Metabolic costs of daily activity in older adults (Chores XL) study: Design and methods

Duane B. Corbetta a, Amal A. Wanigatunga b, Vincenzo Valiani a, Eileen M. Handberg c, Thomas W. Buford d, Babette Brumback d, Ramon Casanova e, Christopher M. Janelle f, Todd M. Manini a,∗

a Department of Aging and Geriatric Research, Gainesville, FL 32611, USA
b Department of Epidemiology, Gainesville, FL 32611, USA
c Division of Cardiovascular Medicine, Gainesville, FL 32610, USA
d Department of Biostatistics, Gainesville, FL 32611, USA
e Department of Biostatistical Sciences, Winston-Salem, NC 27157, USA
f Department of Applied Physiology and Kinesiology, Gainesville, FL 32611, USA

Article info
Article history:
Received 28 October 2016
Received in revised form 6 February 2017
Accepted 9 February 2017
Available online 11 February 2017

Keywords:
Physical activity
Metabolism
Aging
Energy expenditure
Functional impairment

ABSTRACT

Background: For over 20 years, normative data has guided the prescription of physical activity. This data has since been applied to research and used to plan interventions. While this data seemingly provides accurate estimates of the metabolic cost of daily activities in young adults, the accuracy of use among older adults is less clear. As such, a thorough evaluation of the metabolic cost of daily activities in community dwelling adults across the lifespan is needed.

Methods: The Metabolic Costs of Daily Activity in Older Adults Study is a cross-sectional study designed to compare the metabolic cost of daily activities in 250 community dwelling adults across the lifespan. Participants (20 + years) performed 38 common daily activities while expiratory gases were measured using a portable indirect calorimeter (Cosmed K4b2). The metabolic cost was examined as a metabolic equivalent value (O2 uptake relative to 3.5 mL min−1/C0/kg−1), a function of work rate− metabolic economy, and a relative value of resting and peak oxygen uptake.

Results: The primary objective is to determine age-related differences in the metabolic cost of common lifestyle and exercise activities. Secondary objectives include (a) investigating the effect of functional impairment on the metabolic cost of daily activities, (b) evaluating the validity of perception-based measurement of exertion across the lifespan, and (c) validating activity sensors for estimating the type and intensity of physical activity.

Conclusion: Results of this study are expected to improve the effectiveness by which physical activity and nutrition is recommended for adults across the lifespan.

© 2017 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Background

The Compendium of Physical Activities provides estimates of metabolic equivalents (METs) for hundreds of daily activities [1]. Health care practitioners often use it as a resource to prescribe physical activity at a safe intensity for their patients [2]. However, while this resource has been used for the past two decades, it lacks representation of older adults with and without functional impairment, which could lead to misguided recommendations in this population [3−6].

Previous work has shown that the metabolic cost of ambulation increases with age − a function of adopting slower and more variable physical movements [7]. However, it is unclear how the metabolic cost of a wide variety of daily activities differs across the lifespan. In addition, little attention has been given to the moderating effect of functional impairment on the metabolic cost of activities [8]. In fact, a growing number of older adults − 26% of those over 75 years of age − report having one or more limitations when performing daily activities essential for maintaining independence in the community [9]. Despite this knowledge, the effect of
functional impairment on the metabolic cost of daily activities is not completely understood. As a result, the Physical Activity Guidelines Advisory Committee has recommended expanding objective data on physical activity intensity in special populations [10]. A precise estimation of metabolic demands across the lifespan and understanding the impact of functional impairment will aid practitioners in prescribing physical activity to an aging America.

Perceived exertion is defined as detecting and interpreting sensations arising from the body during human movement [11] and is a recommended method to adjust the intensity of both aerobic and muscle-strengthening activities to meet Federal Physical Activity Guidelines [10]. The Borg Rating of Perceived Exertion (RPE) scale has become a ubiquitous instrument for measuring perceived exertion in clinical and public health settings [12]. Validation studies supporting the prescriptive use of RPE have compared exertional responses to criterion variables such as oxygen consumption and heart rate [13]. However, few studies have carried out thorough evaluations of the RPE scale in older adults. In fact, a meta-analysis of 105 studies only found one that was performed in adults >70 years [13]. Additionally, validity of the RPE scale is most commonly derived during incline- or load-incremented protocols on the treadmill. Yet, there is little known about the accuracy of the RPE scale for gauging exertion during daily activities and the potential factors associated with under and over-estimating exertion across the lifespan [14].

In addition to concerns associated with the accuracy of existing assessments, technological advancements offer emerging opportunities for more comprehensive real time data acquisition and usage. In particular, there is a pervasive and rapidly growing use of wearable physical activity monitors in both public and research settings. The growing use of technology has enhanced the ability to achieve objective measures of movement, primarily accelerometer-based, that have become a necessity in physical activity research. However, the validity of their current use for measuring intensity among older adults is suspicious. In addition, as this technology is expanding with faster and additional hardware components (e.g., accelerometers, gyroscopes, altimeters, etc.), advanced machine learning algorithms are necessary to map the large amounts of data. Inputs of METs for activity intensity and descriptive information about the type of activity are used to calibrate the algorithms. Additional inputs such as age, cognitive status, and specific disease conditions may further refine their accuracy [15].

These gaps in knowledge provided the impetus for “The Metabolic Costs of Daily Activity in Older Adults (Chores XL) Study”, an observational cross-sectional study designed to measure the metabolic cost of daily activities commonly engaged among community dwelling adults across the lifespan (age 20 + years). The four major objectives and hypotheses of the study are to:

1.1. Determine age-related differences in the metabolic cost of daily activities

Aging is hypothesized to be associated with different metabolic costs during common daily activities. The metabolic cost of activities was objectively measured via indirect calorimetry during a variety of daily activities in adults 20 to 80 + years. The metabolic cost of each activity was assessed in three ways: 1) as a MET value ($O_2$ uptake relative to 3.5 ml/kg/min), 2) as a function of work rate—metabolic economy, and 3) as a relative value of resting and peak $O_2$ uptake.

