes on the power of social influence to modify the behavior of the group by providing users the ability to connect and interact with their "clique". Fish'n'steps, on the other hand, is similar to Flowie and provides a localized animation of a fish-tank for feedback. Healthy activity is encouraged through incentives (unlocking different kinds of fishes). The strategies adopted by these applications are targeted toward teenagers and young adults. These concepts may not be directly applicable to older adults.

UbiFit and Flowie conform to an accepted form of metaphorical feedback. The usability tests conducted by Albaina, Vastenburg and van der Mast[18] with older adults found that the flower is an abstract representation that communicates information adequately while simplifying interaction. This is vital for our target population. They also found that the flower does not evoke the same expectations as a realistic avatar would. For example, an avatar of a doctor stating that they are bound to get stronger might discourage them when the expectation of greater strength is not met. Another advantage of the flower (not stated in their work) is that it is a gender-neutral representation. For these reasons we have chosen to use a similar representation in our feedback system.

In addition to the pictorial representation, we also wanted to include numeric and meter-based feedback, as not all users would respond to the same type of feedback. In addition to this multiple-feedback requirement, our aim was to develop the system on a single mobile platform. This requirement introduces new challenges; the feedback would need to be made available on a small screen while ensuring readability, the interface would need to be simple for ease of use and the system should be able to support activity monitoring continuously without loss of power. To meet these requirements we chose to develop our application, *ReadySteady*, on the iOS mobile platform. Development on this platform enabled us to make use of the sensor-integrated environment of the iPod-Touch and iPhones. These devices are equipped with an in-built accelerometer and have a relatively (compared to other hand-held mobile devices) large screen. In addition to the description of this system, we present the results of initial experiments conducted to confirm its validity in this work.

Background

Caspersen, Powell and Christenson[19] define physical activity as body movement that is produced by skeletal muscles and results in energy expenditure. This energy expenditure is measured in METs (metabolic equivalent of task), the ratio of metabolic rate during a specific physical activity to the resting metabolic rate. MET values are indicative of the intensity of physical activity. Low intensity activities (<3 METs) include sleeping, working at a desk and walking at a speed up to 2.5 mile per hour (mph). Moderate intensity activities (3-6 METs) include brisk walking (at speeds up to 3.5 mph), jogging and bicycling. Running is considered to be a high intensity activity (>6 METs)[20]. While MET values, for a particular task, can vary between individuals (accounting for weight differences), it is a widely used standard for measuring activity intensity.

Measurement Tools: Sensors typically used for capturing physical activity include pedometers and accelerometers. While pedometers track the frequency of activity (step count), accelerometers capture the intensity of dynamic movement encountered. For this reason, accelerometry based activity monitoring is often preferred in physical activity research.

There are several commercially available accelerometers that have been validated for tracking activity levels. The Actigraph GT1M and GT3X[21], Caltrac[22] and Mini Motionlogger[23] are some of the most frequently used accelerometers in physical activity research[24,25]. Typically, these devices measure acceleration along one, two or three axes[26]. The analog data is then sampled at a particular frequency, ranging from 1Hz to 128 Hz[27], to provide a set of discrete values. These values describe the acceleration experienced by the device at various discrete time internals. These values are then aggregated over a specific time period or *epoch* (ranging from 1 second to 1 minute). The aggregated value is the "activity count" that is correlated with energy expenditure (METs) to obtain a meaningful result. Albinali, Intille, Haskell and Rosenberger[26] state as activity counts utilize aggregated information, the process may reduce the resolution of the data and consequently affect the recognition of certain activities. While this may be the case, aggregated information aids in the removal of noise and the effect of gravity from the input data stream.

Measurement Modes: Data is accumulated from an accelerometer in one of three different ways, (i) Zero Crossing Mode (ZCM), (ii) Proportional Integral Mode (PIM) and (iii) Time Above Threshold (TAT)[25,28]. ZCM provides a count of the number of times the accelerometer waveform crosses zero or a set threshold for each epoch. In other words, ZCM measures the frequency of the activity. PIM, on the other hand, measures the area under the accelerometer waveform curve, and adds that size for each epoch. PIM reflects the intensity of the activity. Finally, TAT, measures the length of time that the wave is above a certain threshold. TAT measures duration of the activity. Most devices allow users to choose between these modes depending on their individual requirements.

