Development of a real world simulation to study cognitive, locomotor and metabolic processes in older adults

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ABSTRACT

The purpose of this paper was to demonstrate a proof of concept concerning the design and implementation of a simulation that replicates a real world environment in order to evaluate a complex task of shopping within a mall while measuring cognitive, motor and metabolic aspects of the task. The paper presents the experimental protocol and results from four young healthy and two elderly adults who performed the Multiple Errands Test in both simulated and real world settings. These initial findings show the feasibility of the protocol in both environments.

1. INTRODUCTION

Increased life expectancies now enable people to live 20 to 25% of their lives in retirement. They wish and are expected to maintain a more active life style. Nine out of 10 seniors continue to live in their own homes. However, the ability to accomplish what has become known as “successful aging” demands certain accommodations to support and compensate for declining functional abilities (Bowling, 2007). Universal design embodies the concept of designing all products and environments to be usable by and supportive to the greatest extent possible of everyone, regardless of age, ability, or status (Buiza et al, 2009). Despite such lofty ideals, aging is associated with increased physical and cognitive disability that lead to considerable daily challenges in social participation and/or the full accomplishment of life habits including every day, basic or instrumental activities such as shopping. Fricke & Unsworth (2001) found that 90.9% of older participants spent half their day on tasks related to Instrumental Activities of Daily living (IADL); they perceived the most important IADL to be transportation (walking as well as driving). Food shopping is also a necessary daily activity which contributes to a person’s sense of independence (Thompson et al, 2011).

Although research of older age has grown substantially, not enough is known about how older adults perform in complex life situations; this is partially due to technical limitations of measurement tools. Mitchell (http://livinglabs.mit.edu/) proposed the concept of “Living Labs as a research paradigm for sensing, prototyping, validating and refining complex solutions in multiple and evolving real life contexts”. The Living Lab aims to provide the definitive realization of participatory design to identify true behaviour (Følstad, 2008).

One of the goals of a “Living Lab” is to assess behaviour in complex settings and to find ways to overcome environmental barriers as in the strategic interdisciplinary and multi-sectorial research study that is exploring the

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principal obstacles, either physical or psychosocial, to social participation and inclusion for persons with disabilities in a commercial mall environment (www.crir-livinglabvivant.com). Simulation of these complex settings enables analysis of performance with greater accuracy as well as evaluation of various solutions before their implementation in a real environment. Simulations running on a range of virtual reality (VR) platforms enable objective and accurate measurement of behaviour in challenging, ecologically-valid and safe environments, while controlling delivery of stimulus and maintaining standardization of measurement protocols (Rizzo & Kim, 2005). Over the years many functional virtual environments (VEs) were developed in order to measure or train skills needed for daily activities (e.g., Kizony et al. 2010; Klinger et al, 2004; Rand et al, 2005; Fung et al, 2006). Research has shown transfer of these skills to real world settings (e.g., Stanton et al, 2002; Rand et al, 2009a; 2009b).

Recently, simulations of almost identical replications of real world environments (e.g., a shopping mall or a house) were created to assess clients' cognitive-functional skills (Koenig et al, 2011; Koenig, 2012; Sangani et al, 2012; 2013). However, most VEs do not enable the replication of task complexity in the real world, i.e., walking at a self-selected speed while stopping to perform a task such as buying an item and then continuing to walk. Rather, measurement in most VEs is restricted to isolated motor or cognitive aspects of task performance. Recent literature suggests that the use of assessment strategies that focus on body function and/or activity (i.e., isolated tasks) rather than on participation (i.e., complex functional tasks) do not sufficiently take into account all of the factors that contribute to or detract from successful functioning (Burgess et al, 2006) and especially do not account for age-dependent decline. In addition, most studies have examined the contribution of isolated factors (e.g., cognition or metabolism) to participation, which limits a full understanding of performance in complex life situation. Whether decline in function due to aging is viewed as a disease or whether it is viewed as a natural process, it is important to understand and characterize the ways in which age-related impairment of cognitive, motor and physiological processes, individually or in combination, impede the ability of elderly persons to accomplish daily tasks in complex life situations. This may only be accomplished via a multi-dimensional approach to experimental design and data collection.