1.2. Investigate the effect of functional impairment on the metabolic cost of daily activities

MET value of daily activities is predicted to be lower in older adults with functional impairment compared to those without. Functional impairment will also be associated with poor metabolic economy compared to older adults without impairments. The relative metabolic cost of performing daily activities will be higher in the functionally impaired.

1.3. Evaluate the validity of perception of exertion across the lifespan

Accuracy in perception-based measurement of exertion is expected to be impaired with aging. Demographic, psychological, clinical and physiological factors were also examined to explain age-related differences in rating exertion for improving rating accuracy.

1.4. Validate accelerometry for estimating the type and intensity of physical activity

The goal is to model accelerometer data using machine learning classification algorithms that estimate the type and intensity of physical activity with greater accuracy than conventional methods. We tentatively assert that accelerometer data can be more effectively modeled using machine learning techniques. The location of monitor placement was also compared using five body locations (wrist, ankle, hip, upper arm and thigh).

2. Methods

2.1. Study design

The Chores XL study was descriptive, cross-sectional study comparing the metabolic cost of daily activities in a population-based representative sample of apparently healthy community dwelling adults across the lifespan. Participants performed standardized lifestyle, exercise and sedentary type physical activities in a clinic laboratory setting (all tasks and descriptions are listed in Table 3). Data collected from this study will be used to provide evidence of potential age-related differences in the metabolic cost of daily activities between young, middle-aged, and older adults. With the acknowledgement of an important distinction between laboratory and home-based metabolic costs, METs were also compared at home versus in the laboratory in a random subset of individuals on tasks with asterisks in Table 3.

2.2. Participant eligibility

The complete list of inclusion and exclusion criteria are provided in Table 1. The eligibility criteria were designed to encompass a full age range (20 + years) of community dwelling adults. Participants were required to understand and speak English, have stable body weight for at least three months, and willing to undergo all testing procedures. To understand the effect of functional impairment on the metabolic cost of daily activities, a subset of older adults with a Short Physical Performance Battery (SPPB) score <10 (of 12) was also included in the study [16]. All study procedures were approved by the University of Florida (UF) Institutional Review Board. All individuals provide written informed consent before study participation according to institutional and federal guidelines.

2.3. Recruitment

A total of 250 participants were needed to address the objectives of the study. Recruitment targeted 56% women, 18% racial minorities, and 10% Hispanic or Latino ethnic minorities. The goal was to recruit approximately 25 participants in the following age decades:
The treadmill protocol was modified to accommodate individuals who had previous weight reduction surgery, known neuromuscular disorder (Rhabdomyolysis, Myasthenia Gravis, Ataxia, Apraxia, post-polio syndrome, mitochondrial myopathy, etc.) or diagnosed neuropathy causing pain. Symptomatic peripheral arterial disease was defined as a known diagnosis of dementia or short, <24 on Mini-Mental State Exam. Severe cardiac disease, including NYHA Class III or IV congestive heart failure, clinically significant aortic stenosis, recent history of cardiac arrest, use of a cardiac defibrillator, or uncontrolled angina was evaluated. Other significant comorbid disease discovered during medical screening, e.g. renal failure on hemodialysis, psychiatric disorder (e.g. bipolar, schizophrenia), excessive alcohol use (>14 drinks per wk); chronic fatigue syndrome. Use of anabolic medications (testosterone, estrogen, or steroid pills) was contraindicated to graded exercise testing.

Protocol was used to adjust the intensity in a graded fashion [19]. Criteria: plateau in VO2, heart rate (HR) within 10 beats/min of age-predicted maximum HR, RER >1.1, respiratory exchange ratio >1.1, and perceived exertion (15–20 on Borg CR-10 scale). The treadmill test was terminated if the participant met any one of the following conditions: (a) exhaustion during the test. Tests were graded on the following relative metabolic scale as a function of measured resting metabolic rate and peak oxygen capacity.

Resting metabolic rate (RMR) was measured following a 4-h restriction of caffeine, food, and tobacco. Participants were also asked to refrain from strenuous physical activity for 24 h prior to testing. Expiratory gases were collected for 20 min and the final 30 min of data were averaged and RMR calculated using the Weir formula [18].

A graded treadmill exercise test was conducted to assess peak metabolic rate (e.g. cardiopulmonary capacity). A modified Bruce Protocol was used to adjust the intensity in a graded fashion [19]. The treadmill protocol was modified to accommodate individuals with physical impairments (e.g. reduce the speed of the treadmill). Participants were given strong verbal encouragement to achieve exhaustion during the test. Tests were graded on the following criteria: plateau in VO2, heart rate (HR) within 10 beats/min of age-related differences in the metabolic cost of daily activities. To satisfy this objective, oxygen consumption was measured as previously described using a portable indirect calorimeter (Cosmed K4b2) [8]. Notably, the mass of this device (1.5 kg) was added to total body mass in calculating MET values [17]. Oxygen consumption was measured breath-by-breath through a mask that was fitted to the participants face. To prevent poor quality metabolic data, participants were asked to refrain from talking while wearing the mask unless they feel unsated.

Data collected by the Cosmed K4b2 were subsequently smoothed using a 30-s moving average and then converted to MET values, defined as the oxygen uptake (VO2 = milliliter min<sup>−1</sup> kg<sup>−1</sup>) during a steady state rate expressed as a function 3.5 mL min<sup>−1</sup> kg<sup>−1</sup>. Data were also expressed as metabolic economy, defined as the oxygen uptake for a given workload. A higher oxygen uptake for a given workload indicates a poorer metabolic economy. Lastly, oxygen consumption was also calculated on a relative metabolic scale as a function of measured resting metabolic rate and peak oxygen capacity.