Energy Expenditure Estimation Methods: In order to correlate activity counts to energy expenditure (EE), the accepted approach is the development of regression models using controlled experiments[29,30,31]. Typically these experiments involve recruiting a large population (between 25 and 75 adults) to perform specific activities such as walking on a treadmill, putting on a golf course or mowing a lawn while wearing an accelerometer-enabled device. The data captured are utilized to develop regression models for specific activities. Crouter et al.[32] build on existing methods to develop a two-regression model. This model introduces an initial step of preliminary classification of the intensity of activity (high and low). Once classified, appropriate regression models are applied to compute the associated energy expenditures.

Measurement tools, mode of operation and energy estimation methods are the critical components in developing an activity monitoring system. The following section describes our approach to the design and development of this application.

Methods

ReadySteady System Architecture

Figure 1 depicts the various modules that form the ReadySteady app. Features of physical activity, namely, intensity, duration and frequency are captured by the accelerometer running the background. Once sensed, the data is processed to estimate activity levels. The output feedback screen is updated according to the activity levels and all data is stored locally on the device for post-hoc review. The following sections will describe the background processing and output interface in detail.

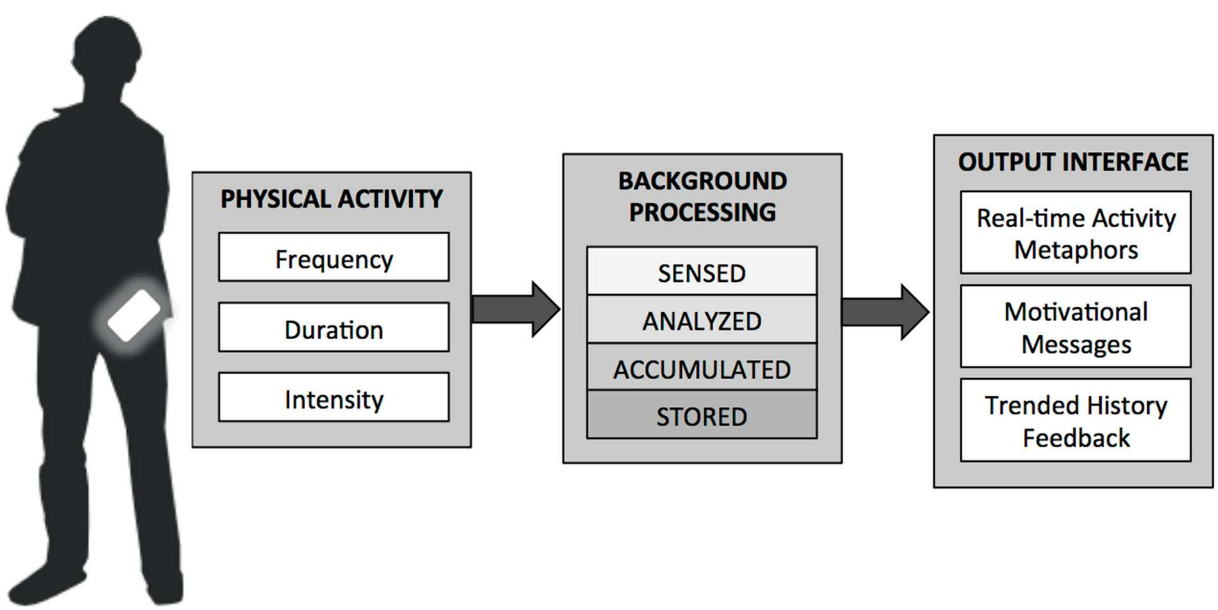

Figure 1. System overview of ReadySteady

Background Processing

Measurement Tool Description: Our application, *ReadySteady,* utilizes the in-built tri-axial accelerometer sensor that is available on the iPod-Touch/iPhone platform as the measurement tool. The sensor is capable of an output data rate of 100 Hz. Similar to the Actigraph[21], the accelerometer on the iPod Touch is sampled at 10 Hz for a specified interval of time (epoch). While it is possible to have higher frame rates, we found that in order to optimize battery consumption 10 Hz was adequate. Data is accumulated in this manner over 5 second epochs every 15 seconds. This is our default setting. The length of an epoch is customizable and can be of lengths varying from 1 to 60 seconds. Epochs will be sampled at regular intervals across a minute to ensure that each minute's activity is adequate represented in the data.