The objectives of this paper are to (1) describe the process of creating and implementing a realistic simulation of an actual complex environment that can be navigated and used to perform functional tasks; (2) describe the functional tasks created within this simulation and the outcomes used to monitor the metabolic, locomotion and cognitive aspects of the task; (3) show proof of concept by comparing performance of a small number of healthy young adults in the simulation to their performance in the real world, as a first step prior to the testing of older adults.

2. METHODS

2.1 Simulation and real world shopping malls

A simulation of a small shopping mall located at the Sheba Medical Center (Tel Hashomer, Israel) was created. The first stage before building the simulation was to sketch the mall structure and take photographs of the stores within it. Additional photographs were taken inside some of the stores (e.g., shelves, items for sale) to enable the creation of functional tasks within these stores. The VE was created with XSI (Autodesk®) using two main techniques: (1) Inserting the photographs onto a 2D grid (x and y axes) in order to create 2D objects that produce the illusion of 3D spaces (see Figures 1and 2). (2) A skeleton of the mall (corridors, floors, ceiling, tables) and items in several stores and kiosks (e.g., lottery tickets, magazines) were created as 3D objects. The 3D objects were wrapped by textures from the photographs taken in the real mall. The participants were able to interact with, i.e., "buy" these items.

The simulation runs in the CAREN™ (Computer Assisted Rehabilitation Environment) Integrated Reality System using DFlow software (www.e-motek.com) and is projected onto a 52" wall-mounted monitor. The participant walked on an interactive, self-paced instrumented treadmill (VGait; Motek Medical B.V.) facing the monitor and navigated through the simulation with a joystick (see Figure 3). The scene is shown to advance in accordance with the speed of the treadmill, i.e., the participant's self-paced speed of gait. In addition, 20 passive markers were placed on the participant's anatomical landmarks and sampled at 120 Hz to record 3D trunk and limb motion. The markers were detected by an optokinetic system which consists of 12 VICON infra-red cameras having a resolution of 2 megapixels (www.vicon.com). The markers were detected by CAREN to activate the self-paced treadmill and to enable interaction with the 3D objects. Data from the simulation, treadmill and markers were recorded and synchronized via CAREN.

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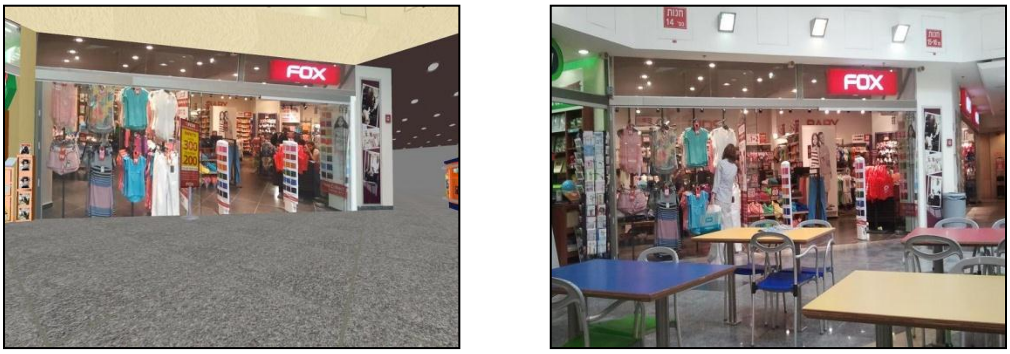

Figure 1. A *screen shot of simulated clothing store (left) and a photo of the actual store (right) in the Sheba Medical Center shopping mall.*