Recruitment strategies included the use of newspaper advertisements, direct mail, and community presentations, senior centers, medical clinics, and churches.

### 2.4. Study measures

#### 2.4.1. Primary study outcome

The primary objective is to determine the age-related differences in the metabolic cost of daily activities. To satisfy this objective, oxygen consumption was measured as previously described using a portable indirect calorimeter (Cosmed K4b2) [8]. Notably, the mass of this device (1.5 kg) was added to total body mass in calculating MET values [17]. Oxygen consumption was measured breath-by-breath through a mask that was fitted to the participants face. To prevent poor quality metabolic data, participants were asked to refrain from talking while wearing the mask unless they feel unsated.

Data collected by the Cosmed K4b2 were subsequently smoothed using a 30-s moving average and then converted to MET values, defined as the oxygen uptake (VO2 = milliliter min<sup>−1</sup> kg<sup>−1</sup>) during a steady state rate expressed as a function 3.5 mL min<sup>−1</sup> kg<sup>−1</sup>. Data were also expressed as metabolic economy, defined as the oxygen uptake for a given workload. A higher oxygen uptake for a given workload indicates a poorer metabolic economy. Lastly, oxygen consumption was also calculated on a relative metabolic scale as a function of measured resting metabolic rate and peak oxygen capacity.

Resting metabolic rate (RMR) was measured following a 4-h restriction of caffeine, food, and tobacco. Participants were also asked to refrain from strenuous physical activity for 24 h prior to testing. Expiratory gases were collected for 20 min and the final 30 min of data were averaged and RMR calculated using the Weir formula [18].

A graded treadmill exercise test was conducted to assess peak metabolic rate (e.g. cardiopulmonary capacity). A modified Bruce Protocol was used to adjust the intensity in a graded fashion [19]. The treadmill protocol was modified to accommodate individuals with physical impairments (e.g. reduce the speed of the treadmill). Participants were given strong verbal encouragement to achieve exhaustion during the test. Tests were graded on the following criteria: plateau in VO2, heart rate (HR) within 10 beats/min of age-related differences in the metabolic cost of daily activities. To satisfy this objective, oxygen consumption was measured as previously described using a portable indirect calorimeter (Cosmed K4b2) [8]. Notably, the mass of this device (1.5 kg) was added to total body mass in calculating MET values [17]. Oxygen consumption was measured breath-by-breath through a mask that was fitted to the participants face. To prevent poor quality metabolic data, participants were asked to refrain from talking while wearing the mask unless they feel unsated.

Data collected by the Cosmed K4b2 were subsequently smoothed using a 30-s moving average and then converted to MET values, defined as the oxygen uptake (VO2 = milliliter min<sup>−1</sup> kg<sup>−1</sup>) during a steady state rate expressed as a function 3.5 mL min<sup>−1</sup> kg<sup>−1</sup>. Data were also expressed as metabolic economy, defined as the oxygen uptake for a given workload. A higher oxygen uptake for a given workload indicates a poorer metabolic economy. Lastly, oxygen consumption was also calculated on a relative metabolic scale as a function of measured resting metabolic rate and peak oxygen capacity.

Resting metabolic rate (RMR) was measured following a 4-h restriction of caffeine, food, and tobacco. Participants were also asked to refrain from strenuous physical activity for 24 h prior to testing. Expiratory gases were collected for 20 min and the final 30 min of data were averaged and RMR calculated using the Weir formula [18].

A graded treadmill exercise test was conducted to assess peak metabolic rate (e.g. cardiopulmonary capacity). A modified Bruce Protocol was used to adjust the intensity in a graded fashion [19]. The treadmill protocol was modified to accommodate individuals with physical impairments (e.g. reduce the speed of the treadmill). Participants were given strong verbal encouragement to achieve exhaustion during the test. Tests were graded on the following criteria: plateau in VO2, heart rate (HR) within 10 beats/min of age-related differences in the metabolic cost of daily activities. To satisfy this objective, oxygen consumption was measured as previously described using a portable indirect calorimeter (Cosmed K4b2) [8]. Notably, the mass of this device (1.5 kg) was added to total body mass in calculating MET values [17]. Oxygen consumption was measured breath-by-breath through a mask that was fitted to the participants face. To prevent poor quality metabolic data, participants were asked to refrain from talking while wearing the mask unless they feel unsated.

Data collected by the Cosmed K4b2 were subsequently smoothed using a 30-s moving average and then converted to MET values, defined as the oxygen uptake (VO2 = milliliter min<sup>−1</sup> kg<sup>−1</sup>) during a steady state rate expressed as a function 3.5 mL min<sup>−1</sup> kg<sup>−1</sup>. Data were also expressed as metabolic economy, defined as the oxygen uptake for a given workload. A higher oxygen uptake for a given workload indicates a poorer metabolic economy. Lastly, oxygen consumption was also calculated on a relative metabolic scale as a function of measured resting metabolic rate and peak oxygen capacity.
predicted maximal HR, respiratory exchange ratio >1.10, exhaustion defined as RPE of 9–10 on the Borg CR-10 scale, or achievement of predicted maximal work rate [20].

2.4.2. Secondary outcomes

Physical function — To investigate the effect of functional impairment on the metabolic cost of daily activities calculated as METs, metabolic economy, and relative metabolic cost of daily activities, were compared between high and low functioning older adults. SPPB was used to categorize participant’s functional status. This scale is reliable and valid for predicting institutionalization, mortality, and disability [16]. The test is based on timed 4 m walk, 5 repeated chair stands, and 3 balance tests. Each test is used to create a summary SPPB score that ranges from 0 (worst performers) to 12 (best performers) [21].

