Assessing muscle disease related to aging using ambient videogames

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***Abstract*— Sarcopenia is defined as the loss of skeletal muscle mass that occurs with aging, and is recognized as a major contributing factor to disability and loss of independence in the elderly. Recent evidence shows that age-related loss of muscle strength and power (dynapenia), as well as muscle fatigue are a better predictor of disability. In this paper we describe three ambient casual games that have been designed to measure arm muscle strength and fatigue utilizing a custom-designed interaction device that provides a natural user interface for the games. The games are designed to be used frequently and for short periods of time. We conducted a formative evaluation of the games with 5 older adults to assess ease of use and their interest in playing them. We compare the results of traditional measures of muscle strength using a clinical dynamometer with those obtained using the videogame. The higher frequency with which measures can be obtained from playing the videogame can result in a more reliable and timely assessment of risks of dynapenia and frailty.**

Keywords- Game design, ambient videogames, embodied interfaces, frailty, muscle fatigue, dynapenia.

I. Introduction

By 2030 more than 50 countries are expected to have at least 20% of their population over 65 and according to the United Nations Population Division, 1 in 5 people worldwide are expected to be 65 or older by 2035 [1]. This demographic shift is becoming particularly acute in developing countries that have seen their fertility rates drop sharply in the last few decades and which have more limited resources to cope with the problem.

One of the main issues related to the care of elders is the diagnosis of their physical condition. One way to detect functional decline in an older adult, and therefore, the increase of dependency, is through the measure of their frailty. Rockwood et al [2] described the concept of frailty as a multidimensional syndrome which involves loss of physical and cognitive reserves and ultimately an increase of vulnerability. Another Geriatric syndrome related to frailty that has attracted considerable attention from the geriatric community is sarcopenia, which is defined by the European Working Group on Sarcopenia in Older People (EWGSOP) as "a syndrome characterized by progressive and generalized loss of skeletal muscle mass and strength with a risk of adverse outcomes such as physical disability, poor quality of life and death" [3]. Sarcopenia is recognized as a hallmark of ageing and for years the term encompassed both the loss of strength and muscle mass; however there is evidence that the loss of muscle strength is the critical factor in maintaining physical function, mobility and vitality [4] and a better predictor of disability and mortality [5].

Clark et al [6] proposed the term "dynapenia" to refer to age related loss of strength. Based on the analysis of the literature they argued that several aging studies offer evidence of a dissociation between the loss of muscle mass and strength, also the use of anabolic substances such as the growth hormone and testosterone to improve muscle growth while failing to provide the gains in strength and, finally, changes in muscle mass and changes in strength resulting from alterations in physical activity don't follow the same time course. It is thus suggested that the gains in strength are not entirely related to factors associated with the capacity of the muscle itself but to other physiological factors as well.

Dynapedia can be diagnosed using a working decision algorithm proposed in [7]. This algorithm begins assessing several risk factors such as age greater than 60 years and then uses a grip strength test and a knee extension strength assessment. On the other hand, leg strength measures may not be practical in clinical settings since it requires large and inconvenient equipment while hand grip strength is a simple, reliable, and inexpensive substitute to measure overall muscle strength and a valid predictor of physical disability and mobility limitation [3, 8].

Another important aspect related to frailty and physical decline is the sensation of fatigue. Muscle fatigue is defined as the ability to produce sustained muscle effort. Fatigue has also been closely associated to frailty [9]. In fact, it might be considered a better indicator of frailty than muscle strength since performing Activities of Daily Living (ADL) do not require a maximal effort but rather a sustained moderate effort over a period of time [10]. In addition, poor muscle fatigue resistance could explain the sensation of fatigue, which is considered a predictor of disability in pre frail subjects [11] and even mortality [12]. Muscle fatigue is a complex phenomenon that can be caused by many factors including psychological aspects. It can be assessed using instruments to measure self-perceived fatigue [13], or through direct measurement. Hand grip performance has been found to be closely correlated to self-perceived fatigue, and a method has been proposed to

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measure muscle resistance with aged subjects utilizing the Maximum Voluntary Contraction (MVC) with a dynamometer [21]. Usually these type of measurements are lengthy given that the muscle needs time to recover, thus verbal encouragement has been used to motivate the subject to obtain their maximum performance [14].

One possible solution to motivate the patient's involvement in these procedures is the development and use of video games. Recent studies reveal that more than 65% of households in the USA play videogames [15] and the numbers are growing. More surprising is the fact that there are more people over 50 that play games than children [15]. When Nintendo launched its Wii console, introducing a simplified controller with a unique and intuitive control scheme, it opened the door to a new class of players. These types of games have been referred to as "ambient games", games that incorporate a new paradigm of interaction, which allows an embodied, physically active way of engaging with the game.