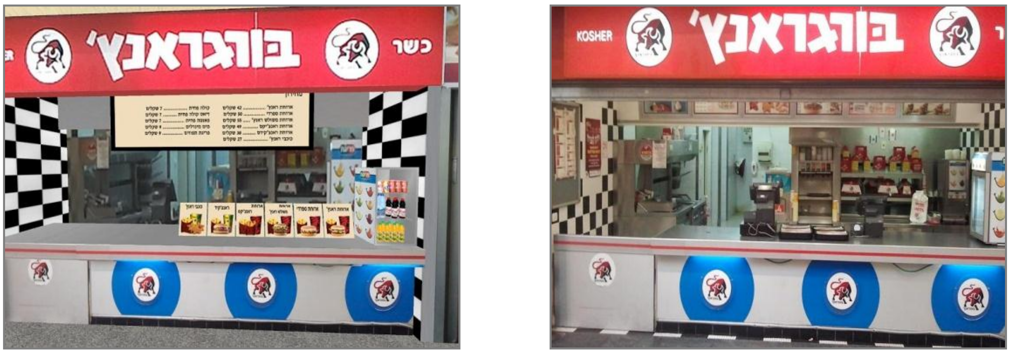

Figure 2. A *screen shot of simulated fast food restaurant (left) and a photo of the actual fast food restaurant (right) in the Sheba Medical Center shopping mall.*

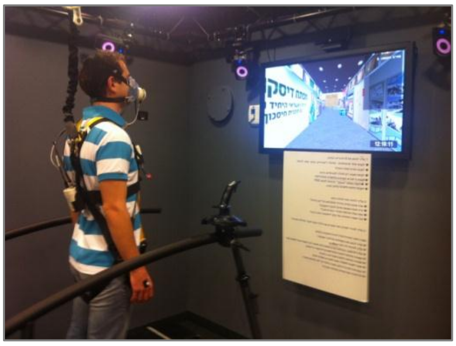

Figure 3. A *screen shot of the simulation's set up at the Center of Advanced Technologies in Rehabilitation, Sheba Medical Center, Tel Hashomer, Israel*.

The real mall is a small shopping area of about 12 stores all located on the same floor of a building at the Sheba Medical Center. The mall contains stores that sell clothing, books, handbags as well as a coffee shop, a fast-food outlet, a lottery and other kiosks and a bank.

2.2 Experimental tasks and apparatus

The Multiple Errands Test-Simplified Version (MET-SV or MET) (Alderman et al, 2003) was designed to examine Executive Functions (EF) in a real mall environment. The participant was asked to perform three types of tasks in the shopping mall: purchase six items, obtain and record four pieces of information, and meet the examiner at a preset location and time while abiding by certain rules. The examiner observed the participant, recording strategies and mistakes. The MET-SV has been validated on a variety of populations (Dawson, 2005; Revach & Katz, 2005). The Virtual MET (VMET) (Rand et al, 2009a) is an adapted version of the MET. It consists of the same number of tasks but the products have been changed to those that may be found in the simulated mall. In both MET and VMET, lower scores represent better performance. Metabolic and gait parameters were measured while performing the MET and the VMET.

Metabolic measures included oxygen consumption (VO_2) and respiratory frequency (RF) as markers for energy expenditure and respiratory function and were measured using the $K4b^2$ system, a portable transmitting unit affixed to a chest harness and a receiving unit. The $K4b^2$ has been shown to be an accurate method of assessing VO_2 and RF over a wide range of exercise intensities (McLaughlin et al, 2001). Heart rate (HR) was measured with a Polar heart rate monitor strapped around the chest.

The Mobility lab System (http://www.apdm.com/gait-and-posture/Mobility-Lab/) was used to measure gait variables (e.g., speed, stride time and length, cadence) during the MET and VMET. It consists of six small wireless OPAL™ movement monitors that are affixed to the participant's hands, legs and waist. The monitors do not interfere with walking. It has been shown to be sensitive and reliable (Salarian et al, 2010).

The Six-Minute Walk test (6MWT) (Montgomery & Gardner, 1998); participants were asked to walk in their self-selected comfortable speed for a 6 minute period.