Perception of exertion — To evaluate the accuracy of perception-based measurement of exertion, RPE was compared using estimation and production protocols. The Borg CR-10 scale was used as it accomplishes better simplicity by compressing the number of categories and improved the terminology by including descriptive language [12]. For the production protocol, participants were asked to walk for 5 min for CR-10 levels of “1—very weak” and “5 — strong (heavy)”. The estimation protocol entailed performing the physical activities listed in Table 3 and having participants estimate their RPE using the CR-10 scale. RPE was administered during the task—approximately at the halfway point of completing the task. As done in our preliminary studies, certified research assistants administered the CR-10 scale according to standardized instructions that satisfy Maresh and Noble’s criteria for adequate instructions [12]. To explain potential differences in RPE, the measure of an individual’s pain was ascertained both before and after the completion of each task. Concentration on the task was also ascertained following the completion of each task.

Movement Sensors — To validate accelerometers for estimating the type and intensity of physical activity, participants wore five Actigraph GT3X + BT (Actigraph Inc. Pensacola FL) accelerometers on the right side of the body (wrist, upper-arm, hip, thigh, and ankle) during all tasks listed in Table 3. The monitors were programmed to collect accelerations on three orthogonal axes in the raw form (units of gravity) at 100 Hz.

2.4.3. Additional measures

In addition to the primary, secondary, and tertiary outcomes, a number of measures to characterize participants were collected for use as covariates in statistical analysis. A full descriptive list of these measures is provided in Table 2. Briefly, these measures included assessments of functional ability, cardiac health, body composition, and a variety of questionnaires related to descriptive characteristics, psychological health, general health, physical activity, and laboratory-specific activity.

2.5. Assessment schedule

Assessments occurred over 4 visits. Each visit was designed to reduce participant burden (2–3 h of testing) and fatigue associated with performing physical activity. Based on a strategy developed through the preliminary study [8], all tasks were performed in a hierarchal order from lowest to highest metabolic demand.

2.6. Rational and description for tasks of daily living

All participants performed standardized lifestyle, exercise and sedentary type physical activities in a clinic laboratory setting (all tasks and descriptions are listed in Table 3). These tasks were chosen because they are common among most Americans and they are consistent with average time spent in the 2010 American Time Use Survey [22]. Adults spend on average 50% (9–10 h) of their day doing personal care and household activities. Thirty-three percent (33%) of the day is spent in sedentary, exercise and shopping activities.

2.7. Home testing

Data are available to suggest that the metabolic costs of daily activities are higher when performing the tasks in a home environment compared to a laboratory environment [23]. To investigate this further, the metabolic costs of daily tasks was compared between tasks performed in laboratory and home settings. For this objective, a subset of participants was selected to perform 8 tasks in their home (Table 3). The tasks were chosen because they have a high likelihood of requiring different metabolic costs in the home compared to the laboratory. For example, room sizes can vary considerably across households, which could influence metabolic costs of tasks such as dusting and straightening up. Participants randomly chosen were first screened to determine whether their home environment is suited to conduct testing. A research assistant transported the portable metabolic system and activity monitors to the participants’ home. All the tasks were performed in a hierarchal order from lowest to highest metabolic demand as in the laboratory setting [8].

2.8. Analytical considerations

The primary analysis will be performed using stepwise multiple linear regression techniques for the primary outcome of metabolic cost with age as the primary exposure variable. Results will also be used to derive a correction factor for individual MET scores based on age and significant confounders. Similar techniques will be used to compare high functioning older adults with functionally impaired older adults in terms of METs for lifestyle activity and also for exercise activity for both laboratory and home environments. The validity of perception-based measurement of exertion will be evaluated by examining age-related differences in the correlation (Pearson R) between RPE and the criterion measure of physiological response of oxygen consumption using linear regression for the primary outcome of RPE with metabolic cost as the primary exposure variable.

The type and intensity of physical activity will be estimated using body worn tri-axial accelerometers. The high resolution data collected from these monitors are suited for machine learning approaches to identifying patterns that can be used to classify the type and intensity of activity listed in Table 3. First, the data will be reduced into windowed features that constitute both the time (e.g. mean amplitude) and frequency (e.g. harmonic compositions) domains. Next, to estimate performance and compare methods, the data will be partitioned multiple times in training and testing datasets (80%–20%). The features will then be analyzed using random forest [24] and support vector machines [25] to assess their prediction fit to actual MET values and discriminate capability for activity type. For classification analyses, the overall accuracy and choice of analytic approach will be assessed by examining the area under the receiver operating characteristic curve. For MET values, the technique that reduces mean squared error will be used.

For aim 1, our sample size estimate (N = 180) provides sufficient power to address the primary hypothesis while allowing flexibility to conduct exploratory analyses. The assumed SD for age is about 20 and that for METs is about 1.25. We further assume that the R² measuring the association between age and the confounders (add the confounders) is 0.25; this leads to an effective sample size of (1–0.25)*180 = 135 for those without functional impairment. With
Indirect calorimetry

Expiratory gases collected breath-by-breath using a portable metabolic cart. The device measures, among other expiratory measures, VO2, R-value, VE, VCO2, FeO2, and FeCO2. Data were expressed as MET values, metabolic economy, and relative oxygen consumption as a function of both resting metabolic rate and peak oxygen capacity.

RMR: Resting Metabolic Rate (RMR) was measured by indirect calorimetry. Participants were evaluated following a 4-h food restriction and he instructed to abstain from strenuous physical activity for 24 h before the test. The test consisted of being still on table for 20 min. Participants were instructed not to move or sleep during the test. RMR was calculated using the Weir formula.

- Daily activities: Measured for up to 15 min for each activity listed in Table 3.
- Peak: Conducted during treadmill exercise test.

Accelerometry

Five activity monitors and a mobile phone was used to collect tri-axial accelerometer data for the entirety of each task listed in Table 3. Activity monitors were placed in the following locations: upper arm, wrist, waist, thigh, and ankle. The mobile phone was placed on the waist. All devices were placed on the right side of the body.