This paper describes the design and evaluation of ambient videogames aimed at assessing muscle strength and fatigue to assist in the detection of early signs of dynapenia and fatigue without waiting for a visit to the physician for a clinical assessment. We propose that the continuous unobtrusive assessment performed while playing a videogame could be equal or more effective that the assessment performed in a clinical environment. The continuous use of the games may reveal a more complete picture of the measured strength and fatigue, motivating the patient to participate, eliminating the stress induced by these tests, while increasing the ecological validity of these measurements. While a clinical assessment in a controlled environment might provide more accurate measurements, their low frequency might fail to detect natural daily or weekly variations.

II. VIDEO GAMES AND OLDER ADULTS

Videogames can have a positive impact on the elder's mental and physical condition, according to recent studies. In one of these studies, subjects over 60 years-old played the game "Tetris" for a period of five hours a week over a five-week period. The results suggested that the use of games enhance their attention, hand-eye coordination, fine-motor skills, short-term memory, problem solving capacity, and reaction time [16]. Another study focused on the diagnosis of illnesses associated with age, like Alzheimer's disease or mild cognitive impairment [17]. In this study a version of "Freecell" was developed to measure the user's performance based on the number of movements which allowed to separate the subjects with cognitive impairment from a group of healthy elders. Videogames have also been used for occupational therapy or to bring a sense of accomplishment and improve self-esteem in a long-term care facility [18]. In addition videogames have also been observed to promote social interaction with peers of the same age and strengthen intergenerational relationships [19].

III. DESIGN OF VIDEOGAMES TO MEASURE MUSCLE STRENGTH AND FATIGUE

The design of videogames to detect dynapenia requires the development of a device capable of measuring the user's grip strength as he plays the videogames. For that purpose a Vernier Hand Dynamometer [20] was chosen as the core element of the interface along with additional electronic circuitry to augment the interface with more interaction affordances to the player such as an accelerometer and digital buttons. The interface consists of a Digital Signal Controller (DSC), an accelerometer, an IEEE 802.15.4 radio chip to allow wireless communication. In the prototype the DSC is a Microchip dsPIC33f64GP802, the accelerometer is a MMA7455 and we used an XBee module for the IEEE 802.15.4 network implementation. The DSC regularly (around 100 times a second) gathers the readings of all the sensors and then structures the data in a packet format to be transmitted through the IEEE 802.15.4 link. Another IEEE 802.15.4 module acts as a receptor connected to a PIC18F2550 microcontroller to gather the sensors' data through a USB interface. In this way we can reprogram the controller firmware over the air to make adjustments of the data or calibration.

To test the precision of the video game interface we compared the measurements obtained with a clinical dynamometer with those gathered using the device developed for this project. Measurements were taken from 10 participants using both devices and both hands. The correlation coefficient obtained is 0.98. Thus, the interface device properly measures grip strength.

3.1 Games to measure muscle strength

During the design process, the designers proposed several game concepts during brainstorming sessions and two initial concepts were selected based on the design insights obtained from the focus group session. The first videogame was based on a game of pool given that most aged players are familiar with this concept and requires the user to throw a white ball using the measured strength. The ball must be directed strategically to hit other balls of different color placed on a table in order to insert them in a hole marked with the same color. In that way, the player needs to figure out how to hit the balls to match the color patterns from the balls and the holes. When this happens a sound is played, giving positive feedback to the player.

Several affordances are included to give feedback of the amount of strength used in the controller like a sliding bar and a sound indicating an increase of the strength with which the ball will be hit. Once the player releases the pressure in the controller it will throw the ball with the amount of power registered in the bar. We decided to add strategy and physics based reaction of the game elements to deliver a more engaging experience.

The games were developed using action script 3 and the physics engine Box2D to provide the visual elements and C# and the .NET 3.0 framework to handle the low level interaction with the devices.

The second game was selected for simplicity so as not to provide a complicated plot for inexperienced players that are not familiar with the common conventions of current games. This game was based on the old platform games and requires the player to control a bird utilizing hand strength. When the player presses the controller, the bird will gain height and speed trying to avoid the planes flying randomly on the screen and at the same time enabling the player to collect items. If the bird collides with a plane an explosion will occur and the player will lose points. On the other hand if the player hits the items, he will earn score points. The use of these items was intended to give a sense of motivation and a defined goal. Figure 1 shows a user interacting with a game.