Measurement Mode Description: The method employed for data accumulation would need to be robust against noise, gravity and indirect movement (such as rides in elevators and cars). As an initial step the data is smoothed using averages computed over a sliding window. This removes any noise that may be present in the data. The next step is to remove constant offsets, such as acceleration due to gravity. One method to achieve this is to calibrate the device, as is done with Actigraph[21]. The key requirement of ReadySteady was to keep the interaction simple and support ease of use for older adults. As the addition of a calibration step would not support this requirement, we use an alternate estimate or measurement mode to assess intensity of activity. We utilize the derivative of acceleration, namely jerk (j).

$$j = \lambda * \left[\sqrt{(ax_2 - ax_1)^2 + (ay_2 - ay_1)^2 + (az_2 - az_1)^2}\right]$$

where, an_t is the acceleration along axis-*n* at a time instant *t* and λ is a scaling factor. The key assumption behind utilizing jerk is that most gross human movement involves some jerk. The jerk can be estimated and utilized as a proxy for activity. Estimating jerk also has the advantage of compensating for constant offsets, such as gravity, without the need for additional calibration. In addition, the estimations are independent of device orientation. Consequently, our users do not have to carry the device in any specific manner. This supports the overall ease of use of the system. For these reasons, jerk was implemented in the place of existing measure modes (ZCM, PIM and TAT).

Energy Estimation Methodology: While regression models provide near accurate estimates of energy expenditure, one of the main disadvantages is that the models may be skewed toward the population recruited for experimentation. It may not be possible to apply existing regression models to data gathered from older adults. As many segments of this target population have chronic conditions, acquiring data to develop regression models across intensity levels would be considered high risk for this population. Consequently, for ReadySteady we utilize a simple rule based classifier in order to correlate outputs with MET values. Thresholds were estimated (through trial and error) for light (<3 METs with activity measurement values of 15-100), moderate (3-6 METs with activity measurement values of 101-160) and vigorous (>6 METs with activity measurement values greater than 161) activities. The average jerk estimated over an epoch was compared to the threshold and appropriately classified. As the primary goal of ReadySteady is to estimate gross activity in a minute, this classifier is appropriate.

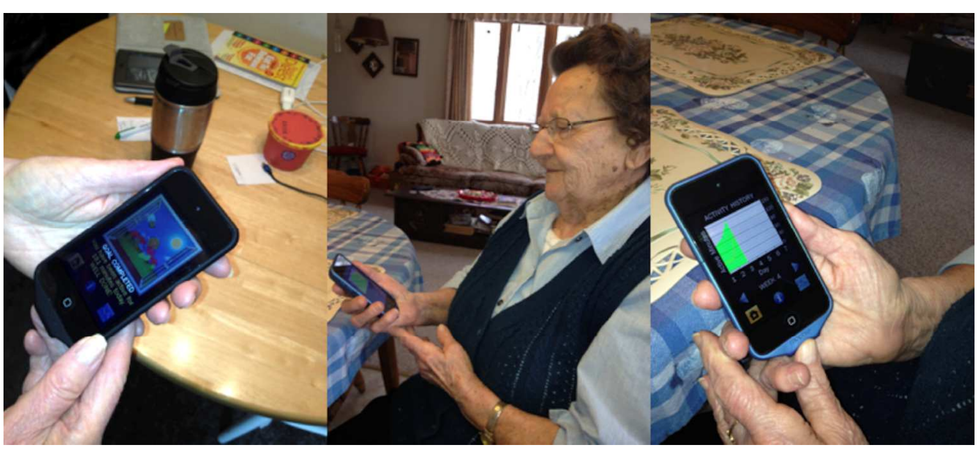

Figure 2. ReadySteady app being used by an older adult

Output Interface for Persuasive Feedback and Interaction

Figure 2 shows the ReadySteady application being used by an older adult in her home. A key challenge in getting older adults to adopt new technology is providing interesting features while minimizing the frustration that may be encountered during the learning phase. By implementing large buttons and font sizes we ensured that the interfaces were legible. We also chose to present the users with only 3 buttons (for main page or home, help and feedback history). By simplifying the interaction with the system, we enabled our users to navigate easily though the various screens. The key features accessible to the user are described below.