Questionnaires

Descriptive

- General information was collected on all participants for descriptive purposes. These include demographic, social, and economic information (e.g., age, race, gender, etc.).
- Medication and dietary supplement inventory

Psychological

- Self-efficacy for various walking activities was measured based on the Self-Efficacy for Walking Scale [27]. The modified version of this scale asked whether the participants could successfully perform tasks, with a 100-point percentage scale comprising 10-point increments ranging from 10% (highly uncertain) to 100% (complete certainty).
- Perceived competence for tolerating effort during physical tasks was assessed using a modified version of the Perceived Competence Scale [28].
- Positive and negative affect were measured using the Positive and Negative Affect Schedule (PANAS) [29]. The PANAS comprises two mood scales, one that measures positive affect and the other which measures negative affect. Participants completed a 20-item test using 5-point scale that ranges from very slightly or not at all (1) to extremely (5).
- Focus of attention during physical activity were assessed using the Attentional Focus Questionnaire (AFQ) [30]. The AFQ is a 30-item inventory that contains three subscales: association, dissociation, and distress. Participants used a 7-point Likert scale (1 = not at all, 7 = all the time) to indicate how far they engage in each of the items during physical activity.
- The State-Trait Anxiety Inventory was used to assess state and trait anxiety [31]. To assess state anxiety, the inventory consists of 20 statements with 4-point Likert scale to ask how individuals feel “right now” or at a particular time in the recent past or a hypothetical future situation. For trait anxiety, the assessment is similar but the root is modified to ascertain how individuals feel generally.
- The Behavioral Inhibition and Activation Scales were used to determine aversion motivation and appetitive motivation [32]. Participants can indicate how much they agree or disagree by answering for 24 statements with 4-point Likert scale ranging from 1 (very true for me) to 4 (very false for me).
- The Profile of Mood States (POMS) was used to measure mood [33]. POMS is a validated psychological test containing 65 words or statements with 5-point Likert scale ranging from 0 (not at all) to 4 (extremely), through which people can indicate how they have been feeling in the past week including today. The 6 subscales of this test are tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment. The scores for each component are combined to form an overall mood state, called total mood disturbance.
- Global domains of cognition were assessed using the NIH Toolbox [34]. The NIH Toolbox is a comprehensive computer-based battery of brief assessment tools. The battery takes 30–40 min to complete and contains six domains:
  - Executive function – the capacity to plan, organize, and monitor the execution of behaviors that are strategically directed in a goal-oriented manner. Assessed via the Dimensional Change Card Sort test – a measure of cognitive flexibility — and the Flanker Inhibitory Control and Attention test — a measure of both attention and inhibitory control.
  - Attention – the allocation of one’s limited capacities to deal with an abundance of environmental stimulation. Assessed via the flanker test.
  - Episodic memory – the cognitive processes involved in the acquisition, storage and retrieval of new information. Assessed via the Picture Sequence Memory Test.
  - Language – the mental processes that translate thought into symbols (words, gestures) that can be shared among individuals for purposes of communication. Assessed via the Picture Vocabulary Test and the Oral Reading Recognition Test.
  - Processing speed – the amount of time it takes to process a set amount of information, or, the amount of information that can be processed within a certain unit of time. Assessed via the Pattern Comparison Processing Speed Test.
  - Working memory – a limited-capacity storage buffer that becomes overloaded when the amount of information exceeds capacity. Assessed via the List Sorting Working Memory Test.

Laboratory-specific activity

- Perception of effort was assessed at the halfway point of each task listed in Table 3 using the Borg CR-10 scale [12,13].
- Perception of pain was assessed immediately before and immediately after completion of each task listed in Table 3 using a 10-point pain scale that ranges from 0 (no pain) to 10 (worst pain possible) [12].
- Affective state was assessed immediately after completion of each task listed in Table 3 using an 11-point feeling scale ranging from ~5 (very sad) to +5 (very good).
- Attentional behavior was assessed immediately after completion of each task listed in Table 3 using a 10-point scale ranging from 0 (external thoughts daydreaming, environment) to 10 (internal thoughts, how body feels, breathing, technique). The scale is designed to represent the continuum of attentional strategies from pure dissociation (0) to pure association (10).

General health

- The Patient-Reported Outcome Measurement Information System (PROMIS) was used to document global health [35]. PROMIS is a computer-based assessment that asks questions pertaining to physical health which include: global health, function, pain interference, and fatigue. The mental health component consisted of questions pertaining to depression and anxiety.
- Medical and hospital admission history questionnaire consisting of questions relating to self-perceived health, lifestyle habits, chronic conditions, problems, and diseases, surgeries, and instances when they sought the advice of a medical professional for any reason.
- Late-Life Function and Disability Instrument (LLFDI) and falls efficacy questionnaire [36]. The LLFDI was used to document disability status using a scale from 0 to 100, with higher scores indicating higher levels of function. The instrument includes 16 tasks representing a broad range of disability indicators that assesses both frequency of doing a task and perceived limitation. Fatigability was evaluated using the Pittsburgh Fatigability Scale—a short questionnaire that asks about physical and mental fatigue while performing 10 different daily activities [37].
- The Activities-specific Balance Confidence (ABC) scale was also administered to assess fall-efficacy [38]. The ABC scale ascertains the level of confidence (from 0 to 100%) doing 15 activities without losing balance or becoming unsteady.

Physical activity

- All participants completed the Physical Activity Assessment and the Sedentary Behavior Questionnaire. Adults 60 years and older also completed the Community Healthy Activities Model Program for Seniors Activities Questionnaire – a validated questionnaire that asks about activities more appropriate for older adults. Each questionnaire assessed the weekly frequency and duration of various physical activities and sedentary behaviors [39].