Perceived exertion was measured by Borg's scale, rated from 6 (minimal effort) to 20 (maximal effort). Validity of the scale has been established by the demonstration of correlations between the rate of perceived exertion (RPE) and heart rate, %VO2 max (Carvalho et al, 2009).

The Short Feedback Questionnaire (SFQ) (Kizony et al, 2006) is based, in part, on a translated version of Witmer and Singer's Presence Questionnaire (1998) and was administered after the participants experienced the VMET. These six items query participant's (1) feeling of enjoyment, (2) sense of being in environment, (3) success, (4) control, (5) perception of the environment as being realistic and (6) whether the feedback from the computer was understandable. An additional question was added to inquire whether the participants felt any discomfort during the experience.

2.3 Procedure

Participants were tested during two 120-minute sessions, separated by up to three weeks. Data were collected in two locations at the Sheba Medical Center (Tel Hashomer, Israel); the MET was performed at the Medical Center's shopping mall and the VMET was performed at the Center of Advanced Technologies in Rehabilitation. During the first session, baseline metabolic measures were obtained while the participant sat quietly (15 min) and then during the 6MWT at a self-selected comfortable pace. Thereafter, the participant performed the MET in the real mall or the VMET in the simulation. Before the VMET was performed, a 10 minute training period in the simulation was given to familiarize participants with the setting, interaction and walking on a self-paced treadmill. After completion of the VMET, each participant was asked to rate the SFQ items. While performing the MET and VMET tasks, O2 consumption, CO2 production and heart rate were monitored. During the second session, a baseline of metabolic measures was obtained as described above.

3. RESULTS

3.1 Feasibility of protocol

To date, four healthy young adults (2 male, 2 female; aged 20.5, 21, 25 and 29 years) and two older adults (male; aged; 83 and 69.5), cognitively intact (Mini-Mental State Exam equal to 29 and 30 respectively) completed the full protocol.

The young adults and the 69 year old male were able to perform the task and testing protocols in both the real and simulated environments while data were collected via the gait and metabolic systems. The 83 year old male was able to complete the practice tasks within the simulation but encountered difficulties when trying to perform the multitasking. In addition the protocol was not completed due to technical issues. Due to technical issues with the measurement tools gait variables from the APDM system were not recorded for participants 1 and 2 in the real world, and metabolic variables were not collected for participant 1 in the real world.

3.2 Performance of the MET and VMET

Results from the MET and VMET are presented in Table 1. Time to complete the task was the same or shorter in the simulation. However, 4/6 participants performed worse in the simulation.

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Table 1. *Performance (time and scores) of the MET and VMET. Lower scores on the MET and VMET represent better performance. N/A indicates that data are not available.*

			Time to complete (min)		Total Score	
Participant	Age (years)	Gender	MET	VMET	MET	VMET
1	21.0	male	19.0	15.4	3	6
2	29.0	female	17.0	17.0	6	2
3	25.0	male	22.15	15.0	0	8
4	20.5	female	11.3	12.32	3	5
5	83.0	male	29.38	N/A	5	10
6	69.5	male	24.33	18	1	1

Table 2. *Gait speed and metabolic outcomes for each participant during three conditions. Mean and (standard deviations) are shown when applicable. N/A indicates that data are not available. Data are presented as means (standard deviation).*