Real-time Activity Metaphors: Figure 3 includes screen shots from the ReadySteady to show the various forms of feedback available to the user. The metaphorical representation is a view of a garden from a window. As shown in the figure, the garden blooms with flowers as the user become more active. When the user completes their daily goal, a final state is reached (a bird is depicted in the garden). In addition to this pictorial representation, users are also provided numeric feedback on their progress. Note that the sun in the diagram also serves as a meter; filling in as the user gets closer to completing their goal.

Motivational Messages: When users touched the screen, a motivational message appears. These messages were developed based on the wellness motivation theory. While all messages have a positive affect, the message changed in tone as the user came closer to reaching their goal. For example, "Every bit helps" is a message that appears when the user has completed less than 25% of their daily goal. Messages, such as, "Energy, attitude and persistence conquer all!" appears when the users have met their daily goal.

Activity History Feedback: We have also included a graphical representation of the users' activity levels. Users may utilize this feature to assess their performance and ability to meet goals over each week they have utilized the application. The feedback screen depicts their daily activity level (in green) with respect to their daily goal (red line across the graph).

Figure 3. Feedback transition on output interface as goal is achieved[33]

Experiments and Results

Figure 4 depicts the results of a pilot experiment conducted with younger adults (ages between 25 and 35 years) to assess the sensitivity and response of activity measurement by the ReadySteady app. While this experiment could need to be conducted with our target population (older adults in the +65 years age group), controlled tests on a treadmill for an extended duration of time would pose a major health risk for the participants. In addition, many older adults may not be able to sustain physical activity equivalent jogging or running. For these reasons, the experiments were conducted with a younger population.

Four adults carried an iPod-touch enabled with the ReadySteady application while on a treadmill. The speed of treadmill was increased from 0 miles per hour (mph), the rest state to 5 mph. Every 90 seconds the speed was increased by 0.5 mph. A one-way ANOVA was used to assess the differences between the measures of activity reported for each increment of the treadmill speed. The average jerk sensed for each increment was found to be significantly different ($p<0.001$). In a controlled setting, the application is sensitive to activity changes in the order of 0.5 mph.

The figure also indicates the thresholds for light (15-100), moderate (101-160) and vigorous activity (>160) that was established through trial and error. While further experimentation is required to firmly establish the accuracy of these thresholds, the figure indicates they there are reasonable for establishing if a person has been active and for providing an approximate measure of activity intensity.