Functional assessments

Physical performance

(continued on next page)
this effective sample size, we project 81% power for alpha level 0.05 two-sided test to detect a slope of 0.015 METs/year; for individuals 20 years apart. This corresponds to an average difference of 0.30 METs. For the second aim, 70 participants with functional impairment compared to those without impairment provides at least 80% power for a two-sided level 0.025 hypothesis test to detect a difference of 0.58 METs. For Aim 3, exertional error measurements, the power for a two-sided level 0.025 hypothesis test to detect a difference compared to those without impairment provides at least 80%

### Cardiac measures

**Vitals**
- Resting blood pressure and resting heart rate were measured. Vital measures are collected to assess eligibility criteria and for safety purposes for performing physically demanding tasks.

**ECG**
- A standard 12-lead electrocardiogram (ECC) was used during the graded exercise test to monitor for cardiac abnormalities. In the event of serious abnormalities or symptoms, qualified staff encouraged additional follow-up and/or evaluation.

### Body composition assessments

**Anthropometry measures including weight, height, and waist circumference were collected for descriptive purposes.**

**DXA**
- Dual-energy X-ray absorptiometry (DXA) whole body scans were used to assess lean mass, fat mass, and bone density. Participants were required to lie on the scan table, lightly dressed, as the scanner briefly passes over their entire body. Scans were performed on all participants by certified technicians.

## 3. Discussion

The Chores XL Study will produce the largest dataset to date of metabolic costs for daily activities across the lifespan, with the results likely to have significant public health implications. Overall, the results of the study will provide a clearer understanding of the degree to which increased age and functional impairment alter the metabolic demands of physical activities and perceptions associated with those demands. Consequently, the results will advance the U.S. Department of Health and Human Services physical activity guidelines for recommending the type and intensity of movements for improving the health of adults across a wide age-spectrum. In addition, the results may also contribute to advances in several fields including: 1) nutritional science — by providing objective estimates of energy expenditure of daily tasks, 2) physical therapy — by delivering home-based physical activities capable of improving fitness, 3) geriatric medicine — by describing the metabolic demands faced by functionally impaired patients, and 4) epidemiology — by supplying accurate MET values for older adults to more accurately categorize the intensity and energy expenditure on questionnaire-based research that links specific activities to normative MET data.

There is accumulating evidence that the metabolic costs of physical activity rise with age [3–8]. Previous work by Mian et al. examined the metabolic cost of treadmill walking across four speeds between young (27 ± 3 years) and older (74 ± 3 years) men. The metabolic cost of walking was found to be significantly higher among the older individuals across all four speeds [5]. While this evidence limits the age related difference in metabolic cost of ambulatory activities, further work by Gunn et al. suggests this effect may exist through non-ambulatory activities as well [3]. In their study, a cohort of older men (55–65 years) was compared to a previously measured younger sample (35–45 years) in the metabolic cost of performing four household and garden activities. Their analysis showed that while three activities had no difference in metabolic cost, there was a significant difference in the metabolic cost of window cleaning with the older individuals performing the activity at a higher relative intensity. While their work was specific to men, the work of Jones and colleagues suggests the trend is also not sex specific [4]. In their study, they found the metabolic cost of self-selected paced walking was significantly higher in a cohort of older women (50–79 years) compared to a younger sample (25–49 years). Similar results were found by Voorrips and colleagues who demonstrated a significantly higher energy expenditure while performing standardized walking on a treadmill among a cohort of older women (72 ± 4 years) compared to a middle-aged cohort (42 ± 1 years) [6].

With growing interest in the age effect on the metabolic cost of activity, there has also been interest in whether discrepancies exist between laboratory-measured metabolic cost of activities performed by older adults and the suggested metabolic cost per normative data provided by the Compendium of Physical Activities. Knaggs and colleagues investigated this potential discrepancy with the results showing a higher laboratory-measured metabolic cost of

### Table 2 (continued)

| Test                          | Description                                                                 |
|-------------------------------|-----------------------------------------------------------------------------|
| **Exercise stress testing**   | Two protocols: Portable Bruce and defended Bruce tests were used to test the  |
|                               | endurance capacity of the participants.                                       |
| **Maximally intense exercise**| The protocol involves maximum intensity exercise to determine the metabolic  |
|                               | cost of activities.                                                           |
| **Sub-maximal exercise**      | The protocol involves sub-maximal intensity exercise to determine the metabolic  |
|                               | cost of activities.                                                           |
| **Cardiac stress testing**    | Two protocols: Portable Bruce and defended Bruce tests were used to test the  |
|                               | cardiovascular function of the participants.                                  |
|                               | The protocol involves maximum intensity exercise to determine the metabolic  |
|                               | cost of activities.                                                           |
| **Sub-maximal exercise**      | The protocol involves sub-maximal intensity exercise to determine the metabolic  |
|                               | cost of activities.                                                           |

**RESULTS**

The results showed a significant difference in the metabolic cost of activities performed by older adults and the suggested metabolic cost per normative data provided by the Compendium of Physical Activities. Knaggs and colleagues investigated this potential discrepancy with the results showing a higher laboratory-measured metabolic cost of

### Table 2

| Test                          | Description                                                                 |
|-------------------------------|-----------------------------------------------------------------------------|
| **Exercise stress testing**   | Two protocols: Portable Bruce and defended Bruce tests were used to test the  |
|                               | endurance capacity of the participants.                                       |
| **Maximally intense exercise**| The protocol involves maximum intensity exercise to determine the metabolic  |
|                               | cost of activities.                                                           |
| **Sub-maximal exercise**      | The protocol involves sub-maximal intensity exercise to determine the metabolic  |
|                               | cost of activities.                                                           |
| **Cardiac stress testing**    | Two protocols: Portable Bruce and defended Bruce tests were used to test the  |
|                               | cardiovascular function of the participants.                                  |
|                               | The protocol involves maximum intensity exercise to determine the metabolic  |
|                               | cost of activities.                                                           |
| **Sub-maximal exercise**      | The protocol involves sub-maximal intensity exercise to determine the metabolic  |
|                               | cost of activities.                                                           |