Participant	Variable	Comfortable speed	MET	VMET
1	Gait Speed (m/s)	1.04 (0.11)	N/A	0.6 (0.1)
	Metabolic equivalents	3.3 (0.7)	N/A	2.3 (0.8)
	HR (b/min.)	99 (3.8)	N/A	94 (3.7)
	RF (b/min.)	21.4 (3.2)	N/A	17.5 (3.8)
	Borg's Scale	N/A	6	11
2	Gait Speed (m/s)	1.5 (0.08)	N/A	0.7 (0.3)
	Metabolic equivalents	3.57 (0.9)	2.32 (1)	2.12 (0.8)
	HR (b/min.)	105.2 (1.5)	103.5 (5.1)	100.3 (3.1)
	RF (b/min.)	26.3 (4.9)	27 (6.4)	26.7 (6.9)
	Borg's Scale	N/A	10	11
3	Gait Speed (m/s)	1.5 (0.09)	1.1 (0.07)	0.7 (0.1)
	Metabolic equivalents	3.0 (1.3)	2.2 (0.8)	2.8 (1)
	HR (b/min.)	115 (3.5)	123.8 (6.7)	115.4 (5.5)
	RF (b/min.)	26.6 (13.3)	24.9 (9.3)	23.5 (4.5)
	Borg's Scale	N/A	9	12
4	Gait Speed (m/s)	1.7 (0.1)	1.3 (0.1)	0.7 (0.1)
	Metabolic equivalents	4.19 (0.3)	2.3 (0.6)	1.5 (0.27)
	HR (b/min.)	124 (4.6)	108 (10.5)	78 (3.4)
	RF (b/min.)	40.7 (1.7)	37.5 (3.4)	29 (2.4)
	Borg's Scale	N/A	11	11
5	Gait Speed (m/s)	1.2 (0.8)	0.9 (0.05)	0.7 (0.07)
	Metabolic equivalents	2.9 (0.2)	1.6 (0.4)	N/A
	HR (b/min.)	84 (0.9)	89 (2.6)	N/A
	RF (b/min.)	15.7 (0.8)	16.7 (3.3)	N/A
	Borg's Scale	N/A	11	15
6	Gait Speed (m/s)	1.5 (0.09)	1.3 (0.09)	0.5 (0.2)
	Metabolic equivalents	2.7 (0.2)	1.6 (0.6)	1.6 (0.3)
	HR (b/min.)	92 (1.9)	91 (7.0)	76 (6.0)
	RF (b/min.)	23.1 (2.2)	24 (2.7)	22.8 (2.3)
	Borg's Scale	N/A	7	9

3.3 Metabolic measurements

Mean values of metabolic equivalents, heart rate (HR) and RF of the participants as well as their gait speed are presented in Table 2. Data from the last four minutes of the 6MWT (comfortable speed) and during the time while shopping in the simulated mall and in the real world have been analyzed to date. Metabolic equivalents were calculated by dividing the mean VO_2 during the activity by 3.5 (which is a generic value of resting oxygen consumption). Intensity of physical activity is classified based on the metabolic equivalents with metabolic equivalents lower than 3 (indicating light intensity), between 3 and 6 (representing moderate intensity), and higher than 6 (representing vigorous intensity) (ACSM's guidelines, 2009). Metabolic equivalent values indicate that performing the shopping task either in the simulation or the real world involved activity at light intensity across the participants tested so far. The perceived exertion as measured by Borg's scale supports the metabolic measurements indicating activity at light intensity, except for the 83 year old participant who rated his exertion during the activity in the simulation as hard (Carvalho et al, 2009). Intensity of comfortable walking in comparison with the activities in either the simulation or real world was slightly higher and reached the lower end of moderate intensity in the young participants and the higher end of the range of light intensity in the older participants. HR and RF values did not present consistent pattern.

3.4 Locomotion measurements

Gait outcomes that are sensitive to changes in cognitive load and task complexity are presented in Tables 2 and 3. Means and SDs of gait speed (Table 2) and cadence (Table 3) as well as number of strides, coefficient of variance (CoV) of stride length and stride time (Table 3) are presented. The gait parameters represent data that was cleaned from turns and stops that were done due to the nature of the task. Gait speed decreased from 6MWT to MET and was the slowest during the VMET. In most cases, this was accompanied by and an increase in CoV of stride length and time with the largest CoV shown during the VMET. Distance walked within the simulation ranged between 100 and 286 meters.

3.5 Short feedback questionnaire

Participants enjoyed the experience in the simulation (scores of 4.5/5 for the younger participants and 3/5 for the older participants) but they all reported that it was only moderately realistic (scores varying between 3/5-4/5). Five participants stated that the feedback for their actions was very clear (5 out of 5). No cybersickness-type side effects were reported by the participants.