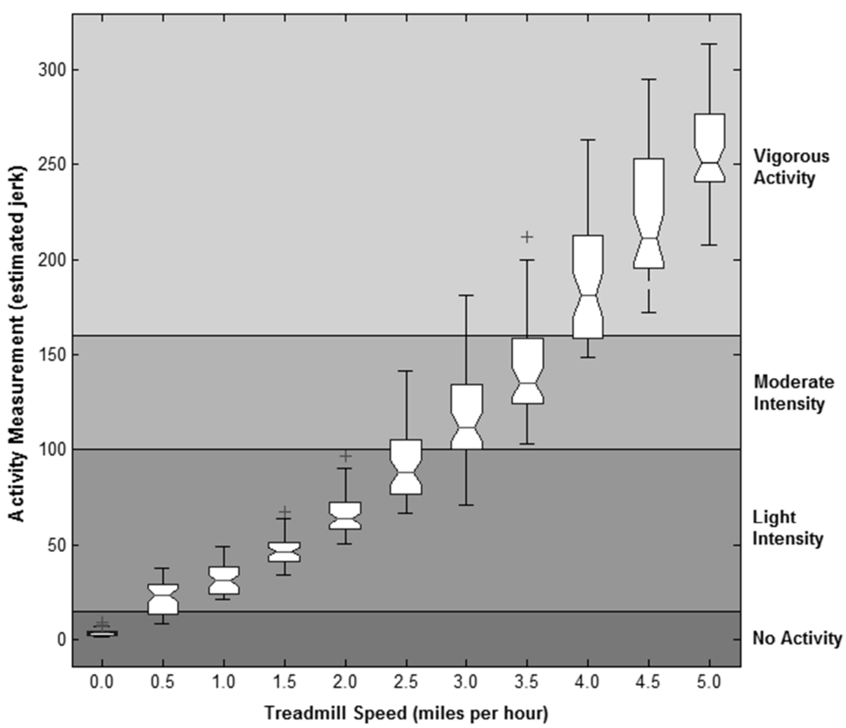

Figure 4. Activity measurement verses treadmill speed

We also had the opportunity to pilot the application with some older adults. Four participants between the ages of 69 and 75 years were provided with the iPod-touch device to use as a part of their daily routine for a week. Participants were also encouraged to maintain an activity log, when possible. As the activity logs were sporadic and not all adults performed the same kind of activity (for example only one for the four participants went jogging), we extracted only those measurements that had an explicitly associated activity log. Figure 5 shows the distribution of the activity measurements obtained from ReadySteady against the activities annotated on the data (based off of user logs).

The physical activities recorded included sitting, standing, rocking in a chair, driving a car (vehicle), performing strength and balance exercises (SB exercise), housework, yard work, walking and jogging. Data was also captured when the device was placed on a counter for charging, which we included this in the graph to establish a baseline for comparison. While it is not possible to reach any significant conclusions based on these results, this graph reveals a number of interesting findings. For example, sedentary activities such as sitting do fall with the thresholds for "No Activity". In the development of persuasive technology for this population, given the widespread sedentary lifestyles, one could argue that it is critical to accurately identify sedentary activity[34] and sublevels of low intensity activity[35]. While the system accurately identifies sedentary activity, standing, rocking and driving a vehicle are considered to be low light intensity activities. This indicates that the existing activity thresholds may need to be further refined, in order to capture finer gradients of activity intensity within the low and moderate bands.