**RESULTS**

The results showed a significant difference in the metabolic cost of activities performed by older adults and the suggested metabolic cost per normative data provided by the Compendium of Physical Activities. Knaggs and colleagues investigated this potential discrepancy with the results showing a higher laboratory-measured metabolic cost of
### Table 3
Activities assessed.

| Activity                        | Description                                                                 |
|---------------------------------|-----------------------------------------------------------------------------|
| Trash removal                   | Consolidate weighted trash bags (4.5 lbs.) from five small cans around the perimeter of a 200 sqft room into one large weighted bag (5 lbs.). Place consolidated bag (27.5 lbs) into weighted wheeled can (20 lbs.). Organize recyclable items into two standard recycling bins. Place wheeled can and recycling bins outside room (distance 6 m), one at a time. |
| Mopping                         | Use a weighted (4.5 lbs.) mop and bucket with damp rag at bottom to clean dry erase marks off tile floor. |
| Leisure walk                    | Walk at leisurely pace.                                                     |
| Rapid walk                      | Walk at a rapid pace.                                                       |
| Light gardening                 | Fill an 11-gallon plastic bucket with handles with 2.5 gallons of soil, carry the bucket (20 lbs.), a distance of 4-m, place on the ground and plant -12 artificial flowers using a small shovel. |
| Heavy gardening                 | Vacuum the carpet of a long hallway and office area. Move chairs (4) to vacuum around/under small table. |
| Vacuuming                       | Fill 11-gallon plastic buckets with soil by digging holes with a shovel. The buckets were emptied and reset by the study team. |
| Sweeping                        | Use a broom to sweep paper debris scattered across 25 sqft. area into a pole. Load paper debris into small waste bin using a dustpan. |
| Washing windows                 | Use paper towels and glass cleaner to remove dry erase marks from two eye level 9 sqft. windows and two ground level 4.5 sqft. windows. |
| Ironing                         | Use an iron and ironing board to simulate flattening wrinkled clothes. Place finished items on hanger or fold. |
| Laundry                         | Move standard fully-sized load of clothes from washer to dryer (ground level cabinets with baskets). Sort second standard fully-sized load of clothes into two piles (light/dark) and place one pile in washer. Move clothes from dryer to table and fold or hang items as necessary. |
| Shopping                        | Navigate two grocery isles (one-sided, 20 ft. long) with a shopping cart to accumulate items on grocery list. Retrieve a few select high shelf items. Take cart to checkout area to place items bagged. Take cart to adjacent room and place bags onto waist level shelf. Return cart to start. |
| Washing/drying dishes           | Rinse and wash dishes by hand with washcloth, abrasive pad, and/or brush. Place cleaned dishes in drying racks. |
| Straightening up/ dusting       | Remove dishes from dinner table and place in sink. Push in chairs around dinner table (4) and banquet table (16). Use a small duster to clean paintings (12) around a room (878 sqft). Use a spray bottle and washcloth to wipe down the surface of the banquet table (100 sqft). Gather small foam balls (25) scattered on the floor and place them into a bag. |
| Unloading and storing dishes    | Hand dry dishes in drying rack and store them in the corresponding cabinet or drawer. Unload dishes from dishwasher (ground level cabinet and waist level drawers) and store them in corresponding cabinet or drawer. |
| Personal care                   | Mmike bathing in simulated shower, drying off with a towel, and styling while standing in front of a mirror. |
| Dressing                        | Take of shoes and socks. Put on jeans, belt, and dress shirt overtop of existing clothes. Remove shoes, socks, jeans, belt, and dress shirt. May be done while setting down if normal to do so. |
| Stair ascent                    | Ascend stairs (22 flights) at self-selected pace.                          |
| Stair descent                   | Descend stairs (22 flights) at self-selected pace.                        |
| Yard work                       | Rake plant debris in 75 sqft. area into large pile. Using hand (gloves optional), transfer pile into large trash bin. |
| Heavy chores                    | Stack five unweighted chairs (17 lbs) and slide the stack across to the room (15 lbs) to a table. Unstack the chairs and place them around the table. Carry five weighted chairs (23 lbs.) one at a time and place them around the table. Repeat process to return chairs to start. |
| Preparing/serving a meal        | Place a pan on the stove (small tabletop), then fill a pot with water and place it on the stove. Use modeling clay in a mixing bowl to make four patties. Use a serving platter to place the patties to the stove and place them in the pan. Next, use a rolling pin, cookie cutter, and modeling clay to cut four cookies. Place the cookies on a baking sheet and place it in the oven (chair top). Pour pot of water back into the sink and then set a small table for four with placemats, plates, bowls, glasses, and silverware. Lastly, fill a pitcher with water, then use the pitcher to fill the water glasses on the table. Use a spatula to serve the patties and cookies to each place setting at the table. |
| Replacing sheets on a bed       | Dress a mattress on top of a large waist high table with a fitted sheet, flat sheet, and comforter. Tuck the flat sheet and comforter under the mattress. Dress two pillows with pillow cases and place them on the mattress accordingly. |
| Standing still                  | Stand in place with arms at sides.                                         |
| Light home maintenance          | Assemble and disassemble a plastic 6-shelf shelving unit. Replace the battery in a nearby smoke detector. |
| TV watching                     | Watch TV while sitting.                                                     |
| Walking on a treadmill          | At absolute speed of 1.5 mph at 0% grade and at 1.7 mph at 5% grade. These measures were collected during the first two stages of the treadmill test. |
| Strength exercise               | Strength exercises were done on the leg extensors, leg flexors and chest press. Participants performed 2 sets of each exercise using a predetermined amount of weight based on existing normative data, age, and body weight. The first set (30% 1RM) was done as a warm up set of 10 repetitions followed by one minute of rest. The second set (60% 1RM) was done until volitional failure (when the participant can’t lift the weight any longer) followed by one minute of rest. |
| Stretching and yoga             | Upper and lower body stretching. Tasks performed standing and on the floor. |

*Activities also assessed during optional home visit.*

daily activity among older adults (70–90 years) compared to the predicted metabolic costs from the Compendium of Physical Activities [8]. In addition, they also found that the presence of mobility impairment further compounded metabolic cost of activity. Similarly, Peterson and Martin showed that the metabolic cost of walking was lower for young (25 ± 3 years) versus older (71 ± 4 years) adults [7]. Their results suggested age-related lower extremity neuromuscular adaptations may lead to changes in coactivation that increase the metabolic cost of walking for older adults.