4. CONCLUSIONS

The main purpose of this paper was to demonstrate a proof of concept of the design and implementation of a simulation and the real world environment that it replicates. Both enabled evaluation of the complex task of shopping within a mall while measuring motor, cognitive and metabolic variables. This was accomplished by testing four healthy young adults and two healthy older adults, as a step before the recruitment of older adults with Minimal Cognitive Impairment. The results demonstrated the feasibility of the protocol during both the simulated and the real world tasks. We were able to collect the metabolic and cardiopulmonary as well as locomotion data in both environments even though the collection of metabolic data requires the wearing of a mask. The disturbance to the participant's ability to communicate and field of view due to the mask did not appear to unduly constrain performance during either the MET or VMET tasks.

The measurement of performance during realistic activities is often difficult to achieve due to issues related to encumbrance, ecological validity and valid monitoring. Previous attempts to accomplish this goal usually involved simpler experimental paradigms and, hence, more limited data outcomes. For example, tasks described in the literature were performed either while standing (e.g., Rand et al, 2009a) or walking through one aisle without stopping to shop as would normally occur in the real world (e.g., Kizony et al, 2010). In contrast, the simulation developed for the current study supports the participant's need to engage in multi-tasking activities, such as walking at their comfortable speed and stopping to "shop" for items in accordance with the task's demands.

For the four young and one older participants tested so far, the MET and the VMET were easy to perform, from both physical and cognitive aspects, as reflected by the total scores of the tests and the metabolic outcomes. The oldest participant (83 years) had more difficulties during the VMET and whether it was due to aging or due to technological issues should be further examined. The estimated metabolic equivalents reported in the compendium of physical activities for this type of activity (i.e., food shopping) are 2.3 (Ainsworth et al, 2000) which is similar to the metabolic equivalents calculated for our participants in both environments. This indicates that the demands of the tasks used in our protocol appear to be similar to real world shopping tasks.

The simulation described in this paper appears to have considerable potential to assess behaviours similar to those seen in the real world but at a higher resolution which may provide results that will be useful in designing a "living lab" in the future. However, differences in gait parameters and their influence on performance should be further examined. We believe that these combined metabolic, gait and cognitive data will help to explore the strategies used by participants to accomplish functional tasks such as shopping.

Table 3. *Gait outcomes during the three conditions (Comfortable speed, MET, VMET). Mean and (standard deviations) are shown when applicable. N/A indicates that data are not available.* Cov = coefficient of variance

Participant		**Comfortable speed**	**MET**	**VMET**
1	Number of strides	170	N/A	128
	Stride Length (Cov)	0.09	N/A	0.3
	Stride time (Cov)	0.08	N/A	0.13
	Cadence (steps/min)	85.5 (13.3)	N/A	77.3 (12.5)
2	Number of strides	322	N/A	289
	Stride Length (Cov)	0.04	N/A	0.2
	Stride time (Cov)	0.03	N/A	0.3
	Cadence (steps/min)	114.2 (3.3)	N/A	73 (0.2)
3	Number of strides	313	229	330
	Stride Length (Cov)	0.04	0.09	0.2
	Stride time (Cov)	0.03	0.06	0.09
	Cadence (steps/min)	113.5 (6.8)	116.5 (10.8)	92.1 (9.5)
4	Number of strides	357	168	63
	Stride Length (Cov)	0.04	0.12	0.17
	Stride time (Cov)	0.03	0.08	0.1
	Cadence (steps/min)	124.7 (4.0)	113.6 (10.8)	69.7 (7.8)
5	Number of strides	287	158	88
	Stride Length (Cov)	0.05	0.16	0.14
	Stride time (Cov)	0.03	0.08	0.07
	Cadence (steps/min)	103.2 (3.7)	107.3 (10.1)	99.2 (11.8)
6	Number of strides	321	266	193
	Stride Length (Cov)	0.04	0.09	0.3
	Stride time (Cov)	0.07	0.06	0.2
	Cadence (steps/min)	114.1 (4.6)	106.3 (6.9)	81.1 (0.2)

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