Figure 1. A user playing the games with the video game interface.

3.2 Preliminary evaluation of the game

After several iterations within the design team we conducted a formative evaluation with the target audience. We invited five participants from a community center to play with the games. The group's mean age was 71 years old and only one had experience playing video games before. After inquiring demographic data, the prototypes were presented to the participants in a 30 minutes play session. The purpose of the session was to find out if the game play devised was intuitive enough and verify if the difficulty settings were appropriate for the elders. For that purpose we conducted observations during the game play and asked them several open questions after they played.

After the play sessions the participants revealed that the pool game was more appealing to the male participants, maybe because of previous experiences, while the female participants preferred the bird game. Both games were easy to understand but the pool game needed more time to master because it required more skill and strategy than the other game but kept most players trying to improve their performance. On the contrary, the bird game was very easy to learn but some of the players found it little engaging after some time. So we found that adding more depth to a game play in general results in a more engaging experience when the rules are simple enough but it takes a learning curve that not all the players are willing to experience.

Further refinement and play testing with older adults is planned in order to adjust the appropriate level of difficulty and to improve the usability of the game interfaces.

3.3 Fire alert: a videogame to measure muscle fatigue

With the purpose of measuring muscle fatigue we designed a third game considering the method described by Bautmans *et al.* [21] to assess fatigue. In this procedure the user is instructed to perform a maximum voluntary contraction using the dynamometer and then to hold this level of force for as long as possible. The time between the maximum force and when it drops to 50% of the maximum is the muscle fatigue resistance. Considering this mechanic we devised a simple game play based on the old arcade games. In this game the user controls a vehicle with the mission to extinct an imminent conflagration in a forest. The user needs to appease the fire of a group of burning trees as quickly as possible by first grabbing water from a lake nearby using the force applied to the dynamometer and then retain the force to hold the water in the vehicle as it is moved towards the fire. The user can then move the vehicle to the burning building moving the hand and, controlling the angle with the accelerometer, to finally release the retained water to try to control the spreading fire. So as to make it equally challenging regardless of the user's muscle strength the game presents different scenarios that can be customized to take different measures. Figure 2 shows a snapshot of the game's screen. Playing this game we can measure fatigue resistance as the time it takes for muscle strength to decline 50% of the maximum force. Figure 3 the results of a measurement obtained using the interface device and the estimation for fatigue.

Figure 2. Firefighting videogame to measure muscle fatigue

I. CONCLUSION AND FUTURE WORK

In this paper we presented the design and development of three casual ambient games that involved the use of a prototype of an embodied video interface. We found that this device accurately measures grip strength to assist in the detection of early signs of dynapenia. In addition, muscle fatigue was measured using a videogame that requires the participant to sustain maximum strength for as long as possible. We also conducted a preliminary usability test and found that these games resulted appropriate and can be played by older adults although the results revealed differences in perception about difficulty based on gender and past experiences. This suggests that several game concepts need to be explored in order to attract a broader audience of older adults. We plan to propose an adaptation. Our aim is to develop gaming components associated to the interface device that can be easily incorporated into games to measure muscle strength and eventually other parameters of interest for the assessment of frailty among the elder. These components should adapt automatically based on the signals received from the sensors to balance the difficulty presented with the skills perceived or the physical condition to provide better incentives for player engagement.

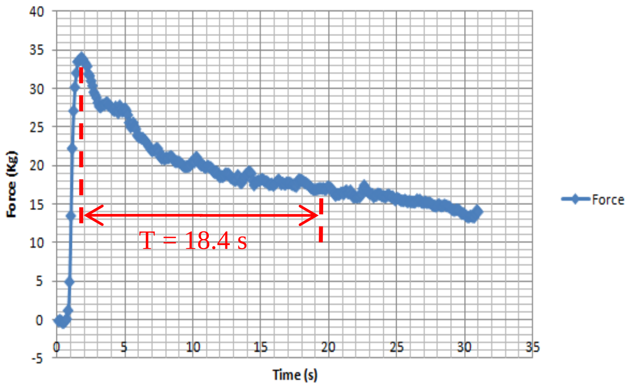

Figure 3. Muscle fatigue measured as the time it takes to reach 50% of the maximum force when playing "Fire alert"

Future directions may involve a better organization and treatment of the data gathered by the game to assess possible abnormal physical conditions. Another interesting improvement could be to introduce game play auto adaptation based on the signals received from the sensors to balance the difficulty presented with the skills perceived or the physical condition to provide better incentives for player engagement.

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