There is also growing concern that the current Federal Physical Activity Guidelines are used to prescribe physical activity duration and intensity based on normative data that is seemingly lacking validity among older adults [26]. As the case for RPE, a meta-analysis by Chen and colleagues showed the validity for measuring exercise intensity may not be as high as previously thought [13]. In fact, many studies focused on RPE included samples of only younger adults with only 4 studies out of the 64 included in the analysis reporting samples that include older adults (≥65 years). A similar knowledge gap appears to exist in the literature for accelerometer-based measurement of exercise intensity. Rejeski and colleagues called attention to this concern using data collected from the Lifestyle Interventions and Independence for Elders study — a clinical trial designed to test the effectiveness of exercise on delaying or preventing mobility disability among at risk older adults (70–89 years) [15]. In their analysis, they found that using traditional fixed accelerometer-based cutpoints resulted in up to 75% of participants being unable to reach the prescribed exercise intensity, however, they responded to the intervention as if they clearly did.

There is a general lack of knowledge for practitioners to appropriately prescribe daily physical activities for healthy and mobility-impaired older adults. Furthermore, in compilation of these select studies, the study could help guide the Physical Activity Guidelines Advisory Committee call for research to expand objective data on physical activity intensity in special populations which serves as the ground work of the current study [10]. In satisfying this call, our results aim to provide implications for practitioners to...
appropriately prescribe daily physical activities for healthy and mobility-impaired older adults.

In particular, those who suffer from functional impairment would gain tremendous benefit from tailored guidelines that meet their physical abilities. While this was not the first to study to measure the metabolic costs of daily activities [8], it represented one of the most comprehensive efforts to address the hypothesized age-associated differences. The results of the Chores XL Study provides a new understanding of age-related differences in exertional errors while identifying factors that are associated with this error. Finally, the design of the study provided a unique opportunity to apply novel mathematical methods to estimate the type and intensity of physical activity using movement sensors. Overall, the Chores XL Study aimed to initiate a line of research that would develop a deep understanding and new tools to study the metabolic science of activities of daily living across the lifespan.

Conflict of interest
None declared.

Ethical approval
The study was approved by the Institutional Ethics Committee.

Acknowledgements
Funding: The Metabolic Costs of Daily Activity in Older Adults Study is funded by the National Institutes of Health (NIH)/National Institute on Aging (NIA) (R01AG042525). The research is partially supported by the Claude D. Pepper Older Americans Independence Centers at the University of Florida (1P30AG028740) and by support for Dr. Duane Corbett (University of Florida) from the NIH/NIA (1T32AG049673-01). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

References
[1] B.E. Ainsworth, W.L. Haskell, S.D. Herrmann, N. Meckes, D.R. Bassett Jr., C. Tudor-Locke, J.L. Greer, J. Vezina, M.C. Whitte-Glover, A.S. Leon, Compendium of physical activities: a second update of codes and MET values, Med. Sci. Sports Exerc. 43 (8) (2011) 1575–1581, 2011.
[2] B.E. Ainsworth, W.L. Haskell, A.S. Leon, D.R. Jacobs Jr., H.J. Montoye, J.F. Sallis, R.S. Stanish, Jr., Compendium of physical activities: classification of energy costs of human physical activities, Med. Sci. Sports Exerc. 25 (1) (1993) 71–80.
[3] S.M. Gunn, A.G. Brooks, R.T. Withers, C.J. Gore, J. Plummer, J. Cormack, The energy cost of household and garden activities in 55- to 65-year-old males, Eur. J. Appl. Physiol. 94 (4) (2004) 476–486.
[4] L.M. Jones, D.L. Waters, M. Legge, Walking speed at self-selected exercise pace is lower but energy cost higher in older versus younger women, J. Phys. Act. & Health 6 (3) (2009) 327–332.
[5] O.S. Mian, J.M. Thom, L.P. Arsigo, M.V. Narici, A.E. Minetti, Metabolic cost, mechanical work, and efficiency during walking in young and older men, Acta Physiol. (Oxf) 186 (2) (2006) 127–139.
[6] L.E. Voorrips, T.M. van Acker, P. Deurenberg, W.A. van Staveren, Energy expenditure at rest and during standardized activities: a comparison between elderly and middle-aged women, Am. J. Clin. Nutr. 58 (1) (1993) 15–20.
[7] D.S. Peterson, P.E. Martin, Effects of age and walking speed on coactivation and cost of walking in healthy adults, Gait Posture 31 (3) (2010) 355–359.
[8] J.D. Knaggs, K.A. Larkin, T.M. Manini, Metabolic cost of daily activities and effect of mobility impairment in older adults, J. Am. Geriatr. Soc. 59 (11) (2011) 2118–2123.
[9] V.A. Freedman, L.G. Martin, R.F. Schoeni, J.C. Cormack, Declines in late-life disability: the role of early- and mid-life factors, Soc. Sci. Med. 66 (7) (2008) 1588–1602.
[10] P.A.G.A. Committee, in: Physical Activity Guidelines Advisory Committee Report, U.S. Dept. of Health and Human Services, Washington, DC, 2008.
[11] W. Morgan, Psychological factors influencing perceived exertion, Med. Sci. Sports Exerc. 5 (2) (1973) 97.