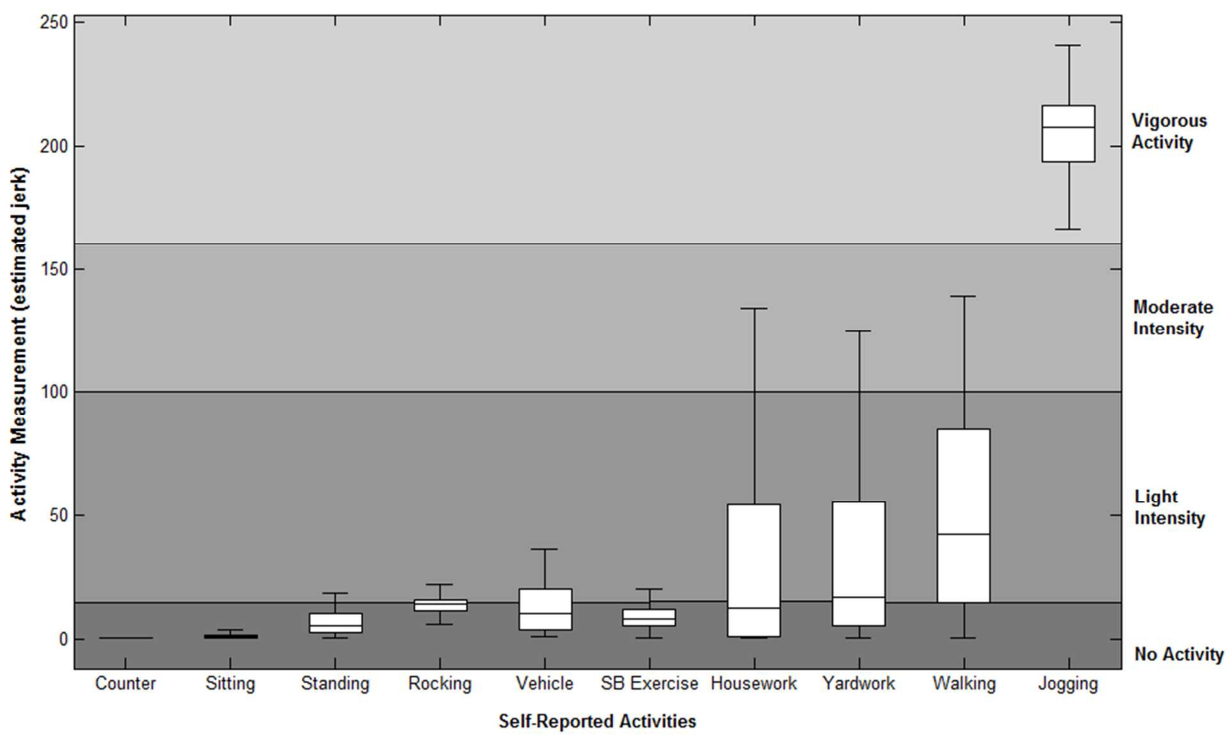

Figure 5. Measurements across various common physical activities

Housework, yard work and walking, exhibited a range of measurements spanning from light activity to moderate levels of activity. While this is not unexpected it does point to the fact that these activities may be difficult to truly measure without temporal analysis of activity patterns. This is a feature that can be added to the background-processing environment of the application in future versions.

Jogging was classified as a vigorous activity. It is not possible to draw any conclusions without more information (such as incline of the job or user bio-data), it should be noted that for many older adults jogging, at even 3-4 mph, can be considered to be a high intensity activity. Copeland and Esliger[36] found that the cut off points for moderate to vigorous physical activity was lower for older adults. While the system should persuade users to become more active, encouraging them to take undue risks in performing vigorous activities (that could potentially result in falls) should be avoided. This supports the argument that determination of levels of activity need not be based on traditional standards such as METs. While these standards are useful in validating the functionality of activity measurement, they may need to be modified to suit the target audience and support the persuasive cause.

The system, however, has some drawbacks as well. Strength and balance exercises are as important as cardio-vascular workouts, if not more given the benefits to fall prevention. As the system measures only gross body movement, fine-tuned measurements of activities performed using the extremities are poorly represented (as seen in Figure 5 – SB Exercise). One solution is to incorporate an additional sensor (such as Fitbit[37]). Such a sensor can be worn on the foot, thereby providing the necessary information for making inferences about activities dealing with extremities. This solution, however, introduces the challenge of persuading older adults to use multiple sensors in their daily life without added frustration.

We share results, while acknowledging that the power of the in-vivo pilot is low and that self-reported logs may suffer from user bias. Our future work involves gathering more data and information that will address the issue of power. The bias of self-reported logs cannot be avoided. This, however, is not new to the physical activity research community and is, in fact, one of the central driving forces behind the development of objective methods of activity measurement.

Conclusions

ReadySteady is a persuasive tool, designed to enable older adults to monitor their daily activity and become motivated to achieve recommended levels of activity. In this paper, we present some of the unique challenges involved in the development of such a tool. We addressed the challenges by making trade-offs.

We chose to develop the application on a single mobile platform in order to ensure that older adults will be able to integrate the system into their daily routine without added frustration and learning. In doing so, we faced the issue of lower battery-life. Systems such as Flowie and UbiFit can be operational for more than a month because of their distributed architecture. In our case, we found battery life to be between 5 to 6 hours. In order to extend the battery life, we dimmed the brightness of the screen and limited the length of sensing epoch to as low as five for every fifteen seconds. With all the modifications we were able to get a battery life of approximately 7 hours. Consequently, we chose to supplement the iPods with external sleeve batteries. This sufficiently increased operation time to 10-12 hours, while having a limited effect on the device form factor. This allowed users to charge their device once a day, at night.

The other trade-off made was accuracy of activity measurement for ease of use. If multiple sensors are added, more detailed information about gross body movement and exercises with the extremities can be measured. To support the goals of our persuasive system, capturing time spent being sedentary and engaging in light intensity activity is critical. To capture this information and provide estimates of approximate activity intensity measurement of gross body movement was adequate.

Future work, in this research, includes developing models of some daily-living activities to differentiate sedentary and light intensity ranges. Additionally, assessment of the persuasive system through interventions presented to control and experiment groups are underway.

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